IUCN WATER AND NATURE INITIATIVE

PANGANI BASIN WATER BOARD[1]

PANGANI RIVER BASIN FLOW ASSESSMENT

The Scenarios Report

The analysis of water-allocation scenarios for the Pangani River Basin

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

November 2009

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Pangani Basin Water Office

EXECUTIVE SUMMARY

1.1 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.

1.2 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 Mm^3a^{-1}
  - Moshi 15.7 Mm^3a-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 E.1: 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.

Table E.1 Water supply priorities used in the hydrological model WEAP. PD = Present Day.

Scenario	Basic Human Needs	Urban	Agri-culture	HEP	Environ-ment	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 Lower: 4	Upper: 4 Lower: 3	Residual	n/a
13. Combination of storage u/s of NyM, with Max Agric AND storage d/s of NyM, with Max HEP.	1	2	Upper: 3 Lower: 4	Upper: 4 Lower: 3	Residual	n/a
14. Mixed benefits, include storage upstream and downstream of NyM	1	2	Upper: 3 Lower: residual	Upper: 4 Lower: 4	Residual 3	n/a
15. Optimise PD (Agric with storage)	1	3	4	Residual	2	n/a

Predictions were made regarding the likely consequences of changes in flow using existing biophysical and socio-econonomic 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.

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.

1.3 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 then 25 m^3s^{-1} in the Pangani at Kirua and thus greater inundation of Kirua swamp
   - slight increase in dry-season lows 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 Predicted response of the river ecosystem

2.1 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 E.2) 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.

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.

Table E.2 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

2.2 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 E.1). 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).

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.

Table E.3 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

2.3 Nyumba ya Mungu

The average lake area decreases under all scenarios. 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.

Table E.4 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
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

2.4 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 E.5 Change in area of Kirua swamp, fish and vegetation abundance 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

3 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 E.1). These percentage losses come from a very low base level, as income in these two zones is already very low under the PD scenario.

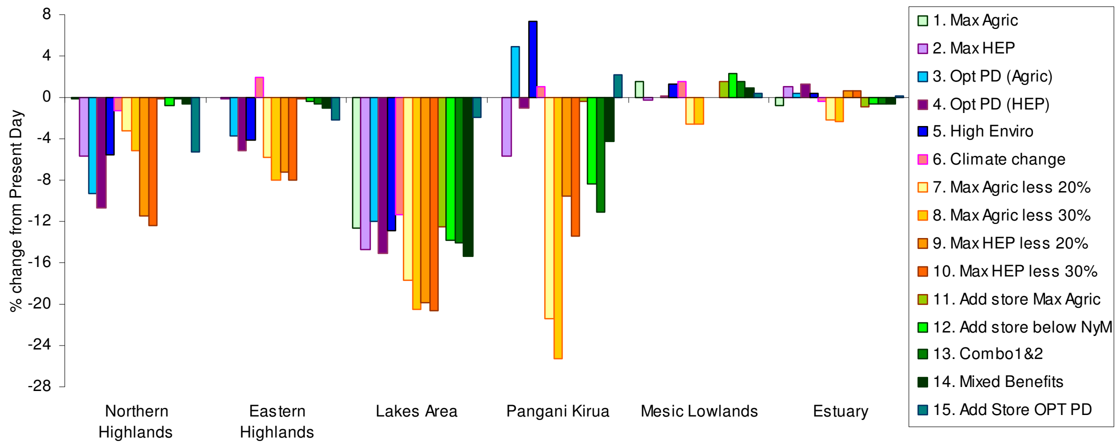

Figure E.1 Impacts on societal well-being for the 15 scenarios.

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 as well that describing PD with 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 E.2).

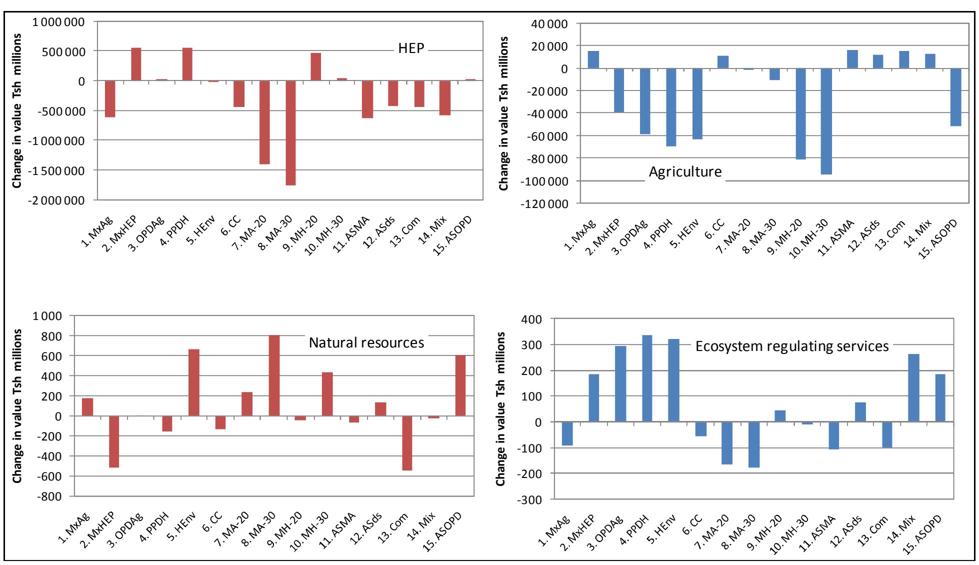

Figure E.2 Changes relative to Present Day in million Tsh for the economic values showing the relatively large impacts of hydroelectric power and agriculture relative to natural resources and ecosystem services.

Table E.6 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
Present Day	*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 E.7). 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 E.7 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
Present Day	*31.1*	-	*1 042*	*602 647*	*5*	*133*	*0*
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 E.3). 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.

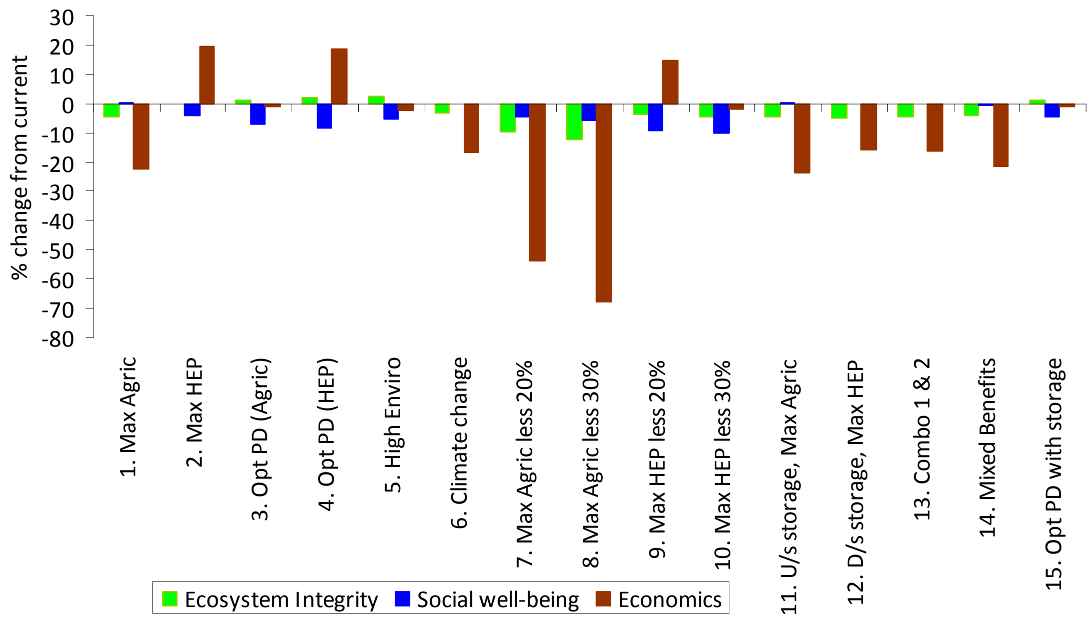

Figure E.3 **Percentage change from present day in terms of ecosystem integrity, social well-being and economic values**.

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ABBREVIATIONS AND ACRONYMS

BHN	Basic Human Needs
D&I	Domestic and industrial
DRIFT	Downstream Response to Imposed Flow Transformation
DSS	Decision Support System
EMA	National Environmental Management Act, 2004
FA	Flow Assessment
ha	hectares
HEP	Hydroelectric power
High Env	High environment (environmental provision second priority after basic human needs)
IUCN	International Union of Conservation of Nature
IWRM	Integrated Water Resource Management
MAR	Mean annual runoff
Max Agric	Maximise agriculture (Agriculture expands as much as possible)
Max HEP	Maximise hydroelectric power (HEP production at maximum capacity is always prioritised)
MCM	Million Cubic Metres
MoW	Ministry of Water
NAWAPO	National Water Policy, 2002
NyM	Nyumba ya Mungu
Opt PD	Optimise present day (present day flows distributed as optimally as possible for ecological condition)
PD	Present Day
PWBO	Pangani Basin Water Office
Tsh	Tanzanian shilling
UCT	University of Cape Town
WEAP	Water Evaluation And Planning System

1. PREPARATION

1.1. 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. Each scenario described the consequences of a development pathway in terms of changes in river condition, the economics of the natural resources of the river, HEP generation, irrigated agriculture, and social impacts. Some scenarios also included projections of how flows would be affected by global climate change.

In summary, the objectives were to:

- generate baseline data of the condition of the Pangani River system against which the impact of water-related decision-making could 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 simple 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).

The FA project was originally divided into a series of ten tasks, as follows:

1. Hydrology of the Basin
2. Study area delineation and site selection
3. Health assessment of the river and estuary
4. Baseline socio-economic assessment
5. Synthesis of understanding of the river systems and its economies and identification of major gaps
6. Specialist studies to address major knowledge gaps
7. Creation and evaluation of scenarios
8. Practical application of scenario evaluation by National Core FA team
9. Final Reporting
10. Awareness-raising at the basin and national level.

During the course of the project, two additional tasks were added, to reinforce capacity building:

1. Training course – inserted between Tasks 6 and 7

2. Tanzanian team mentoring visit to Cape Town to develop hands-on expertise in all aspects of scenario creation and to complete the analysis of an additional eight scenarios – inserted within Task 7.

During the project, ten major project reports, and six specialist reports, were produced.

- Project reports:

1. The hydrology of the Pangani River Basin
2. Development and application of a system model for the Pangani River Basin
3. Basin Delineation Report
4. Scenario Selection Report
5. River Health baseline assessment
6. Estuary Health baseline assessment
7. Socio-economic baseline assessment
8. Summary understanding of the ecological and economic systems of the Pangani River system
9. Pangani Basin: State of the Basin Report
10. Scenario Report
11. Project Summary Report.

- Specialist reports:

1. Development of climate change scenarios
2. Macroeconomic model of the Pangani Basin
3. Fish and invertebrate life histories and important fisheries of the Pangani River Basin
4. Hydroelectric power modelling study
5. Hydraulic study of Lake Jipe, Nyumba ya Mungu Reservoir and Kirua Swamps
6. The vegetation of the Pangani River Basin and its association with flow regimes

This document is the Scenario Report, the tenth document in the project report series. It reports on Tasks 7 and 8, and includes some outputs from Task 12. It contains detailed technical information on the Present Day situation in the catchment, scenario-creation process, the chosen scenarios, the predicted outcomes of each scenario, and the predicted effect of climate change. It also describes how this information can be used and suggests some management options for consideration.

To set the scene, earlier findings that are relevant to the scenarios, already reported in detail in earlier reports in the project series, are summarised below.

1.2. Division of the Pangani River catchment

Scenarios cannot address every part of the basin of concern, and instead routinely use the concept of representative sites. These are locations that, through a process of analysis, are deemed to be characteristic of relatively homogeneous lengths of river or areas of the basin. Data collection may focus on these sites, and the predictions of change are made for them and then extrapolated to the full river length or basin area that they represent.

In this project, the basin hydrological model set up could simulate the flow conditions for any point along most parts of the river system (some streams, such as the Muraini River, had no measured flow data for model calibration and could not be simulated hydrologically). To aid the link up with the data of the river specialists, however, the basin was divided into five main catchments (the Ruvu, Kikuletwa, Mkomazi, Luengera and Pangani) that together comprise 14 sub-catchments. The five main catchments have significantly different hydrological characteristics, and flow simulations were produced for the outlets of each of these (PBWO/IUCN 2006a). The link to the river sites is outlined in the Delineation Report (PBWO/IUCN 2006b).

The river system itself was divided into nine river zones (PBWO/IUCN 2006b): mountain torrent, mountain stream, upper foothills, swamps and lakes, floodplains, lower foothills, rejuvenation zone, lower river and estuary. Some of these zones appeared at multiple points in the basin; mountain stream zones, for instance, were identified in the Himo, Nduruma, Sanya, Tengeru, Mkomazi and Luengera Rivers at altitudes of 1000-1200 m and gradients of about 0.03-0.04. The river(s) in each zone have different physical, chemical and biological properties from those in other zones, will react differently to disturbance, and are used in different ways by people. Their current states were described, using 13 representative sites for the river (PBWO/IUCN 2007a) and ten sites for the estuary (PBWO/IUCN 2007b), in the health assessment reports and in the State of the Basin Report (PBWO/IUCN 2007c). Ultimately, out of these 23 sites, ten were chosen for the Flow Assessment (FA) (Table 1.1, Figure 1.1).

Peoples' links with the river were described in the socio-economic assessment report (PBWO/IUCN 2007d). Eight homogeneous areas were recognized, which differed in land-use and the reliance on the river system. Strongest links with the river, for instance, were in the Northern Highland area (irrigation) and the Lakes area (fishing), while the Western and South-western Arid regions had least reliance on the river. Only six zones, with demonstrated substantial links with the river, were used in the scenarios, the two Arid regions being omitted (Table 1.1, Figure 1.2).

Table 1.1 The Flow Assessment (FA) sites, their river zone and the corresponding socio-economic zone

FA Site	Site name	River zone	Socio-economic zone
1	Upper Kikuletwa	Upper foothill	Northern Highlands
2	Lower Kikuletwa	Lower foothill	Northern Highlands
3	Upper Ruvu	Lower foothill	Northern Highlands
4	Lower Ruvu	Lower foothill	Eastern Highlands
5	Nyumba ya Mungu	Lake	Lakes
6	Kirua Swamp and Pangani River	Swamp	Kirua
7	Lower Mkomazi	Lower foothill	Eastern Highlands
8	Lower Luengera	Lower foothill	Mesic Lowlands
9	Lower Pangani	Mature lower river	Mesic Lowlands
E	Estuary	Estuary	Estuary

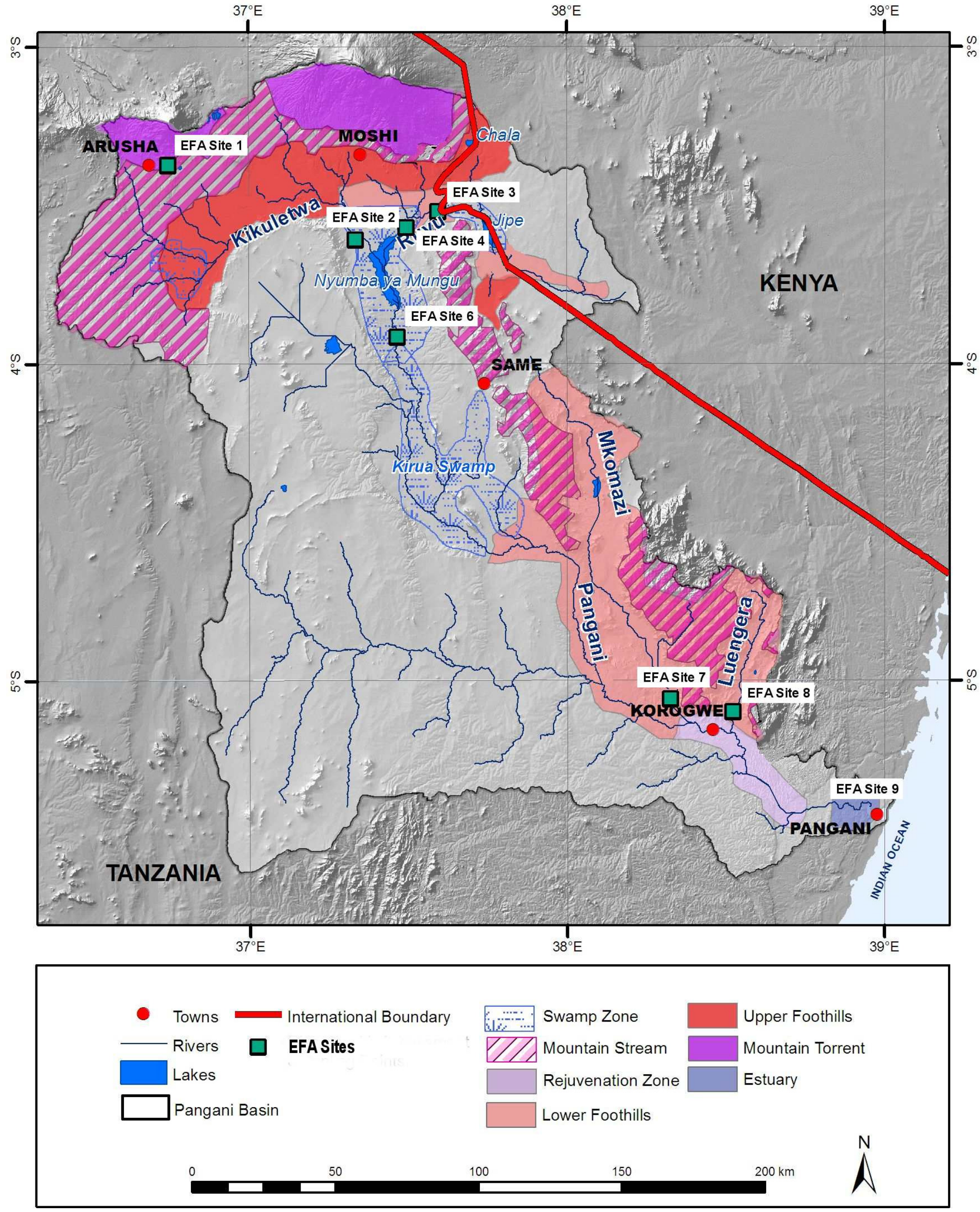


Figure 1.1 Flow Assessment sites of the Pangani River Basin

The final objective of the delineation exercise was to harmonise representative hydrological sites, ecological zones and social areas so that management-driven changes in flow could be interpreted as changes in river condition and resources and thus as positive or negative impacts on people. Because of the nature of the available data and how they could be used, the harmonisation exercise brought together data at different scales of resolution. Local simulated hydraulic data were linked to one of the nine biophysical zones, which were then matched with one of six social zones (one or more river zones per social zone), which in turn were combined in one basin-wide economic zone. Thus, whilst the scenarios could describe changes in ecological condition at the zonal level and in social condition at the area level, the economic consequences of change were described at the basin level.

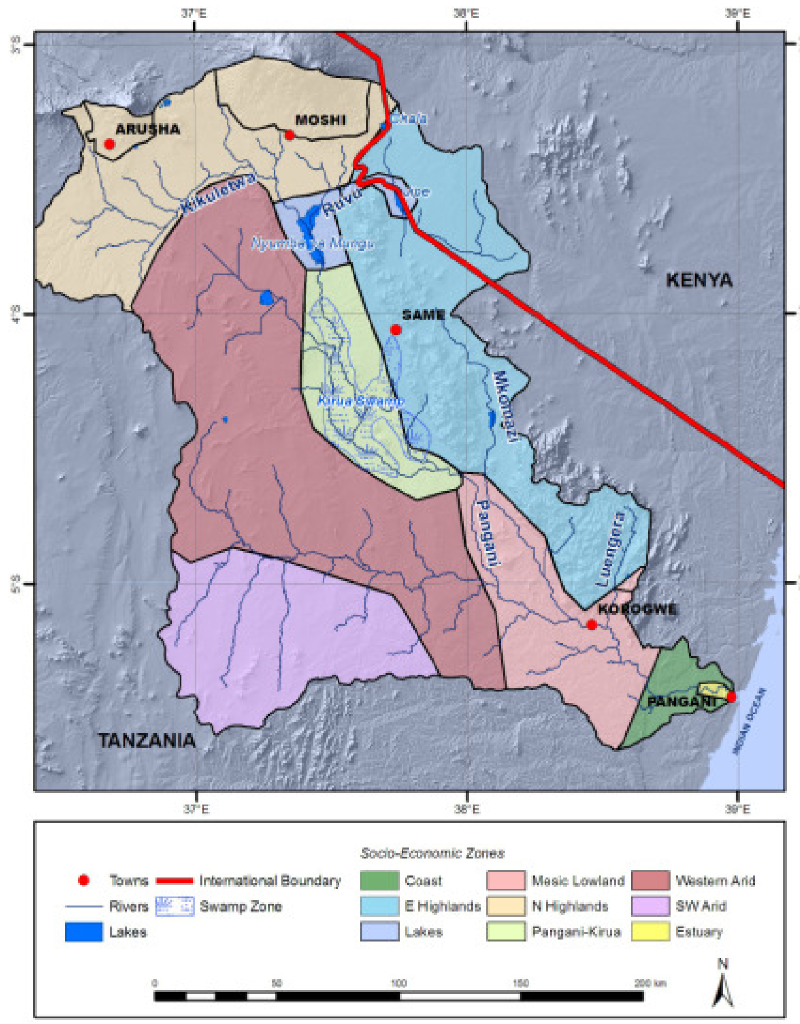


Figure 1.2 Socio-economic zones of the Pangani River Basin

1.3. Preparation for scenarios

A major aim of the project was the creation of a range of possible development pathways (scenarios), with their positive and negative consequences, and the use of these to identify possible future strategies for optimising the basin's water resources.

The database of information set up during the project enables any scenario of interest to be explored, but for the purposes of this project a limited number of scenarios was needed to demonstrate the consequences of major potential development trends and highlight possible management strategies. The process of choosing this limited list of scenarios began in a Stakeholder Workshop in March 2006, when water-related issues of concern to a wide range of stakeholders were recorded.

Emanating from this workshop, a preliminary list of 12 scenarios was created, and taken forward for further discussion (PBWO/IUCN 2006c). Each scenario showed a different level and priority of allocation of water to the various water users, and almost all gave water for basic human needs (BHN), and domestic and industrial (D&I) use first priority. The list included scenarios addressing, for instance:

- Prioritisation of water (after BHN and D&I) for HEP, with agriculture allocated its most likely normal-growth amount, and the river receiving any residual flow.
- Prioritisation of water (after BHN and D&I) for agriculture, with HEP allocated its most likely normal-growth amount, and the river receiving any residual flow.
- Prioritisation of water (after BHN) for the river ecosystem, then for D&I, with either agriculture or HEP allocated the next priority and the other receiving any residual water.

During the course of the project this initial list of scenarios was re-visited on two occasions. In July 2007, at a meeting in Morogoro attended by water managers, IUCN representatives and project staff, the list of scenarios was refined to six (Table 1.2), with three held in reserve for completion later in the project (Dr Kelly West, email, 25 July 2007).

It was requested that each of the scenarios incorporates the best estimate of climate change, and that each incorporates irrigation efficiency to the extent it was relevant.

Further discussion led to a suggestion that scenarios 1 and 3 (Maximise Agriculture and Business as Usual) would likely be very similar (email from Dr J King to IUCN/ PBWO 26 October 2007) and could be collapsed into one that was called 'Maximise agriculture'. Additionally, as inserting climate change into each scenario would mask changes occurring because of different priority allocations to sectors, it was suggested that climate change not be included in any of the scenarios except a new one named 'Status quo plus climate change'. This scenario would demonstrate how climate change over the next two decades could affect the current situation if no other development was to occur. Climate change could be added to more scenarios of interest identified at the November 2007 workshop.

This strategy was approved by IUCN/PBWO on 31 October 2007 (Table 1.3).

Table 1.2 Six scenarios chosen for the Pangani Task 7 Scenario Workshop in November 2007

Name	#	1st priority	2nd priority	3rd priority	4th priority	Residual	Purpose
Maximise Agriculture	1	Basic Human Needs	Domestic & Industrial	High Agric	Most Likely HEP	Environ-ment	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	Environ-ment	Demonstrates the impact on other sectors if HEP production at maximum capacity is always prioritised
Business as Usual	3	Basic Human Needs	Domestic & Industrial	Most Likely Agriculture	Most Likely HEP	Enviro-nment	Demonstrates the future if present trends continue
Max river condition + Water Policy	4	Basic Human Needs	Best Possible Environ-ment	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 Environ-ment	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 Environ-ment	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

Table 1.3 Final list of scenarios for the November 2007 workshop. WDM = Water Demand Management

Name	#	1st priority	2nd priority	3rd priority	4th priority	Residual	Purpose
Maximise Agriculture	1	Basic Human Needs	Domestic & Industrial	High Agric	Most Likely HEP	Environ-ment	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	Environ-ment	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	Environ-ment	Demonstrates the impact on the present situation of climate change
Maximise River Condition + Water Policy	4	Basic Human Needs	Best Possible Environ-ment	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 Environ-ment	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 Environ-ment	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

1.3.1 Additional scenarios added after November 2007

At the November workshop, 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 (numbers 7-10) were:

- Maximise Agriculture, less 20% wet season rainfall (Max Agric, less 20%).
- Maximise Agriculture, less 30% wet season rainfall (Max Agric, less 30%).
- Maximise HEP, less 20% wet season rainfall (Max HEP, less 20%).
- Maximise HEP, less 30% wet season rainfall (Max HEP, less 30%).

See Section 3.3.6 for details.

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. 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 and so more investigations are presently being done by UCT. The information in this report is based on the original climate-change modeling and, because of the present 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.

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 (numbers 11-15) were:

- Storage upstream of NyM, with Maximise Agriculture.
- Storage downstream of NyM (Luengera), with Maximise HEP.
- Combination of storage upstream of NyM, with Maximise Agriculture AND storage downstream of NyM (Luengera), with Maximise HEP.
- Mixed benefits, which include storage upstream and downstream of NyM.
- Storage upstream of NyM, with Optimised Present Day flows for the ecosystem.

1.4. Use of information generated by the scenarios

The purpose of the scenarios is to outline a range of possible future development pathways for the basin, for consideration by government and other stakeholders. Ideally, the information would be transformed from technical to more accessible language (such as was done in the State of the Basin Report) so that all stake-holders, from major commercial enterprises to subsistence users of the river, could understand the options outlined by the scenarios and be in a position to voice their level of acceptability of each. This feedback would then form part of the government's deliberations before development or other water-management decisions are made.

A conceptual framework that describes this whole process was developed to support such planning and decision making, which is described in PBWO/IUCN (2006e) and summarised here. The process has two parts: planning at the basin level, and planning at the project level.

1.4.1 Planning at the basin level

The process starts with the selection of the scenarios as described above, and then simulation of the new flow regime of each using the basin hydrology model (Figure 1.3). The custom-built Decision Support System (DSS) is then used to describe the predicted *costs* of the flow changes in terms of changes in river and estuary condition, in the delivery of ecosystem good and services for people and in the knock-on effects on peoples' livelihoods and local economies. Additionally, the *benefits* are described in terms of, for instance, increased HEP generation and irrigated crops. The three streams of information emanating from the DSS – environmental, social and economic – thus address the three pillars of sustainable development: ecological integrity, social justice and economic.

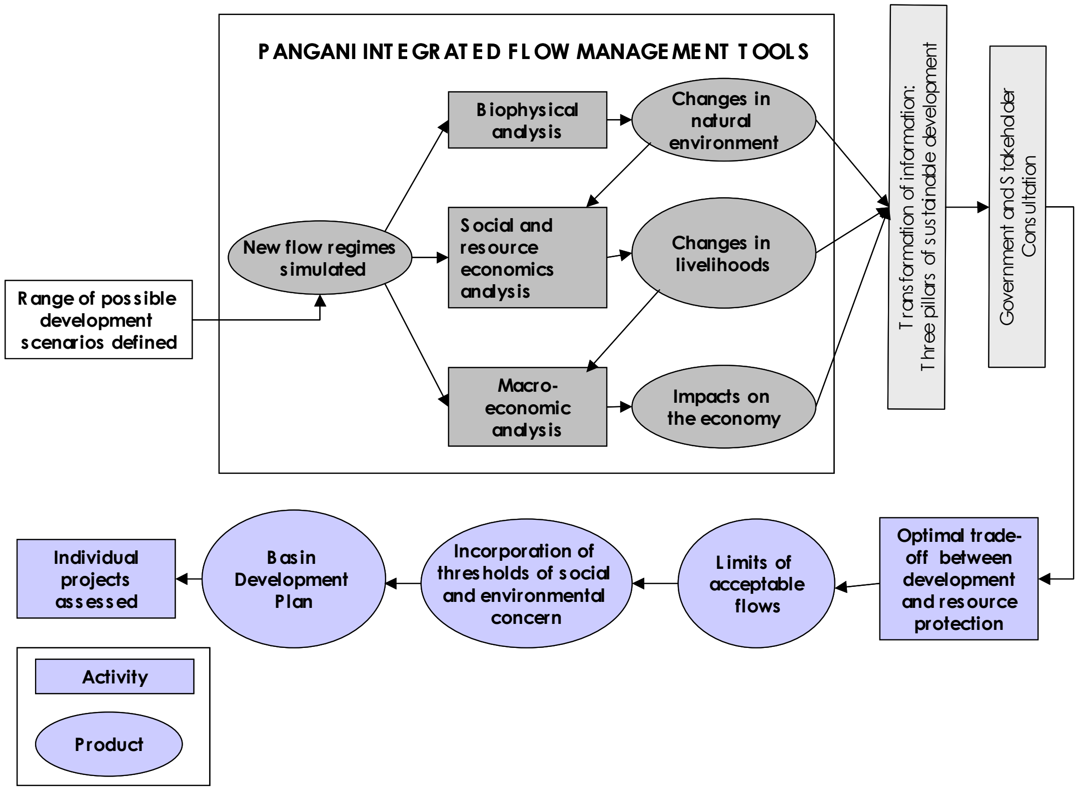


Figure 1.3 Planning at the basin level

With the three sets of information delivered, trade-offs between development and decision-makers and other stakeholders can consider protection of the river system's resources in the search for an optimal water-allocation solution. This optimal trade-off, finally decided upon by the decision-makers, could be defined as a Basin Development Plan or a Framework for Basin Development, against which individual proposed developments could then be assessed. Such an exercise of negotiation and balanced decision-making meets the requirements of Integrated Water Resource Management (IWRM). IWRM 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 catchment or regional approach that takes into account the overall scarcity of water resources and needs of other potential water users.

1.4.2 Planning at the project level

With a Basin Development Plan in place, proposed projects can be assessed on a project-by-project basis to ascertain if they comply with the Plan (Figure 1.4).

Once the Basin Development Plan is in place, any possible future water management activity (development or rehabilitation) can be assessed for compliance with it in terms of the Limits of acceptable flow (Figure 1.3). If it complies, its impacts are then predicted using the FA Tools, and assessed by government and other stakeholders in much the same way as for the basin planning level. Projects that fail at any level of the assessment could be re-designed or declined.

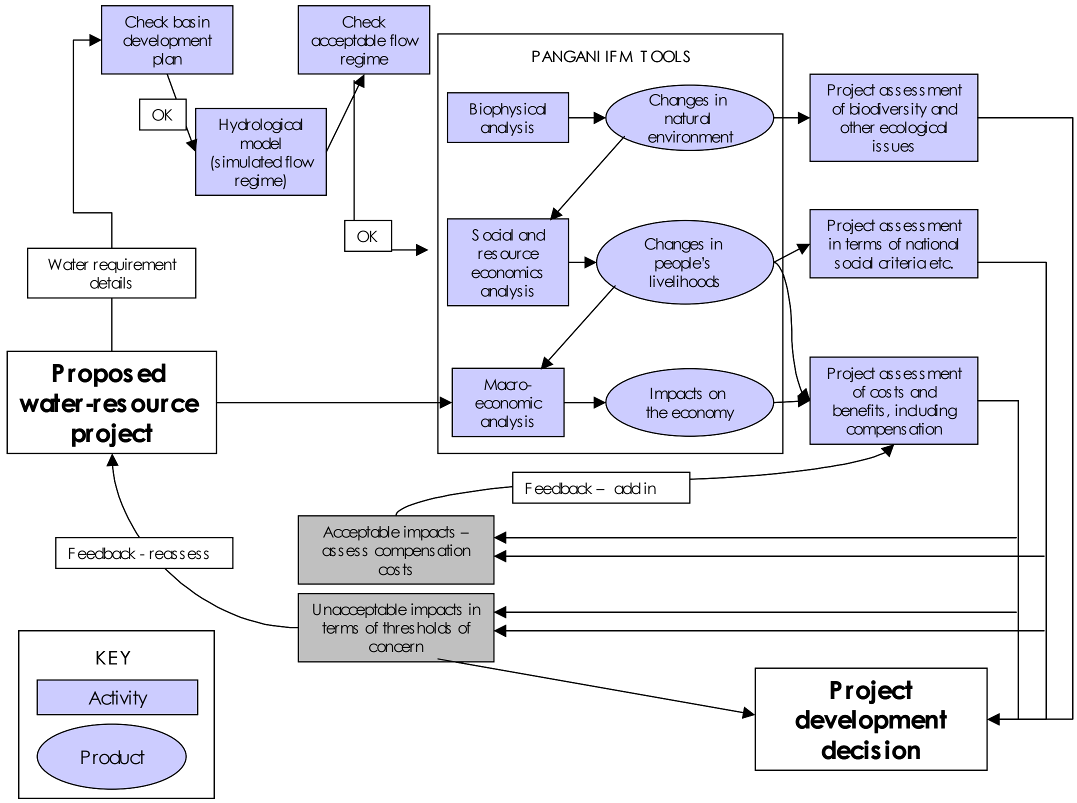


Figure 1.4 Planning at the project level

The DSS developed in the Pangani FA project, and the multiple scenarios it can produce for investigation, take the FA project half way through the basin planning process outlined above. The next step could be to develop the protocols for stakeholder consultation, decision-making and definition of the Basin Development Plan.

1.5. Cross-checking

Once the scenarios are created and analysed, inconsistencies may be revealed. For this reason, a process of systematic cross-checking was adopted, as follows:

Hydrology:

- Check the Mean Annual Runoff (MAR) used/created by WEAP with the MAR used/created by DRIFT-HYDRO.
- Check that the DRIFT summary data demonstrate the expected trends. By example, the scenario describing Maximise Agriculture less 20% wet season rainfall because of climate change should result in lower wet season flows than Maximise Agriculture without climate change.
- Check that the inundation volumes estimated for Kirua swamp demonstrate the expected trends.
- If any unexpected trends emerge investigate and explain their origin.

Environmental:

- Check that the percentage changes shown in each scenario for each indicator agree with the changes that might be expected from the DRIFT summary data.

By example, if the DRIFT summary data showed a loss of small floods did this show as a prediction of reduction in fish abundance.
- Check that overall condition changes in the direction expected.
- If any unexpected trends emerge investigate and explain their origin.

Social:
- Check that the percentage changes shown in each scenario for each resource fall within reasonable range of extrapolation of the response curves.
- Check that the responses are in the expected direction and magnitude (making sure to check the rationale given next to the response curve)
- If any unexpected trends emerge investigate and explain their origin

1.6. Limitations of the project

The project faced financial, time and knowledge constraints that influenced its outputs. The major of these limitations were as follows.
- Limited measured flow data with which to calibrate the basin hydrology model, leading to no simulations for some parts of the system and modest confidence in the simulations for a few other parts.
- Very limited data collection: Some data were collected for the river health, estuary and social baseline assessments, but most of these data were for their specific purposes and only indirectly usable for the ensuing FA. The specialist reports (Task 6), the objective of which was to address major knowledge gaps, were a disappointment, perhaps partially because the consultants were not team members and had not had the opportunity to develop an understanding of the new kinds of data required for FAs. Only one of the specialist reports gave reliable information that could be used in the FA, and that was of very modest proportions. No data specifically for the FA were collected by anyone other than Task 6 specialists, and so population of the DSS by the project team with flow/ecosystem relationships or ecosystem/people relationships was done largely using expert knowledge of such relationships globally. These relationships were checked by the Tanzanian Core Team and adjusted where necessary.
- Data and knowledge of representative sites were extrapolated to river zones, social areas or the whole catchment as accepted practice. Inevitably, this leads to coarse generalization about areas that fails to detect the subtle nuances of ecosystem functioning or socio-economic interactions.
- For simplicity, feedback loops were not built into the DSS. This meant, for instance, that the effects of interventions in one part of the river system on other parts of the system were not defined. This would generally mean that predictions of change are conservative, and could be worse than stated.
- Quantification: because of the lack of ecosystem research and data collection, the starting points for the project in terms of abundances of, for instance, fish or pools were unknown. To address this, all predictions of change were made in terms of percent change from present-day conditions. Scenarios could thus be compared in terms of their relative impacts on the river and its users. In the case of the consumptive use of resources, the starting amounts were known, and changes were estimated quantitatively. Intangible benefits were estimated qualitatively as a degree of change from present.
- Simplistically linking and interpreting many kinds of data, from hydrological and geomorphological, through fisheries and riparian trees, to household use and incomes, and finally economics, lead to information and texture being lost at each step. The results are coarse descriptions of likely change.

- The climate change data from the specialist report were of low confidence and have been criticized by reviewers. This led to very low confidence results for the climate change scenarios.

In any FA, data will be limited and uncertainty high as this is a new branch of science and new kinds of data are needed. Ecologists are not the only professionals facing this uncertainty: engineers, economists, medical practitioners and others all face similar levels of uncertainty, but have to keep practicing and trying to help governments and people make wise decisions. In FA work, an understanding of the nature and functioning of a river ecosystem and its users cannot be gained in one or two short field trips, but rather takes years to build up. This is not a reason for not doing anything, however: it is never too early to get started. International knowledge, local wisdom and expert opinion can all be brought to bear to help build up a picture of the possible consequences of planned management actions. The results of this project should be viewed through this lens, and the scenarios produced by the project's DSS should be used for comparative purposes. Each scenario shows the predicted change from present, allowing insights that can inform discussions and negotiation by governments and its stakeholders on an acceptable way forward.

1.7. Layout of this report

After this introductory chapter, Chapter 2 provides background information on the project, and Chapter 3 summarises the Present Day situation in terms of the characteristics of the river system, its uses and users. Chapter 4 describes the scenarios chosen for analysis and the assumptions made when creating them. Chapter 5 explains how the scenarios were interpreted and Chapter 6 compares the outcomes for the original group of scenarios. Chapter 7 then considers a suite of eight scenarios focusing on Climate Change and Chapter 8 the scenarios that include storage of water in the upper catchment. Chapter 9 finalises the body of the report with conclusions and the outline of a possible way forward. Thereafter follows a series of Appendices, of which number 1 provides details of the DRIFT hydrological analyses, and 2 – 16 give information on individual scenarios.

2. DESCRIPTION OF PRESENT DAY

2.1. Hydrology

Present-day flow sequences represent the flows that can be expected under currently prevailing water-use levels, subject to a history of variable rainfall. These sequences were developed to provide a baseline flow regime for the scenario assessments, and were generated at the outlets of 14 sub-catchments. The sub-catchments are grouped into five main catchments (the Ruvu, Kikuletwa, Mkomazi, Luengera and Pangani) shown in Figure 2.1.

Figure 2.1 Catchment discretisation

To illustrate the extent to which the water resources of the Basin have been developed, estimates of mean annual runoff at the outlets of the five main catchments are shown in Table 2.1.

Table 2.1 Mean Annual Runoff (MCM[2]/annum)

Component	Kikuletwa	Ruvu	Mkomazi	Luengera	Pangani estuary
Natural Runoff including endorheic runoff	884	928	302	175	3 119
Net natural runoff	884	928	90	117	1 424
Present day runoff	663	879	38	110	1 227

[2] Million Cubic Metres

The runoff estimates 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.

In spite of large reductions in dry-season flows in the Kikuletwa catchment, the river is still perennial at the point where it flows into Nyumba ya Mungu Dam. 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 presently dry completely in the dry season, even in years with normal runoff conditions.

The high utilisation of runoff in the Mkomazi catchment has caused the formerly perennial river to dry up 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 and Luengera catchments have been significantly reduced, but to nowhere near the extent seen in the Kikuletwa and Mkomazi catchments.

Figure 2.2 shows a comparison of monthly natural and present day runoff at the Pangani Estuary.

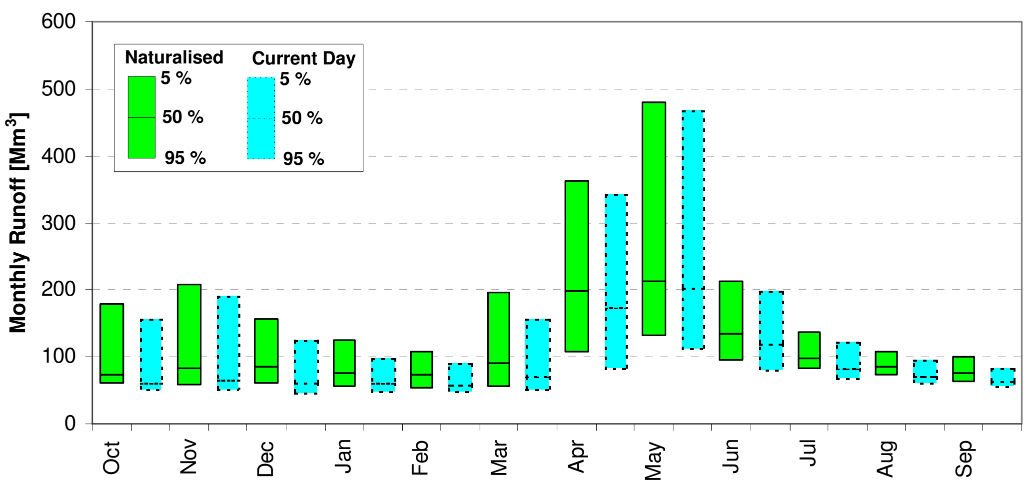


Figure 2.2 Comparison of Naturalised and Present day Flows – Pangani Estuary

Present day inflows to the Pangani Estuary 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.

2.2. Irrigated agriculture

The exact irrigated area in the Pangani Basin is unknown, but it is estimated to be about 81 000 ha (this study). This includes large commercial estates (mainly coffee, also sugar); flower farming and small-scale mixed cropping. Most of the irrigated area, however, is under small-scale farming, where plots are about 0.1 – 0.2 ha in the highlands, increasing to 0.8-1.5 ha in the lowlands (Turpie *et al*. 2003). Small-scale farmers make use of an estimated 2000 traditional furrows. Some of these have been improved in more modernised irrigation schemes, with the result that efficiency of water use ranges from less than 15% to >50%. Most small-scale farmers grow a variety of crops, but maize is the most ubiquitous. Coffee is grown within the highland forest belt, in association with bananas and maize. Bananas are also grown by about a third of households in the lowlands. Tomatoes are grown in all areas, but tend to be more frequent in irrigated areas, particularly in the highland area. Beans are very commonly grown in the upper basin and highlands, but not in the lowlands. While the highlands are too cool for rice production, it is a major crop of irrigated areas in the upper basin, and is planted to a small extent in the lowlands, in irrigation areas or in close proximity to flooding areas. Farmers in the highlands and upper basin that do not have access to irrigation concentrate their efforts on maize and beans, as well as a variety of fruits and vegetables. Sugar is a very minor crop on smallholder farms, but grown throughout the basin. At the Pangani estuary, farmers concentrate on coconuts, betelnuts, cassava, sweet potato, pumpkin, maize and bananas, and there is very little irrigation (Turpie *et al*. 2003).

Irrigation farming yields about twice the income of non-irrigation farming, and farmers throughout the basin report shortages of water for irrigation (IUCN/PBWO 2007). The area currently under irrigation is significantly smaller than the potential irrigation area.

2.3. Hydropower production

The Pangani River makes a substantial contribution to Tanzania's power output. The country's power supply is mainly from HEP, with three HEP stations in the basin contributing about 17% of the country's capacity. The power output never reaches the installed capacity, however, due to shortages of water flow. Power production at Nyumba ya Mungu relies on storage of water in the dam during rainy seasons and then a relatively constant release of water through the turbines. This regulation by the NyM dam also ensures a relatively even flow to the downstream power stations at Hale and New Pangani. The latter are more modern and translate flow into power far more efficiently, with New Pangani being eight times more efficient than NyM in terms of output per unit of water.

The way in which flows are allocated to different parts of the basin has a major influence on power generation from the basin as a whole, and this is of national significance. A loss of 50% of power output from the basin can amount to a loss of almost 10% of the national power output.

2.4. Environmental condition

As part of this project, an assessment of river health and estuary health was completed (PBWO/IUCN 2007a,b). At points along the river system several variables were assessed in both the wet and dry season:

- the flow regime (pattern of flows)
- the river channel
- water quality
- habitat integrity (condition of habitat for riverine plants and animals)
- the plants communities
- the animal communities.

The results were reported as health categories for the various river zones (Table 2.2). Some zones show two or three health categories, either because the zone was transitional between the two conditions or because where it occurred in different parts of the system it was in different condition. In several of the zones the system is now largely or extensively modified (C to D), which means that there has been a large loss of ecosystem health and functioning, which will be impacting on river services used by people (PBWO/IUCN 2007c).

Table 2.2 Ecological health categories for the various river zones

Zone	Health category					
	Flow regime	Channel	Water quality	Vege-tation	Aquatic invertebrates	Fish
Mountain torrent	A	-	-	-	AB (estimated)	A
Mountain stream	BC	-	AB	BC	AB	AB
Upper foothill	CD	-	BCD	ACD	BCD	D
Upper basin swamps & Lake Jipe	D	B	BC	C	B	CD
Kirua floodplain	D	C	C	B	C	BC
Rejuvenated foothills	CD	C	D	D	D	BC
Lower foothills	D	B	CD	BCD	BCD	C
Mature lower river	D	D	C	B	C	C
Estuary	B	D	D	C	D	C

Flow regimes are changing, even in the upper parts of the catchment, with some once-perennial rivers now drying out for part of the year because of water abstraction. The Mkomazi and Upper Kikuletwa sub-basins are the most highly developed and show the greatest change in flows, both drying out annually. Dams regulate flows over large parts of the system, and have virtually eradicated flood flows onto Kirua Swamp and other floodplain areas. The dams also influence flows into the estuary, which are markedly different from natural, mostly through small floods being stored in the reservoirs. As a result, many of the features of a natural flow regime that support the river's plant and animal life have become distorted or even lost, impacting the goods the river can provide.

The river channel has been altered by bridges, roads, abstraction of fine materials, dams, and channelisation – particularly through swamp areas. Changes are most obvious on the Kikuletwa (channel widening) and Himo (gravel mining), and at the Kirua Swamp, which no longer functions as a floodplain. Degraded river beds no longer provide good-quality habitat for riverine plants and animals and so valued plants and animals (such as fish) generally decline and may disappear completely.

Water quality generally deteriorates downstream, with some areas of poorest quality in the middle reaches. Poor quality is mostly associated with increased levels of dissolved salts, nutrients, faecal coliforms, decaying organic material and turbidity. Oxygen levels are extremely low in places, especially upstream and downstream of the Hale and Pangani Falls dams and in the upper estuary. Agricultural runoff is a major cause of the poor quality, with effluents from sisal farms being prominent, along with increased turbidity downstream of the dams and the use of the river for washing and waste disposal.

Bank and floodplain vegetation has deteriorated locally rather than along the whole system, due to clearance for agriculture or urban areas, harvesting of plants, or invasion by exotic species. Degraded areas no longer provide goods such as wood, grazing, fruit or medicines, or services such as shelter. Such areas no longer act as a buffer between catchment activities and the river, leaving the system vulnerable to pollution and other disturbances.

The small animals of the river - the aquatic invertebrates - process organic particles of both natural of man-made origin, cleansing the water as it flows past. They also act as the basic foodstock for larger animals such as fish and birds, typically occurring as tens to hundreds of species in each part of a river system and in abundances of hundreds to thousands per square metre of river bed. As conditions deteriorate in the river the communities of small animals change, often with sensitive species disappearing and pest species becoming more abundant. This is a present-day general downstream trend in the Pangani system, although there are localities with improved invertebrate community structure indicating that the river is still able to rehabilitate to some extent.

Twenty fish species were found along the river, including three families of species that migrate between the ocean and the river. In general, river health as judged by its fish was good in the upper reaches declining to moderate in the lower reaches. The areas around Kirua and Lake Jipe rated as less healthy, largely due to their declining water and inundation levels.

The main areas of present concern identified by the State of the Basin Report (PBWO/IUCN 2007c) were:

- Lake Jipe: a thriving fishery has virtually collapsed and a productive wildlife area declined due to upstream water abstractions, increased nutrients and poorer water quality from farming activities, and increased siltation of the lake from inflowing sediments.
- Nyumba ya Mungu: the reservoir replaced a natural wetland and supports a fishery that is now declining in abundance due to upstream abstraction of water and over-fishing.
- Kirua Swamp: this, the largest wetland in the basin is now largely dry, its flooding flows regulated by NyM dam and channelisation of flows through the swamp. A once-vibrant fishery has declined drastically and the remnant is now largely confined to the river channel. Flood-recession agriculture and furrow irrigation continue in a few areas close to the river.
- The Kikuletwa River at Wahoga Chini: river health was rated D, very degraded, mostly due to the river channel drying out in the dry season and almost all bank vegetation having been eradicated.
- The Ruvu River at Kifaru: River health rated as D. Water quality was extremely poor: very high nutrient levels, extremely low oxygen levels and ammonia levels high enough to be toxic to aquatic life. The main sources of pollution appeared to be dwellings close to the river and decaying vegetation within the river.
- Pangani River at Hale: Highly modified river flow because of the dam, linked with poor water quality resulted in an all-round D classification. No fish were recorded in the dry season.
- Mkomazi River downstream of Kalimawe Dam. Highly modified flows because of the dam, poor water quality and destruction of the natural riparian vegetation resulted in C/D classification, with only tolerant species present.
- Pangani Estuary: compared with similar tropical estuaries around the world, the Pangani is in poor condition, with fewer fish, birds and other animal species. Seawater intrudes further upstream as river flow weakens, affecting agriculture and eroding banks. Pollutants and fine silts carried down by the river result in oxygen levels so low that most aquatic animals cannot survive there. A once-abundant fishery is now seriously depleted.

In summary, there are still areas of moderate to good river health within the system but the general trend is a downstream decline in river health due to catchment activities, flow modification and water abstractions. Many benefits have accrued to the people of the basin from use of the river, such as HEP, food crops and other cash crops. This has been at the expense of the natural services supplied by the river, such as wild river and estuarine fisheries, flood-recession agriculture and good-quality drinking water.

2.5. Livelihoods and societal well-being

There are about 191 000 households that live within 5 km of the main rivers in the basin, accounting for 47% of all the rural households in the basin. The urban populations of the Northern Highlands (Moshi and Arusha) are not included. The affected people live in different socio-economic zones (Table 2.3, Figure 1.1). The majority of affected households are found in the higher lying parts of the basin and in the coastal areas, but a small proportion of affected households occurs in the relatively arid Lakes and Pangani-Kirua zones and in the small estuary zone (Table 2.3).

Table 2.3 The number of rural households in each socio-economic zone, the number of these found within 5 km of rivers (= affected households), and the percentage of total affected households in each zone

	N Highlands	E Highlands	Lakes	Pangani-Kirua	Mesic Lowlands & Coast	Estuary
Rural Households per zone	236 431	112 336	1 662	5 459	57 411	1 616
Rural hh within 5 km (affected households)	91 450	43 206	1 662	5 459	47 427	1 616
% of affected households in each zone	48%	23%	1%	3%	25%	1%

2.5.1 Tangible benefits from aquatic ecosystems

On average, households derive incomes of between Tsh 140 000 and Tsh 630 000 from the use of natural resources, with a total of at least Tsh 6 687 million derived in total from aquatic natural resources (Table 2.4). Income from aquatic ecosystem resources ranges from under Tshs 20 000 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 is 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. The overall value of aquatic ecosystem resources in relation to other sources of income is given in Table 2.4.

Table 2.4 Aggregate net income per zone for households within 5 km of rivers, lakes or the estuary (Tsh millions per year)

Source of income	N Highlands	E Highlands	Lakes	Pangani Kirua	Mesic Lowlands	Estuary	Total
Business, employment & pension	37 651	11 613	530	1 349	5 977	1 077	58 197.3
Crops	97 917	16 315	390	2 061	15 520	338	132 541.2
Livestock	30 785	6 742	234	2 554	2 273	335	42 923.9
Upland resources	19 030	2 904	110	594	5 355	130	28 122.3
Wetland resources	1 749	2 043	614	178	1 837	266	6 687.0
Total	187 132	39 617	1 877	6 737	30 962	2 146	268 471.8

2.5.2 Intangible benefits from aquatic ecosystems

People in the basin have indicated that river systems contribute significantly to religious and recreational activities as well as for washing clothes (Table 2.5).

Table 2.5 Percentage of households considering that aquatic ecosystems make an important or very important contribution to their recreational and cultural experiences

	N Highlands	E Highlands	Lakes	Pangani-Kirua	Lowlands	Estuary
Recreational	38	44	59	81	33	39
Cultural/spiritual	38	44	42	69	33	23

2.6. The economic value of basin resources

2.6.1 The agricultural sector

At present, small scale agriculture in the affected area (within 5 km of rivers in the Pangani Basin) is estimated to contribute some Tsh 132 541 million per annum, and commercial irrigation agriculture is estimated to add a further Tsh 69 850 million per annum to regional income (this study, based on IUCN/PBWO 2007 and Turpie et al. 2003).

2.6.2 The natural resources sector

This is the same as the value described under livelihoods above, but should be considered in terms of the direct value added to national income rather than net income to local households. Due to the low capital inputs and external labour inputs involved at present, the value added is effectively similar to the net income calculated above and has not been adjusted.

2.6.3 Regulating services provided by aquatic ecosystems

Regulating services are the services generated by ecosystems that save on engineering costs (such as water purification and flood attenuation), or that provide inputs into productive systems beyond the ecosystem in question (such as the nursery function of estuaries contributing to marine fisheries production). These services require extensive measurement and modelling in order to quantify in physical terms alone. In this study we estimate the value of two aquatic ecosystem services that are considered important in the Pangani: water treatment by wetlands, and the estuary function as a nursery area. These are valued on the basis of findings from detailed studies of other African wetlands and estuaries in the literature. The area of wetland is currently about 4488 ha, and is estimated to generate water purification services to the value of Tsh 73 million per annum. The 31 529 ha estuary, currently rated as being in a condition which is 54% similar to the natural condition, has an estimated nursery value of Tsh 240 million per annum.

2.6.4 The energy sector

Reduction in the availability of water for power generation raises the costs of power production as the national grid has to source power from other types of generators that have higher production costs. In reality, shortages of HEP during very dry periods cannot always be met in this way, leading to load shedding. This study estimates the direct impact of changes in HEP on the economy in terms of costs or gains in power production based on estimated change in the marginal value of power production. The marginal value is the difference between the cost of generation by HEP versus production from alternative sources. The current value of HEP generation is estimated to be in the order of Tsh 2 511 250 million per annum.

Table 2.6 Summary of current economic values that are affected in the scenario analyses

	Agriculture (within 5 km of rivers)	Aquatic ecosystem resources	Regulating services	HEP
Current value (Tsh millions per annum)	202 391	34 809	314	2 511 250

3. DETAILS OF THE PANGANI RIVER BASIN SCENARIOS

All of the scenarios include sectoral water demands for Basic Human Needs (BHN), Domestic and Industrial, Agriculture, HEP and, for the scenarios where the environment receives more than residual water, pre-estimated environmental water allocations (for the rivers, NYM Dam, Kirua Swamp and the Pangani Estuary); climate change is included in some. Scenarios differ 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 (Section 3.1). Each time the priority of water allocation is changed, or a new allocation added, a new scenario is created.

Initially, afforestation was considered for inclusion in the scenarios but it was later decided not to include it, as the complications and complexities of the relationship between forest cover and water resources in the catchment are not as yet understood.

The fifteen scenarios selected for analysis were:

1. Maximise Agriculture.
2. Maximise HEP.
3. Optimise Present Day, with agriculture (Optimise PD (Agric)).
4. Optimise Present Day, with HEP (Optimise PD (HEP)).
5. High environment (High Env.).
6. Present Day, 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 includes storage upstream and downstream of NyM.
15. Optimise Present Day, with Agriculture and storage in the upper catchment (Optimise PD (Agric with storage)).

The parameters applicable to each of these scenarios are described in more detail below.

3.1. Priority of water allocations

The suite of Pangani River Basin scenarios can be usefully divided into two groups:

- those that prioritise the allocation of water to a use sector such as agriculture or HEP;
- those that prioritise resource sustainability in terms of an allocation of water to the environment.

All of the scenarios in Group 1 (except Scenario 6, Present Day) contain the same sectoral allocation demands, i.e., potential 2025 urban domestic and industrial, irrigation, and HEP demands. They also have no explicit provision for the environment. In these scenarios, BHN, and Urban and Industrial demands, were accorded first and second priority, respectively. Thereafter, agriculture or HEP were each allocated third or fourth priority, depending on which was the focus of the scenario. The environment received the residual water, i.e., whatever was left in the rivers after the allocations had been made. Scenario 6 includes present day sectoral allocations, but with climate change allocated first priority, and the environment receiving residual flows.

The scenarios in Group 2 have an explicit provision for the environment at FA Sites, each of which represent a river zone, and at NYM Dam, Kirua Swamp and the estuary. In these scenarios, BHN were accorded first priority, and the environmental provision second priority in accordance with Tanzanian Water Policy. Thereafter, urban and industrial was accorded third priority, and then one of either agriculture or HEP was allocated fourth priority, and the other received the residual water.

In WEAP, water allocations in the various scenarios are modelled by assigning different water supply priorities to these demands. Even if a demand is assigned a top (1) priority, it will not necessarily be met, as supply will be limited by available water.

Priorities can vary from 1 to 100, with 1 the highest, and 100 the lowest priority. In all the scenarios, BHN was accorded first priority (1). The priority of water supply used in WEAP for the other scenarios is given in Table 3.1.

Table 3.1 Water supply priorities used in WEAP. PD = Present Day

Scenario	Basic Human Needs	Urban	Agri-culture	HEP	Environ-ment	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 Lower: 4	Upper: 4 Lower: 3	Residual	n/a
13. Combination of storage u/s of NyM, with Max Agric AND storage d/s of NyM, with Maximise HEP.	1	2	Upper: 3 Lower: 4	Upper: 4 Lower: 3	Residual	n/a
14. Mixed benefits, include storage upstream and downstream of NyM	1	2	Upper: 3 Lower: residual	Upper: 4 Lower: 4	Residual 3	n/a
15. Optimise PD (Agric with storage)	1	3	4	Residual	2	n/a

3.2. Concepts underlying the allocation of water in WEAP

The allocation of water in WEAP is constrained by the volume available for allocation and the distribution of that volume in time and space. Essentially, rain and snow falling in the catchment result in river flow (Figure 3.1), which can be abstracted for agriculture, stored and used to generate HEP or left in the rivers to support ecosystem functions. The pattern of flow in the rivers is dictated by the seasonal differences in rainfall (i.e., long and short rains, separated by dry seasons), but also by the use to which the water is put. The implications of this for modelling (and indeed managing) agriculture, HEP generation and the environment are outlined in Sections 3.2.1 to 3.2.3, respectively.

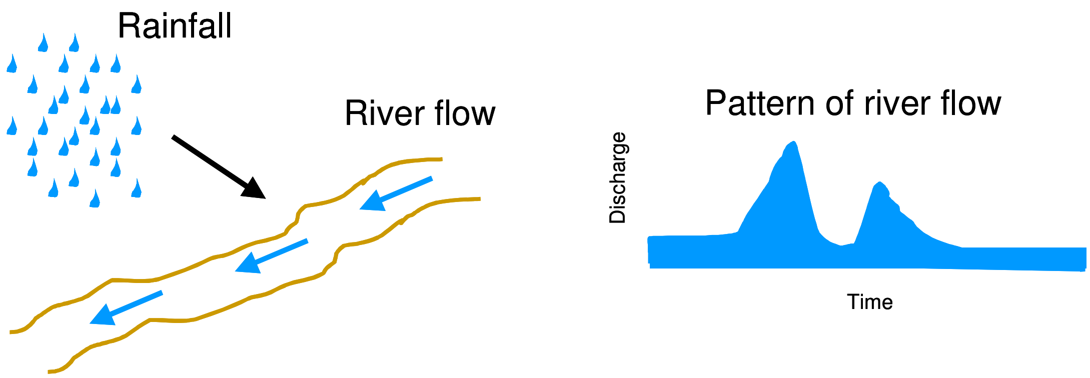


Figure 3.1 Rain and snow falling in the catchment result in river flow with a seasonal pattern of high flows and low flows

3.2.1 Abstraction of water for agriculture

In the Pangani Basin, most of the water abstracted for agriculture is run-of-river abstraction (Nyumba ya Mungu and Kalimawe dams are the exception to this). This means that, particularly in the upper catchment (Kikuletwa and Ruvu catchments) and in the Luengera River, it may be impossible to harvest the high flows in the rivers for agriculture at the peak of the wet seasons, even if needed (Figure 3.2), and essentially only a low volume of water can be accessed for agriculture. Thus in Figure 3.2, only the dark blue portion of the flows can be accessed by run-of-river abstraction, and the rest of the flow regime is left in the river, and is called 'residual' flow in the scenarios.

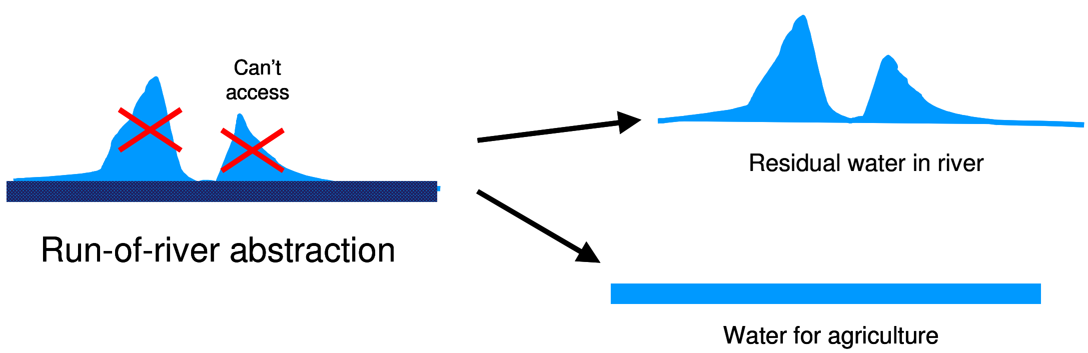


Figure 3.2 Run-of-river abstraction cannot harvest the high flows in the river

Increased storage in the upper catchment would allow capture of a portion of the highflows, thereby increasing the volume of water available to agriculture. This is why the options for increased storage were included in Scenarios 11-15.

3.2.2 Allocation of water for hydroelectric power generation

With hydroelectric power (HEP) plants, flows less than the minimum, or greater than the maximum, operating discharges do not contribute towards HEP generation (see

Section 3.3.3). Thus, to maximise generation of HEP, the natural high flows and low flows in the river are evened out through storage in the dam's reservoir and released in a pattern that optimises the operation of the turbines.

To maximise HEP generation in the Pangani catchment, flows in the upper catchment would need to be left in the river rather than abstracted for agriculture, in order to maximise the volume of water entering NyM. NyM acts as a balancing dam for this water, making relatively constant releases into the downstream river so that the HEP stations can operate optimally (Figure 3.3). Thus, downstream of NyM, the low flows in the river tend to be higher than natural and the high flows lower than natural.

Under the Maximise HEP scenarios, the river flow not taken by agriculture in the upper catchment flows downstream in a relatively natural pattern of high and low flows and thus benefits the environment. Similarly, downstream of NyM dam, discharges of 25 $m^3 s^{-1}$ or greater in the section of the Pangani River adjacent to Kirua Swamp will result in some flooding of the swamps (the greater the discharge above 25 $m^3 s^{-1}$, the greater the inundation of the swamp).

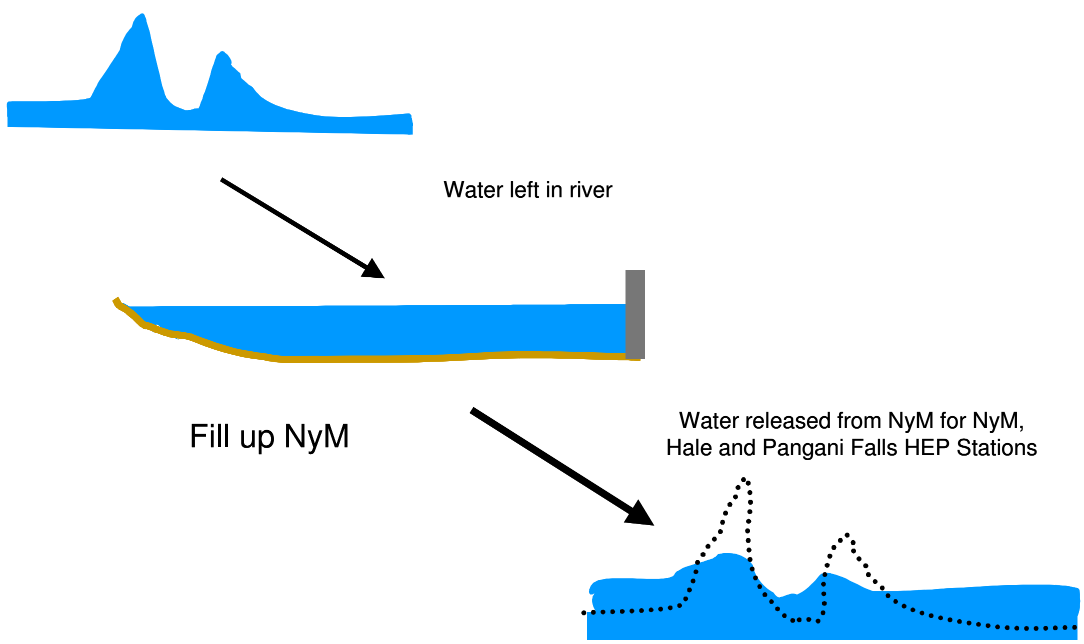


Figure 3.3 **For HEP generation, high and low flows are stored in NyM before being released down the river as more even flows to drive the HEP stations**

3.2.3 Allocation of water for environmental maintenance

The flow regime of a river consists of several different kinds of flow, each of which contributes to the river's overall maintenance (Table 3.2). Naturally, a river exists in a state of dynamic equilibrium, able to respond to seasonal and annual fluctuations in climate because its species have different tolerance ranges and so differ in their abundances as conditions change. Thus, at any time there is a mix of species that can cope efficiently with prevailing conditions, while other species may be present in lower numbers or surviving as, for instance, eggs, seeds or spores, until more suitable conditions occur. The mix of species and numbers of individuals present usually result, in the natural situation, in assemblages where no one species proliferates to pest proportions (Brown and King 2000).

Table 3.2 Different kinds of river flow and their importance to ecosystem functioning (Brown and King 2000)

Lowflows	Lowflows are the flows in the river outside of floods. They maintain the basic ephemeral, seasonal or perennial nature of the river, thereby determining which animals and plants can survive there. The different magnitudes of lowflow in the dry and wet seasons create more or less wetted habitat and different hydraulic and chemical conditions, which directly influence the balance of species. For instance, species which need to spend several months in water to complete their life-cycles are rare in temporary rivers, though specific riparian tree species may be able to live on such a river's banks if the groundwater conditions are favourable.
Large floods	Large floods occur more rarely than once a year. They dictate the general geomorphological character, shape and size of a river channel. Floods mobilise sediments and deposit silt, nutrients and seeds on floodplains. They inundate backwater areas, and trigger the emergence of adults of aquatic insects, which provide food for fish, frogs and birds. They maintain moisture levels in the banks that support the trees and shrubs, and prevent the riparian vegetation from being dominated by any one species. Floods also scour estuaries, ensuring, amongst other things, accessibility to marine fish dependent on them as nursery areas, and the maintenance of habitat diversity.
Small floods	Small floods occur several times within a year. They stimulate spawning in fish, flush out poor quality water, mobilise sandy sediments, and contribute to flow variability. They re-set a wide spectrum of conditions in the river, triggering and synchronising activities as varied as upstream migration of fish and germination of riparian seedlings.

Flow variability, on a daily, seasonal or annual basis, acts as a form of natural disturbance. This maintains biological diversity through increased heterogeneity of physical habitats. For instance, lack of variability through the absence of small floods may favour fish species adapted to breed under conditions of more constant discharge, with resulting alterations in the relative numbers of fish species and/or loss of native species (Figure 3.4). Variability in lowflows dictates the width of the vegetation belt along the water line, which protects the banks against erosion. A loss of variability results in a narrowing of this band because the lower portion is no longer regularly exposed or the upper portion regularly inundated.

Manipulations of flow regimes represent unnatural disturbances to rivers, with these disturbances increasing in severity the further the flow regime is altered from what lies within the realm of normal for that system. Responses of rivers to flow manipulation can take many forms. For instance, hydrological cues that trigger fish spawning or seed germination may occur at the wrong time of the year or not at all, resulting in affected species perhaps failing to reproduce. Seasonal reversal of wet and dry season lowflows could mean that hydraulic and thermal conditions become mismatched with life-cycle requirements, again causing species to decrease in numbers and abundance. Other species, many seen as pests, are often able to take advantage of such environmental conditions, or the weakening of competition from the affected species, and increase in abundance.

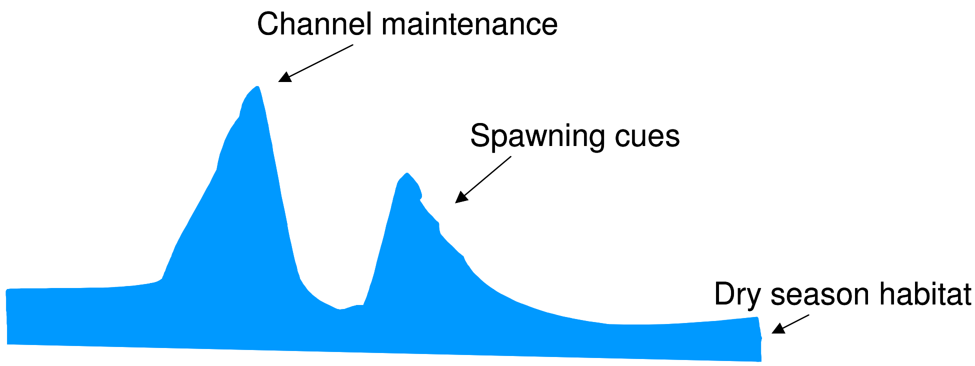


Figure 3.4 The riverine ecosystem is shaped by both the volume of water (MAR) and the natural pattern of flows in the system.

3.2.4 Inclusion of climate change projections

Climate change is driven by changes in temperature, which affect both the amount of rain falling in a catchment and the evaporation from the catchment. When temperatures increase, evaporation will increase BUT rainfall does not necessarily decrease. Indeed changes in thermal patterns may result in a greater concentration of rainfall in an area than previously. Of course, with higher temperatures, more moisture stays in the atmosphere and, in general, this results in less rainfall.

Where climate change is involved in a scenario it is always allocated first priority.

3.3. Main assumptions guiding the scenarios

3.3.1 Assumptions used for urban demand

The two major urban centres in the basin are Arusha and Moshi, both of which are located in the upper reaches. Households (domestic) and industries are both supplied by urban water authorities, and since it is difficult to separate the urban domestic from industrial water use, the term Urban Demand was used to cover both.

The present and projected 2025 demands for each area are given in Table 3.3.

Table 3.3 The 2006 and projected 2025 demands for water for the major urban areas in the Pangani River Basin

Urban centre	Date	Demand (MCM/a)
Arusha	2006	22.2
	2025	39.0
Moshi	2006	8.9
	2025	15.7

3.3.2 Assumptions used for agriculture demand

The demand for agriculture was estimated by projecting historical growth rates into the future leading to continued high growth until 2025, or, in some areas, until some time before 2025 when the maximum agricultural potential (in terms of irrigable soils) is reached.

Efficiency of water use in agriculture is slowly improving through development projects and in the scenario analysis it is assumed that overall efficiency has increased from an average of 25% to an average of 32%, i.e., an increase of 30%. These were expected to result from:

- conversion of 10% of the current earth canals to concrete canals, and;
- replacing 15% of the current flood irrigation with sprinkler irrigation.

These improvements meant that there were small decreases in demands in catchments where no further growth was assumed. It also meant that, in other areas, the same volume of water would irrigate approximately <u>30% more area</u> than under current efficiencies.

In this project it is assumed that increased water supply (through increased efficiency or absolute availability) will lead to growth in agricultural production. If more water was available, there would be expected to be an expansion in irrigation practice among small-scale farmers generally, both in terms of irrigating a higher proportion of their land holding, and in terms of expanding into new areas.

Before the scenarios were applied it was assumed that the irrigated area was 30% greater in 2025 than at present, or as close as possible subject to available agricultural land area. Any changes brought about by a change in water supply were then applied to this area using the response curves in the socio-economics tool. This assumes that as water becomes scarcer, so efficiency continues to increase.

For each scenario, an upper and lower estimate of the resultant irrigation area is estimated using two extreme assumptions. In the first, it is assumed that irrigation would first expand into fields currently under dryland agriculture. In the second, it is assumed that all expansion is into new agricultural lands.

Note: While demand is expressed in volume, the scenario interpretation is more usefully done in irrigated area, because of the more interpretable links to human welfare.

The projected 2025 irrigation demands for each sub-catchment are given in Table 3.4.

Originally it was intended to also analyse a ‘Business as Usual’ scenario (Table 1.2), which would have projected current trends into the future. However, as agricultural development in the past has taken place at the expense of other users, projecting current trends to produce a 2025 situation would have resulted in a situation similar to the Maximise Agriculture scenario. Thus, the ‘Business as Usual’ scenario was dropped.

The value of water supplied to agriculture is closely tied to the level of assurance at which that water can be supplied. The level of assurance of supply refers to the percentage of time that a particular volume can be guaranteed. For instance, 10 MCM supplied at a level of assurance of 75% means that for 75% of the time 10 MCM will be available for the farmer’s use, but for the remaining 25% of the time the farmer may have to make do with less. Some crops are more tolerant of drought than others, and can therefore be grown at a lower level of assurance.

Table 3.4 Projections in water demand for agriculture, per sub-catchment, as used in WEAP

River	Sub-catchment	2006 MCM	2025 Demand MCM	Increase in demand: 2005-2025 MCM
Kikuletwa	1dd1	420.8	636.7	215.9
	1dd54	193.6	285.5	92.0
	1dd55	137.8	127.0	-10.8
	Total	752.0	1049.0	297.0
Ruvu	1dc1	154.7	142.5	-12.2
	1dc2a	77.0	115.0	38.0
	Total	232.0	258.0	26.0
Pangani Mainstem	1d10	47.6	54.4	6.8
	1d14	24.4	44.2	19.8
	1d17	1.7	3.2	1.4
	Total	74.0	10.2	28.0
Mkomazi	1db17	200.4	408.3	207.9
	1db18	111.0	220.9	110.0
	1db19	0.2	0.2	0.0
	1db2a	31.8	29.5	-2.3
	Total	343	659.0	316.0
Luengera	1da1	6.5	6.0	-0.5
	1da3a	2.2	2.1	-0.2
	Total	9.0	8.0	-1.0
Total Basin		1410.0	2076.0	666.0

For the modelling in this study, a 75% level of assurance was assumed for agriculture. In the years that this could not be met, a lesser volume was allocated to agriculture.

3.3.3 Assumptions used for HEP generation

The level of generation of HEP in the catchment is constrained on the one hand by river flows and on the other by the capacity of the existing HEP plants. No new generation capacity was included in any of the scenarios.

There are three HEP plants in the Pangani Basin, namely, Nyumba ya Mungu, Hale Power Station and Pangani Falls Power Station. The rivers flows for minimum and maximum power generation at these plants are given in Table 3.5.

Table 3.5 The operating discharges for minimum and maximum power generation at the three HEP plants in the Pangani Basin (Luteganya and Kizzy 2008).

Hydropower plant	Minimum flow (monthly average)	Maximum flow (monthly average)
Nyumba ya Mungu	9.8 $m^3 s^{-1}$	35 $m^3 s^{-1}$
Hale Power Station	8.5 $m^3 s^{-1}$	45 $m^3 s^{-1}$
Pangani Falls Power Station	9 $m^3 s^{-1}$	45 $m^3 s^{-1}$

Discharges below the minimum flows provided in Table 3.5 will not be sufficient to drive the turbines at the respective HEP plants, and no electricity will be generated. Discharges higher than the maximum flows will not generate any more electricity than can be generated by the maximum flows.

3.3.4 Assumptions used for optimising Present Day flows

Scenarios 3, 4 and 5 require an up-front input of water for ecosystem maintenance. Scenarios 3 (Optimise PD Agric) and 4 (Optimise PD HEP) are aimed at optimising present-day flows: no more water is asked for than presently flows down the river but the way in which high and low flows are distributed through the year is changed in order to improve river condition. Scenario 5 (High Env) is aimed at improving eco-system condition and thus asks for a greater volume of water than present day, again in a required distribution of high and low flows. As the flows required are never greater than natural, they could be achieved by reducing abstractions.

The flow regimes required for each of these three scenarios were determined using the DRIFT-CATEGORY routine in the River FA Tool (Brown and Joubert 2003). This displays the relationship at a site between the volume of water remaining in the river and river condition. The volume can be displayed as the volume of water either in million cubic metres (MCM) or as % mean annual runoff (MAR). The DRIFT-Category plot for FA Site 2 on the Lower Kikuletwa River is provided in Figure 3.5 as an example.

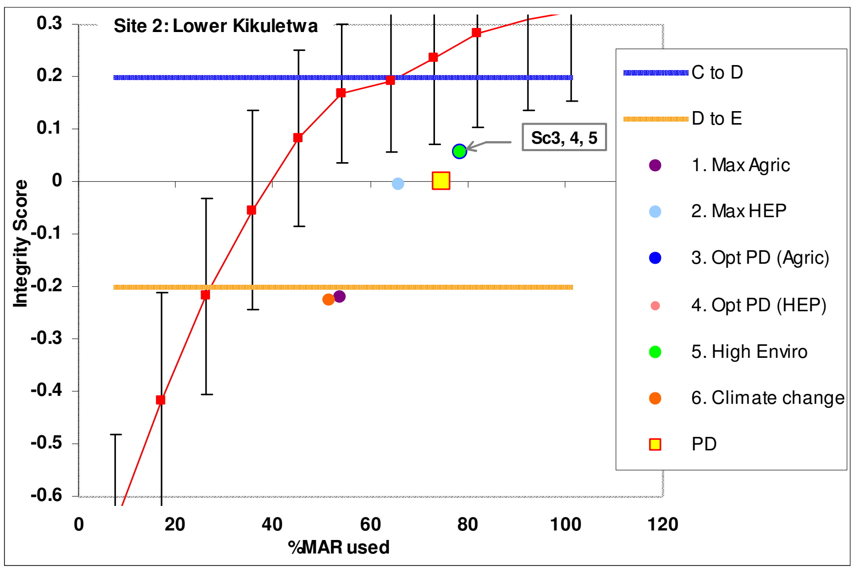


Figure 3.5 The DRIFT-CATEGORY plot for the Lower Kikuletwa at FA Site 2.

The DRIFT-Category plots for all the FA sites are provided in Appendix 1.

In Figure 3.5, the red squares denote the relationship between river condition (DRIFT Integrity Score) (y-axis) and the percentage of the naturalized MAR left in the river (x-axis), with the distribution of that volume of water done in the least ecologically damaging manner. The present day ecological condition of the river at FA Site 2 is at zero on the y-axis, and all changes in the river are expressed as a move away from natural (-ve) or a move towards natural (+ve) relative to the present day condition. The present day condition AND the present day flow regime (volume and distribution) is shown by the yellow and red square (PD), showing that at present approximately 80% of the volume of the natural MAR flows through FA Site 2.

The volume of water at a site is, however, only part of what maintains the ecological condition. How that water is distributed across the seasons and between the high and low flows is equally important. In the case of FA Site 2, most of the water abstracted from the river is taken in the dry season, resulting in dry-season lowflows that are abnormally low and so support a degraded ecosystem. In fact, the data displayed in Figure 3.5 suggest that as little as 40% of the natural MAR would support the river in its present condition, provided the flows were distributed in a more ecologically optimal manner than at present. Conversely, maintaining *c*. 80% of the MAR at FA Site 2, and improving the present distribution of flows by re-introducing dry-season flows, will lead to an improvement in the ecological condition of the river. The improvement would not take river condition up to the red line on the graph (which shows optimum river condition for any volume of water), because flow is just one of the factors influencing ecological condition at FA Site 2. Other factors include removal of the riparian vegetation, with resulting sediment inputs that cover the naturally rocky-bottom riverbed reducing habitat for aquatic life. Importantly, however, IF these other factors were ameliorated, the improved distribution of flows would result in a greater improvement in ecological condition than by only adjusting flows.

At some of the FA sites, the red line crossed the y-axis at the same place as the Present Day condition, as for example at FA Site 1 on the Upper Kikuletwa (Figure 3.6). This means that the current flow regime at that site was optimally distributed for the amount of water available, and there was thus no need to change the distribution. In sites where this was the case, the flow regime used in the Optimise Present Day scenario was identical to the present day flow regime.

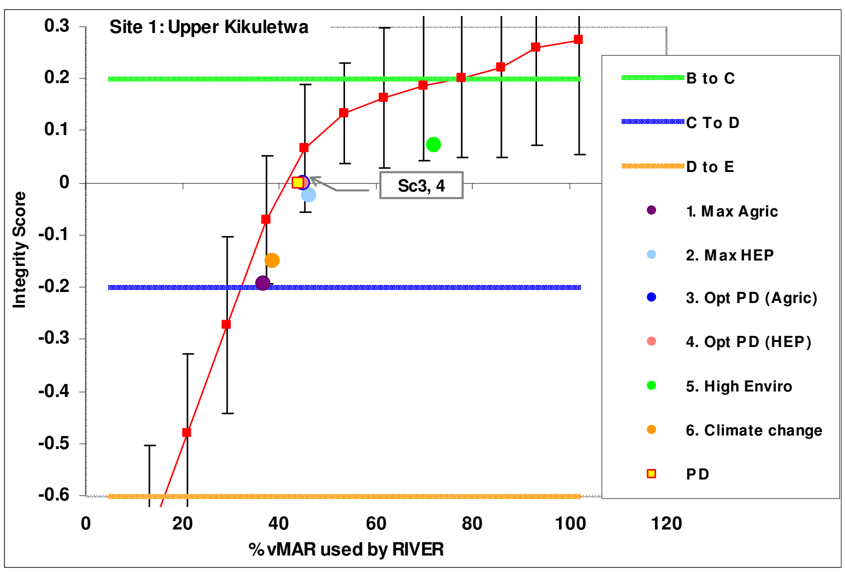


Figure 3.6 DRIFT-CATEGORY plot for the Upper Kikuletwa at FA Site 1.

The seasonal distribution and the distribution between high and lowflows for the present day flow regimes are given in Table 3.6, and those for Optimise Present Day in Table 3.7. Only those FA sites that are shaded in Table 3.7 have Optimise Present Day flow regimes that differ from present day, *viz*. the flow regimes for the Optimise Present Day Scenarios differed from the present day flow regime only at FA sites 2, 4, 6, and 7. The condition of the unchanged sites could not be improved by changing the present day distribution of flows. Note also, that the volumes of present day MAR and the Optimise Present Day Scenario MAR are not always identical. The slight differences between them stem from the way DRIFT-CATEGORY selects portions of the flow regime.

Table 3.6 Seasonal distribution and the distribution between high and lowflows for the Present Day, i.e., actual flows in the river under conditions similar to those prevailing in *c.* 2006

	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Present Day MAR (MCM)	62.8	661.2	206.4	897.3	875.0	38.3	105.0	1241.5
WSLF - Volumes (MCM)	23.1	374.4	96.2	501.0	281.0	10.6	39.2	574.0
DSLF - Volumes (MCM)	26.6	154.7	86.9	220.0	560.0	12.5	40.3	498.6
Class 1 - Annual Frequency	5	2	0	2	0	1	2	0
Class 2 - Annual Frequency	3	3	0	3	1	3	7	1
Class 3 - Annual Frequency	2	4	3	3	0	2	4	2
Class 4 - Annual Frequency	1	4	3	3	0	1	2	2
1:2	P	P	P	P	A	P	P	P
1:5	P	P	P	P	A	Reduced - Use P	P	P
1:10	P	P	P	P	A	P	P	P
1:20	P	P	P	P	A	P	P	P

Table 3.7 Seasonal distribution and the distribution between high and lowflows for the Optimise Present Day scenarios

	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario MAR (MCM)	62.8	604.4	206.0	733.8	800.0	38.0	105.0	1241.5
WSLF - Volumes (MCM)	23.1	278.0	96.0	388.0	316.0	8.9	39.2	574.0
DSLF - Volumes (MCM)	26.6	262.0	86.0	242.0	258.0	12.5	40.3	498.6
Class 1 - Annual Frequency	5	2	0	2	0	1	2	0
Class 2 - Annual Frequency	3	3	0	3	2	4	7	1
Class 3 - Annual Frequency	2	2	3	3	2	4	4	2
Class 4 - Annual Frequency	1	4	3	3	4	1	2	2
1:2	P	P	P	P	A	P	P	P
1:5	P	P	P	P	A	P	P	P
1:10	P	P	P	P	A	P	P	P
1:20	P	P	P	P	P	P	P	P

3.3.5 Assumptions used to generate the High Environment demands

The flow regimes for the High Environment Demand Scenario were also determined with the assistance of the DRIFT-CATEGORY routine. At each FA site, a flow regime that differed from present day and/or the Optimise Present Day Scenarios was only recommended if changing the flows was likely to result in an appreciable improvement in ecological condition for the river reach represented by that site. Thus, using the DRIFT-CATEGORY plots, High Environment Demand flow regimes were only considered for sites where the red line extended above zero on the y-axis, such as in Figure 3.5 and Figure 3.6, as opposed to Figure 3.7, where the data suggest that it is not possible to improve ecological condition by increasing the amount of water allocated to the river, i.e., the red line does not extend above zero on the y-axis. In this situation interventions other than flow adjustments would be needed to improve river condition.

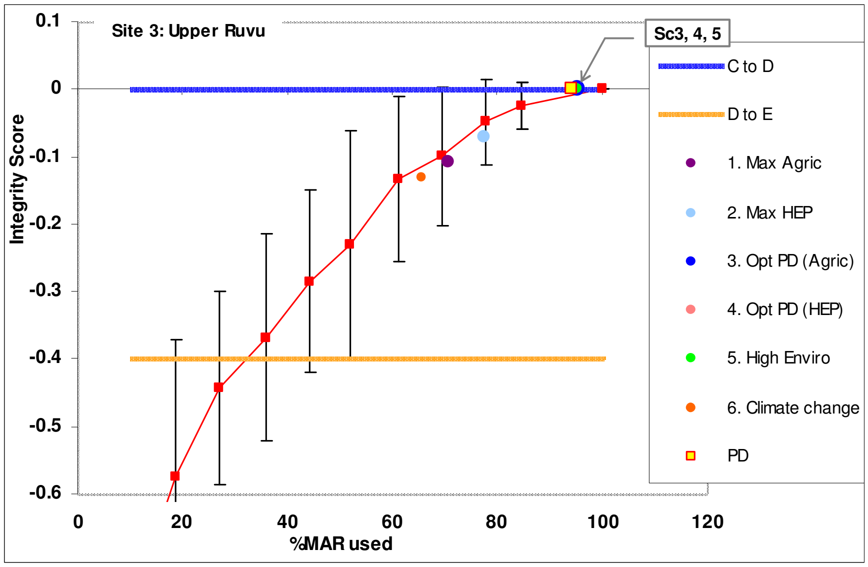


Figure 3.7 DRIFT-CATEGORY plot for the Upper Ruvu at FA Site 3

Thus, as was the case for the Optimise Present Day Scenarios, High Environment flows were only recommended for some of the FA sites, specifically FA sites 1, 6 and 7 (Table 3.8, highlighted columns). For FA sites 2 and 4, the High Environment Scenario had the same flows as the Optimise Present Day Scenarios (in bold and italics in Table 3.8), and for the remaining sites, the High Environment Scenario was the same as present day.

Furthermore, as was the case with the Optimise Present Day Scenario, the improvement is not expected to be all the way to the level of the red line, because flow is just one of the factors influencing ecological condition at the sites.

Table 3.8 Seasonal distribution and the distribution between high and lowflows for the High Environment scenario

	Site 1	*Site 2*	Site 3	*Site 4*	Site 6	Site 7	Site 8	Site 9
MAR (MCM)	102.0	***604.4***	206.0	***733.8***	953.1	50.3	105.0	1241.5
WSLF - Volumes (MCM)	30.1 - adjusted to 29.3	***278.0***	96.0	***388.0***	368.6	25.5	40.3	574.0
DSLF - Volumes (MCM)	56.4 - adjusted to 54.7	***262.0***	86.0	***242.0***	413.8	12.5	1.6	498.6
Class 1 - Annual Frequency	5	***2***	0	***2***	0	1	7	0
Class 2 - Annual Frequency	3	***3***	0	***3***	2	4	4	1
Class 3 - Annual Frequency	3	***2***	3	***3***	2	3	2	2
Class 4 - Annual Frequency	1	***4***	3	***3***	4	3	0	2
1:2	P	***P***	P	***P***	P	P	P	P
1:5	P	***P***	P	***P***	P	P	P	P
1:10	P	***P***	P	***P***	P	P	P	P
1:20	P	***P***	P	***P***	A	P	P	P

3.3.6 Assumptions used for climate change

Two sets of data were used in the climate change scenarios (Scenarios 6-10). The first was generated by the Climate Change specialist report (Mkhandi *et al.* 2007;

Task 6). This was used for Scenario 6: Present Day with Climate Change. In this scenario, the naturalized runoff sequences (water available in the rivers) were generated by modifying rainfall sequences and evaporation averages with percentage adjustments from the climate change study (Table 3.9), using the estimates for the 2020-2029 period. In Table 3.9 decreases from present day are highlighted in yellow and increases in light blue. Missing change estimates for June (blank in Table 3.9) were patched by interpolation between May and July, and white blocks with numbers indicate uncertain results.

Table 3.9 **Simulated monthly rainfall in the Pangani Basin as percent changes from natural.** Yellow blocks show a decrease from present day, blue blocks an increase, white blocks uncertain results and white blocks with no numbers were interpolated. Values for empty boxes were interpolated (see text). (Mkhandi *et al.* 2007)

Station	Catchment/ Location		Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1dd55	Kikuletwa	Kikuletwa at Karangai	2020s	-3.3	44.1	6.7	-1.8	-0.2	-8.9	-27.6	88.7	132.5	-66.4	-1.8	7.2
			2050s	-19.5	43.9	-14.7	0.8	-2.3	-30.2	-12.8	91.9	159.3	-100	-13.2	1.1
			2080s	-33.5	35.1	-4.8	-2.4	-0.4	-36.9	2.5	75.1	168.7	-100	-45.8	-8.0
1dd54		Kikuletwa at Powerstation	2020s	2.6	5.4	18.2	0.8	-20.5	9.2	-5.9	-16.1	7.2	11.8	-11.6	16.5
			2050s	-65.1	-10.3	2.7	3.3	-14.8	24.3	13.0	-65.8	-30.5	-46.0	-25.1	4.5
			2080s	-90.9	13.6	16.4	-3.2	-16.9	10.8	-14.4	-100	-10.3	-44.2	-63.7	8.0
1dd1		Kikuletwa at TPC	2020s	1.2	67.8	-23.6	4.9	1.6	1.6	-27.7	13.8	-11.7	-100	-79.7	4.0
			2050s	-46.8	154.3	-18.5	10.7	-6.4	73.7	-51.8	19.4	32.6	-100	-100	-10.1
			2080s	-79.2	265.2	29.4	9.6	-11.1	6.7	-60.1	21.3	-39.3	-100	-100	-19.0
1dc11	Ruvu	Himo at Moshi-Himo Rd	2020s	-30.4	6.5	-6.7	-2.3	0.0	5.4	-3.3	-1.1	-0.3	-40.2	-37.4	9.8
			2050s	-100	-70.0	11.1	3.6	11.7	11.9	22.9	-2.2	-14.8	-43.0	-61.2	-10.5
			2080s	-100	-59.4	34.0	4.1	3.5	11.4	-2.4	-0.5	-14.5	-77.3	-99.7	-21.8
1dc1		Ruvu at Railway Bridge	2020s	-46.9	67.4	-9.0	-3.0	70.8	-32.5	0.6	10.1	38.9	-40.5	-13.5	9.9
			2050s	-71.9	43.6	-45.2	-2.2	72.2	-42.6	0.8	15.2	15.2	-45.3	-21.2	-3.8
			2080s	-100	107.1	-36.0	1.1	78.0	-43.5	-18.8	13.8	-15.7	-48.6	-35.8	2.8
1dc2a		Ruvu at Tanga Rd Bridge	2020s	-19.2	39.8	11.5	0.8	15.2	3.5	24.8	10.3	24.3	42.5	-1.8	20.6
			2050s	-100	-67.6	8.2	7.5	25.0	10.9	36.0	-3.7	-69.7	45.5	-3.1	3.7
			2080s	-100	-41.4	0.8	8.4	33.5	4.7	59.8	-51.8	-100	144.0	-4.2	13.0
1d10	Pangani Mainstem	Pangani at Buiko	2020s	0.6	49.3	2.9	-8.9	8.9		68.7	20.7	26.7	-70.3	-3.3	-8.3
			2050s	-21.1	13.4	6.4	-4.1	16.7		40.5	0.5	14.4	-97.1	-18.5	-17.8
			2080s	-55.9	-6.8	7.3	-2.0	5.1		71.0	-13.6	13.8	-100	-40.3	-19.6
1d14		Pangani at Korogwe	2020s	25.5	11.1	-1.1	7.0	-12.7		7.9	7.8	115.6	-32.5	9.6	-20.6
			2050s	48.0	11.1	-5.3	-0.7	-6.4		32.6	72.2	166.1	-37.0	2.3	-21.2
			2080s	63.8	9.3	-11.4	6.2	-2.7		-14.9	74.4	192.5	-51.3	-15.2	-21.5
1d17		Pangani at Hale	2020s	1.4	260.1	13.3	5.7	-4.6		6.9	25.8	59.2	-23.0	8.7	-10.8
			2050s	-20.6	263.4	2.8	6.9	10.6		19.0	45.2	370.6	-25.6	2.2	-18.0
			2080s	-55.7	254.3	-18.9	17.1	37.4		-37.8	48.4	507.6	-36.7	-13.0	-19.7
1db2a	Mkomazi	Saseni at Gulutu	2020s	-47.2	35.3	16.9	-6.2	16.7	64.3	15.4	-1.0	14.1	-29.6	-6.0	-20.5
			2050s	8.6	14.9	7.9	6.0	5.9	72.6	22.0	-19.8	-12.3	-83.6	-29.9	-10.0
			2080s	-97.4	27.1	6.2	-2.2	7.3	186.4	18.7	-20.1	-9.5	-95.1	-61.3	-31.1
1db19		Soni at Soni	2020s	8.6	139.9	14.2	-5.8	-7.1		4.7	-11.7	119.9	-20.5	-7.2	8.1
			2050s	-15.1	159.6	7.0	2.0	-11.4		9.1	-20.4	67.6	11.0	-10.2	6.5
			2080s	-31.3	166.9	-14.1	-14.7	-0.1		7.2	-37.2	61.2	36.2	-14.0	3.7
1db18		Hingilili at Kiruka	2020s	-33.3	55.6	25.7	-9.6	-11.7		15.4	-1.0	14.1	-89.5	-48.9	-11.5
			2050s	61.1	54.1	14.4	1.4	-9.1		22.0	-19.8	-12.3	-100	-69.5	-21.9
			2080s	-22.5	51.1	26.8	-1.3	-16.6		18.7	-20.1	-9.5	-100	-100	-24.1
1db17		Mkomazi at Gomba	2020s	-8.8	147.8	20.3	8.6	-1.0		-16.9	-8.7	102.7	-22.6	-86.0	-28.6
			2050s	-51.3	172.5	15.1	7.0	-11.7		-15.4	-24.4	34.9	16.1	-100	-10.6
			2080s	-53.7	183.0	-6.9	5.4	-6.8		-10.7	-38.3	64.7	47.0	-100	-18.0
1da1	Luengera	Luengera at Korogwe	2020s	-21.3	29.0	-2.2	3.0	-3.5		2.9	-47.8	-29.1	-20.7	-5.4	-4.2
			2050s	-79.7	2.0	-9.1	4.9	-3.0		9.8	-27.3	-84.3	-29.0	-24.5	-11.5
			2080s	-83.0	12.1	-24.2	14.6	-2.2		5.1	6.1	-93.6	-83.8	-53.7	-12.3
1da3		Luengera at	2020s	8.5	17.1	-2.6	14.0	5.1		11.2	1.3	194.3	-12.5	-3.4	8.0

Station	Catchment/ Location		Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1dd55	Kikuletwa	Kikuletwa at Karangai	2020s	-3.3	44.1	6.7	-1.8	-0.2	-8.9	-27.6	88.7	132.5	-66.4	-1.8	7.2
			2050s	-19.5	43.9	-14.7	0.8	-2.3	-30.2	-12.8	91.9	159.3	-100	-13.2	1.1
			2080s	-33.5	35.1	-4.8	-2.4	-0.4	-36.9	2.5	75.1	168.7	-100	-45.8	-8.0
1dd54		Kikuletwa at Powerstation	2020s	2.6	5.4	18.2	0.8	-20.5	9.2	-5.9	-16.1	7.2	11.8	-11.6	16.5
			2050s	-65.1	-10.3	2.7	3.3	-14.8	24.3	13.0	-65.8	-30.5	-46.0	-25.1	4.5
			2080s	-90.9	13.6	16.4	-3.2	-16.9	10.8	-14.4	-100	-10.3	-44.2	-63.7	8.0
1dd1		Kikuletwa at TPC	2020s	1.2	67.8	-23.6	4.9	1.6	1.6	-27.7	13.8	-11.7	-100	-79.7	4.0
			2050s	-46.8	154.3	-18.5	10.7	-6.4	73.7	-51.8	19.4	32.6	-100	-100	-10.1
			2080s	-79.2	265.2	29.4	9.6	-11.1	6.7	-60.1	21.3	-39.3	-100	-100	-19.0
		Magoma	2050s	-14.9	41.0	-39.3	12.1	4.5		-6.9	35.4	212.3	-23.2	-6.5	12.1
			2080s	-30.8	49.0	-36.2	6.5	6.6		-12.1	6.3	228.5	-24.8	-10.8	26.2
Estuary			2020s	-30.4	11.7	-6.1	-10.0	4.0	10.6	18.1	-14.6	-26.3	-10.4	-3.4	-31.4
			2050s	101.5	11.6	-12.3	-7.3	20.5	-23.7	6.4	-22.6	-77.7	-11.3	-33.5	-38.3
			2080s	-31.4	8.9	-60.0	-18.8	49.1	-26.2	-4.2	-47.9	-64.7	-12.6	-47.5	-88.3

The UNDP, however, expressed concern over the accuracy of the results generated in that study and, therefore, additional scenarios were developed. Twenty and 30 percent declines in wet season rainfall were modeled and applied in order to test the sensitivity of activities in the catchment to decreases in rainfall. These data were used as input to Scenarios 7 and 9, and 8 and 10, respectively.

The reductions were applied as follows:

20% reduction: Rainfall reduced by 20% in November, December, March, April, May and June.

30% reduction: Rainfall reduced by 30% in November, December, March, April, May and June.

Additional climate change modeling is being undertaken, which may produce different results, and would require further analysis.

3.3.7 Assumptions used for upper catchment storage

The estimates of possible storage in the upper catchment that were incorporated into Scenario 11: Optimise PD (Agric with storage), were determined as follows:

- It was assumed that 50% of the dam/reservoir localities in the upper catchment identified in the Basin Situation Assessment Report could be developed.
- The capacity of each dam/reservoir was assumed to equal 1 MCM.

Thus for the Kikuletwa catchment, 56 MCM of storage was included in the model, and for the Ruvu catchment, 10 MCM of storage was included.

3.3.8 Assumptions used in social assessments

The affected population comprises the rural households in the basin that are potentially directly affected by the changes in irrigation water supply available to small-scale farmers, and the changes in the condition of the aquatic ecosystems of the Pangani River Basin.

The scenario analyses were conducted by estimating the state of things in the year 2025 after following a certain policy direction regarding the allocation of water between the environment and other uses. By 2025, the affected rural population in the Pangani River Basin can be expected to have increased by some 57% to almost 300 000 households. Over this time, there will have been changes in income, technology and preferences that are difficult to predict with any accuracy, but which would affect the demand for water and natural resources. The increasing population will also mean that more households will have to share limited resources. This makes it difficult to predict how income per household will change over time based on changes in one or two circumstances only – in this case irrigation water and aquatic natural resources.

While we have not accounted for other changes that will take place with inevitable development in the basin, these potential influences should be kept in mind when evaluating the outcomes of the alternative scenarios. Within the scope of this scenario planning exercise, it is simpler to evaluate the relative merits of alternative scenarios while holding as many factors constant as possible. Thus the results are presented in aggregate, to illustrate the expected total change in income from two kinds of activities only (agriculture and extraction of natural resources) and do not attempt to quantify how this will affect individual household incomes. If nothing else were to change, then the percentage change in overall net income to the affected area from these sources would provide a fair reflection of the percentage change in individual household income.

The livelihood strategies of most households tend to be mixed, with small-scale agriculture being the main source of livelihood of the majority of households, and with most engaging in a range of additional activities including the harvest of natural resources (see socio-economic assessment, this study). However, not all affected households will be affected in the same way, since varying proportions of these households in each zone make use of irrigation (e.g. via traditional furrows) or harvest natural resources from the river systems. The results present an average impact, but it should be borne in mind that these reflect a range of impacts on individual households that differ in the level of dependence on different livelihood sources.

Both tangible and intangible benefits from water use, the environment and employment opportunities are considered.

Tangible impacts can be measured in monetary terms, and include:

- Cash income from employment;
- Cash income from sale of agricultural surplus;
- Cash income from sale of harvested goods or their products; and
- The value of foods, medicines and raw materials harvested by the household for own use.

Intangible values are difficult to measure in monetary terms, and are considered using indices or scores. These include:

- Recreational benefits obtained from rivers
- Cultural and religious benefits obtained from rivers
- The sense of well-being gained or loss as a result of changed health and biodiversity of river systems (akin to "non-use value")

Each of these factors is influenced by a change in water allocation in the basin. The current status for most of these factors is understood for each of the socio-economic zones in the basin because of the baseline surveys that were done. The degree to which they would change for the better or worse under different scenarios is what is assessed here.

In the scenario analysis, the impact of change in resource abundance on use value is estimated using a series of response curves which predict the % change in value resulting from a % change in resource stocks, based on qualitative considerations of supply and demand.

The impact of a change in ecosystem quality on intangible values is expressed in terms of the way in which current utility derived from all sources would be affected. Current utility is taken as being 100. The impact of an environmental change depends on the degree to which aquatic ecosystems contribute to current recreational and spiritual well-being.

Overall change in well-being is expressed as a weighted sum of tangible and intangible values. The weighting used here is 80:20 for tangible and intangible value, respectively.

3.3.9 Assumptions used in economic assessments

The extraction of water from natural systems provides an input into economic production in the form of irrigation agriculture, mining, industry and domestic consumption. These activities generate income in the economy, which constitutes direct value added to the regional and national economy. Changes in the management of aquatic ecosystems affect the supply of water to the agricultural sector, water available for HEP generation, and the delivery of ecosystem services. These services include provisioning services (harvested natural resources), regulating services (e.g. water purification) and cultural services (e.g. recreation) of the ecosystem. In this study, impacts on all but the latter (cultural services) are estimated in terms of direct monetary impacts on the economy.

Change in the direct value added by these activities is estimated using the following assumptions:

- Agriculture: it is estimated that the response of commercial irrigation responds to a similar extent to small-scale agriculture in response to proportional changes in water supply. This is a simplistic assumption that requires further study.
- Natural resources: It is assumed that the direct value added is similar to the private value to households, since capital and labour costs are small.
- HEP: the marginal value of HEP production is the differential between the cost of production of HEP and the cost of production from alternative sources, and the marginal value decreases with increasing power output.
- Ecosystem services: It is assumed that values per unit area are similar to other African floodplain wetlands, and that the marginal value is constant. The latter is a simplistic assumption that requires further research.

3.4. Brief explanation of the scenarios

3.4.1 Scenario 1: Maximise Agriculture

The Maximise Agriculture scenario comprised the following (in order of priority):

- Full allocation of 2025 BHN and Urban/Industrial water demands to Arusha and Moshi.
- As much water as can be abstracted at a 75% level of assurance allocated to agriculture.
- The remaining water used to generate HEP.
- Environment received whatever water was left.

Thus in the upper catchment, the residual flows in the river (after agricultural abstraction, which meant that flow in the river ceased altogether at times) were available to the riverine ecosystem before they flowed into NyM.

Within the constraints of meeting demands to maximise agriculture, water not used in that way was released from NyM and Kalemawe dams to optimise HEP generation at the NyM, Hale and Pangani Falls HEP stations. Thereafter, the fluctuations in the level of NyM were calculated for input to the Lake FA Tool.

The resultant flows in the river, swamp and estuary were analysed to determine the environmental conditions that could be expected to result.

3.4.2 Scenario 2: Maximise HEP

The Maximise HEP scenario comprised the following (in order of priority):

- Full allocation of 2025 BHN and Urban/Industrial water demands to Arusha and Moshi.
- Abstraction for agriculture restricted, particularly in the upper catchment, in order to maximise the amount of water that could be released from NyM and Kalemawe dams for HEP generation. This water was released in a pattern as close as possible to optimum for the operation of the HEP stations.
- Water that could not be used for HEP generation was allocated to agriculture.
- Environment received whatever water was left.

Thus, in the upper catchment, the residual flows in the river were close to natural as most of the water was required for maximising storage in NyM to supply the downstream HEP plants.

Water was released from NyM and Kalemawe dams to optimise HEP generation at the NyM, Hale and Pangani Falls HEP stations. Thereafter, the fluctuations in the level of NyM were calculated for input to the Lake FA Tool.

The resultant flows in the river, swamp and estuary were analysed to determine the environmental conditions that could be expected to result.

3.4.3 Scenario 3: Optimise Present Day, with Agriculture (Optimise PD (Agric)).

The Optimise Present Day with Agriculture scenario comprised the following (in order of priority):

- Supply of water for BHN
- Supply of present day volumes of river flow in a revised pattern of flows to improve ecosystem condition, at river sites 1, 2, 3, 4, 6, 7, 8 and 9, and at Kirua Swamps and the estuary.
- Allocation of water to Arusha and Moshi towards (but not necessarily reaching) the 2025 Urban/Industrial demands.
- Remaining water abstracted at a 75% level of assurance for agriculture.
- The river flows (made up primarily of environmental flows) were used to generate HEP.

Environmental flow demands for optimal present day river conditions were met at all the river sites, Kirua Swamp and the estuary.

3.4.4 Scenario 4: Optimise Present Day with HEP (Optimise PD (HEP)).

The Optimise Present Day with HEP scenario comprised the following (in order of priority):

- Supply of water for BHN
- Supply of present day volumes of river flow in a revised pattern of flows to improve ecosystem condition, at river sites 1, 2, 3, 4, 6, 7, 8 and 9, and at Kirua Swamps and the estuary.
- Allocation of water to Arusha and Moshi towards (but not necessarily reaching) the 2025 Urban/Industrial demands.
- The river flows (made up primarily of environmental flows) were used to generate HEP.
- Any remaining water abstracted at a 75% level of assurance for agriculture.

Environmental flow demands for optimal present day river conditions were met at all the river sites, Kirua Swamp and the estuary.

3.4.5 Scenario 5: High Environment with Agriculture

The High Environment with Agriculture scenario comprised the following (in order of priority):

- Supply of water for BHN
- Supply of an increased volume of water in a pattern of flows for high environmental condition at river sites 1, 2, 3, 4, 6, 7, 8 and 9, and at Kirua Swamps and the estuary.
- Allocation of water to Arusha and Moshi towards (but not necessarily reaching) the 2025 Urban/Industrial demands.
- Any remaining water abstracted at a 75% level of assurance for agriculture.
- The river flows (made up primarily of environmental flows) were used to generate HEP.

Environmental flow demands for high environmental condition were met at all the river sites, Kirua Swamp and the estuary.

3.4.6 Scenario 6: Present Day with Climate Change (Climate Change).

The Present Day with Climate Change scenario comprised the following (in order of priority):

- Using the predicted changes in rainfall (Table 3.9), rainfall-runoff models used to predict change in flows in the rivers.
- Allocation of present day water demands for BHN, Urban and Industrial to Arusha and Moshi.
- Allocation of present day agricultural demands.
- Allocation towards present day HEP demands.
- Environment received whatever water was left.

3.4.7 Scenario 7: Maximise Agriculture with 20% Less Rainfall

The Maximise Agriculture with 20% Less Rainfall scenario comprised the following (in order of priority):

- Selecting 20% across the catchment reduction in wet season rainfall, rainfall-runoff models used to predict change in flows in the rivers.
- Allocation of 2025 BHN and Urban/Industrial water demands to Arusha and Moshi.

- Allocation towards 2025 agricultural demands.
- Allocation towards 2025 HEP demands.
- Environment received whatever water was left.

3.4.8 Scenario 8: Maximise Agriculture with30% Less Rainfall

The Maximise Agriculture with 30% Less Rainfall scenario comprised the following (in order of priority):

- Selecting 30% across the catchment reduction in wet season rainfall, rainfall-runoff models used to predict change in flows in the rivers.
- Allocation of 2025 BHN and Urban/Industrial water demands to Arusha and Moshi.
- Allocation towards 2025 agricultural demands.
- Allocation towards 2025 HEP demands.
- Environment received whatever water was left.

3.4.9 Scenario 9: Maximise HEP with 20% Less Rainfall

The Maximise HEP with 20% Less Rainfall scenario comprised the following (in order of priority):

- Selecting 20% across the catchment reduction in wet season rainfall, rainfall-runoff models used to predict change in flows in the rivers.
- Allocation of 2025 BHN and Urban/Industrial water demands to Arusha and Moshi.
- Abstraction for agriculture restricted, particularly in the upper catchment, in order to maximise the amount of water that could be released from NyM and Kalemawe dams for HEP generation. This water released in a pattern as close as possible to optimum for the operation of the HEP stations.
- Water that could not be used for HEP generation allocated to agriculture.
- Environment received whatever water was left.

3.4.10 Scenario 10: Maximise HEP with 30% Less Rainfall

The Maximise HEP with 30% Less Rainfall scenario comprised the following (in order of priority):

- Selecting 30% across the catchment reduction in wet season rainfall, rainfall-runoff models used to predict change in flows in the rivers.
- Allocation of 2025 BHN and Urban/Industrial water demands to Arusha and Moshi.
- Abstraction for agriculture restricted, particularly in the upper catchment, in order to maximise the amount of water that could be released from NyM and Kalemawe dams for HEP generation. This water was released in a pattern as close as possible to optimum for the operation of the HEP stations.
- Water that could not be used for HEP generation allocated to agriculture.
- Environment received whatever water was left.

3.4.11 Scenario 11: Storage upstream of NyM, with Maximise Agriculture

The Storage upstream of NyM, with Maximise Agriculture scenario comprised the following (in order of priority):

- Basic Human Needs
- Allocation of water for Urban/Industrial to Arusha and Moshi towards the 2025 demands.

- 56 MCM storage in the Kikuletwa catchment and 10 MCM storage in the Ruvu catchment to store some wet-season flows. As much water as can be abstracted at a 75% level of assurance allocated to agriculture.
- The remaining water used to generate HEP.
- Environment received whatever water was left.

3.4.12 Scenario 12: Storage downstream of NyM (Luengera), with Maximise HEP

The purpose of providing storage downstream of NyM (Luengera) is to supplement HEP flows that have been reduced by agricultural development in the upstream catchments. The scenario comprised the following (in order of priority):

- Basic Human Needs
- Allocation of water for Urban/Industrial to Arusha and Moshi towards the 2025 demands.
- In the upper basin: As much water as can be abstracted at a 75% level of assurance allocated to agriculture.
- In the lower basin: 20 MCM storage in the lower Luengera to regulate water for HEP. Abstraction for agriculture restricted, to increase the amount of water that is available for HEP generation.
- Environment received whatever water was left.

3.4.13 Scenario 13: Combination of storage upstream of NyM, with Maximise Agriculture AND storage downstream of NyM (Luengera), with Maximise HEP

The Combination of storage upstream of NyM, with Maximise Agriculture AND storage downstream of NyM (Luengera), with Maximise HEP scenario comprised the following (in order of priority):

- Basic Human Needs
- Allocation of water for Urban/Industrial to Arusha and Moshi towards the 2025 demands.
- In the upper basin: 56 MCM storage in the Kikuletwa catchment and 10 MCM storage in the Ruvu catchment to store some wet-season flows. As much water as can be abstracted at a 75% level of assurance allocated to agriculture.
- In the lower basin: 20 MCM storage in the lower Luengera to regulate water for HEP. Abstraction for agriculture restricted, to increase the amount of water that is available for HEP generation.
- Environment received whatever water was left.

3.4.14 Scenario 14: Mixed Benefits, which includes storage upstream and downstream of NyM

The Mixed Benefits scenario comprised the following (in order of priority):

- Basic Human Needs
- Allocation of water for Urban/Industrial to Arusha and Moshi towards the 2025 demands.
- In the upper basin: As much water as can be abstracted at a 75% level of assurance allocated to agriculture.
- In the lower basin: Supply of present day volumes of river flow in a revised pattern of flows to improve ecosystem condition at Kirua Swamps. Abstraction for agriculture restricted, to increase the amount of water that is available for HEP generation.
- Environment received whatever water was left.

3.4.15 Scenario 15: Optimise Present Day with Agriculture and Storage in the Upper Catchment

The Optimise Present Day with Agriculture and Storage scenario comprised the following (in order of priority):

- Basic Human Needs
- Supply of present day volumes of river flow in a revised pattern of flows to improve ecosystem condition at river sites 1, 2, 3, 4, 6, 7, 8 and 9, and at Kirua Swamps and the estuary.
- 56 MCM storage in the Kikuletwa catchment to store some wet-season flows.
- 10 MCM storage in the Ruvu catchment to store some wet-season flows.
- Allocation of water for Urban/Industrial to Arusha and Moshi towards the 2025 demands.
- Any remaining water abstracted at a 75% level of assurance allocated to agriculture.
- The river flows (made up primarily of environmental flows) were used to generate HEP.

4. INTERPRETATION OF SCENARIO OUTCOMES

4.1. Irrigation agriculture

For each scenario, the change in area (ha) under irrigation is presented as a lower and upper estimate.

4.2. Hydropower production

The change in hydropower production is provided in terms of MWh and value. The value of a decrease in power generation can be interpreted as the extra cost that would have to be incurred in order to meet current power outputs. The value of an increase can be interpreted as cost savings incurred by generating additional power requirements using HEP as opposed to alternative sources.

4.3. Hydrology

The residual flows in the river for each of the scenarios are summarized in the DRIFT summary tables (e.g., Addendum Table 1). These tables provide an indication of the expected MAR for each scenario plus an indication of the annual distribution of flows in terms of:

- volume of the wet-season lowflows;
- volume of the wet-season lowflows;
- number of intra-annual floods;
- number of extra annual floods.

If one of these scenarios becomes the chosen way forward, additional information is also available in the form of:

- lowflow flow duration curves
- flood timing, magnitude and duration,

This information will be needed to implement the agreed flows.

4.4. Environmental condition

4.4.1 Rivers and estuary

For each scenario, river and estuary condition is evaluated in two ways:

- estimated percentage changes from present day in the abundance, area or concentration of key indicators (Table 4.1);
- estimated change in overall ecological condition, relative to present day, using DRIFT-CATEGORY Integrity Scores (King *et al*. 2003). These scores provide an estimate of:
  - the shift in river condition from present day towards or away from natural;
  - the resultant estimated ecological category in a range A to F (Table 4.2)

Table 4.1 Indicators used for the predictions of biophysical change

Ecosystem component	Indicators	
Geomorphology	Riffles and rapids Pools Floodplain inundation	Fine sediments Coarse sediments Bank erosion
Water Quality	TSS/turbidity TDS/conductivity	Nutrients – phosphorus Nutrient – nitrogen Dissolved oxygen
Vegetation	Dry bank – trees Dry bank – herbs and shrubs Dry bank – grasses	Wet bank – trees Wet bank – herbs Wet bank – grasses & reeds
Aquatic invertebrates	Sensitive species	Tolerant species Pest Simuliidae
Fish	Clarias gariepinus	Synodoctylin, Tilapia Labeo, Barbus

Table 4.2 Ecological condition categories (DWAF 1999)

CATEGORY	DESCRIPTION
A	Unmodified, natural.
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.
C	Moderately modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred
E	The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.

4.4.2 Kirua Swamp

For each scenario, Kirua Swamp condition is evaluated in two ways:

- estimated percentage changes from present day in the abundance of fish and reeds;
- estimated change in annual inundation relative to present day. The assumption is that annual inundation of a portion of the wetland will re-establish function and support a near natural condition in that portion.

4.5. Societal well-being

The impact on local communities is assessed in terms of changes in well-being as a result of the changes in tangible and intangible benefits derived from the use of water and aquatic ecosystem resources. These changes are expressed as:

- change in household income from agriculture
- change in household income from natural resources

These values include subsistence and cash income and are summed to estimate overall change income.

All values are expressed as the aggregate for all households in the affected area. The overall value is expressed as a percentage change in overall household income, taking all other sources of household income into account. Note that the percentage change might not apply to individual households since, under an expanded population this value might be shared by more households.

Intangible impacts are expressed as the percentage change in overall recreational and spiritual well-being, taking other intangible sources of well-being into account.

4.6. Economic value

Changes in economic value are expressed as direct value added to the national economy in the case of agriculture and natural resources, and cost savings to the economy in the case of HEP and ecosystem services. These impacts have knock-on effects that are not estimated here. The knock-on effects of changes in HEP production can be of national significance, while the impacts of changes in natural resource production and ecosystem services might be only significant at a basin level. Agricultural production effects could be significant at a regional scale.

4.7. Order of discussion of results

It is difficult to compare eleven scenarios, particularly if each comprises slightly different variations on a theme. For this reason, the outcomes of the scenarios are presented in three groups, each of which addresses a different theme.

<u>Group 1: Effects of different sector allocations (Chapter 5)</u>. This group compares the outcomes of five scenarios, namely:

- Maximise Agriculture
- Maximise HEP
- Optimise Present Day, with Agriculture
- Optimise Present Day, with HEP
- High Environment, with Agriculture.

<u>Group 2: Effects of climate change (Chapter 6)</u>. This group compares the outcome for Present Day with modelled Climate Change with six scenarios, namely:

- Maximise Agriculture
- Maximise Agriculture, Less 20% Rainfall
- Maximise Agriculture, Less 30% Rainfall
- Maximise HEP
- Maximise HEP, Less 20% Rainfall
- Maximise HEP, Less 30% Rainfall

<u>Group 3: Effects of storage (Chapter 7)</u>. This group compares the outcomes of seven scenarios. The first two represent the main sectoral allocations, namely:

- Maximise Agriculture
- Maximise HEP

and the remaining five explore the effects of storage in various parts of the basin:

- Storage upstream of NyM, with Maximise Agriculture
- Storage downstream of NyM (Luengera), with Maximise HEP
- Combination of storage upstream of NyM, with Maximise Agriculture AND storage downstream of NyM (Luengera), with Maximise HEP
- Mixed Benefits, which includes storage upstream and downstream of NyM

- Optimise present day, with agriculture and storage

Because the present day situation is a reference point for the environmental and economic outcomes, a description of it is provided first in Chapter 2. The scenario groups are dealt with in Chapters 5 to 7.

5. EFFECTS OF DIFFERENT SECTORAL ALLOCATIONS

5.1. Group 1 scenarios

The following scenarios are considered and compared in this section (see Section 3.4):

- Maximise Agriculture
- Maximise HEP
- Optimise Present Day, with Agriculture
- Optimise Present Day, with HEP
- High Environment.

Further details for each scenario are provided in Appendix 2-6, respectively.

5.2. Hydrological implications

The hydrological implications of each of the five scenarios under consideration are summarised in Table 5.1.

Table 5.1 Summary of hydrological changes relative to present day

Scenario	Summary of hydrological changes relative to present day
Maximise Agriculture	• Drastic reduction in dry-season low flows particularly in the upper catchment and the Mkomazi River (Sites 1-4,7), with extended periods of no flow
Maximise HEP	• Slight reduction in dry-season low flows in upper catchment • Increased inundation of Kirua swamp • Increased lowflows in Lower Pangani River at the estuary
Optimise Present Day, with Agriculture	• Present-day flow volumes re-distributed so that temporal distribution more ecologically friendly • Low flows re-instated in upper catchment • Floods re-instated downstream of NyM • Increased inundation of Kirua swamp
Optimise Present Day, with HEP	• See Optimised Present Day, with Agriculture
High Environment	• Dry season flows re-instated in upper catchment. • Increased wet-season flows in lower catchment • Decreased dry-season flows in lower catchment • Increased frequency of small to medium floods through-out but mainly in lower catchment and Mkomazi River

5.3. Allocations to different sectors

The water allocations for urban, industrial, domestic and agriculture, and expected HEP production are provided in Table 5.2.

Table 5.2 Water allocations for urban, industrial, domestic and agriculture, and expected HEP production

Scenario	Urban, industrial and domestic	Irrigation (@ 75% assurance)	HEP
	Mm^3a^{-1}	Mm^3a^{-1}	MWh
Present Day	31.1	1 042	602 647
Maximise Agriculture	54.7	1 032[3]	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

5.4. Effects on irrigation agriculture

Despite a mild decrease in the absolute quantity of water supplied due to growth in domestic, urban and industrial demands, the area of small-scale irrigation would be higher then Present Day under the Maximise Agriculture scenario due to the assumed increase in efficiency that will have taken place in the interim. With the same assumed improvement in efficiency, the area irrigated decreases under the remaining scenarios 2 to 5 (Figure 5.1). The trend in commercial irrigation, such as for coffee, sugar and flowers, was assumed to be identical, though involving a fraction of the area.

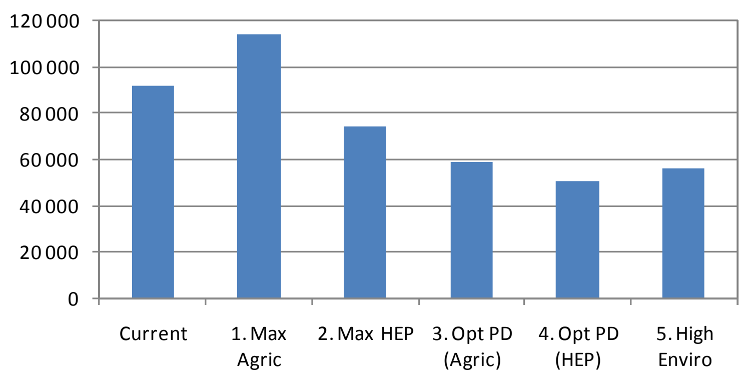


Figure 5.1 Area (ha) under small-scale irrigation under different sectoral allocations as compared with the present day

5.5. Effects on HEP production

HEP outputs decrease by about 30% under the Maximise Agriculture scenario, but are maintained or increased under the remaining scenarios. Outputs increase by about 30% under the Maximise HEP and Optimise Present Day (HEP) scenarios (Figure 5.2).

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.

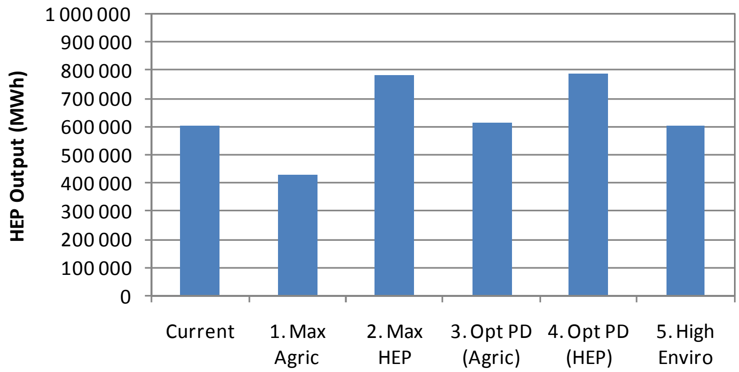


Figure 5.2 **Hydropower (HEP) output (MWh) under different sectoral allocations as compared with the present day**

5.6. Effects on environmental condition

5.6.1 Rivers

The three scenarios aimed at improving ecological condition of the system show that all sites attain some improvement with the exception of the Lower Pangani site. Under the Maximise Agriculture and Maximise HEP scenarios there is a large to moderate decline in condition respectively at most sites.

Table 5.3 **Changes in ecological integrity relative to Present Day for each of the river sites under each of the scenarios** (0 = present day; –ve = move away from natural; +ve = move towards natural; red = large decline in condition; orange = moderate decline in condition; light blue = moderate improvement in condition; darker blue = large improvement in condition).

River site	Max Agric	Max HEP	Optimised PD		High Environment
			With Agric	With HEP	
1	**-0.193**	-0.025	0.000		0.072
2	**-0.221**	-0.007	0.055		0.055
3	**-0.107**	-0.072	0.000		0.000
4	-0.061	-0.013	0.010		0.010
6	0.024	0.186	0.319		0.515
7	**-0.971**	**-0.474**	0.050		0.204
8	0.000	0.017	0.036		0.036
9	-0.049	0.068	0.000		0.000

5.6.2 Estuary

Change in health status of the various ecosystem components for the five scenarios are shown graphically in Figure 5.3 while actual scores are presented in Table 5.4. Effects on the different ecosystem components and overall health differ between scenarios with some clear trends evident (Figure 5.3, Table 5.4). These can be summarised as follows:

- Effects of the Maximise Agriculture scenarios are negative for all ecosystem components as well as for estuary health as a whole.
- Effects of the Maximise HEP are positive for most ecosystem components except geomorphology, and is positive for estuary health as a whole.

- Effects of Optimise Present Day with Agriculture or with HEP as well as of the High Environment scenario are positive for all ecosystem components, and are positive for estuary health as a whole.
- Of the three scenarios where environment is given highest priority, maximum benefit accrues to estuarine health under the Optimise Present Day with HEP scenario. This is true for all component ecosystem health parameters as well, aside from geomorphology where greater benefit accrues under the High Environment scenario.
- In order from high to low of the relative benefit of the five scenarios for estuarine health: Optimised Present Day with HEP is highest, followed by Maximise HEP, High Environment, Optimise Present Day with Agriculture and lastly Maximise Agriculture.

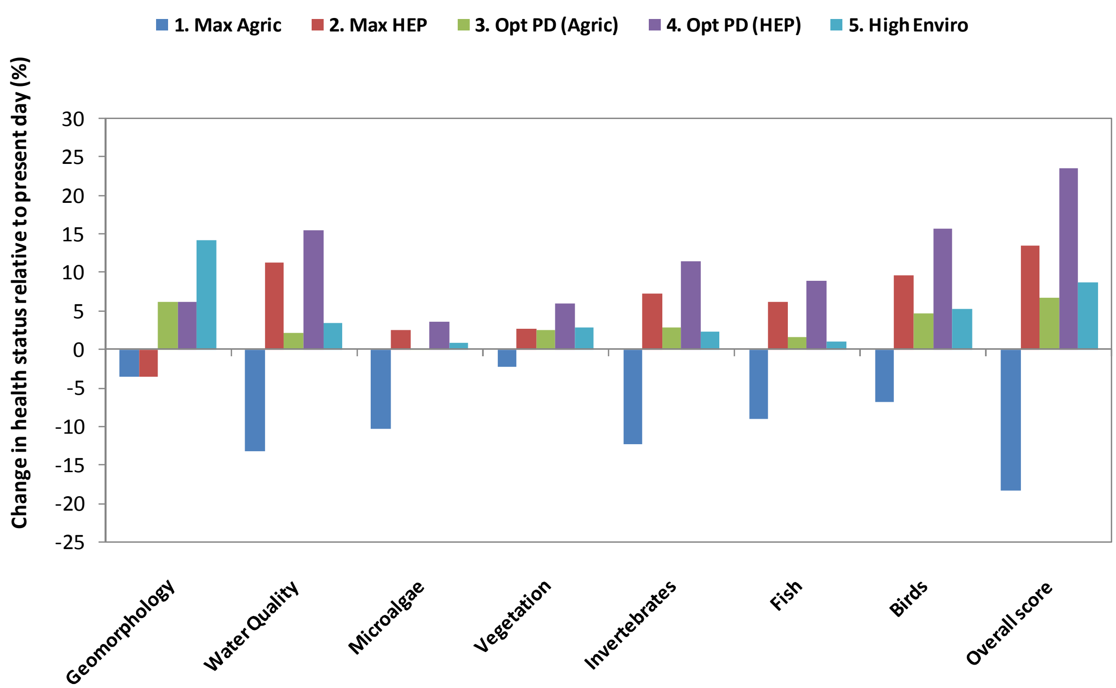


Figure 5.3 Change in health status relative to present day for all estuary ecosystem components under the five scenarios

Table 5.4. Percentage change in health status relative to Present Day for each of the estuarine ecosystem components under the five scenarios (0 = no change from present day; –ve = move away from natural; +ve = move towards natural; red = large decline in condition; orange = moderate decline in condition; light blue = moderate improvement in condition; darker blue = large improvement in condition)**.**

	Geo-morphology	Water Quality	Microalgae	Vegetation	Invertebrates	Fish	Birds	Overall % change in score
1. Max Agric	-3	**-13**	**-10**	-2	**-12**	-9	-7	-18
2. Max HEP	-3	11	3	3	7	6	10	14
3. Opt PD (Agric)	6	2	0	3	3	2	5	7
4. Opt PD (HEP)	6	15	4	6	12	9	16	24
5. High Enviro	14	4	1	3	2	1	5	9

5.7. Effects on livelihoods

5.7.1 Impacts on household income

Household income is affected by changes in income from agriculture and natural resources. These changes often move in opposite directions, thus dampening the impacts, but can also move in the same direction, exacerbating impacts. The overall impacts on household income in each of the socio-economic zones are summarised in Figure 5.4 as percentage change relative to the present day. Under the Maximise Agriculture scenario, there are increases in income in the highlands and in the Mesic Lowlands, but decreases in the other three zones. The Maximise HEP scenario results in decreases in income in all but the Estuary zone. Scenarios 3 to 5 result in the largest negative impacts on income in the upper zones (Highlands and Lakes), but generate some benefits in the lower zones. The Optimise Present Day (Agric) and High Environment scenarios result in significant increases in household income in the Pangani-Kirua zone, while Optimise Present Day (HEP) is the scenario most beneficial to households around the Estuary.

Overall impact is positive for the Maximise Agriculture scenario and is worst for the three environment-oriented scenarios, particularly the Optimise Present Day (HEP) scenario (Figure 5.4).

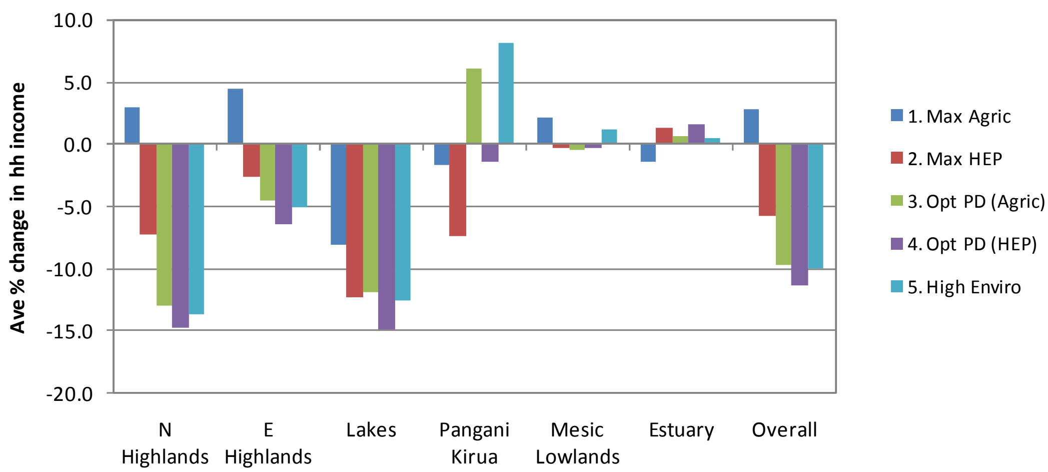


Figure 5.4 Percentage change in aggregate income to households within 5 km of rivers under different sectoral allocations as compared with the present day

5.7.2 Impacts on recreational and spiritual well-being

Recreational and spiritual well-being is affected most in the upper zones (Figure 5.5). The Maximise Agriculture scenario has very strong negative implications for utility in these zones. Maximise HEP has a positive impact in the highlands but has a very negative effect in the Lakes area. The environment-oriented scenarios Opt PD (Agric), Opt PD (HEP) and High Enviro lead to positive impacts in the Northern Highlands, but negative impacts at the Lakes. Impacts in the lower zones are minor.

Overall, impacts are positive under all but the Maximise Agriculture scenario, and are most positive under the High Environment scenario (Figure 5.5).

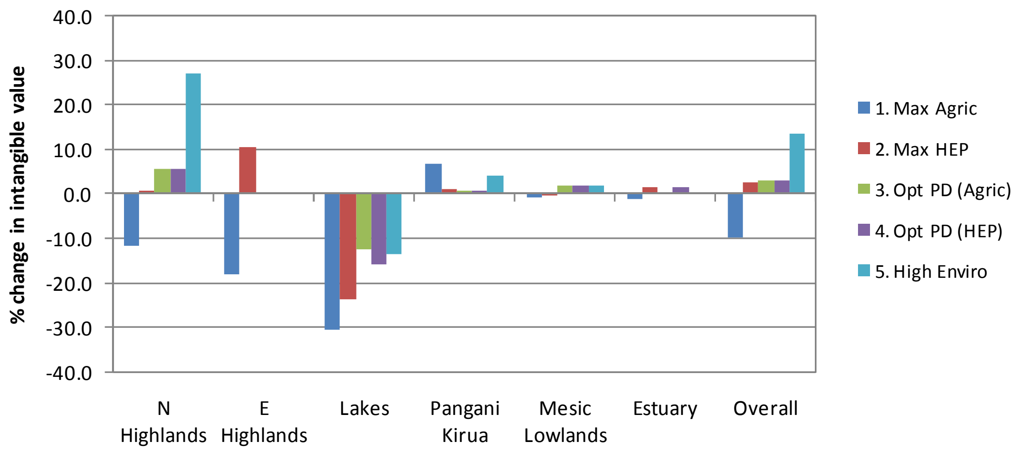


Figure 5.5 **Percentage change in recreational and spiritual well-being among households within 5 km of rivers under different sectoral allocations relative to a score of 100 for the present day**

5.7.3 Overall impacts on well-being

All five scenarios have a negative impact on overall well-being in the upper zones and variable but smaller impacts in the lower zones. Pangani-Kirua benefits under Opt PD (Agric) and Opt PD (HEP) scenarios. The overall impact is positive under Maximise Agriculture, and negative under all other scenarios, particularly the Optimise Present Day scenarios (Figure 5.6).

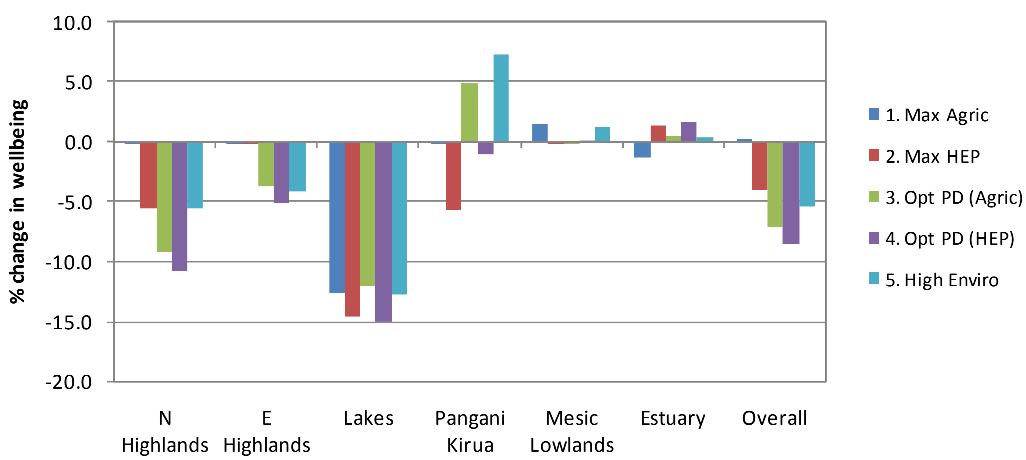


Figure 5.6 **Percentage change in overall well-being of households within 5 km of rivers under different sectoral allocations relative to a score of 100 for the present day**

5.8. Effects on economic value

Values generated by natural resources increase under the Maximise Agriculture and High Environment scenarios, and decrease under the HEP scenarios (Figure 5.7). The scenario Optimise Present Day (Agric) has little impact on natural resource values. There is a loss of value from ecosystem regulating services under Maximise

Agriculture, but all other scenarios improve the values generated by the wetlands and estuary. The changes in agricultural value are two orders of magnitude greater than the changes in values of ecosystem provisioning and regulating services. Overall impacts are positive under Maximise Agriculture, but there are large losses in agricultural value under all the other scenarios, particularly the environment-oriented scenarios. The changes in value of HEP production are two orders of magnitude greater than the changes in agricultural value. The Maximise Agriculture scenario generates loss of some Tsh 6 billion, whereas Maximise HEP generates gains in the order of Tsh 5 billion. It is important to note that the HEP benefits under the Optimise Present Day (HEP) scenario are almost as high as for the Maximise HEP one (Figure 5.7).

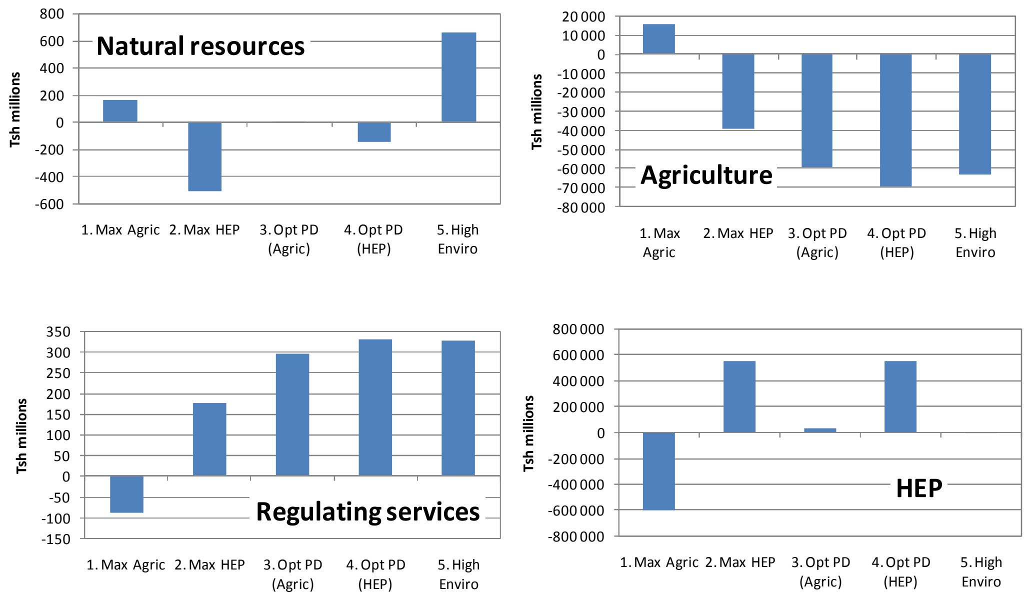


Figure 5.7 **Losses or gains in the value for the natural resources, agricultural and HEP sectors as well as in the value of ecosystem regulating services (water purification and nursery value for marine fisheries).**

5.9. Summary

Overall ecosystem integrity within the basin decreases under the Max Agric and very slightly under Max HEP, but improves under the Opt PD (Agric), Opt PD (HEP) and High Enviro scenarios. Social well-being is largely unchanged under Max Agric and declines under all other scenarios. Economic values generated by water and aquatic ecosystems decrease under Max Agric, Opt PD (Agric) and High Enviro, and increase under Max HEP and Opt PD (HEP). This is because the changes in the value of HEP are orders of magnitude larger than other economic impacts.

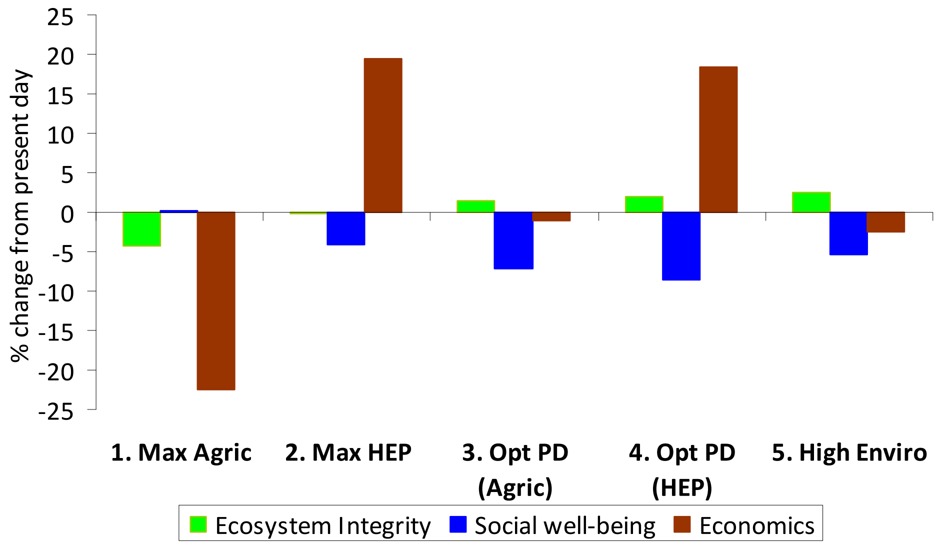


Figure 5.8 **Percentage change in ecosystem integrity, social well-being and economic value under five scenarios**

6. Impacts of climate change

6.1. Group 2 scenarios

The following eight scenarios are considered and compared in this section (see Section 3.7):

- Modelled Climate Change results imposed on Present Day, compared with Present Day with no climate change
- 20% and 30% wet-season rainfall reduction imposed on Maximise Agriculture scenario, compared with Maximise Agriculture with no reduction in rainfall
- 20% and 30% wet-season rainfall reduction imposed on Maximise HEP, compared with Maximise HEP with no reduction in rainfall.

Details for each of the climate change model results imposed on present day and the rainfall reduction scenarios are provided in Appendices 7-11.

6.2. Climate change model results imposed on Present Day

6.2.1 Hydrological implications

The hydrological implications of the Modelled Climate Change scenario are summarized in Table 6.1.

Table 6.1 Summary of hydrological changes relative to present day

Scenario	Summary of hydrological changes relative to Present Day
Modelled Climate Change	• Drastic reduction in dry-season low flows • Mainly decrease in intra-annual floods, but variable over the basin • Big floods significantly higher in frequency

6.2.2 Allocations to different sectors

The water allocation to urban, industrial, domestic and agriculture, and expected HEP production, are provided in Table 6.2.

Table 6.2 Water allocation to urban, industrial, domestic and agriculture, and expected HEP production

Scenario	Urban, industrial and domestic	Irrigation (@ 75% assurance)	HEP
	Mm^3a^{-1}	Mm^3a^{-1}	MWh
Present Day	31.1	1 042	602 647
Modelled Climate Change	54.7	1 0164	472 371

6.2.3 Effects on irrigation agriculture

Under this scenario, there are increases in all irrigated areas. In proportion to the current scenario, the most substantial is in the Mesic Lowlands. See Appendix 7.

4 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.

6.2.4 Effects on HEP production

HEP output is reduced to 78.4% of current output, resulting in an output of 472 371 MWh. See Appendix 7.

6.2.5 Effects on environmental condition

1.1.1.2 Rivers

Under the Modelled Climate Change scenario, there is a general trend of a large decline in river condition in the upper reaches, and a more moderate decline in the lower reaches. The Kirua Swamp area improves in condition due to increased variability in intra-annual floods and a more natural distribution of wet and dry season lowflows.

Table 6.3 Changes in ecological integrity relative to Present Day for each of the river sites under the Modelled Climate Change scenario (0 = present day; –ve = move away from natural; +ve = move towards natural; red = large decline in condition; orange = moderate decline in condition; light blue = moderate improvement in condition; darker blue = large improvement in condition).

River site	Modelled climate change
1	**-0.149**
2	**-0.227**
3	**-0.131**
4	-0.055
6	0.047
7	**-0.583**
8	-0.095
9	-0.044

1.1.1.3 Estuary

Change in health status of the various ecosystem components of the Pangani estuary are shown graphically in Figure 6.1 while actual scores are presented in Table 6.4. Impacts of flow changes under the Modelled Climate Change scenario on the estuary are negative for all components aside from geomorphology (due to a projected reduction in sediment supply) and also negative for the estuary as a whole. Projected change is not as severe as that projected for the Maximise Agriculture scenario, however. It must be remembered, though that these effects are independent and could thus be superimposed on one another (i.e. could be additive). This effect can be seen more clearly later in this chapter where the impacts on estuary health of maximising agriculture coupled firstly with a 20% reduction in rainfall and secondly with a 30% reduction in rainfall are examined (Figure 6.4, Table 6.8). This is then followed with a similar assessment of the impacts of maximising HEP under a 20% or 30% reduction in rainfall scenarios (Figure 6.5, Table 6.9).

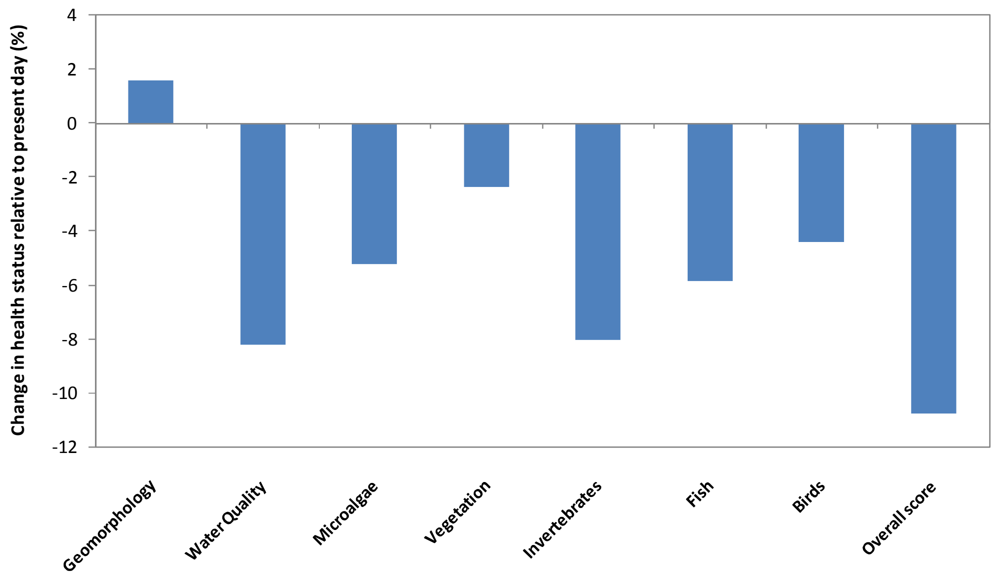


Figure 6.1 Change in health status relative to present day for all estuary ecosystem components under the Modelled Climate Change scenario.

Table 6.4 Health scores (as % of natural) for the estuary as a whole and the component parameters under the Modelled Climate Change scenario

	Present day	This scenario	Percentage change from PD (+/-)
Geomorphology	40%	41%	2%
Water Quality	53%	49%	-8%
Micro-algae	40%	38%	-5%
Vegetation	60%	59%	-2%
Invertebrates	60%	55%	-8%
Fish	50%	47%	-6%
Birds	40%	38%	-4%
Overall health score	57%	51%	-11%

6.2.6 Effects on livelihoods

See Appendix 7.

6.2.7 Effects on economic value

See Appendix 7.

6.2.8 Summary

Under the climate change scenario there is a 3.3% loss in overall ecosystem integrity, a 0.1% gain in societal well-being, and a 16.6% loss in the economic values considered.

6.3. Impacts of rainfall reduction

6.3.1 Hydrological implications

The hydrological implications of each of the five scenarios under consideration are summarized in Table 5.1.

Table 6.5 Summary of hydrological changes relative to present day

Scenario	Summary of hydrological changes relative to present day
Maximise Agriculture	• Drastic reduction in dry-season low flows particularly in the upper reaches and the Mkomazi River (Sites 1-4,7), with extended periods of no flow
Maximise Agriculture – less 20%	• 30-60% reduction in wet-season low flows in all rivers except Luengera River; no-flow conditions common • Drastic reduction in dry-season low flows particularly in the upper reaches and the Mkomazi River (Sites 1-4,7), with extended periods of no flow • General reduction in intra-annual floods, except at Site 6 (Pangani at Kirua), where there is an increase in intra-annual floods
Maximise Agriculture – less 30%	• Similar trends to those reported for Maximise Agriculture less 20%, but slightly more extreme
Maximise HEP	• Slight reduction in dry-season low flows in upper reaches • Increased inundation of Kirua swamp • Increased low flows in Lower Pangani River and the estuary
Maximise HEP – less 20%	• 20-30 % reduction in wet-season low flows in upper reaches • Low flows at Pangani at Kirua are similar to present day • Dry-season low flows elevated at Sites 1, 2, 7, 8, 9 • Increased intra-annual floods in general over all rivers
Maximise HEP – less 30%	• Similar trends to those reported for Maximise HEP less 20%, but slightly more extreme

6.4. Allocations to different sectors

The water allocation to urban, industrial, domestic and agriculture, and expected HEP production, are provided in Table 6.6.

Table 6.6 Water allocation to urban, industrial, domestic and agriculture, and expected HEP production

Scenario	Urban, industrial and domestic	Irrigation (@ 75% assurance)	HEP
	Mm^3a^{-1}	Mm^3a^{-1}	MWh
Present Day	31.1	1 042	602 647
Maximise Agriculture	54.7	1 032[5]	428 134
Maximise Agriculture – less 20%	54.7	873	225 815
Maximise Agriculture – less 30%	54.7	807	141 347
Maximise HEP	54.7	634	782 601
Maximise HEP – less 20%	54.7	286	755 227
Maximise HEP – less 30%	54.7	203	614 810

6.4.1 Effects on irrigation agriculture

Despite a decrease in the absolute quantity of water supplied, irrigation area increases under the Maximise Agriculture scenario due to the assumed increase in efficiency of water use that will have taken place in the interim. Irrigation area also

[5] 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.

increases under scenarios 7 and 8 (Maximise Agriculture with 20% and 30% reductions in rainfall), although the increase is smaller due to the reduction in available water (Figure 6.2). Increased irrigation efficiency is also assumed in the HEP scenarios, but the reduction in water availability leads to a reduction in irrigation area in all HEP scenarios, the degree of reduction increasing dramatically as rainfall decreases (Figure 6.2).

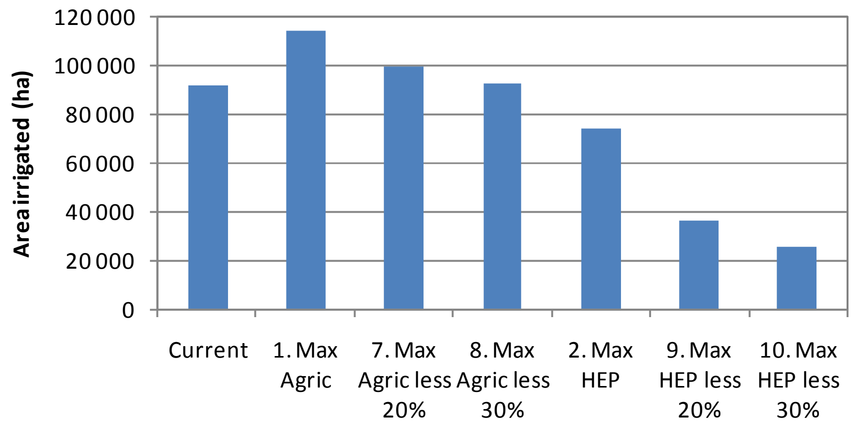


Figure 6.2 Area (ha) under small-scale irrigation under the Maximise Agriculture and Maximise HEP scenarios with current and two levels of reduced rainfall, as compared with the Present Day

6.4.2 Effects on HEP production

HEP outputs decrease by about 30% under the Maximise Agriculture scenario, and are further decreased under the two Maximise Agriculture scenarios with reduced rainfall. Outputs increase by about 30% under the Maximise HEP scenarios, but the increase is smaller in the two reduced rainfall scenarios, with the result that, under Maximise HEP less 30%, output is similar to present (Figure 6.3).

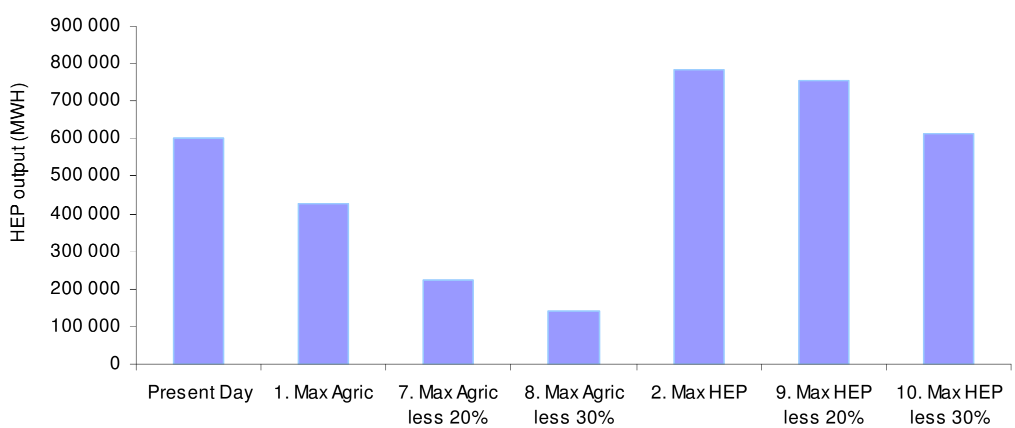


Figure 6.3 Hydropower (HEP) output (MWh) under six scenarios prioritising agriculture or HEP compared with Present Day

6.4.3 Effects on environmental condition

1.1.1.4 Rivers

The four scenarios with climate change included show the greatest deterioration in river condition, with the Maximised HEP scenario showing the least. The Kirua Swamps area shows some improvement in most scenarios.

Table 6.7 Changes in ecological integrity relative to Present Day for each of the river sites under each of the scenarios (0 = present day; –ve = move away from natural; +ve = move towards natural; red = large decline in condition; orange = moderate decline in condition; light blue = moderate improvement in condition; darker blue = large improvement in condition).

River site	Max Agric	Max Agric – less 20%	Max Agric – less 30%	Max HEP	Max HEP – less 20%	Max HEP – less 30%
1	**-0.193**	**-0.587**	**-0.726**	-0.025	**-0.383**	**-0.470**
2	**-0.221**	**-0.558**	**-0.610**	-0.007	**-0.266**	**-0.337**
3	**-0.107**	**-0.155**	**-0.412**	-0.072	**-0.205**	**-0.275**
4	-0.061	**-0.274**	**-0.289**	-0.013	**-0.239**	**-0.276**
6	0.024	**-0.204**	**-0.377**	0.186	0.165	0.056
7	**-0.971**	**-1.124**	**-1.143**	**-0.474**	**-0.311**	**-0.148**
8	0.000	**-0.509**	**-0.663**	0.017	**-0.467**	**-0.500**
9	-0.049	**-0.200**	**-0.388**	0.068	0.059	-0.009

1.1.1.5 Estuary

Maximising agricultural potential in the Pangani catchment under a 20% and a 30% reduction in rainfall clearly will have very severe impacts on the estuary. Under the Maximise Agriculture scenario coupled with a 20% reduction in rainfall, estuary health declines by 41% and by a further 4% (total reduction in health = 45%) under a 30% reduction in rainfall relative to the present day. In terms of a change in health class this represents a change from a highly modified system (D class) to a highly degraded system (E class) for both scenarios. Overall health score under the Maximise Agriculture with 20% less rainfall drops to 34% from the present day 57%, and to 32% under the Maximise Agriculture less 30% (Figure 6.4; Table 6.8).

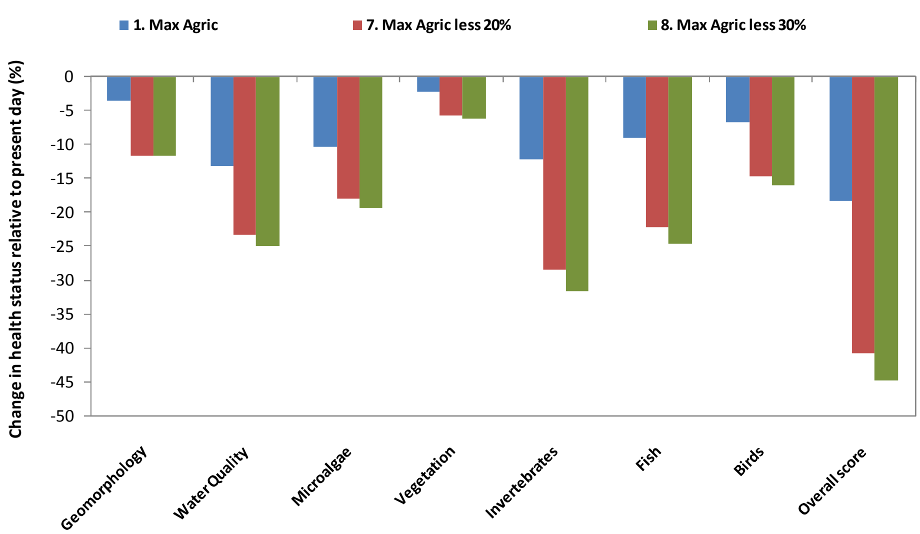


Figure 6.4 Change in health status relative to present day for all estuary ecosystem components under the Maximise Agriculture, Maximise Agriculture less 20% Rainfall and Maximise Agriculture less 30% Rainfall

Table 6.8 Change in health scores for all estuary ecosystem components under the Maximise Agriculture, Maximise Agriculture less 20% Rainfall and Maximise Agriculture less 30% Rainfall scenarios

	Maximise Agriculture	Maximise Agriculture less 20%	Maximise Agriculture less 30%
Geomorphology	-3	-12	-12
Water Quality	-13	-23	-25
Microalgae	-10	-18	-19
Vegetation	-2	-6	-6
Invertebrates	-12	-28	-32
Fish	-9	-22	-25
Birds	-7	-15	-16
Overall % change in score	-18	-41	-45

Maximising HEP potential in the Pangani catchment under a 20% and a 30% reduction in rainfall is much less costly than maximising agricultural potential in terms of environmental impacts on the estuary. Under the Maximise HEP scenario coupled with a 20% reduction in rainfall estuary health actually improves marginally from the present day (2% increase) while no change from present day is expected under the Maximise HEP coupled with a 30% reduction in rainfall scenario (Figure 6.5, Table 6.9).

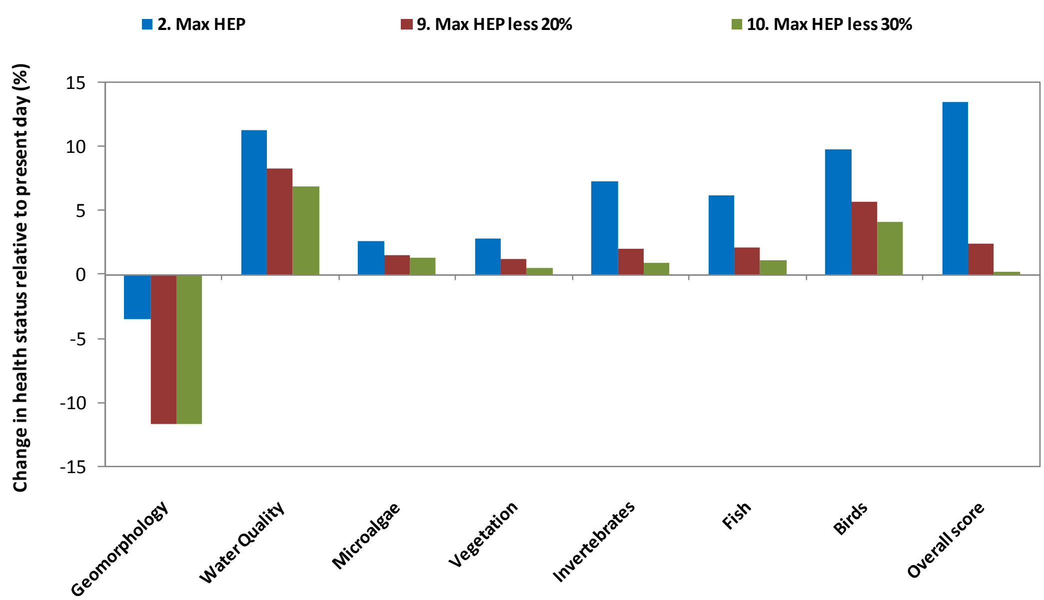


Figure 6.5 Change in health status relative to present day for all estuary ecosystem components under the Maximise HEP, Maximise HEP less 20% Rainfall and Maximise HEP less 30% Rainfall scenarios

Table 6.9 Change in health scores for all estuary ecosystem components under the Maximise HEP, Maximise HEP less 20% Rainfall and Maximise HEP less 30% Rainfall scenarios

	Maximise Hydropower	Maximise Hydropower less 20%	Maximise Hydropower less 30%
Geomorphology	-3	-12	-12
Water Quality	11	8	7
Microalgae	3	2	1
Vegetation	3	1	1
Invertebrates	7	2	1
Fish	6	2	1
Birds	10	6	4
Overall % change in score	14	2	0

6.4.4 Effects on livelihoods

1.1.1.6 Impacts on household income

Household income is affected by changes in income from agriculture and natural resources. These changes often move in opposite directions, thus dampening the impacts, but can also move in the same direction, exacerbating impacts. The overall impacts on household income in each of the socio-economic zones are summarised as percentage change relative to the present day.

Under the Maximise Agriculture scenario, there are increases in income in the highlands and in the Mesic Lowlands, but decreases in the other three zones. Maximising HEP results in reduced income in all but the Estuary zone. The scenarios with decreased rainfall worsen the impacts in all zones apart from the Mesic Lowlands, where there is a very slight increase in income the HEP scenarios with reduced rainfall. In the upper zones, and in the basin overall, the Maximise Agriculture scenarios are better than Maximise HEP scenarios, even with reduced rainfall (Figure 6.6).

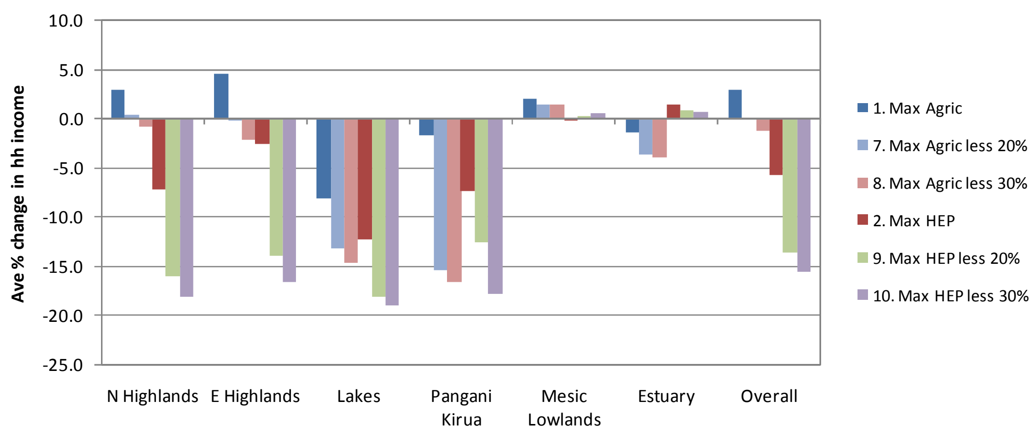


Figure 6.6 Percentage change in aggregate income to households within 5 km of rivers under Maximise Agriculture and Maximise HEP scenarios with current and reduced rainfall, as compared with the Present Day

1.1.1.7 Impacts on recreational and spiritual well-being

The Maximise Agriculture scenario has negative implications for utility of the river system in the upper zones and estuary, and slightly positive implications in the Pangani-Kirua zone (Figure 6.7). The Maximise HEP scenario has a positive impact in the highlands but has a very negative effect in the Lakes area and little impact in the lower zones. The reduced rainfall scenarios tend to exacerbate the impacts in the same directions, with the exception of Pangani-Kirua, where the impact of Maximise Agriculture becomes very strongly negative under reduced rainfall scenarios.

Overall, the Maximise HEP scenarios are all positive, whereas the Maximise Agriculture scenarios are all negative (Figure 6.7).

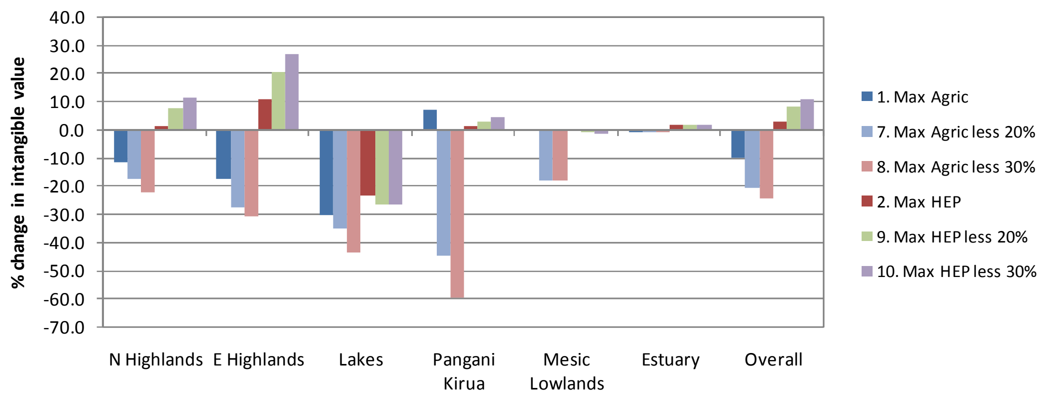


Figure 6.7 Percentage change in recreational and spiritual well-being among households within 5 km of rivers under the Maximise Agriculture and Maximise HEP scenarios with current and reduced rainfall, relative to a score of 100 for the present day

1.1.1.8 Overall impacts on well-being

All six scenarios have a negative impact on overall well-being in all zones apart from the Mesic Lowlands, where the Maximise Agriculture scenario is positive, and the Estuary, where all HEP scenarios have a positive impact. Overall, the reduced rainfall scenarios result in negative, rather than slightly positive impacts, and exacerbate the already negative impacts of the HEP scenario (Figure 5.7).

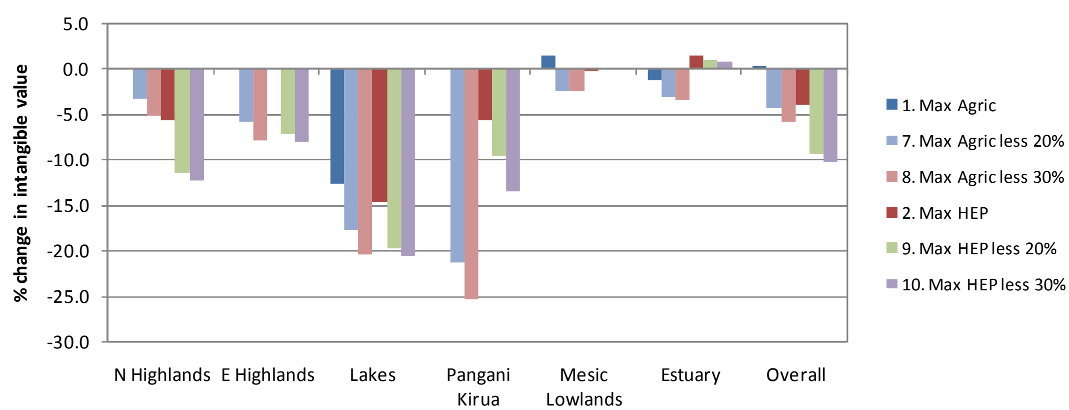


Figure 6.8 Percentage change in overall well-being of households within 5 km of rivers under the Maximise Agriculture and Maximise HEP scenarios with current and reduced rainfall, relative to a score of 100 for the present day

6.4.5 Effects on economic value

Values generated by natural resources increase under the Maximise Agriculture scenario, and these benefits increase under scenarios with reduced rainfall. The value of natural resources decreases under the HEP scenario, but the impact is smaller and becomes positive under the reduced rainfall scenarios (Figure 6.9). There is a loss of value from ecosystem regulating services under Maximise Agriculture, and this is exacerbated under reduced rainfall scenarios. The benefit under Maximise HEP is reduced, becoming slightly negative with reduced rainfall.

The changes in agricultural value are two orders of magnitude greater than the changes in values of ecosystem provisioning and regulating services. Overall impacts are positive under Maximise Agriculture, but decrease to a negative impact with decreasing rainfall. The loss of agricultural production under Maximise HEP becomes more severe under reduced rainfall scenarios. The changes in value of HEP production are two orders of magnitude greater than the changes in agricultural value. The Maximise Agriculture generates loss of some Tsh 6 billion, whereas the Maximise HEP one generates gains in the order of Tsh 5 billion. Under reduced rainfall scenarios, the losses under Maximise Agriculture could be tripled, and the gains under Maximise HEP can be reduced to very small gains from present (Figure 6.9).

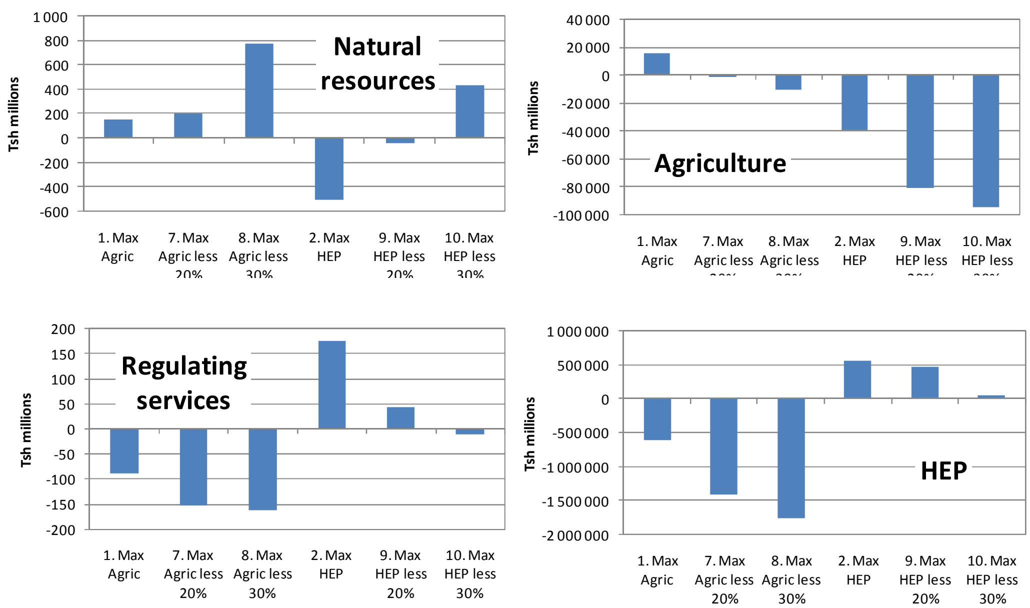


Figure 6.9 **Losses or gains in the value for the natural resources, agricultural and HEP sectors as well as in the value of ecosystem regulating services (water purification and nursery value for marine fisheries).**

6.4.6 Summary

Ecosystem integrity decreases under all the scenarios considered (Figure 6.10). The decreases are lower under HEP than Agric scenarios and are exacerbated under the reduced rainfall scenarios. Societal well-being follows a similar pattern, except that it is more reduced under HEP than Agric scenarios. Economic outputs also decrease with decreasing rainfall, but they are positive under the HEP scenarios except when rainfall is decreased by 30%.

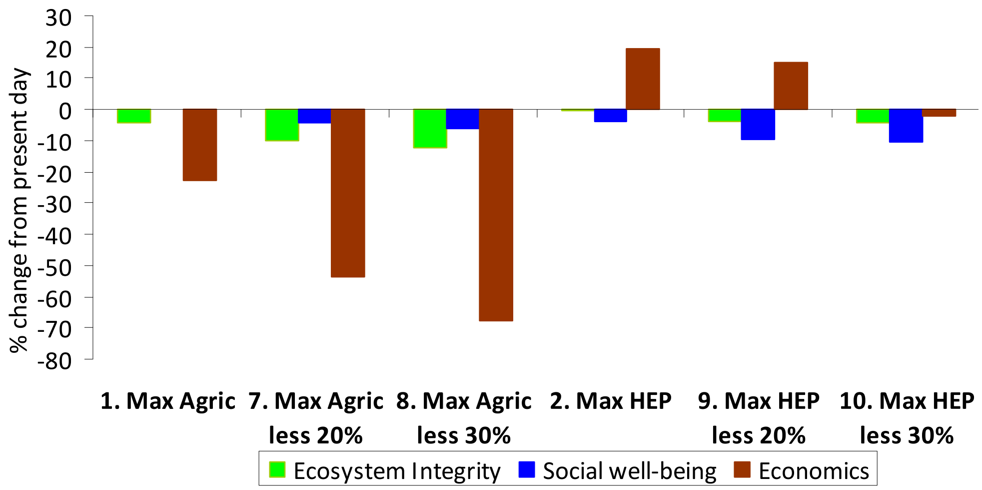


Figure 6.10 Percentage change in overall ecosystem integrity, societal well-being and the economic values considered under each scenario.

7. Impacts of additional storage in the basin

7.1. Group 3 scenarios

This chapter considers and compares five scenarios, all of which involve some additional storage somewhere in the basin, namely:

- Storage upstream of NyM, with Maximise Agriculture
- Storage downstream of NyM (Luengera), with Maximise HEP
- Combination of storage upstream of NyM, with Maximise Agriculture AND storage downstream of NyM (Luengera), with Maximise HEP
- Mixed benefits, which includes storage upstream and downstream of NyM
- Storage upstream of NyM, with Optimise Present Day

Details for each individual scenario are in Appendices 12-16.

The scenarios are also compared with:

- Maximise Agriculture
- Maximise HEP.

7.2. Hydrological implications

The hydrological implications of each of the seven scenarios under consideration are summarised in Table 7.1.

7.3. Allocations to different sectors

The water allocations for urban, industrial, domestic and agriculture, and expected HEP production are provided in Table 7.2.

7.4. Effects on irrigation agriculture

Despite a mild decrease in the absolute quantity of water supplied due to growth in domestic, urban and industrial demands, the area under irrigation would be 24% higher than Present Day under the Maximise Agriculture scenario (113 870 ha compared with 91 470 ha at present) due to the assumed 30% increase in efficiency that will have taken place in the interim. With the same assumed improvement in efficiency, the area irrigated remains similar to the Maximise Agriculture scenario under four of the five new scenarios (11-14; Figure 7.1). Under scenario 15, agricultural area is reduced to 69% of present area, which is less than under the Maximise Hydropower scenario.

Table 7.1 Summary of hydrological changes relative to present day

Scenario	Summary of hydrological changes relative to present day
Maximise Agriculture	• Drastic reduction in dry-season low flows particularly in the upper catchment and the Mkomazi River (Sites 1-4,7), with extended periods of no flow
Maximise HEP	• Slight reduction in dry-season low flows in upper catchment • Increased inundation of Kirua swamp • Increased lowflows in Lower Pangani River at the estuary
Storage upstream of NyM, with Maximise Agriculture	• Drastic reduction in dry-season low flows particularly in the upper catchment and the Mkomazi River (Sites 1-4,7) (similar to Maximise Agriculture); very little change in floods • Reduced inundation of Kirua swamp (*c.* 25% of PD)

Scenario	Summary of hydrological changes relative to present day
Storage downstream of NyM (Luengera), with Maximise HEP	• Drastic reduction in dry-season low flows particularly in the upper catchment and the Mkomazi River (Sites 1-4,7) (similar to Maximise Agriculture); very little change in floods • Increased dry season lowflows in the Luengera • Increased inundation of Kirua swamp (3 x PD), similar to Maximise HEP • Decreased lowflows and floods in the Lower Pagani and estuary
Combination of storage upstream of NyM, with Maximise Agriculture AND storage downstream of NyM (Luengera), with Maximise HEP	• Drastic reduction in dry-season low flows in the upper catchment and the Mkomazi River (Sites 1-4,7) (very similar to Maximise Agriculture); very little change in floods • Increased dry season lowflows in the Luengera (same as Storage downstream of NyM (Luengera), with Maximise HEP) • Increased inundation of Kirua swamp (2 x PD)
Mixed benefits, which includes storage up-stream and down-stream of NyM	• Drastic reduction in dry-season low flows particularly in the upper catchment and the Mkomazi River (Sites 1-4,7) (similar to Maximise Agriculture); very little change in floods • Increased inundation of Kirua swamp (5 x PD) • Increased dry season lowflows in the Luengera (same as Storage downstream of NyM (Luengera), with Maximise HEP)
Storage upstream of NyM, Optimise Present Day	• Present-day flow volumes re-distributed so that temporal distribution more ecologically friendly • Low flows re-instated in upper catchment • Floods re-instated downstream of NyM • Increased inundation of Kirua swamp

Table 7.2 Water allocations for urban, industrial, domestic and agriculture, and expected HEP production

Scenario	Urban, industrial and domestic	Irrigation (@ 75% assurance)	HEP
	Mm^3a^{-1}	Mm^3a^{-1}	MWh
Present Day	31.1	1 042	602 647
Maximise Agriculture	54.7	1 032[6]	428 134
Maximise HEP	54.7	634	782 601
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

[6] 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.

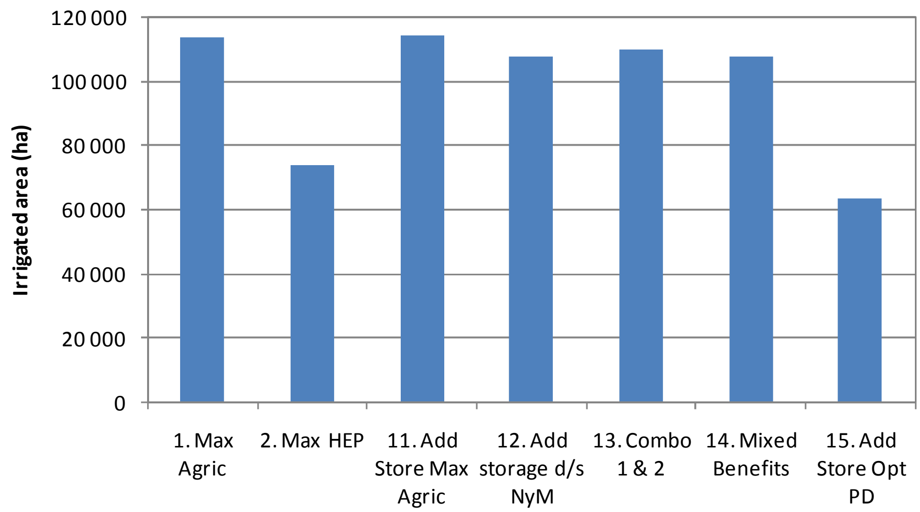


Figure 7.1 **Area (ha) under small-scale irrigation for the different storage options as compared with the present day**

7.5. Effects on HEP production

HEP outputs for the different storage options tend to be comparable with the Maximise Agriculture scenario, in which output is reduced by 30%. The reduction is less severe under scenarios 12 and 13, and under scenario 15 current outputs are not only maintained but slightly improved upon (Figure 7.2). The increase under scenario 15 is not as great as under the Maximise Hydropower scenario, however.

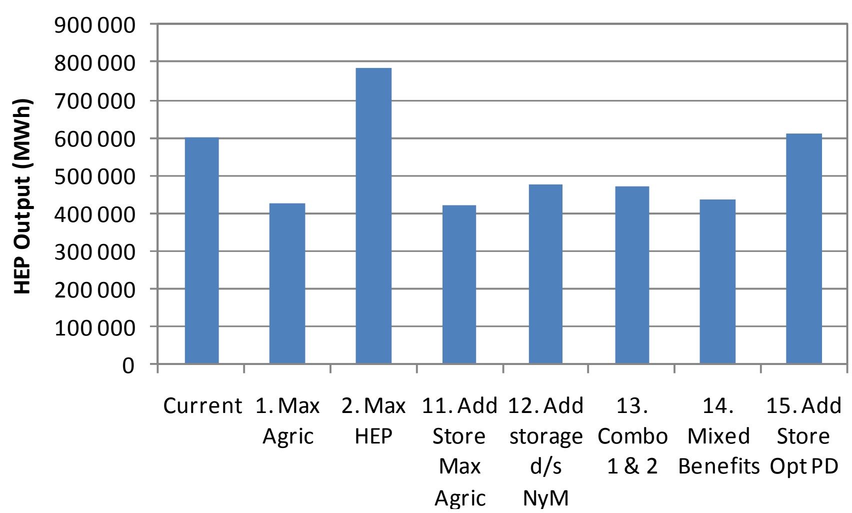


Figure 7.2 **Hydropower (HEP) output (MWh) for the different storage options as compared with the present day**

7.6. Effects on environmental condition

7.6.1 Rivers

Of the five additional scenarios, only Mixed Benefits and Storage u/s NYM with Optimise Present Day have any benefit for the environment (Table 7.3). In the case of Mixed Benefits, this benefit is limited to improved conditions in the Kirua Swamp, but this is less than already reported for Max HEP. The Storage u/s NYM with Optimise Present Day resulted in moderate benefits at most other sites, and a considerable improvement at Kirua Swamp. Under the remaining scenarios there is a large to moderate decline in condition across most sites, the exception being slight improvements at Kirua Swamps for Storage u/s NYM with Maximise Agriculture and Combination of u/s storage with maximise Agriculture and d/s storage with maximize HEP.

Table 7.3 Changes in ecological integrity relative to Present Day for each of the river sites under each of the scenarios (0 = present day; –ve = move away from natural; +ve = move towards natural; pink = low decline in condition; orange = moderate decline in condition; red = large decline in condition; light blue = low improvement in condition; dark blue = moderate improvement in condition).

SITE	Max Agric	Max HEP	Add Store Max Agric	Add storage d/s NyM	Combo 11 & 12	Mixed Benefits	Add Store Opt PD
1	**-0.193**	-0.025	**-0.138**	**-0.132**	**-0.138**	**-0.121**	0.056
2	**-0.221**	-0.007	**-0.227**	**-0.227**	**-0.227**	**-0.227**	0.088
3	**-0.107**	-0.072	**-0.132**	**-0.141**	**-0.132**	**-0.132**	-0.023
4	-0.061	-0.013	-0.053	-0.027	-0.041	-0.067	0.016
6	0.024	0.186	0.014	-0.043	0.014	0.115	0.235
7	**-0.971**	**-0.474**	**-0.971**	**-0.990**	**-0.915**	**-0.915**	0.006
8	0.000	0.017	**-0.169**	**-0.266**	**-0.245**	**-0.215**	0.017
9	-0.049	0.068	-0.061	-0.044	-0.040	-0.044	0.097

7.6.2 Estuary

Changes in health status of the various ecosystem components for the seven scenarios are shown graphically in Figure 7.3 while actual scores are presented in Table 7.4. Effects on the different ecosystem components and overall health differ between scenarios with some clear trends evident (Figure 7.3, Table 7.4). These can be summarised as follows:

- Effects of all scenarios involving additional storage aside from Optimised Present Day are negative for all ecosystem components as well as for estuary health as a whole. The Optimised Present Day with storage scenario is accompanied by a very small improvement in some but not all components.
- Additional storage above NYM combined with a maximum agricultural scenario has the most severe impacts of the other four scenarios, impacts of the other three scenarios being of a similar magnitude.

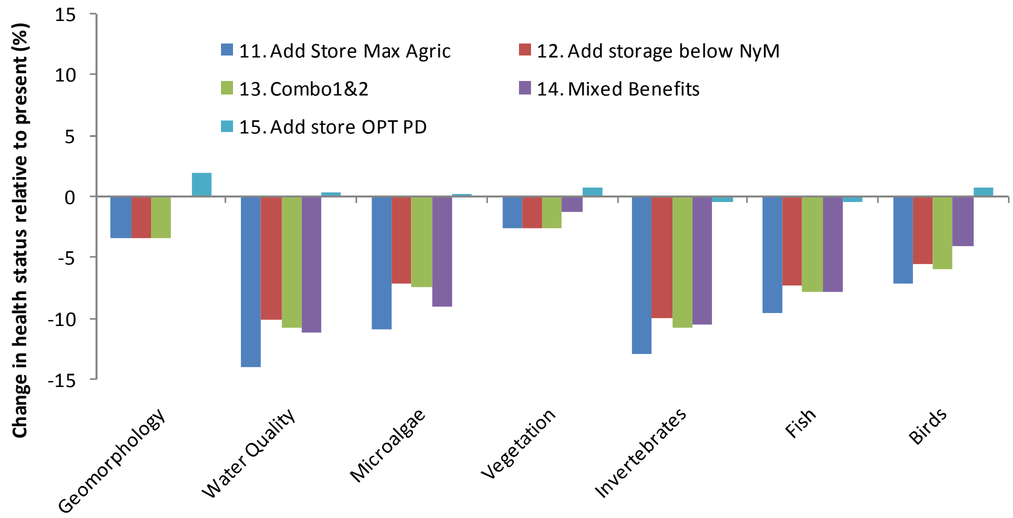


Figure 7.3 **Change in health status relative to present day for all estuary ecosystem components under the seven scenarios**

Table 7.4 **Percentage change in health status relative to Present Day for each of the estuarine ecosystem components under the seven scenarios** (0 = no change from present day; –ve = move away from natural; +ve = move towards natural; red = large decline in condition; orange = moderate decline in condition; light blue = moderate improvement in condition; darker blue = large improvement in condition).

	Geo-morphology	Water Quality	Micro-algae	Vege-tation	Inver-tebrates	Fish	Birds	Overall % change in score
1. Max Agric	-3	-13	-10	-2	-12	-9	-7	-18
2. Max HEP	-3	11	3	3	7	6	10	14
11. Storage u/s NyM with Maximise Agriculture	-3	-14	-11	-3	-13	-10	-7	-19
12. Storage d/s NyM with Maximise HEP	-3	-10	-7	-3	-10	-7	-6	-15
13. Combination of u/s storage with Max Agric and d/s storage with Max HEP	-3	-11	-7	-3	-11	-8	-6	-16
14. Mixed benefits	0	-11	-9	-1	-10	-8	-4	-14
15. Storage u/s of NyM with Optimise PD	5	1	0	1	-1	-1	2	2

7.7. Effects on livelihoods

7.7.1 Impacts on household income

As for the Maximise Agriculture scenario, household income increases in the highland and mesic lowland zones under scenarios 11 to 14, and decreases in the lakes, Pangani-Kirua and estuary zones. Income under scenario 15 follows a similar pattern to the Maximise HEP scenario, which is a general decrease in household income in almost all zones. Overall impact is most strongly positive for the Maximise Agriculture scenario and Scenario 11, and is worst for Scenario 15. Nevertheless, the impacts are relatively small, particularly for the positive scenarios (Figure 7.4).

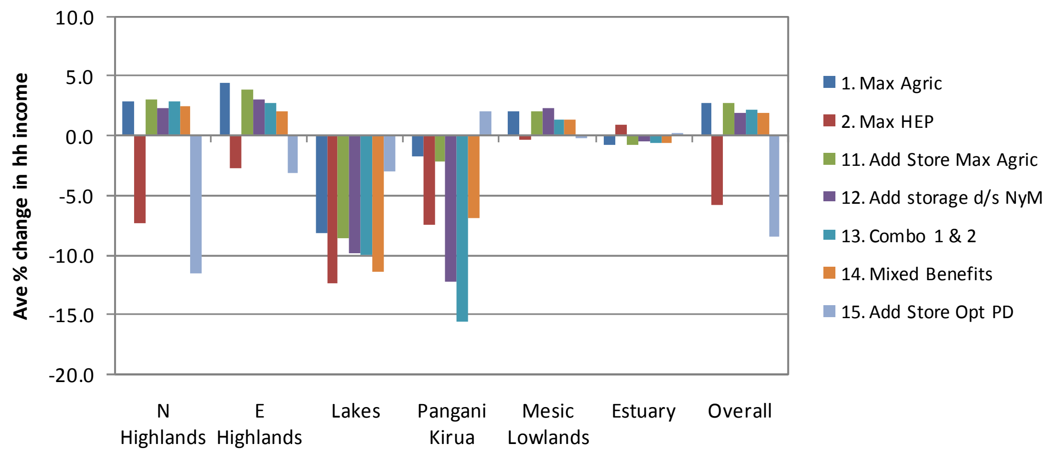


Figure 7.4 **Percentage change in aggregate income to households within 5 km of rivers for the different storage options as compared with the present day**

7.7.2 Impacts on recreational and spiritual well-being

Recreational and spiritual well-being is affected most in the upper zones (Figure 7.5). The Maximise Agriculture scenario has very strong negative implications for utility in these zones. Scenarios 11 to 14 follow a very similar trend. The Maximise HEP scenario has a positive impact in most areas apart from Lakes area. Scenario 15 has a positive impact in most areas and has the strongest overall positive effect.

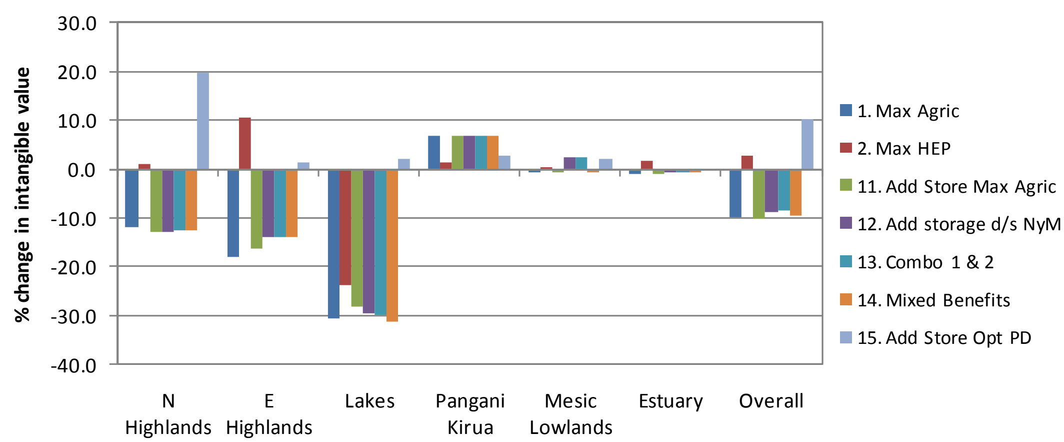


Figure 7.5 **Percentage change in recreational and spiritual well-being among households within 5 km of rivers for the different storage options relative to a score of 100 for present day**

7.7.3 Overall impacts on well-being

All scenarios have a negative impact on overall well-being in the upper zones and variable but smaller impacts in the lower zones. Positive effects are mainly in the Mesic Lowlands. Overall, the effects are negligible, but they are strongest in the Maximum HEP scenario and Scenario 15, in which overall well-being declines by about 4% (Figure 7.6).

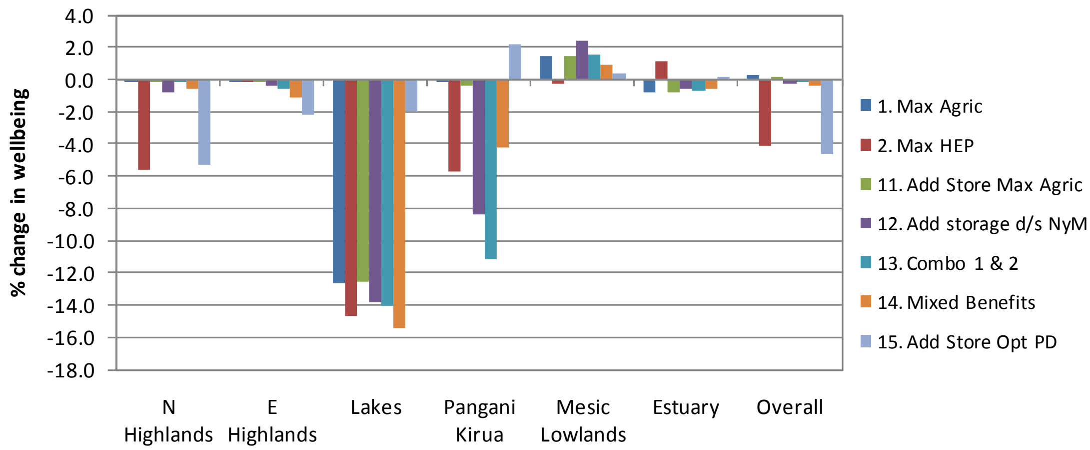


Figure 7.6 **Percentage change in overall well-being of households within 5 km of rivers for the different storage options relative to a score of 100 for present day**

7.8. Effects on economic value

Values generated by natural resources increase under the Maximise Agriculture scenario. A similar effect is seen under Scenario 12, and a dramatic increase is seen in Scenario 15. The sector is negatively impacted under Maximise HEP and Scenario 13 (Figure 7.7). Agricultural outputs increase under Maximise Agriculture and Scenarios 11 to 14, but decrease under Maximise HEP and especially under Scenario 15, which sees a decrease of about a quarter of present value. The value of ecosystem regulating services is negatively affected under all but scenarios 12, 14 and 15. Although both regulating services and natural resources are related to ecosystem condition, the impacts are only in the same direction under four of the seven scenarios. This is probably because the bulk of the two types of values are derived from different parts of the basin, which are affected differently under the different scenarios. HEP value only increases significantly under the Maximise HEP scenario, and there is no loss to this sector under Scenario 15.

7.9. Summary

As reported previously, overall ecosystem integrity within the basin decreases under the Max Agric and very slightly under Max HEP. Three of the five storage scenarios (Add Store Max Agric, Add storage d/s NyM and Combo 11 and 12) were virtually indistinguishable from Max Agric in terms of their impact on ecosystem integrity (Figure 7.8). The Mixed Benefits scenario improved the condition of Kirua Swamps but this is insufficient to have an appreciable influence on overall ecosystem integrity. Ecosystem integrity improves slightly under Add Store Opt PD. Social well-being declines under Max HEP and Add Store Opt PD and slightly under Mixed Benefits, but is unchanged under Max Agric, Add Store Max Agric, Add storage d/s NyM and Combo 11 & 12. Economic values generated by water and aquatic ecosystems decrease under Max Agric, Add Store Max Agric, Add storage d/s NyM and Combo 11 & 12, and Mixed Benefits. This is because these favour agriculture over HEP, to the detriment of HEP production, and the changes in the value of HEP are orders of magnitude larger than other economic impacts.

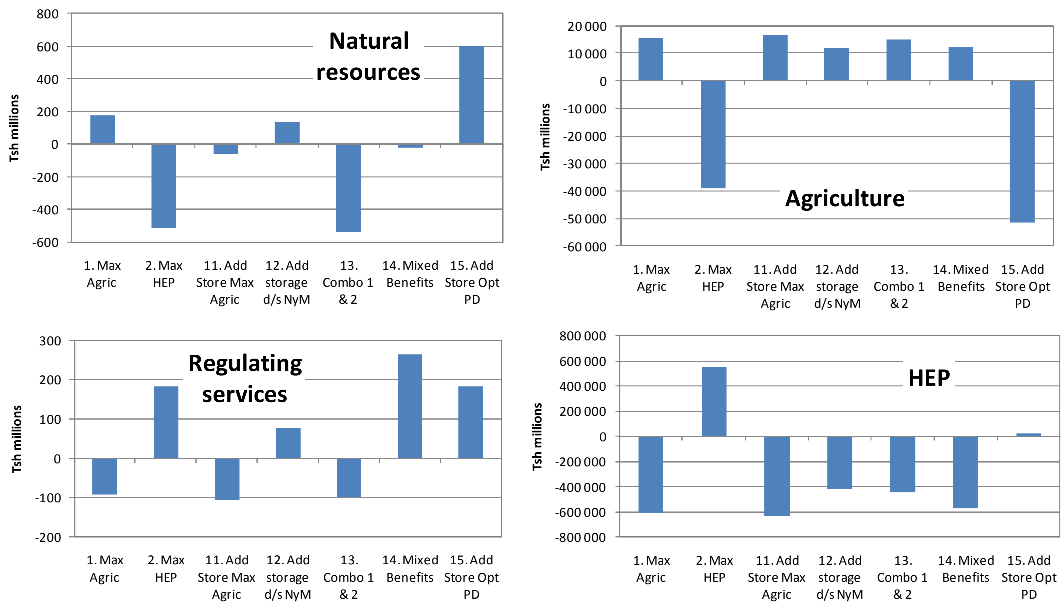


Figure 7.7 **Losses or gains in the value for the natural resources, agricultural and HEP sectors as well as in the value of ecosystem regulating services (water purification and nursery value for marine fisheries).**

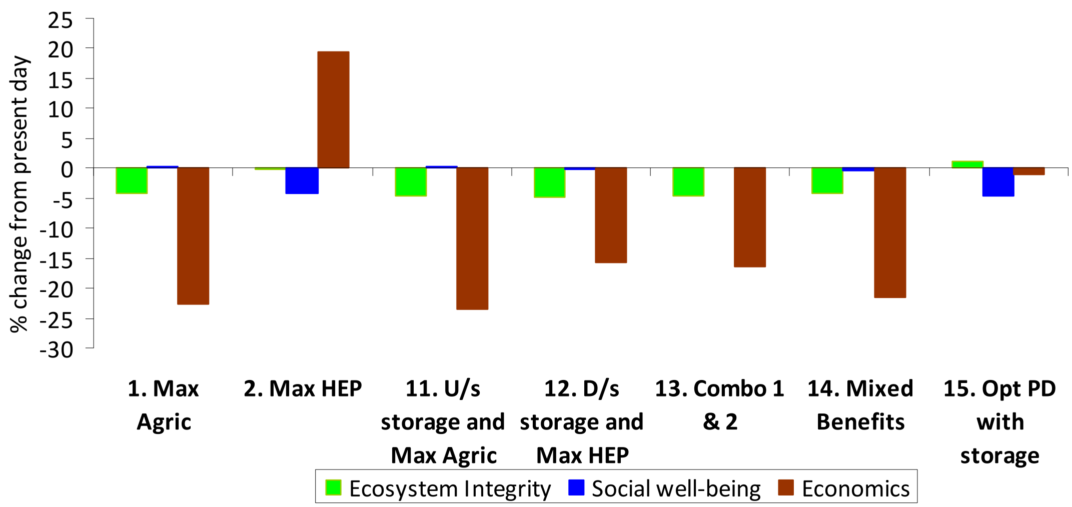


Figure 7.8 **Percentage change in ecosystem integrity, social well-being and economic value under seven scenarios**

8. Overall summary and conclusions

The scenarios provide comparative information that can be used for coarse basin planning. Each scenario predicts a range of costs and benefits based on simulated hydrological data. The hydrological data are interpreted using biophysical data where available, supplemented with local wisdom and general expert understanding of the functioning of river ecosystems. The outcomes of this are descriptions of how the river system could change under each scenario. The human impacts of the changing rivers are then predicted, in terms of economic costs and benefits, and social well-being.

The main features of the scenarios and a summary of cost and benefits are provided below, followed by some discussion on possible management considerations.

8.1. Standard allocations of water per scenario, projected to 2025

Standard allocations of water as at 2025 were made at an early stage of scenario creation, thus reducing the number of variables contributing to the differences between scenarios. These were:

- Urban and industrial:
  - Arusha 39.0 $Mm^3\ a^{-1}$
  - Moshi 15.7 Mm^3a^{-1}
- Agriculture:
  - future growth based on historical growth rates
  - areas capped where all agriculture potential is already used
  - modest improvement in efficiency of use
  - largest increase in use in Kikuletwa and Mkomazi
- HEP operating ranges
  - NyM 9.8 - 35.0 m^3s^{-1}
  - Hale 8.5 - 45.0 m^3s^{-1}
  - Pangani 9.0 - 45.0 m^3s^{-1}
- Climate change
  - applicable/not applicable
- Reserve of water for river ecosystem
  - applicable/not applicable

8.2. The scenarios

Using these allocations, the fifteen scenarios created and assessed to date are:

1. *Maximise Agriculture*: Maximise irrigated area after allocating water for BHN and urban and industrial use
2. *Maximise HEP*: Maximise hydropower generation after allocating water for BHN and urban and industrial use
3. *Optimum Present-Day flows with Agriculture*: The present-day volume of river flow retained but in a pattern of flows that supports ecosystem health; agriculture then prioritised after BHN, urban and industrial allocations met to the extent possible
4. *Optimum Present-Day flows with HEP*: The present-day volume of river flow retained but in a pattern of flows that supports ecosystem health; HEP then prioritised after BHN, urban and industrial allocations met to the extent possible
5. *High Environment with Agriculture*: A higher than present-day volume of river flow allocated in a pattern of flows to improve river condition; agriculture then prioritised after BHN, urban and industrial allocations met to the extent possible

6. *Climate Change*: climate change imposed on the Present Day conditions
7. *Maximise Agriculture with 20% Less Rainfall*: Wet season rainfall reduced by 20%, and then the allocations as per scenario 1
8. *Maximise Agriculture with 30% Less Rainfall*: Wet season rainfall reduced by 30%, and then the allocations as per scenario 1
9. *Maximise HEP with 20% Less Rainfall*: Wet season rainfall reduced by 20%, and then the allocations as per scenario 2
10. *Maximise HEP with 30% Less Rainfall*: Wet season rainfall reduced by 30%, and then the allocations as per scenario 2
11. *Storage upstream of NyM, with Maximise Agriculture*: Some storage in the upper catchment to provide for agricultural demands, and then the allocations as per scenario 1.
12. *Storage downstream of NyM (Luengera), with Maximise HEP*: Some storage in the Luengera River to provide for HEP demands, and then the allocations as per scenario 1.
13. *Combination of storage upstream of NyM, with Maximise Agriculture AND storage downstream of NyM (Luengera), with Maximise HEP*: Combination of scenarios 11 and 12.
14. *Mixed benefits*, which includes storage upstream and downstream of NyM. Similar to scenario 13, but with High Environment allocation to Kirua Swamps.
15. *Storage upstream of NyM, with Optimise Present Day*. Similar to scenario 5, but with storage in the upper catchment.

(Note the comments in Sections 1.3.1 and 3.3.6 regarding Scenarios 6 to 10).

8.3. Priority of water allocation

Within each scenario the priority of water allocation is as shown in Table 8.1.

Table 8.1 Water supply priorities used in the hydrological model WEAP. PD = Present Day

Scenario	Basic Human Needs	Urban	Agri-culture	HEP	Environ-ment	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 Lower: 4	Upper: 4 Lower: 3	Residual	n/a
13. Combination of storage u/s of NyM, with Max Agric AND storage d/s of NyM, with Maximise HEP.	1	2	Upper: 3 Lower: 4	Upper: 4 Lower: 3	Residual	n/a
14. Mixed benefits, include storage upstream and downstream of NyM	1	2	Upper: 3 Lower: residual	Upper: 4 Lower: 4	Residual 3	n/a
15. Optimise PD (Agric with storage)	1	3	4	Residual	2	n/a

8.4. Changes in flow regime

The hydrological consequences of each scenario were summarised in terms that could be used for social and ecological interpretation. In summary, the changes in river flow were predicted to be:

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 then 25 m^3s^{-1} in the Pangani at Kirua and thus greater inundation of Kirua swamp
   - slight increase in dry-season lows 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 Present Day
    - 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

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.

8.5. Response of the river ecosystem

8.5.1 River

The three scenarios that redistribute river flow (scenarios 3-5) and, for scenario 5, increase its volume, result in a low to moderate improvement in river condition throughout the system compared to Present Day (Table 8.2).

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 of the above scenarios indicate a low to moderate improvement in condition in the Kirua area (site 6). This is noticeably so not only for the three 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.

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.

The scenarios that most impact river condition are those that maximise agriculture.

Table 8.2. **Colour coding to illustrate shift in condition from PD at the FA sites for the 15 scenarios.** pink: low decline; orange: moderate decline; red: severe decline; pale blue: low improvement; dark blue: moderate improvement.

Scenario / Site	1	2	3	4	6	7	8	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. Add storage Max Agric	-0.138	-0.227	-0.132	-0.053	0.014	**-0.971**	-0.169	-0.061
12. Add storage d/s NyM	-0.132	-0.227	-0.141	-0.027	-0.043	**-0.990**	-0.266	-0.044
13. Combo 11&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

8.5.2 Estuary

Maximising agricultural production in the Pangani catchment (Scenario1, 7 and 8) is projected to come at a significant cost in terms of changes in estuary health, especially if this is coupled with reductions in rainfall under the projected climate change scenarios (Table 8.3). Projected reductions in rainfall associated with the modelled climate change scenario on it own are also expected to have a modest negative impact on estuary health.

Table 8.3 **Change in estuarine health for 15 scenarios.**

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. Storage u/s NyM with Max Agric	46	-0.373
12. Storage d/s NyM with Max HEP	48	-0.300
13. Combination of u/s storage with Max Agric and d/s storage with Max HEP	48	-0.319
14. Mixed benefits	49	-0.266
15. Opt. PD-Agric & storage	58	0.045

Maximising HEP under the present day rainfall on the other hand 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 reduced rainfall scenarios (Scenarios 9 and 10).

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

8.6. 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 in societal well-being from that of the Present Day (Figure 8.1 and Table 8.4). There are no scenarios that improve well-being anywhere in the highlands and lakes areas, which together contain most of the basin population. Maximise Agriculture and the storage scenarios 11 to 14 are the only scenarios that can maintain the status quo in these areas and the basin as a whole under the increased demand for water in 2025. Pangani-Kirua, the Mesic Lowlands and the Estuary are better off under a range of scenarios, mainly being associated with optimising or maximising environmental flows and HEP.

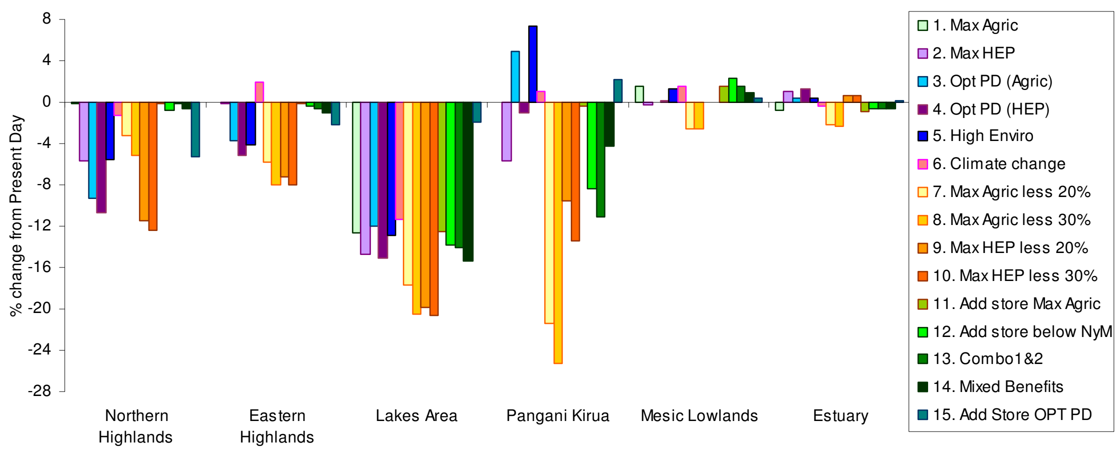


Figure 8.1 Impacts on societal well-being for the 15 scenarios.

Table 8.4 Impacts on societal well-being for the 15 scenarios in terms of percentage change from Present Day.

	Northern Highlands	Eastern Highlands	Lakes Area	Pangani Kirua	Mesic Lowlands	Estuary	Pangani Basin*
1. Max Agric	-0.07	-0.01	-12.66	-0.05	1.49	-0.78	0.23
2. Max HEP	-5.63	-0.07	-14.67	-5.71	-0.25	1.07	-4.08
3. Opt PD (Agric)	-9.30	-3.69	-12.03	4.93	0.00	0.44	-7.18
4. Opt PD (HEP)	-10.77	-5.18	-15.07	-1.04	0.10	1.28	-8.58
5. High Enviro	-5.55	-4.13	-12.85	7.30	1.24	0.40	-5.37
6. Climate change	-1.28	1.95	-11.34	0.99	1.52	-0.36	0.06
7. Max Agric less 20%	-3.27	-5.80	-17.72	-21.37	-2.56	-2.13	-4.30
8. Max Agric less 30%	-5.19	-7.96	-20.50	-25.33	-2.53	-2.38	-5.94
9. Max HEP less 20%	-11.42	-7.16	-19.88	-9.58	-0.03	0.71	-9.43
10. Max HEP less 30%	-12.34	-8.03	-20.60	-13.46	0.00	0.64	-10.38
11. Add store Max Agric	-0.19	-0.12	-12.54	-0.41	1.49	-0.85	0.21
12. Add store below NyM	-0.77	-0.38	-13.84	-8.41	2.36	-0.59	-0.22
13. Combo 11&12	-0.19	-0.61	-14.03	-11.14	1.52	-0.65	-0.04
14. Mixed Benefits	-0.58	-1.09	-15.38	-4.20	0.92	-0.63	-0.37
15. Add Store OPT PD	-5.26	-2.22	-1.99	2.19	0.36	0.18	-4.69

* the aggregate basin score is based on population numbers in the different zones i.e. not simply a sum.

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. These percentage losses come from a very low base level, as income in these two zones is already very low under the Present Day scenario (Figure 8.1).

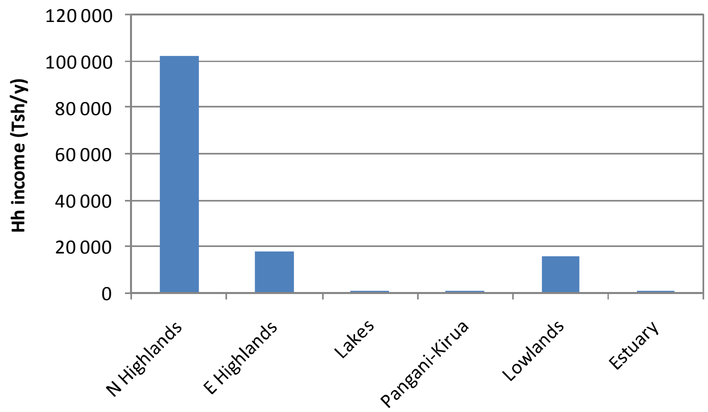


Figure 8.2 Present Day net annual household income in the social zones.

In terms of the factors contributing to changes in household income, change in income from agriculture and employment are the most affected by the scenarios, with those caused by changes in natural resources being relatively small in comparison. Incomes from agriculture and from employment tend to work in opposite directions - when income from agriculture decreases, that from employment increases. Tangible (average household income) aspects increase in value relative to Present Day under the three Maximise Agriculture scenarios if intangibles are excluded.

8.7. Basin-wide summaries

8.7.1 Economics

Direct economic impacts 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 (Figure 8.3); HEP values tend to improve modestly under the same scenarios. The value of both ecosystem services and HEP declines under the scenarios that prioritise agriculture as well that describing Present Day with Climate Change, whilst agriculture gains are minimal if at all. Conversely, agricultural values decline under all scenarios where HEP and the ecosystem are prioritised. Changes in natural resource values are extremely small relative to present day for all scenarios.

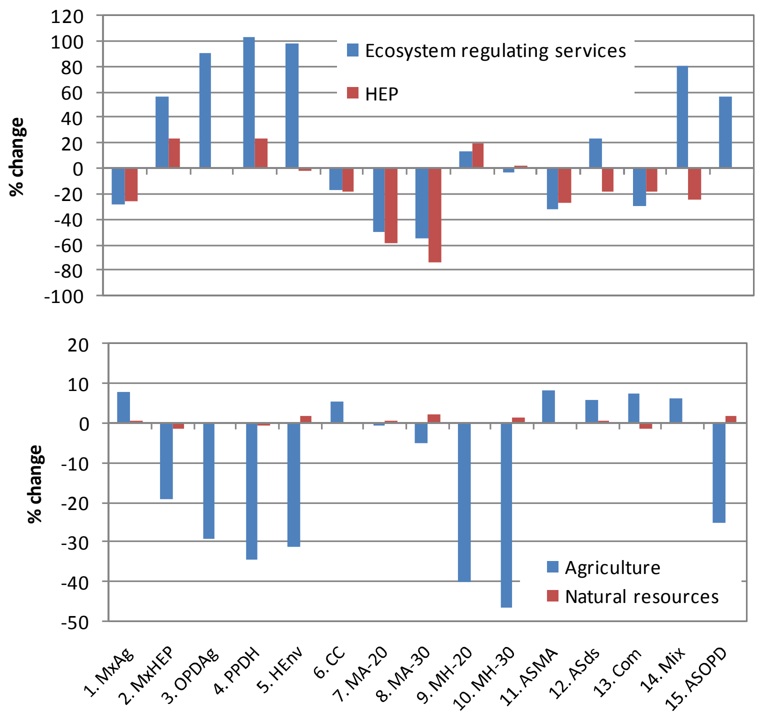


Figure 8.3 Percentage changes in economic values relative to Present Day.

When viewed in terms of absolute changes in Tsh, those for HEP (Figure 8.4, Table 8.5) completely overshadow the others.

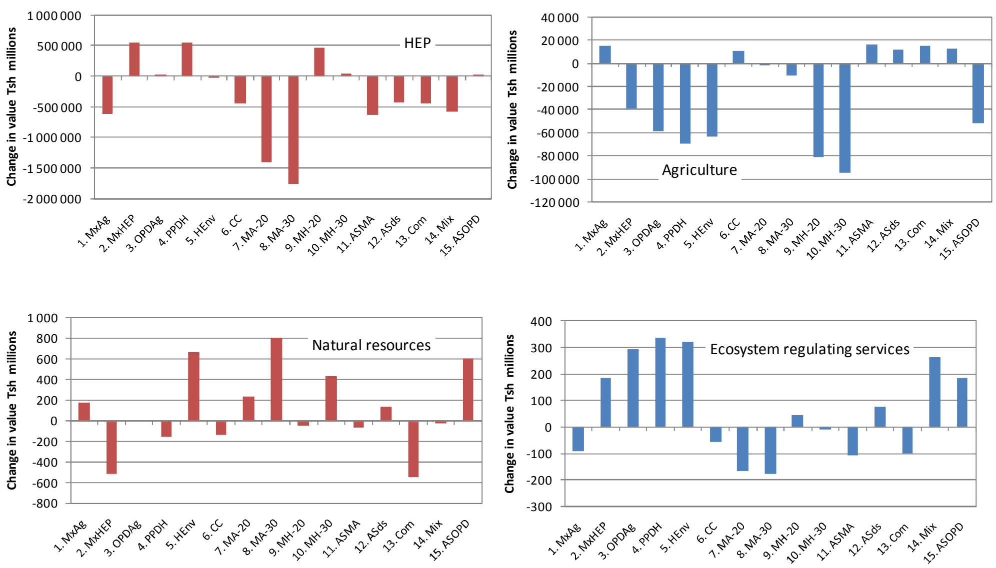


Figure 8.4 Changes relative to Present Day in million Tsh for the economic values showing the relatively large impacts of hydroelectric power and agriculture relative to natural resources and ecosystem services.

Table 8.5 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
Present Day	*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

8.7.2 Status of key basin descriptors

Key indicators are summarised for each scenario (Table 8.6). These provide insights into the expected status of major water-use sectors and river resources.

Table 8.6 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
Present Day	*31.1*	*-*	*1 042*	*602 647*	*5*	*133*	*0*
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 Maximise Agriculture	54.7	125	1 031	420 688	1	31	-4.7
12. Storage d/s NyM with Maximise HEP	54.7	118	934	478 802	13	334	-4.8
13. Combination of u/s storage with Maximise Agriculture and d/s storage with Maximise 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

8.7.3 The triple bottom line of sustainable development

Figure 8.5 and Table 8.7 provide information on what are commonly recognised as the three pillars of sustainable development:

1. ecosystem integrity
2. social justice
3. economic wealth.

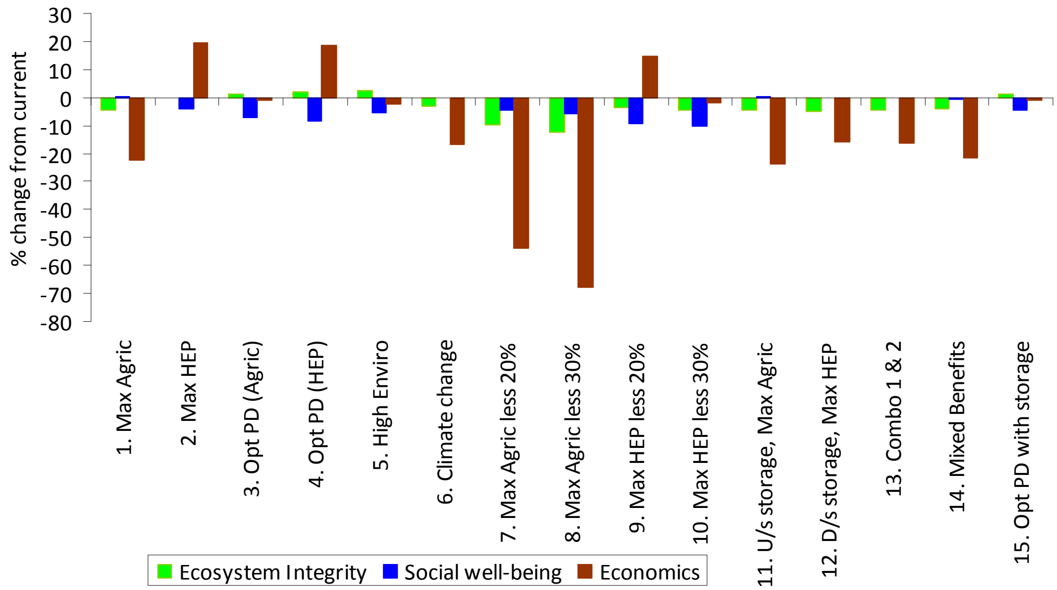


Figure 8.5 **Percentage change from present day in terms of ecosystem integrity, social well-being and economic values**.

Table 8.7 **Percentage change from present day in ecosystem integrity, social well-being and economic value of the fifteen scenarios**

Scenarios	Ecosystem Integrity	Social well-being	Economic value
1. Max Agric	-4.28	0.23	-22.58
2. Max HEP	-0.26	-4.08	19.43
3. Opt PD (Agric)	1.41	-7.18	-1.02
4. Opt PD (HEP)	2.02	-8.58	18.46
5. High Enviro	2.50	-5.37	-2.52
6. Climate change	-3.19	0.06	-16.62
7. Max Agric less 20%	-9.92	-4.30	-53.65
8. Max Agric less 30%	-12.31	-5.94	-67.81
9. Max HEP less 20%	-3.70	-9.43	14.85
10. Max HEP less 30%	-4.48	-10.38	-2.08
11. Storage u/s NyM with Max Agriculture	-4.69	0.21	-23.60
12. Storage d/s NyM with Maximise HEP	-4.82	-0.22	-15.70
13. Combination of u/s storage with Max Agric and d/s storage with Max HEP	-4.54	-0.04	-16.44
14. Mixed benefits	-4.16	-0.37	-21.52
15. Opt. PD-Agric & storage	1.19	-4.69	-0.96

They show that for both river and estuary, scenarios that maximise agriculture have the greatest negative impact, whilst those that boost HEP generation may help improve river condition. Socially, all scenarios have a negative impact on overall well-being in the upper zones and variable impacts in the lower zones. Overall, these 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.

8.8. The effects of water demand management and efficiency of use

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 irrigation area 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 agricultural value and the livelihood value derived from this was 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 been assumed.

8.9. Management considerations

Once a scenario has been chosen as the optimal trade-off between development and resource protection, its flow regime becomes the environmental flow allocated for river maintenance. These flows are summarised for each of the scenarios in the DRIFT summary tables. The numbers provide an indication of the expected MAR for each scenario plus an indication of the annual distribution of flows in terms of:

- volume of the wet-season lowflows;
- volume of the wet-season lowflows;
- number of intra-annual floods;
- number of extra annual floods.

Additional information is also available in the form of:

- lowflow flow duration curves
- flood timing, magnitude and duration.

This information will be needed to implement the agreed flows.

9. REFERENCES

BROWN, C.A. and JOUBERT, A. 2003. Using multicriteria analysis to develop environmental flow scenarios for rivers targeted for water resource development. *Water SA* Vol. 29 (No. 4).

DEPARTMENT OF WATER AFFAIRS AND FORESTRY. (1999) Resource Directed Measures for the Protection of Water Resources. Version 1.0. Pretoria, South Africa.

KING, J.M., BROWN, C.A. and SABET, H. 2003. A scenario-based holistic approach to environmental flow assessments for regulated rivers. *Rivers Research and Application*s 19 (5-6). Pg 619-640.

LUTEGANYA, K.P. and KIZZY, S.M. 2008. Hydroelectric power modelling study. Unpublished specialist report, Pangani Basin Water Office, Moshi and IUCN Eastern Africa Regional Program. 42 pp.

MKHANDI, S. H., VALIMBA, P AND KIMARO T.A. 2007. Development of climate change scenarios. Unpublished specialist report, Pangani Basin Water Office, Moshi and IUCN Eastern Africa Regional Program. 61 pp.

PBWO/IUCN. 2006a. Hydrology and System Analysis. Volume 1 of 2 : The Hydrology of the Pangani River Basin. Report 1: Pangani River Basin Flow Assessment Initiative. Unpublished technical report. Pangani Basin Water Office, Moshi and IUCN Eastern Africa Regional Program. 62 pp

PBWO/IUCN. 2006b. Delineation Report. Report 2: Pangani River Basin Flow Assessment Initiative. Unpublished technical report. Pangani Basin Water Office, Moshi and IUCN Eastern Africa Regional Program 76 pp

PBWO/IUCN. 2006c. Scenario Selection Report. Report 3: Pangani River Basin Flow Assessment Initiative. Unpublished technical report. Pangani Basin Water Office, Moshi and IUCN Eastern Africa Regional Program ,35 pp

PBWO/IUCN. 2007a. River Health Report. Report 4: Pangani River Basin Flow Assessment Initiative. Unpublished technical report. Pangani Basin Water Office, Moshi and IUCN Eastern Africa Regional Program,173 pp

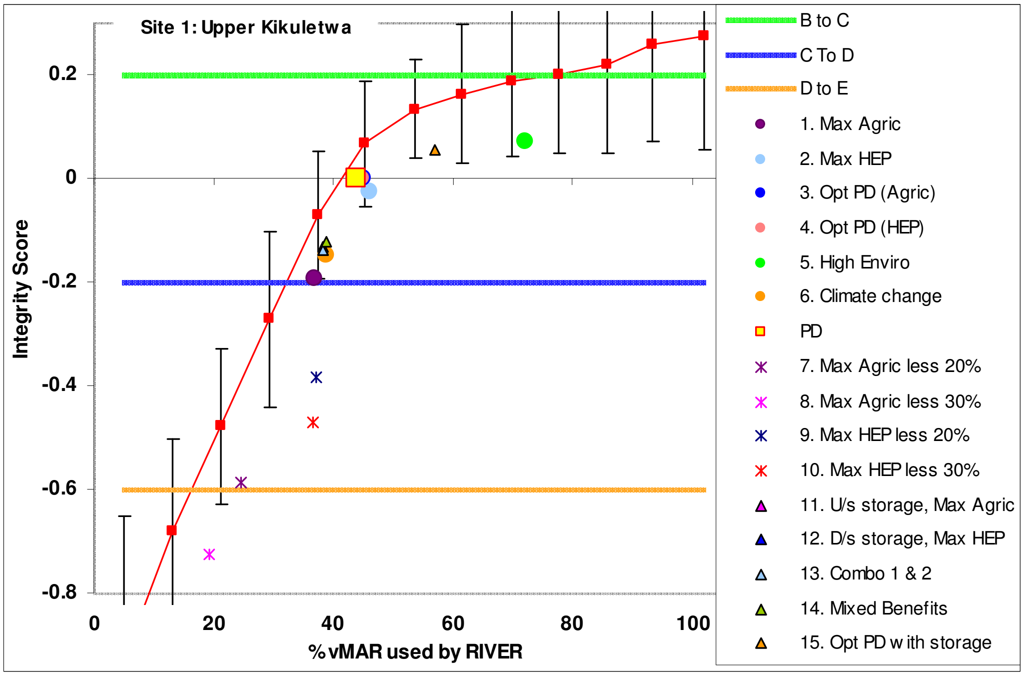
PBWO/IUCN. 2007b. Estuary Health Report. Report 5: Pangani River Basin Flow Assessment Initiative. Unpublished technical report. Pangani Basin Water Office, Moshi and IUCN Eastern Africa Regional Program,127 pp

PBWO/IUCN. 2007c. State of the Basin Report. Report 6: Pangani River Basin Flow Assessment Initiative. Unpublished technical report. Pangani Basin Water Office, Moshi and IUCN Eastern Africa Regional Program,47 pp

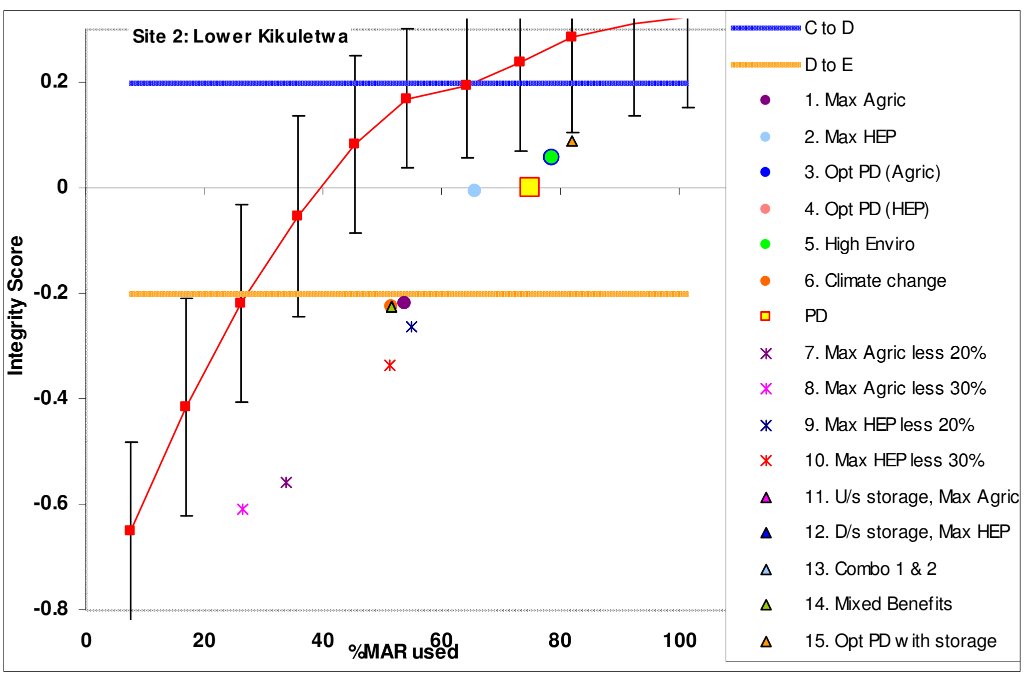
PBWO/IUCN. 2007d. Socio-economic Baseline Assessment Report. Report 7: Pangani River Basin Flow Assessment Initiative. Unpublished technical report. Pangani Basin Water Office, Moshi and IUCN Eastern Africa Regional Program, 337 pp

PBWO/IUCN. 2007e. Developing an understanding of the ecological and economic systems of the Pangani River system. Report 8: Pangani River Basin Flow Assessment Initiative. Unpublished technical report. Pangani Basin Water Office, Moshi and IUCN Eastern Africa Regional Program, 65 pp

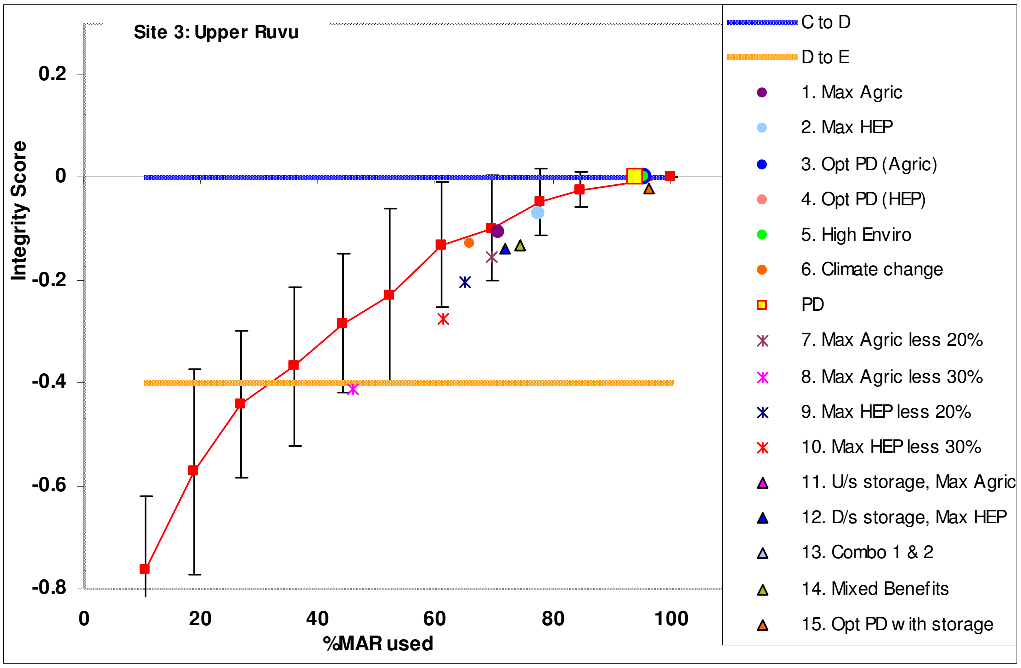
A1 DRIFT CATEGORY PLOTS FOR THE FA SITES



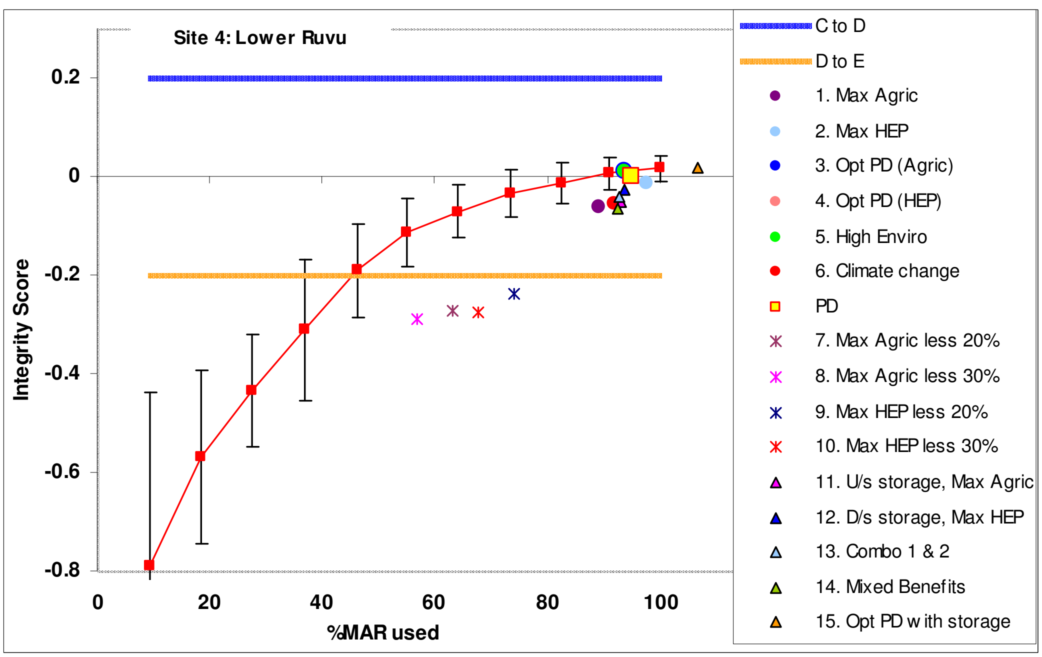
Addendum Figure 1 **DRIFT-CATEGORY plot for the Upper Kikuletwa River at FA Site 1.**



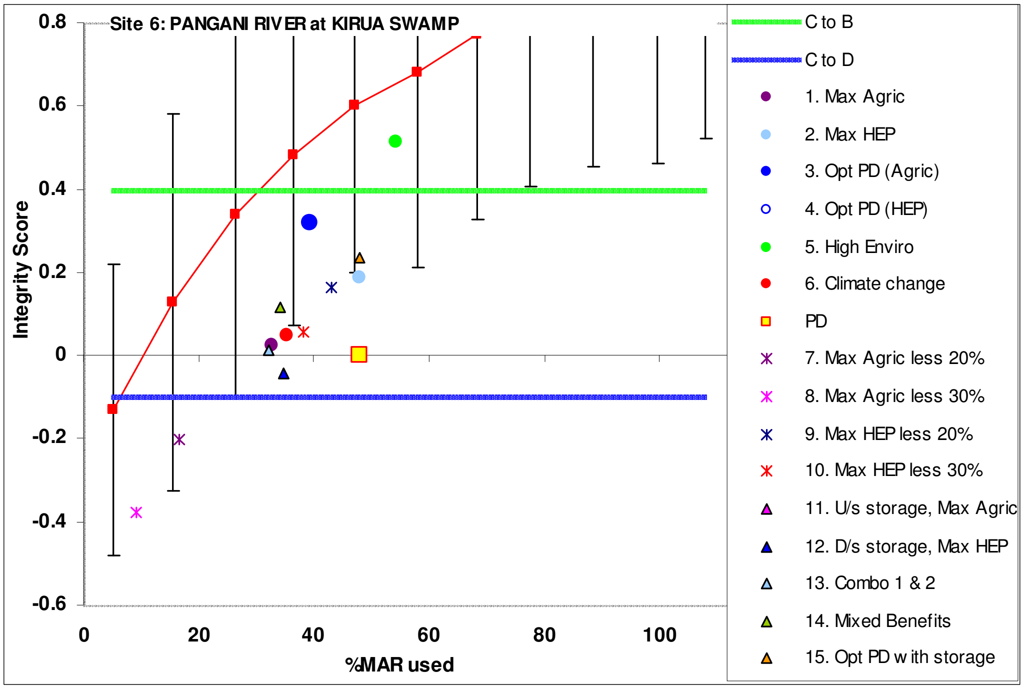
Addendum Figure 2 **DRIFT-CATEGORY plot for the Lower Kikuletwa River at FA Site 2.**



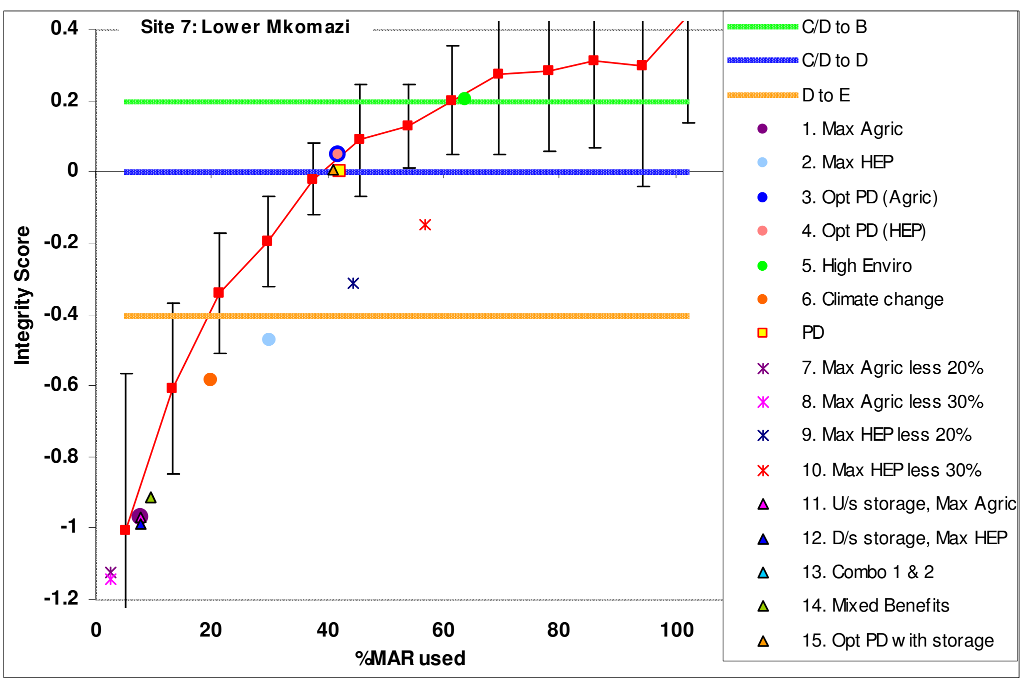
Addendum Figure 3 **DRIFT-CATEGORY plot for the Upper Ruvu River at FA Site 3**



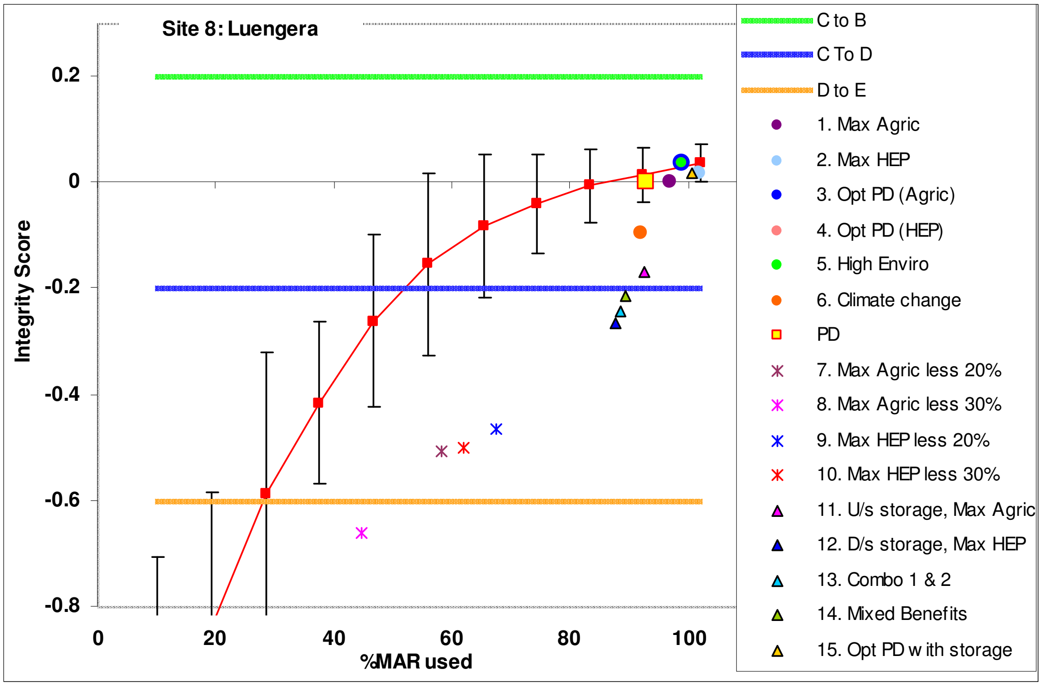
Addendum Figure 4 **DRIFT-CATEGORY plot for the Lower Ruvu River at FA Site 4**



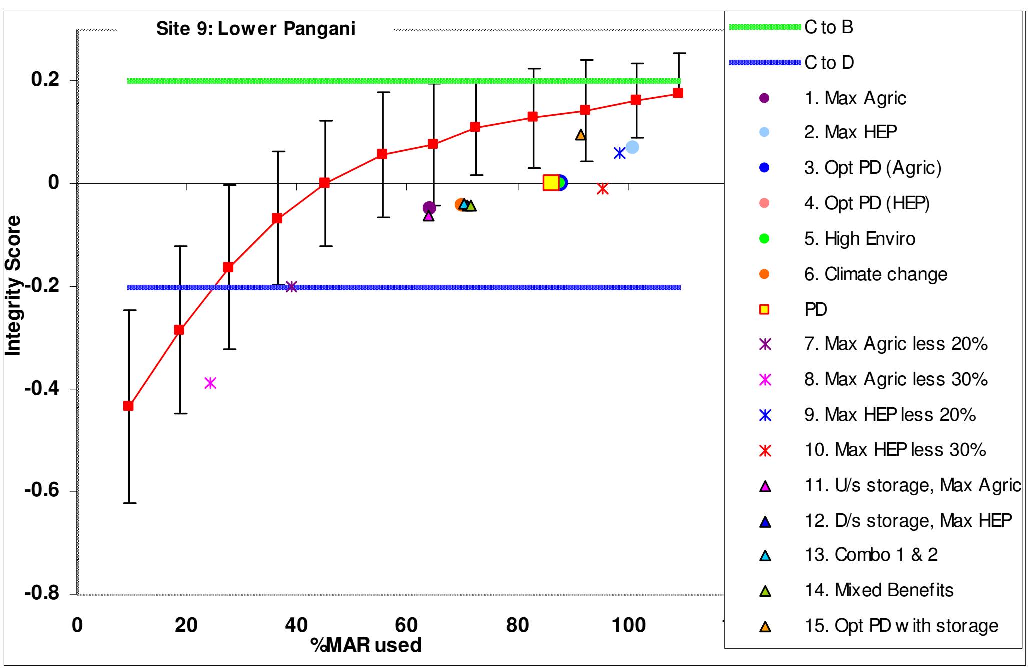
Addendum Figure 5 **DRIFT-CATEGORY plot for the Pangani River at Kirua Swamp at FA Site 6.** (Note – different scale to other sites).



Addendum Figure 6 **DRIFT-CATEGORY plot for the Lower Mkomazi River at FA Site 7.** (Note – different scale to other sites).



Addendum Figure 7 **DRIFT-CATEGORY plot for the Lower Luengera River at FA Site 8**



Addendum Figure 8 **DRIFT-CATEGORY plot for the Lower Pangani River at FA Site 9.**

A2 MAXIMISE AGRICULTURE

A2.1 Description of the scenario

The Maximise Agriculture scenario comprised the following (in order of priority):

- Full allocation of 2025 BHN and Urban/Industrial water demands to Arusha and Moshi.
- As much water as can be abstracted at a 75% level of assurance allocated to agriculture.
- The remaining water used to generate HEP.
- Environment received whatever water was left.

Thus in the upper catchment the residual flows in the river (after agricultural abstraction, which meant that flow in the river ceased altogether at times) were available to the riverine ecosystem before they flowed into NyM.

A2.2 Hydrological implications

A2.2.1 Water allocated per sector

Urban/industrial 54.7 Mcm a^{-1} (PD = 31.1)
Irrigation 1032 Mcm a^{-1} (PD = 1042) but see Section A2.3 for area irrigated
HEP 428 134 MW h^{-1} (PD = 602 647)

A2.2.2 Changes in the flow regime relative to present day

The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 1. There were two main kinds of change relative to present day:

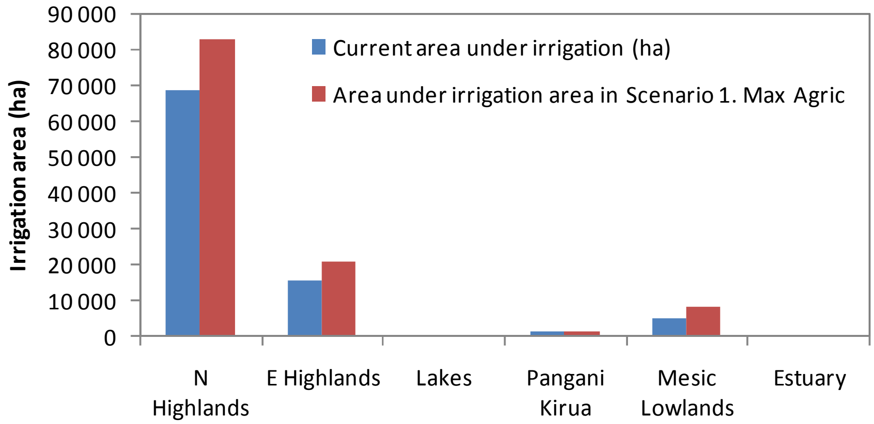
- drastically reduced low flows, particularly in the dry season (Sites 1-4 in upper catchment and Site 7 in the Mkomazi River).
- reduced variability at Site 6, Pangani River at Kirua, due to lower inflows to NyM and thus storage of floods.

Addendum Table 1 DRIFT flow summary data for the Maximise Agriculture scenario

Location	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario MAR (MCM)	52.7	415.1	156.5	781.0	570.8	9.1	105	904.0
WSLF - Volumes (MCM)	16.6	268.6	71.2	463.3	245.9	1.2	39.19	420.4
DSLF - Volumes (MCM)	24.2	66.1	58.6	146.1 - periodic zero flows	300.6	4.5	40.25	344.3
Class 1 - Annual Frequency	4	1	0	3	1	1	1.6	0
Class 2 - Annual Frequency	2	2	1	2	4	1	7	1
Class 3 - Annual Frequency	1	4	2	2	0	0	3.6	3
Class 4 - Annual Frequency	1	3	3	3	0	0	2	1
1:2	P	P	P	P	A	A	P	P
1:5	P	P	P	P	A	A	P	P
1:10	P	P	P	P	A	A	P	P
1:20	P	A	P	A	A	A	P	P

A2.3 Effects on irrigated agriculture

Under this scenario, there are increases in the irrigation area in all zones relative to present day. This is because the impact of increased efficiency is greater than the impact of a reduction in water supply relative to present day (Addendum Figure 9).



Addendum Figure 9 Area under irrigation in Maximise Agriculture scenario as compared with the Present Day.

A2.4 Effects on HEP production

HEP output is reduced to 71% of current output, resulting in an output of 428 134 MWh.

A2.5 Effects on environmental condition

A2.5.1 Summary of biophysical condition in the river

The influence of the residual flows on the condition of the rivers is described in two ways:

- as percentage change relative to present day for key indicators representing each of geomorphology, water quality, riparian vegetation, macroinvertebrates and fish;
- in terms of change in overall river condition as denoted by the integrity score

Note: The present day levels of the indicators have not been quantified, thus the reported change is relative to an unknown quantity.

A2.5.1.1 Geomorphology

The geomorphological changes associated with the Maximise Agriculture scenario are concentrated in the upper portion of the catchment, i.e., upstream of NyM, and in the Mkomazi River (Addendum Table 2). The changes can be summarised as follows:

- noticeable reduction in rocky areas, and thus fish habitat, especially in the upper and lower Kikuletwa River and in the Mkomazi River;
- noticeable loss of pools, and thus fish refuge, at the same sites and Lower Ruvu;
- build up of fine sediments, noticeably at upper Kikuletwa River, and severely in the Mkomazi River;

- severe loss of remaining floodplains at Lower Kikuletwa and Lower Ruvu, and especially in the Mkomazi River. A mild increase in floodplain inundation in the Pangani at Kirua.

Addendum Table 2 Estimated percentage change from Present Day for geomorphological features under the Maximise Agriculture scenario. Lower and Upper columns refer to range of possible change.

Site No.	Name	Riffles and rapids		Pools		Fine sediments		Coarse sediments		Bank erosion		Floodplain inundation	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-60	-40	-40	-20	26	68	-20	0	1	25	0	0
2	Lower Kikuletwa	-40	-20	-80	-60	1	25	0	0	0	0	-60	-40
3	Upper Ruvu	-20	0	0	0	1	25	0	0	0	0	0	0
4	Lower Ruvu	-20	0	-60	-40	0	0	0	0	-20	0	-60	-40
6	Pangani at Kirua	0	0	0	0	1	25	0	0	0	0	26	68
7	Lower Mkomazi	-100	-100	-100	-100	500	800	0	0	0	0	-100	-100
8	Lower Luengera	0	0	0	0	0	0	0	0	0	0	0	0
9	Lower Pangani	-20	0	-20	0	0	0	0	0	1	25	0	0

A2.5.1.2 Water Quality

The significant water-quality changes associated with the Maximise Agriculture scenario are concentrated in the lower Kikuletwa and Mkomazi rivers (Addendum Table 3). The changes can be summarised as follows:

- noticeable increase in conductivity in the Lower Kikuletwa and Mkomazi rivers;
- slightly increased phosphorus levels in the upper catchment, and severely increased levels in the Mkomazi River.

Addendum Table 3 Estimated percentage change from Present Day for water quality under the Maximise Agriculture scenario

Site No.	Name	Turbidity/TSS		Conductivity/TDS		Phosphorus		Nitrogen	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	1	25	1	25	1	25
2	Lower Kikuletwa	1	25	68	250	1	25	-20	0
3	Upper Ruvu	0	0	1	25	1	25	0	0
4	Lower Ruvu	0	0	1	25	1	25	-20	0
6	Pangani at Kirua	0	0	0	0	0	0	0	0
7	Lower Mkomazi	0	0	500	800	251	500	0	0
8	Lower Luengera	0	0	0	0	0	0	0	0
9	Lower Pangani	0	0	0	0	0	0	1	25

A2.5.1.3 Vegetation

The changes in riparian vegetation associated with the Maximise Agriculture scenario (Addendum Table 4) can be summarised as follows:

- small increase in dry bank vegetation in Lower Kikuletwa, Lower Ruvu and Lower Pangani rivers;
- very low increase of wet bank trees in Upper and Lower Kikuletwa and Lower Ruvu (i.e., in the upper catchment) and greater increase in the Pangani at Kirua.
- slight changes in wet bank understory vegetation cover at some sites;

- noticeable increase in all layers of wet bank vegetation in the Lower Mkomazi River.

Addendum Table 4 Estimated percentage change from Present Day for riparian vegetation under the Maximise Agriculture scenario

Site No.	Name	Dry Bank Trees		Dry Bank Herbs & Shrubs		Dry Bank Grasses		Wetbank Trees		Wetbank Herbs		Wetbank grasses and reeds	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-	-	-	-	-	-	1	25	0	0	1	25
2	Lower Kikuletwa	0	0	1	25	1	25	1	25	-40	-20	-20	0
3	Upper Ruvu	0	0	0	0	0	0	0	0	-20	0	26	68
4	Lower Ruvu	1	25	1	25	1	25	1	25	0	0	0	0
6	Pangani at Kirua	-	-	-	-	-	-	26	68	1	25	1	25
7	Lower Mkomazi	-	-	-	-	-	-	500	800	251	500	251	500
8	Lower Luengera	-	-	-	-	-	-	0	0	0	0	0	0
9	Lower Pangani	1	25	1	25	0	0	0	0	0	0	0	0

A2.5.1.4 Macroinvertebrates

The changes in macroinvertebrates associated with the Maximise Agriculture scenario (Addendum Table 5) can be summarised as follows:

- low to moderate decline of sensitive species, but heading toward extinction in Lower Kikuletwa and Mkomazi Rivers;
- low increase or decrease of tolerant species at most sites but noticeable increase in the Upper Kikuletwa and Lower Ruvu Rivers.
- Simuliidae (black flies) are present in the upper and lower Kikuletwa River and in Pangani at Kirua but conditions will not favour them.

Addendum Table 5 Estimated percentage change from Present Day for macroinvertebrates under the Maximise Agriculture scenario

Site No.	Name	Sensitive species		Tolerant species (e.g., Dysticidae, Chironominae and Culicidae)		Pest Simuliidae	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-60	-40	26	68	-20	0
2	Lower Kikuletwa	-100	-80	-20	0	-20	0
3	Upper Ruvu	-60	-40	-20	0	-	-
4	Lower Ruvu	-40	-20	26	68	-	-
6	Pangani at Kirua	-20	0	-20	0	1	25
7	Lower Mkomazi	-100	-100	-60	-40	-	-
8	Lower Luengera	0	0	0	0	-	-
9	Lower Pangani	0	0	0	0	-	-

A2.5.1.5 Fish

The changes in fish associated with the Maximise Agriculture scenario (Addendum Table 6) can be summarised as follows:

- slight decline in *Clarias* group, severe in the lower Mkomazi River;
- severe decline of the *Tilapia* group in the Lower Pangani and toward extinction in the lower Mkomazi River;
- overall decline in *Labeo* group, severe toward extinction at Lower Kikuletwa and Lower Mkomazi Rivers.

Addendum Table 6 Estimated percentage change from Present Day for fish under the Maximise Agriculture scenario

Site No.	Name	*Clarias* group		*Tilapia* group		*Labeo* group	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	-	-	0	0
2	Lower Kikuletwa	-40	-20	-	-	-100	-80
3	Upper Ruvu	0	0	-	-	-60	-40
4	Lower Ruvu	-20	0	-	-	-60	-40
6	Pangani at Kirua	1	25	-	-	-	-
7	Lower Mkomazi	-80	-60	-100	-100	-100	-100
8	Lower Luengera	0	0	0	0	-	-
9	Lower Pangani	0	0	-80	-60	-	-

A2.5.1.6 Overall condition

The changes in overall river condition associated with the Maximise Agriculture scenario are provided in Addendum Table 7. They show a mild decline at most sites, a more noticeable decline in the Kikuletwa, and a very severe decline in the Lower Mkomazi.

Addendum Table 7 Overall condition at each river site for the Maximise Agriculture scenario

Site No.	Name	Present Day River Health Category	Change from Present Day ecological integrity	River Health Category for the scenario
1	Upper Kikuletwa	B/C	-0.193	C
2	Lower Kikuletwa	D	-0.221	D
3	Upper Ruvu	C/D	-0.107	D
4	Lower Ruvu	D	-0.061	D
6	Pangani at Kirua	C	0.024	C
7	Lower Mkomazi	C/D	-0.971	D/E
8	Lower Luengera	C	0	C
9	Lower Pangani	C	-0.049	C

A2.5.2 Summary of biophysical condition in Nyumba ya Mungu

A2.5.2.1 Water level change

The FA Tool assesses likely change in two parameters associated with NyM Dam – fish catch and reed area. These parameters are affected by water area or volume of the lake and the variation in area and volume that are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under the Maximise Agriculture scenario are presented and discussed in the respective sections below.

Addendum Table 8 **Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in Nyumba ya Mungu under the Maximise Agriculture scenario relative to the present day, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario.**

	Present Day	This scenario	% Change
Mean lake area (ha)	103.8	65.6	-37%
Std dev of lake area (m)	1.24	1.62	30%
Max lake area (ha)	137.1	125.3	-9%
Reed area (ha)	33.3	59.7	79%
Mean lake level (m)	15.9	11.7	-26%
Std dev of lake level (m)	1.2	1.6	+33%
Fish catch (tonnes)	3538.8	2555.2	-28%

A2.5.2.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surrounding NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases, provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under the Maximise Agriculture scenario, lake area shrinks by 37%, variability increases by 30%, and maximum area inundated decreases by 9% (Addendum Table 8). The net result of this is that total reed area is expected to expand by 79%.

A2.5.2.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the present day we expect fish populations to expand in response to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under this scenario, variability in lake level increases by 30% but average area declines by 9% (Addendum Table 8). Fish catches as a result, are expected to decline by 28%.

A2.5.3 Summary of biophysical condition in Kirua Swamp

The Maximise Agriculture scenario will result in a further decline in the condition of the Kirua Swamp as a result of reduced flooding relative to present day. Under present day conditions swamp inundation is c. 4% of natural. This will drop to *c*. 2% under this scenario.

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to present day. Under this scenario, fish abundances are predicted to decline to 40% of present day (53 tonnes) and floodplain vegetation to decline to 39% of present day.

A2.5.4 Summary of biophysical condition in the Estuary

A2.5.4.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under the Maximise Agriculture scenario freshwater flows reaching the estuary are lower than the Present Day during all four seasons (average reduction = 26.2%) but are most markedly lower during Dry 1 Season (52.4% reduction) (Addendum Table 9). Agricultural return flows, as a proportion of the total flow, increased in all seasons (average increase = 15.0%) as would be expected under this scenario and are most marked during Dry 1 Season (59.7% increase). Number of months where flow exceeds 250 Mm^3 declines by 25%.

Addendum Table 9 Change in freshwater flows reaching the estuary under the Maximise Agriculture scenario relative to the Present Day.

		Short rains	Dry 1	Long rains	Dry 2	All months
Average monthly flows	Present Day (Mm^3)	91.3	72.7	186.9	80.7	102.1
	Max Agric (Mm^3)	61.3	34.6	166.1	58.0	75.3
	% Change	-32.9	-52.4	-11.1	-28.1	-26.2
Agricultural monthly return flows	Present Day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	Max Agric (Mm^3)	40.5	39.8	21.7	40.9	38.9
	% Change	19.0	59.7	4.5	16.1	15.0
No. months flow >250 Mm^3	Present Day	8.0				
	Max Agric	6.0				
	% Change	-25.0				

Addendum Table 10 Health scores for the estuary as a whole and the component parameters under the Maximise Agriculture scenario

	Present Day	This scenario	% change from PD (+/-)
Geomorphology	40%	39%	-3%
Water Quality	53%	46%	-13%
Micro-algae	40%	36%	-10%
Vegetation	60%	59%	-2%
Invertebrates	60%	53%	-12%
Fish	50%	46%	-9%
Birds	40%	37%	-7%
Overall health score	57%	47%	-18.3

A2.5.4.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the Present Day status of the mouth, which is both wide and deep. Thus, only the extremely high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significantly affect geomorphological conditions in the estuary (e.g. channel width and depth, intertidal area) albeit on a relatively small scale due to the large size of the tidal prism.

These high flows have changed somewhat from the Present Day under this scenario (down by 25%, Addendum Table 9) but as they do not contribute as much to the current mouth status as the tidal flow, the resulting change in geomorphological conditions in the estuary can be expected to be small (down by 3%, Addendum Table 10).

A2.5.4.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Reduced flow volumes have a reduced capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under the Maximise Agriculture scenario, mean monthly flows are lower while the contributions by agricultural return flows increase. The combined effect of these two negative influences is predicted to be a significant reduction in water quality in the estuary – i.e. increased nutrients, lower dissolved oxygen concentrations, and reduced water clarity (higher turbidity). Thus, the water-quality health score decreases to 46% (down by 13%).

A2.5.4.4 Micro-algae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient levels) with the result that phytoplankton concentrations in the system are extremely high. Further increases in nutrient concentration will almost certainly give rise to further increases in the phytoplankton abundance in the estuary with a concomitant reduction in health score associated with this parameter (down from 40 to 36%).

A2.5.4.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As mean monthly flows under the Present Day scenario are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the degradation from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production). The effect of further reductions in flow and increases in agricultural return flows anticipated under this scenario, are consequently anticipated to have a minor negative influence on vegetation communities associated with the estuary, translating to a reduction in the health score of 2% (Addendum Table 10).

A2.5.4.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes in the geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality (reduced water clarity and oxygen levels, increased nutrients and, probably, pesticide residues) from the natural to the Present Day situations. While geomorphological conditions are not expected to change significantly from the Present Day under the Maximise Agriculture scenario, the anticipated reduction in water quality will have a significant impact on macroinvertebrates. The concomitant reduction in health score is anticipated to be in the region of 12% (i.e. from a present day score of 60% to 53%, Addendum Table 10), and will manifest as a further reduction in catches of shrimp and possibly mangrove crabs from the estuary.

A2.5.4.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geomorphological characteristics and water quality as well as by the loss of the macroinvertebrates, which are their main food supply. As such, the current health score is low (50%) and is expected to decline even further under this scenario to 46% (Addendum Table 10). Effects of this will manifest as a reduction in abundance and species richness of the fish fauna in the estuary, with a corresponding reduction in fish landings derived from the estuary.

A2.5.4.8 Birds

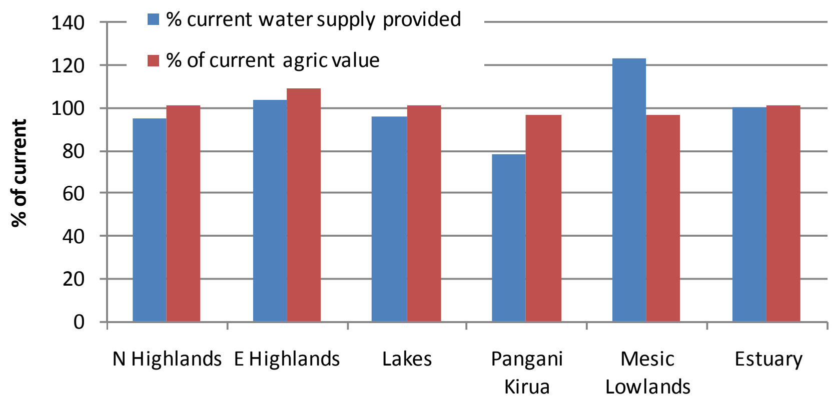
Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the estuary and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). The predicted reductions in invertebrate and fish abundance are likely to be translated into a further reduction in the numbers and species of birds frequenting the estuary albeit not as severe as for the fish and invertebrates (down from 40 to 37%, Addendum Table 10).

A2.5.4.9 Overall condition

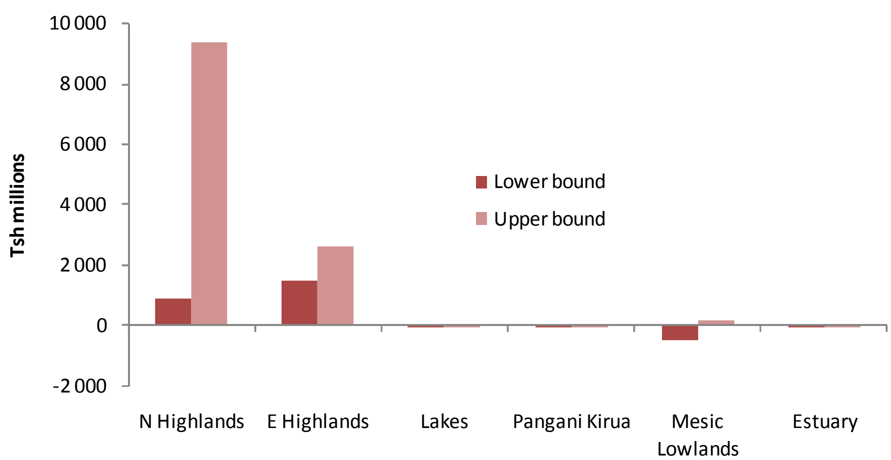
All measured health parameters in the estuary show a decline under the Maximise Agriculture scenario, with the result that the overall health of the system can be expected to decline as well (from 57 to 47%). No change in health class is expected under this scenario, but the estuary would now be near the bottom of the D class, (i.e. ‘largely modified’).

A2.5.5 Income from small-scale agriculture

Addendum Figure 10 shows aggregate net income from agriculture to rural households within 5 km of rivers under the scenario as a percentage of current value. In the Maximise Agriculture scenario, income in the Northern Highlands and particularly the Eastern Highlands is increased, and there is little change in the lower zones. Significant overall gains are seen in the highland zones (Addendum Figure 11).



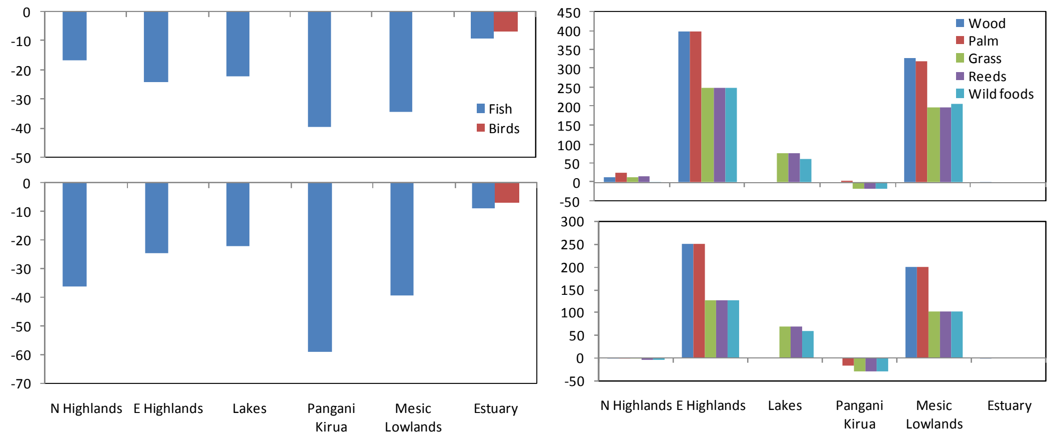
Addendum Figure 10 Area under small-scale irrigation under the Maximise Agriculture scenario as compared with the Present Day



Addendum Figure 11 Lower and upper bound estimates of the aggregate change in income from small-scale agriculture under the Maximise Agriculture scenario

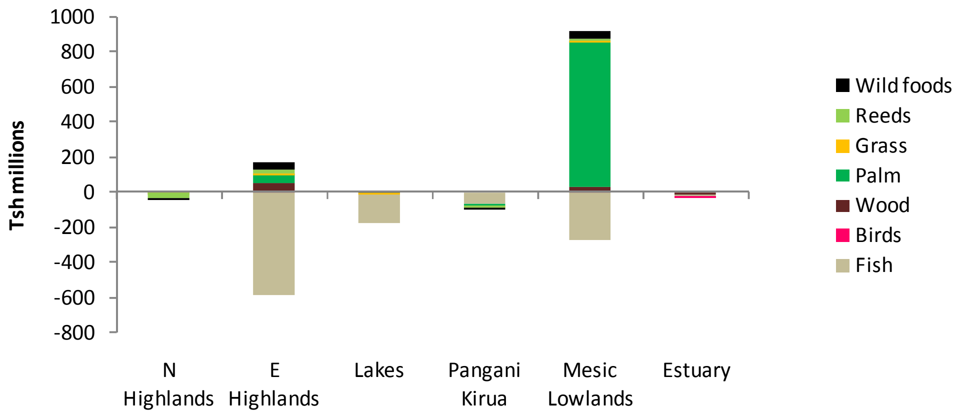
A2.5.6 Income from natural resources

Fish decrease in abundance in all zones under this scenario, with losses in the order of a quarter to a half of current stocks. Bird numbers also decrease. Plant resources are little affected in the Northern Highlands, but are expected to increase in most areas under this scenario, apart from Pangani-Kirua, where decreases of up to 25% are expected (Addendum Figure 12).



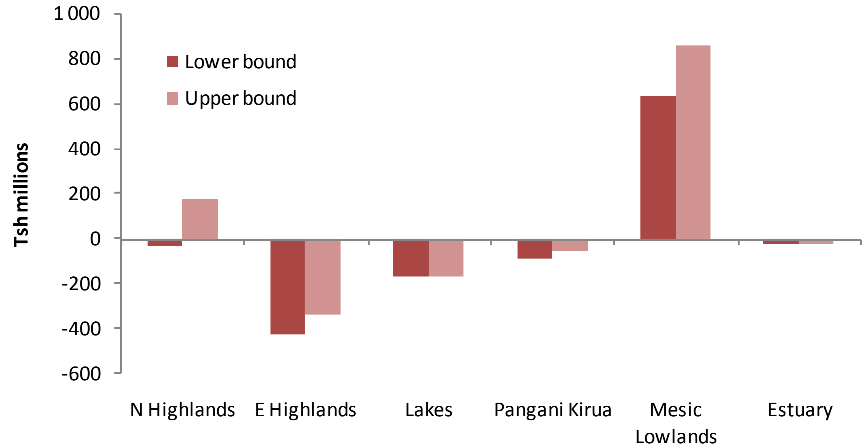
Addendum Figure 12 **Best and worst case estimates of the percentage change from Present Day in the abundance of natural resources used by households, under the Maximise Agriculture scenario**

Impacts of these changes on income to households are shown in Addendum Figure 13.



Addendum Figure 13 **Worst-case estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under the Maximise Agriculture scenario**

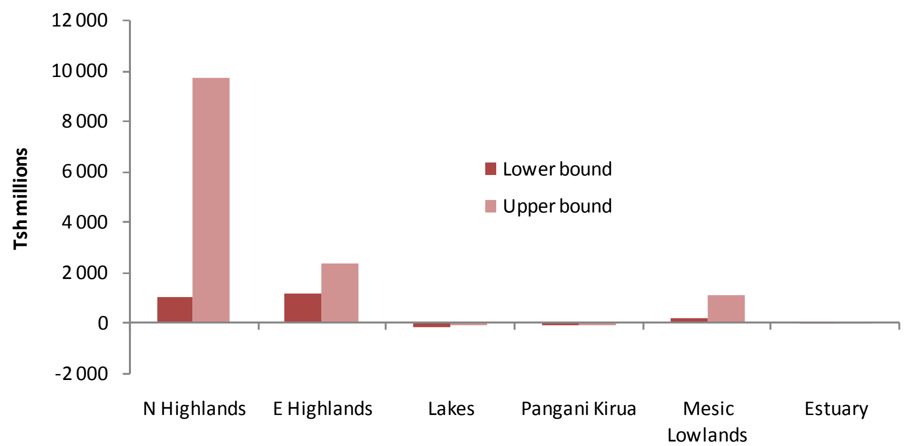
Aggregate income is expected to increase slightly in the Northern Highlands but decrease by about Tsh 400 million in the Eastern Highlands. Large gains in income are expected in the Mesic Lowlands (Addendum Figure 14).



Addendum Figure 14 Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under the Maximise Agriculture scenario

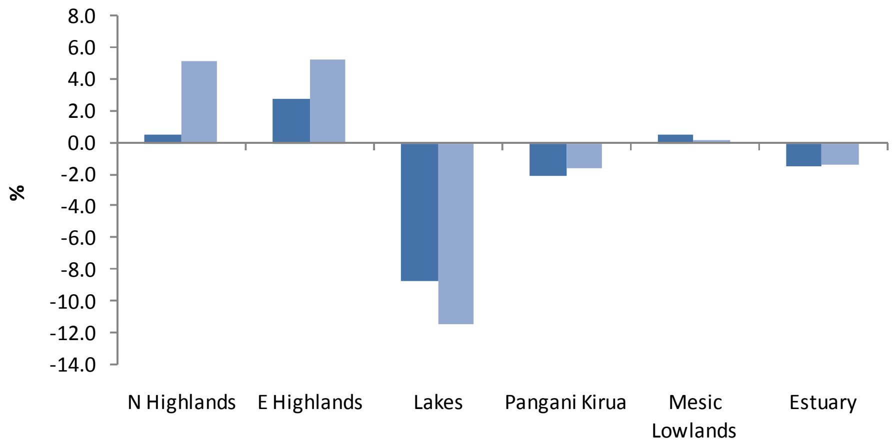
A2.5.7 Overall household income

Overall impacts on household income are expected to be positive in the Highlands and Mesic Lowlands. There are negligible losses in the remaining zones (Addendum Figure 15).



Addendum Figure 15 Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, under maximise agriculture scenario

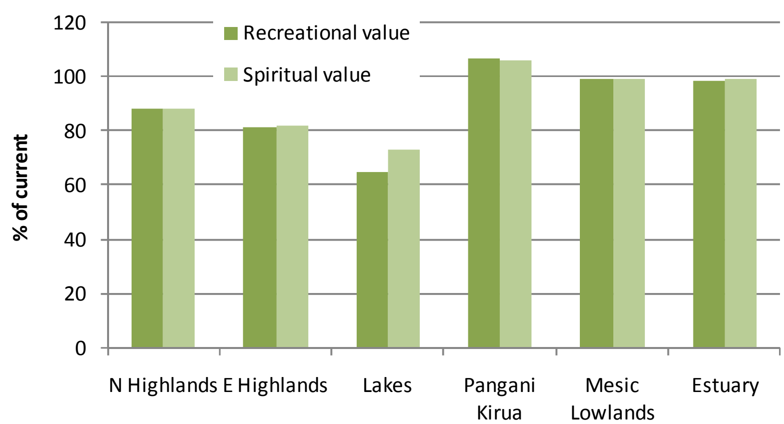
Aggregate household income increases by up to 5% in the Highland areas and a slight increase is expected in the Mesic Lowlands. In the remaining zones there is a decrease in income, particularly in the Lakes zone where income decreases by up to 12% (Addendum Figure 16).



Addendum Figure 16 **Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under Maximise Agriculture scenario**

A2.5.8 Intangible values

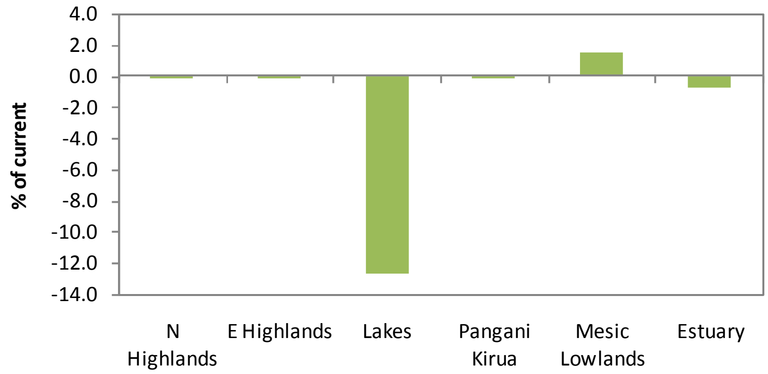
There is a marked decline in recreational and spiritual well-being among households in the Highlands and Lake areas (Addendum Figure 17). A slight increase in utility is enjoyed in Pangani-Kirua, and there is very little change in the last two zones.



Addendum Figure 17 **Overall recreational and spiritual well-being (derived from rivers and other sources) under Maximise Agriculture scenario as a percentage of Present Day well-being**

A2.5.9 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 18. In general, the percentage change in well-being is small, apart from in the Lakes area, where households suffer a significant loss of well-being.



Addendum Figure 18 Percentage change in overall well-being of households within 5 km of rivers under Maximise Agriculture scenario

A2.6 Effects on economic value

Under Maximise Agriculture scenario, changes in environmental quality and function lead to a loss of value in terms of ecosystem regulating services, but a gain in terms of direct value added by the natural resources sector. Much larger gains are obtained through direct value added by the agricultural sector. These gains are eclipsed by very large losses in the energy sector (Addendum Table 11).

Addendum Table 11 Gains and losses in the value of HEP, agriculture, natural resources, and ecosystem regulating services (Tsh millions per year) under the Maximise Agriculture scenario.

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
-606 842	15 540	175	-91	-591 218

A3 MAXIMISE HEP

A3.1 Description of the scenario

The Maximise HEP scenario comprised the following (in order of priority):

- Full allocation of 2025 BHN and Urban/Industrial water demands to Arusha and Moshi.
- Abstraction for agriculture restricted, particularly in the upper catchment, in order to maximise the amount of water that could be released from NyM and Kalemawe dams for HEP generation. This water was released in a pattern as close as possible to optimum for the operation of the HEP stations.
- Water that could not be used for HEP generation was allocated to agriculture.
- Environment received whatever water was left.

Thus, in the upper catchment the residual flows in the river were close to natural as most of the water was required for maximising storage in NyM to supply the downstream HEP plants.

A3.2 Hydrological implications

A3.2.1 Water allocated per sector

Urban/industrial	54.7 Mcm a-1 (PD = 31.1)
Irrigation	634 Mcm a-1 (PD = 1042) but see Section A3.3 for area irrigated
HEP	782 601 MW h-1 (PD = 602 647)

A3.2.2 Changes in the flow regime relative to present day

The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 12. There were three main kinds of change relative to present day:

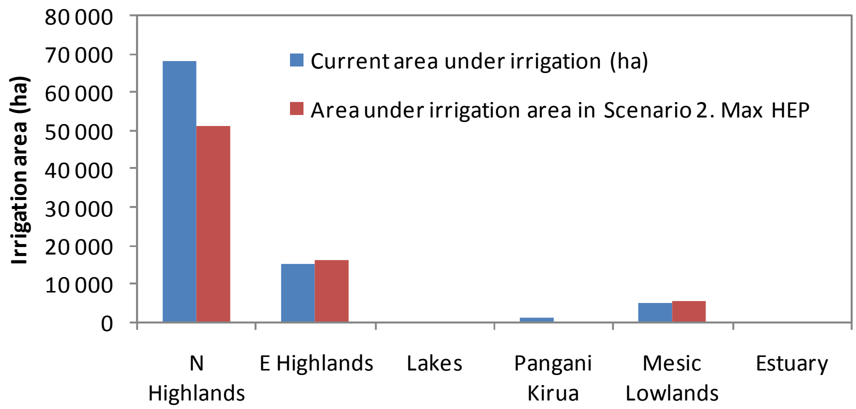
- slightly reduced low flows at Sites 1-2 in upper catchment;
- slightly increased dry-season flows at Site 7 in the Mkomazi River and Site 9 in the lower Pangani River.
- a significant increase in flows greater than 25 m^3s^{-1} at Site 6 (Pangani River at Kirua Swamp), which would inundate a greater portion of the swamp than at present.

Addendum Table 12 DRIFT flow summary data for the Maximise HEP scenario

Location	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario MAR (MCM)	65.6	535.3	184.2	862.8	888.7	29.3	109.3	1523.5
WSLF - Volumes (MCM)	20.6	305.7	74.4	501.6	307.6	3.2	37.2	579.3
DSLF - Volumes (MCM)	31.2	139.2	72.0	189.3	523.2	18.3	46.2	779.9
Class 1 - Annual Frequency	5	1	0	3	2	2	1	0
Class 2 - Annual Frequency	3	3	1	3	11	2	7	0
Class 3 - Annual Frequency	2	4	2	3	1	2	6	7
Class 4 - Annual Frequency	2	3	4	3	0	1	2	1
1:2	P	P	P	P	A	A	P	P
1:5	P	P	P	P	A	A	P	P
1:10	P	P	P	P	A	A	P	P
1:20	P	P	P	P	A	A	P	P

A3.3 Effects on irrigated agriculture

Under this scenario, there is a major reduction in irrigation area in the Northern Highlands, but little impact in the remaining zones (Addendum Figure 19).



Addendum Figure 19 Area under irrigation under the Maximise HEP scenario as compared with the Present Day

A3.4 Effects on HEP production

HEP output is increased by 30%, resulting in an output of 782 601 MWh.

A3.5 Effects on environmental condition

A3.5.1 Summary of biophysical condition in the river

The influence of the residual flows on the condition of the rivers is described in two ways:

- as percentage change relative to present day for key indicators representing each of geomorphology, water quality, riparian vegetation, macroinvertebrates and fish;
- in terms of change in overall river condition as denoted by the integrity score

Note: The present day levels of the indicators have not been quantified, thus the reported change is relative to an unknown quantity.

A3.5.1.1 Geomorphology

The geomorphological changes associated with the Maximise HEP scenario are concentrated in the upper portion of the catchment, i.e., upstream of NyM and in the Mkomazi River (Addendum Table 13). The changes can be summarised as follows:

- noticeable increase in rocky areas, and thus fish habitat in the Pangani River at Kirua and severe decrease in the Lower Mkomazi River;
- an increase and loss of pools respectively, and thus fish refuge, at the same sites;
- build up of fine sediments in the Lower Mkomazi River;
- severe loss of remaining floodplains in the Lower Mkomazi River, but a restoration of the floodplains along the Pangani River at Kirua.

Addendum Table 13 Estimated percentage change from present day for geomorphological features under the Maximise HEP scenario

Site No.	Name	Riffles and rapids		Pools		Fine sediments		Coarse sediments		Bank erosion		Floodplain inundation	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	0	0	0	0	0	0	0	0	0	0
2	Lower Kikuletwa	0	0	0	0	-20	0	1	25	0	0	0	0
3	Upper Ruvu	-20	0	0	0	1	25	0	0	0	0	0	0
4	Lower Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
6	Pangani at Kirua	26	68	68	250	1	25	0	0	0	0	68	250
7	Lower Mkomazi	-100	-100	-80	-60	500	800	0	0	0	0	-100	-100
8	Lower Luengera	1	25	0	0	-20	0	0	0	0	0	0	0
9	Lower Pangani	0	0	1	25	-20	0	0	0	1	25	0	0

A3.5.1.2 Water Quality

The water-quality changes associated with the Maximise HEP scenario are most obvious in the Lower Kikuletwa and Lower Mkomazi Rivers (Addendum Table 14). The changes can be summarised as follows:

- noticeable increase in conductivity in the Lower Kikuletwa and Lower Mkomazi rivers;
- slightly increased phosphorus levels in the upper catchment, and lower Luengera River.

Addendum Table 14 Estimated percentage change from present day for water quality under the Maximise HEP scenario

Site No.	Name	Turbidity/TSS		Conductivity/TDS		Phosphorus		Nitrogen	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	0	0	0	0	0	0
2	Lower Kikuletwa	1	25	26	68	1	25	-20	0
3	Upper Ruvu	0	0	1	25	1	25	0	0
4	Lower Ruvu	0	0	0	0	0	0	0	0
6	Pangani at Kirua	0	0	0	0	0	0	0	0
7	Lower Mkomazi	0	0	26	68	0	0	-20	0
8	Lower Luengera	0	0	0	0	1	25	-20	0
9	Lower Pangani	1	25	0	0	0	0	0	0

A3.5.1.3 Vegetation

The changes in riparian vegetation associated with the Maximise HEP scenario Addendum Table 15) can be summarised as follows:

- increase in all layers of wet bank vegetation in Pangani at Kirua and Lower Mkomazi Rivers and slight changes in understory vegetation cover at some other sites;

Addendum Table 15 Estimated percentage change from present day for water quality under the Maximise HEP scenario

Site No.	Name	Dry Bank Trees		Dry Bank Herbs & Shrubs		Dry Bank Grasses		Wetbank Trees		Wetbank Herbs		Wetbank grasses and reeds	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-	-	-	-	-	-	0	0	0	0	0	0
2	Lower Kikuletwa	0	0	0	0	0	0	0	0	-20	0	0	0
3	Upper Ruvu	0	0	0	0	0	0	0	0	-20	0	1	25
4	Lower Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
6	Pangani at Kirua	-	-	-	-	-	-	26	68	26	68	26	68
7	Lower Mkomazi	-	-	-	-	-	-	26	68	1	25	1	25
8	Lower Luengera	-	-	-	-	-	-	0	0	0	0	0	0
9	Lower Pangani	1	25	1	25	0	0	-20	0	-20	0	-20	0

A3.5.1.4 Macroinvertebrates

The changes in macroinvertebrates associated with the Maximise HEP scenario (Addendum Table 16) can be summarised as follows:

- low decline of sensitive species in the Kikuletwa and Ruvu Rivers and more severe decline in the Lower Mkomazi River;
- low decrease of tolerant species in the Lower Mkomazi River.

Addendum Table 16 Estimated percentage change from present day for macroinvertebrates under the maximise HEP scenario

Site No.	Name	Sensitive species		Tolerant species (e.g., Dysticidae, Chironominae and Culicidae)		Pest Simuliidae	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	0	0	0	0
2	Lower Kikuletwa	-40	-20	0	0	0	0
3	Upper Ruvu	-40	-20	0	0	-	-
4	Lower Ruvu	0	0	0	0	-	-
6	Pangani at Kirua	0	0	0	0	0	0
7	Lower Mkomazi	-80	-60	-40	-20	-	-
8	Lower Luengera	0	0	-20	0	-	-
9	Lower Pangani	0	0	0	0	-	-

A3.5.1.5 Fish

The changes in fish associated with the Maximise HEP scenario (Addendum Table 17) can be summarised as follows:

- Substantial increase in *Clarias* and *Tilapia* in the Pangani at Kirua;
- decline of all fish groups in the lower Mkomazi River, with *Tilapia* and *Labeo* groups heading toward local extinction;
- moderate increase in *Clarias* and *Tilapia* in the lower Pangani River.

Addendum Table 17 Estimated percentage change from present day for fish under the Maximise HEP scenario

Site No.	Name	*Clarias* group		*Tilapia* group		*Labeo* group	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	0	0	0	0
2	Lower Kikuletwa	0	0	0	0	0	0
3	Upper Ruvu	0	0	0	0	-40	-20
4	Lower Ruvu	-20	0	0	0	-20	0
6	Pangani at Kirua	251	500	68	250	0	0
7	Lower Mkomazi	-40	-20	-100	-100	-100	-100
8	Lower Luengera	0	0	0	0	0	0
9	Lower Pangani	1	25	26	68	0	0

A3.5.1.6 Overall condition

The changes in overall river condition associated with the Maximise HEP scenario are provided in Addendum Table 18. There is a very small decline in the Kikuletwa and Ruvu Rivers, with a more substantial one in the Lower Mkomazi. The lower sites, particularly the Pangani Kirua site, show a mild rehabilitation toward natural.

Addendum Table 18 Overall condition at each river site for the Maximise HEP scenario

River site	Site name	Present Day River Health Category	Change from Present Day ecological integrity	River Health Category for the scenario
1	Upper Kikuletwa	B/C	-0.025	C
2	Lower Kikuletwa	D	-0.007	D
3	Upper Ruvu	C/D	-0.072	D
4	Lower Ruvu	D	-0.013	D
6	Pangani at Kirua	C	0.186	C/B
7	Lower Mkomazi	C/D	-0.474	D
8	Lower Luengera	C	0.017	C
9	Lower Pangani	C	0.068	C

A3.5.2 Summary of biophysical condition in NyM

A3.5.2.1 Water level change

The FA Tool assesses likely change in two parameters associated with NyM Dam – fish catch and reed area. These parameters are affected by water area (volume) of the lake and the variation in area, which are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under the Maximise HEP scenario are presented in Addendum Table 19 and discussed in the respective sections below.

Addendum Table 19 Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in NyM under the Maximise HEP scenario relative to the Present Day, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario.

	Present Day	This Scenario	% Change
Mean lake area (ha)	103.8	59.8	-42%
Std dev of lake area (m)	1.24	1.37	10%
Max lake area (ha)	137.1	123.2	-10%
Reed area (ha)	33.3	63.5	90%
Mean lake level (m)	15.9	11.0	-31%
Std dev of lake level (m)	1.2	1.4	+17%
Fish catch (tonnes)	3538.8	2399.4	-32%

A3.5.2.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surround NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under the Maximise HEP scenario, lake area shrinks significantly (by 42%), variability increases marginally (up 10%) while maximum area inundated decreases by 10% (Addendum Table 19). The net result of this is that the total reed area is expected to expand by 90%.

A3.5.2.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the present day we expect fish populations to expand in responses to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under the Maximise HEP scenario, variability in lake level increases marginally by 10% but the average area declines markedly by 42% (Addendum Table 19). As a result, fish catches are expected to decline by 32%.

A3.5.3 Summary of biophysical condition in Kirua Swamp

The Maximise HEP scenario will result in an improvement in the condition of the Kirua Swamp as a result of increased flooding relative to Present Day, from c. 4% of natural to c. 15%.

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to present day. Under this scenario, fish abundances are predicted to increase to 294% of present day (389 tonnes) and floodplain vegetation to increase to 304% of present day.

A3.5.4 Summary of biophysical condition in the Estuary

A3.5.4.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under the Maximise HEP scenario freshwater flows reaching the estuary are higher than the Present Day during all seasons except the Long Rains (Addendum Table 20), while agricultural return flows, as a proportion of the total flow, decrease in all seasons except during the Long Rains due to preferential allocation of water to HEP production (Addendum Table 20). In spite of the increases in average monthly flows, extreme high flows decrease due to the flattening of the hydrograph (down by 25%, Addendum Table 20).

Addendum Table 20 Change in freshwater flows reaching the estuary under the Maximise HEP scenario relative to the Present Day

		Short rains	Dry 1	Long rains	Dry 2	All months
Average monthly flows	Present Day (Mm^3)	91.3	72.7	186.9	80.7	102.1
	Max HEP	123.0	110.4	171.9	118.2	127.0
	% Change	34.7	51.9	-8.0	46.6	24.3
Agricultural monthly return flows	Present Day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	Max HEP	19.4	22.6	21.5	29.0	28.1
	% Change	-31.2	-34.9	4.0	-29.9	-14.6
No. months flow >250 Mm^3	Present Day	8.0				
	Max HEP	6.0				
	% Change	-25.0				

Addendum Table 21 Change in health scores for the estuary as a whole and the component parameters under the Maximise HEP scenario

	Present Day	This scenario	Change (+/-)
Geomorphology	40%	39%	-3%
Water Quality	53%	59%	11%
Micro-algae	40%	41%	3%
Vegetation	60%	62%	3%
Inverts	60%	64%	7%
Fish	50%	53%	6%
Birds	40%	44%	10%
Overall health score	57%	65%	14%

A3.5.4.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the present day status of the mouth, which is both wide and deep. Thus, only the extreme high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significant affect geomorphological conditions in the estuary (i.e. channel width and depth, intertidal area, etc.), albeit on a relative small scale due to the large size of the tidal prism.

These high flows have decreased somewhat from the Present Day under this scenario (down by 25%, Addendum Table 20) but as they do not contribute as much to the current mouth status as does the tidal flow, the resulting change in geomorphological conditions in the estuary can be expected to be small (-3%, Addendum Table 21).

A3.5.4.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Increased flow volumes have a greater capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under the Maximise HEP scenario, mean monthly flows are higher in all seasons except for the Long Rains while the contribution by agricultural return flows decreases in all seasons except for the Long Rains. The combined effect of these two mostly positive influences is predicted to be an improvement in water quality in the estuary i.e. decreased nutrients, higher dissolved oxygen concentrations, and increased water clarity (lower turbidity). Water quality health score is up by 11% to 59% (Addendum Table 21).

A3.5.4.4 Micro-algae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient level) with the result that phytoplankton concentrations in the system are extremely high. Increases in mean monthly runoff and reduced contribution by agricultural return flows are likely to reduce (dilute) nutrient concentrations in the estuary and have a net positive effect on estuary health as indicated by micro-algae through a reduction in phytoplankton concentrations. Health scores under this scenario increase from the Present Day by 3% to 41%.

A3.5.4.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As mean monthly flows under the Present Day scenario are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the contribution from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production).

Restoring some of this flow and reducing the contribution by agricultural return flows, as anticipated under this scenario, are consequently anticipated to have a minor positive influence on vegetation communities associated with the estuary, translating as an increase in the health score by 3% (Addendum Table 21).

A3.5.4.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes in the geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality, such as reduced water clarity and oxygen levels and increased nutrients, between the natural and Present Day situations. While geomorphological conditions are not expected to change significantly from the Present Day under the Maximie HEP scenario, the anticipated increase in water quality will have a modest impact on macroinvertebrates. The concomitant increase in health score is anticipated to be in the region of 7% (i.e. from a present day score of 60% to 64%, Addendum Table 21), and should be manifest as an improvement in catches of shrimp and possibly mangrove crabs from the estuary.

A3.5.4.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geomorphological characteristics and water quality as well as by the decline of their main food supply (invertebrates). As such the current health score is low (50%) but this can be expected to improve modestly under this scenario due to the combined effects of improved water quality and increased food availability (up by 6% to 53%, Addendum Table 21). Effects of this should manifest as an increased abundance and species richness of the fish fauna in the estuary, with a corresponding improvement in fish landings derived from the estuary.

A3.5.4.8 Birds

Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the system and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). The predicted improvement in both invertebrate and fish abundances are likely to be translated into an increase in the numbers and species of birds frequenting the estuary (improved from the current health score of 40% to 44%, Addendum Table 21).

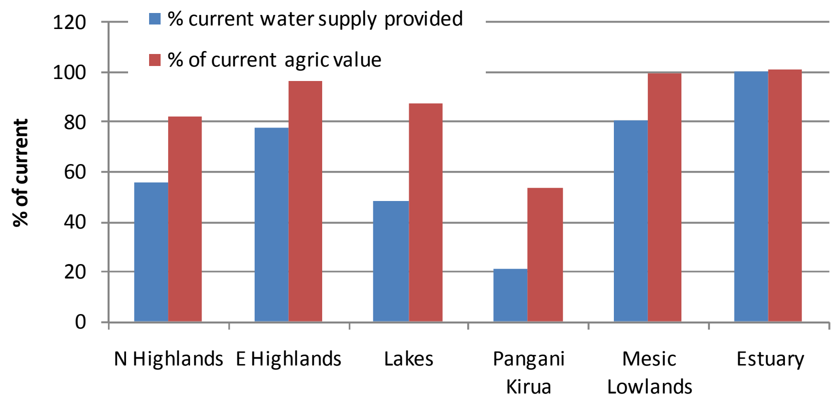
A3.5.4.9 Overall condition

All measured health parameters in the estuary except geomorphology show an improvement under the High HEP scenario due to increased freshwater flow reaching the estuary coupled with a reduction in agricultural return flows, with the result that the overall health of the system can be expected to improve significantly. According to the model, overall health score increases from 57 to 65%, which shifts the estuary up from a D class (largely modified) to a C class (moderately modified).

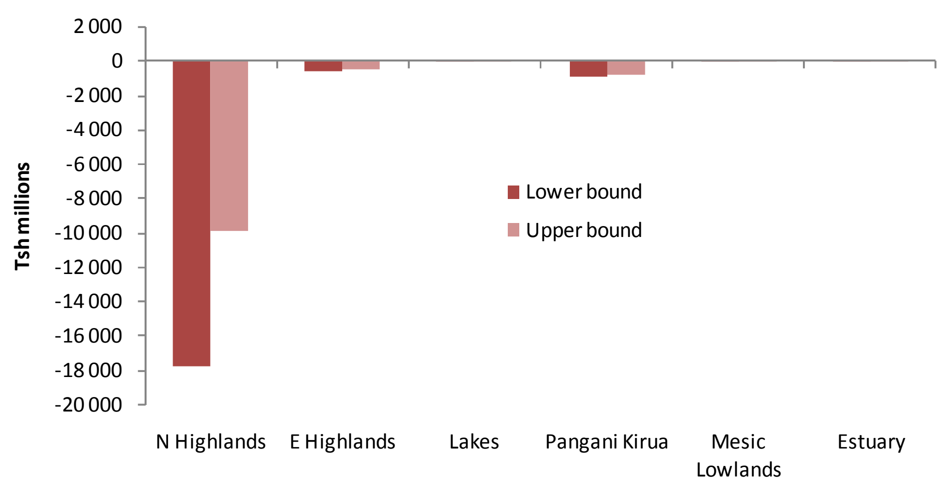
A3.6 Effects on livelihoods

A3.6.1 Income from small-scale agriculture

Addendum Figure 20 shows aggregate net income from agriculture to rural households within 5 km of rivers under the scenario as a percentage of current value. In the Maximise HEP scenario, agricultural income in all but the Mesic Lowlands and Estuary is decreased relative to Present Day, particularly in the Pangani-Kirua area (Addendum Figure 20). The impact on aggregate income is greatest in the Northern Highlands (Addendum Figure 21).



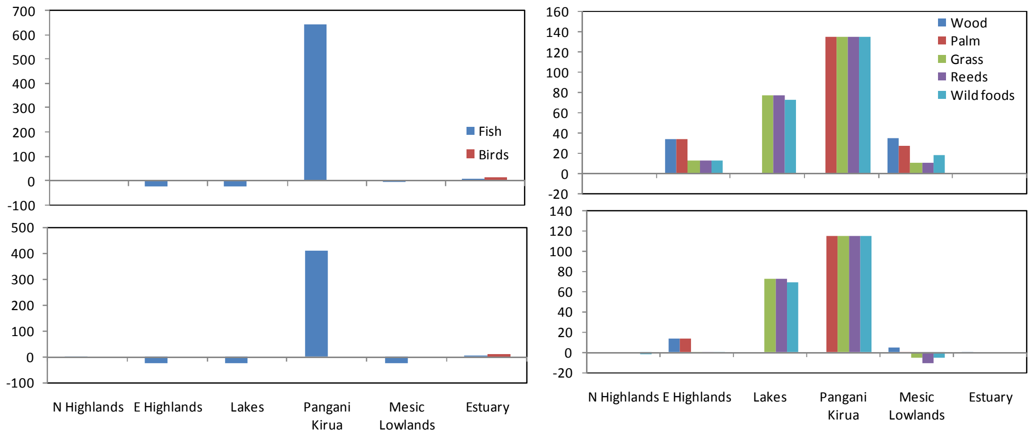
Addendum Figure 20 Area under small-scale irrigation under the Maximise HEP scenario as compared with the present day



Addendum Figure 21 Lower and upper bound estimates of the aggregate change in income from small-scale agriculture under the Maximise HEP scenario

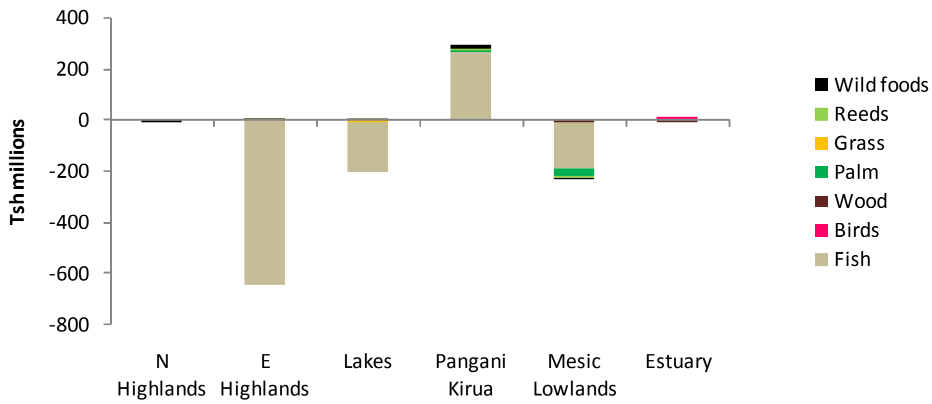
A3.6.2 Income from natural resources

Fish decrease slightly in abundance in all zones below the Northern Highlands except Pangani-Kirua, where abundance increases four to six-fold (Addendum Figure 22), and the Estuary, where there is very little change. Bird numbers improve slightly in the estuary. Plant resources are little affected in the Northern Highlands, but are expected to increase in most areas under this scenario, particularly in the Pangani-Kirua and Lakes zones.



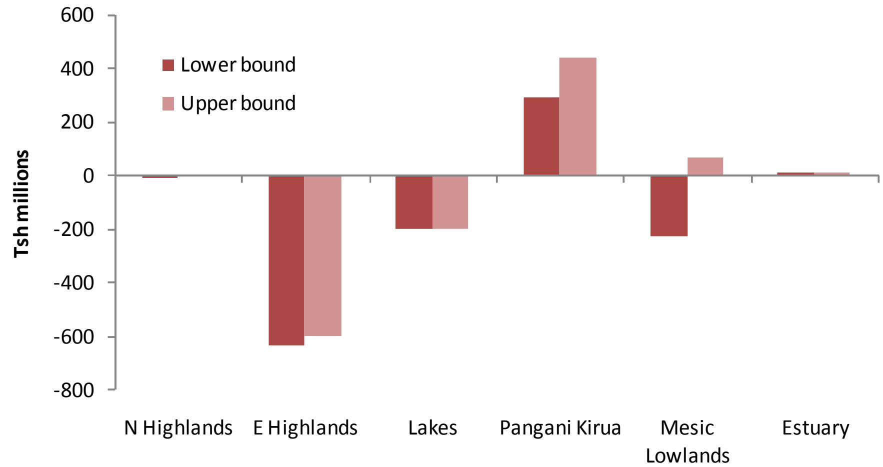
Addendum Figure 22 Best (above) and worst case estimates (below) of the percentage change from Present Day in the abundance of natural resources used by households, under the Maximise HEP scenario

Impacts of these changes on aggregate income to households are shown in Addendum Figure 23.



Addendum Figure 23 Worst-case estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under the Maximise HEP scenario

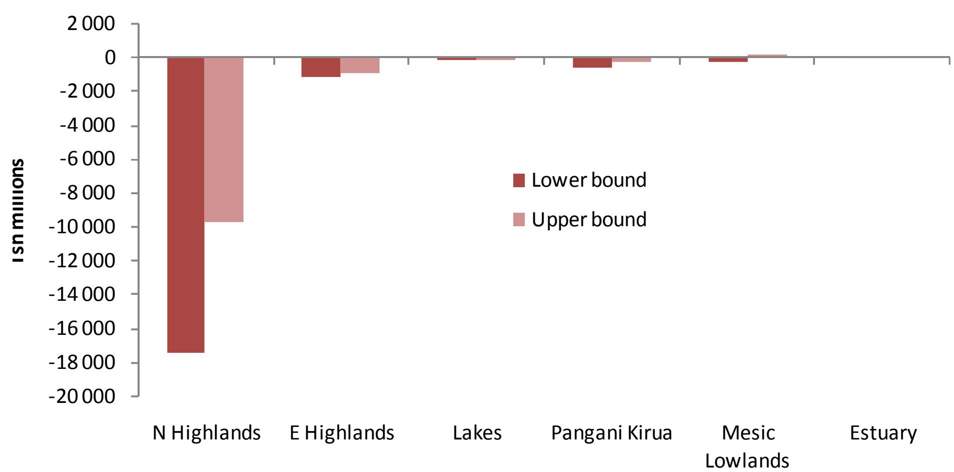
There is no change in aggregate income from natural resources in the Northern Highlands, but major decreases occur in the Eastern Highlands, and some decrease in the Lakes and Mesic Lowlands. Income increases in Pangani-Kirua (Addendum Figure 24).



Addendum Figure 24 **Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under the Maximise HEP scenario**

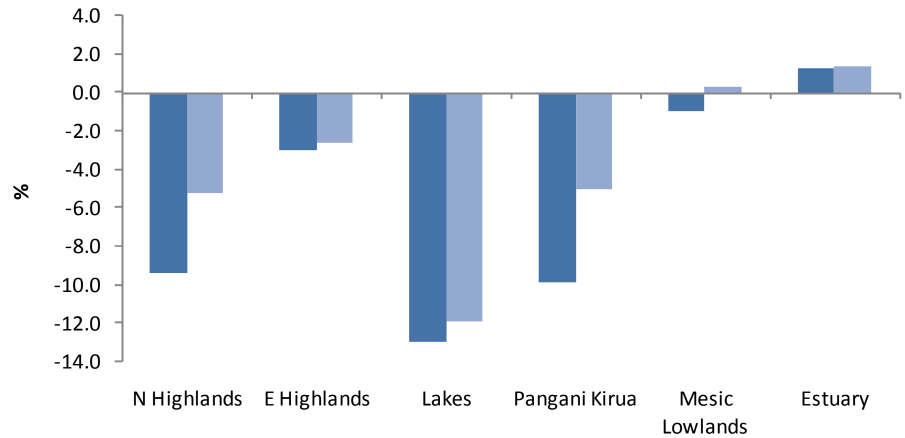
A3.6.3 Overall household income

Overall impacts on household income are negative, with the greatest impact in the Northern Highlands. Changes in the other zones are relatively minor (Addendum Figure 25).



Addendum Figure 25 **Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, under the Maximise HEP scenario**

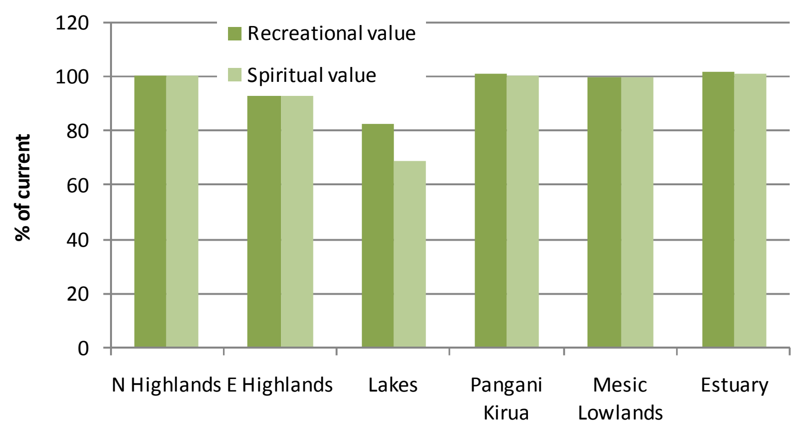
Aggregate household income decreases in all but the Estuary zone, where there is a small increase of about 1%. Income decreases by about 12% in the Lakes area, and by up to almost 10% in the Northern Highlands and Pangani-Kirua areas, because of losses in agricultural income (Addendum Figure 26).



Addendum Figure 26 Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under the Maximise HEP scenario

A3.6.4 Intangible values

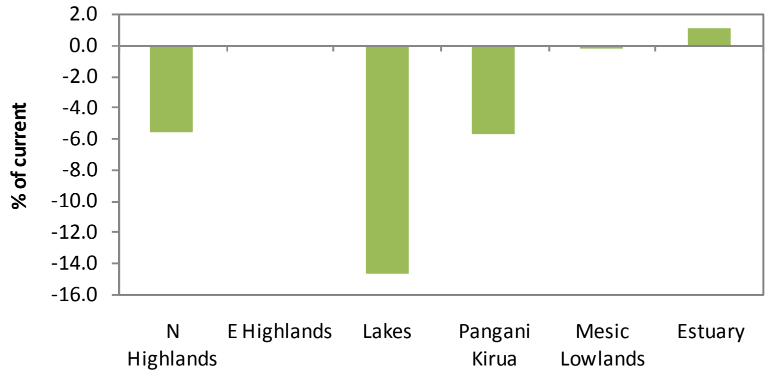
There is no measurable impact on recreational and spiritual well-being in most zones, apart from the Lakes, where there are significant decreases, and a slight decrease in utility in the Eastern Highlands (Addendum Figure 27).



Addendum Figure 27 Overall recreational and spiritual well-being (derived from rivers and other sources) under the Maximise HEP scenario as a percentage of current well-being

A3.6.5 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 28. There is a major decline in well-being in the Lakes area, and significant declines in the Northern Highlands and Pangani-Kirua. Households around the estuary are slightly better off.



Addendum Figure 28 Percentage change in overall well-being of households within 5 km of rivers under the Maximise HEP scenario

A3.7 Effects on economic value

Under The Maximise HEP scenario, changes in environmental quality and function lead to a loss of value in terms of ecosystem regulating services, but a similar-sized gain in terms of direct value added by the natural resources sector. Much larger losses are incurred in terms of direct value added by the agricultural sector. These losses are offset to some extent by gains in the energy sector (Addendum Table 22).

Addendum Table 22 Gains and losses in the value (Tsh millions per year) of HEP, Agriculture, Natural Resources and Ecosystem regulating services under the Maximise HEP scenario

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
547 991	-38 871	-516	183	508 788

A4 OPTIMISE PRESENT DAY WITH AGRICULTURE

NB: This scenario prioritised water allocation for environmental maintenance through optimizing Present Day volumes into a new pattern of flows. This became the second priority after Basin Human Needs.

A4.1 Description of the scenario

The Optimise Present Day with Agriculture scenario comprised the following (in order of priority):

- Supply of water for BHN
- Supply of present day volumes of river flow in a revised pattern of flows to improve ecosystem condition, at river sites 1, 2, 3, 4, 6, 7, 8 and 9, and at Kirua Swamps and the estuary.
- Allocation of water to Arusha and Moshi towards (but not necessarily reaching) the 2025 Urban/Industrial demands.
- Remaining water abstracted at a 75% level of assurance for agriculture.
- The resulting river flows used to generate HEP

A4.2 Hydrological implications

A4.2.1 Water allocated per sector

Urban/industrial	53.6 Mcm a^{-1} (PD = 31.1)
Irrigation	520 Mcm a^{-1} (PD = 1042), but see Section A4.3 for area irrigated
HEP	612 474 MW h^{-1} (PD = 602 647)

A4.2.2 Changes in the flow regime relative to present day

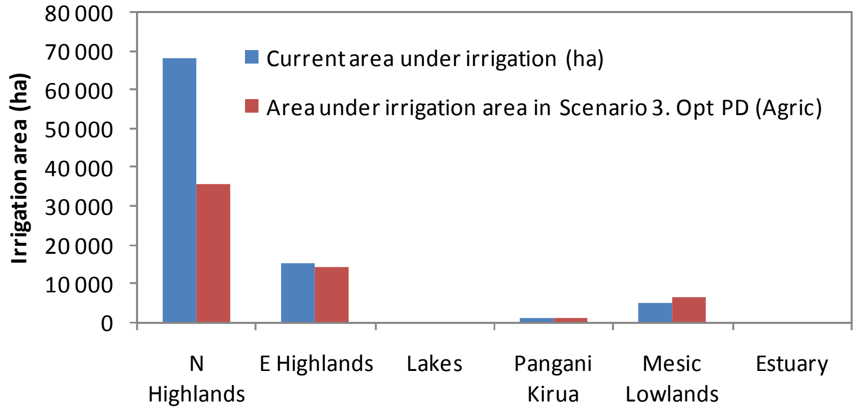
The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 23. There were two main kinds of change relative to present day:

- low flows partially re-instated, particularly in the dry season at the of the catchment (sites 1-4 and the Mkomazi River);
- intra-annual floods re-instated downstream of NyM at Site 6 - Pangani River at Kirua Swamp.

Addendum Table 23 DRIFT flow summary data for the Optimise Present Day with Agriculture scenario

Location	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario MAR (MCM)	62.0	604.4	206.0	733.8	800.0	38.0	105.0	1276.6
WSLF - Volumes (MCM)	23.0	278.0	96.0	388.0	316.0	9.0	39.2	574.0
DSLF - Volumes (MCM)	26.0	262.0	86.0	242.0	258.0	12.5	40.3	498.6
Class 1 - Annual Frequency	5	2	0	2	0	1	2	0
Class 2 - Annual Frequency	3	3	0	3	2	4	7	1
Class 3 - Annual Frequency	2	2	3	3	2	4	4	2
Class 4 - Annual Frequency	1	3	3	3	4	1	2	2
1:2	P	P	P	P	A	P	P	P
1:5	P	P	P	P	A	P	P	P
1:10	P	P	P	P	A	P	P	P
1:20	P	P	P	P	P	P	P	P

Under this scenario, the irrigation area in the Northern Highlands is almost halved relative to present day, and the impacts in other zones are very slight.



Addendum Figure 29 Area under irrigation under the Optimise Present Day with Agriculture scenario as compared with the Present Day

A4.3 Effects on HEP production

HEP output is not significantly different from the present output (101.6% of present) with a total output of 612 474 MWh.

A4.4 Effects on environmental condition

A4.4.1 Summary of biophysical condition in the river

The influence of the requested environmental flows on the condition of the rivers is described in two ways:

- as percentage change relative to present day for key indicators representing each of geomorphology, water quality, riparian vegetation, macroinvertebrates and fish;
- in terms of change in overall river condition as denoted by the DRIFT integrity score (see Section 4.4.1).

Note: The present day levels of the indicators have not been quantified, thus the reported change is relative to an unknown quantity.

A4.4.1.1 Geomorphology

Most of the beneficial geomorphological changes associated with Optimise Present Day with Agriculture scenario are concentrated in the Pangani River at Kirua (Addendum Table 24). At the other sites many of the impacts on condition are non-flow related and hence cannot be restored with flow alone. The changes can be summarised as follows:

- minor improvements in pool condition and reductions in fine sediments at most sites;
- significant improvements in physical habitat and floodplain inundation at Pangani River at Kirua.

Addendum Table 24 Estimated percentage change from Present Day for geomorphological features under the Optimise PD with Agriculture scenario

Site No.	Name	Riffles and rapids		Pools		Fine sediments		Coarse sediments		Bank erosion		Floodplain inundation	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	0	0	0	0	0	0	0	0	0	0
2	Lower Kikuletwa	0	0	1	25	0	0	0	0	1	25	0	0
3	Upper Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
4	Lower Ruvu	0	0	1	25	0	0	0	0	0	0	0	0
6	Pangani at Kirua	68	250	68	250	68	250	0	0	0	0	500	800
7	Lower Mkomazi	1	25	1	25	-40	-20	0	0	0	0	0	0
8	Lower Luengera	1	25	1	25	-20	0	0	0	0	0	0	0
9	Lower Pangani	0	0	0	0	0	0	0	0	0	0	0	0

A4.4.1.2 Water Quality

The water quality changes associated with this scenario are insignificant (Addendum Table 25).

Addendum Table 25 Estimated percentage change from Present Day for water quality under the Optimise PD with Agriculture scenario

Site No.	Name	Turbidity/TSS		Conductivity/TDS		Phosphorus		Nitrogen	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	0	0	0	0	0	0
2	Lower Kikuletwa	-20	0	0	0	0	0	0	0
3	Upper Ruvu	0	0	0	0	0	0	0	0
4	Lower Ruvu	0	0	0	0	0	0	0	0
6	Pangani at Kirua	0	0	0	0	0	0	0	0
7	Lower Mkomazi	0	0	0	0	0	0	0	0
8	Lower Luengera	0	0	0	0	0	0	0	0
9	Lower Pangani	0	0	0	0	0	0	0	0

A4.4.1.3 Vegetation

Most of the beneficial vegetation changes associated with this scenario are concentrated in the Pangani River at Kirua (Addendum Table 26). At the other sites many of the impacts on condition are non-flow related and hence cannot be restored with flow alone. The changes in riparian vegetation associated with the scenario can be summarised as follows:

- dramatically increased wet bank vegetation in the Pangani at Kirua;
- slight improvements to the dry bank vegetation in the Lower Kikuletwa.
- slight reduction in wet bank vegetation in the Mkomazi River.

Addendum Table 26 Estimated percentage change from Present Day for vegetation under the Optimise Present Day with Agriculture scenario

Site No.	Name	Dry Bank Trees		Dry Bank Herbs & Shrubs		Dry Bank Grasses		Wetbank Trees		Wetbank Herbs		Wetbank grasses and reeds	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	0	0	0	0	0	0	0	0	0	0
2	Lower Kikuletwa	1	25	0	0	0	0	0	0	1	25	1	25
3	Upper Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
4	Lower Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
6	Pangani at Kirua	0	0	0	0	0	0	500	800	1	25	68	250
7	Lower Mkomazi	0	0	0	0	0	0	-20	0	-20	0	-20	0
8	Lower Luengera	0	0	0	0	0	0	0	0	0	0	0	0
9	Lower Pangani	0	0	0	0	0	0	0	0	0	0	0	0

A4.4.1.4 Macroinvertebrates

The changes in macroinvertebrates associated with this scenario (Addendum Table 27) can be summarised as follows:

- slight increase in sensitive species in most rivers;
- concommittant decrease of tolerant species in most rivers;
- slight increase in simuliid numbers in the Pangani River at Kirua, mainly as a result of a greater availability of rocky substrata.

Addendum Table 27 Estimated percentage change from Present Day for macroinvertebrates under the Optimise PD with Agriculture scenario

Site No.	Name	Sensitive species		Tolerant species (e.g., Dysticidae, Chironominae and Culicidae)		Pest Simuliidae	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	0	0	0	0
2	Lower Kikuletwa	1	25	-20	0	0	0
3	Upper Ruvu	0	0	0	0	0	0
4	Lower Ruvu	0	0	0	0	0	0
6	Pangani at Kirua	1	25	-60	-40	1	25
7	Lower Mkomazi	1	25	-20	0	0	0
8	Lower Luengera	1	25	-20	0	0	0
9	Lower Pangani	0	0	0	0	0	0

A4.4.1.5 Fish

The changes in fish associated with this scenario (Addendum Table 28) can be summarised as follows:

- significant increase in *Clarias* and *Tilapia* in the Pangani at Kirua;
- slight to moderate increases in fish in several other rivers.

Addendum Table 28 Estimated percentage change from Present Day for fish under the Optimise Present Day with Agriculture scenario

Site No.	Name	*Clarias* group		*Tilapia* group		*Labeo* group	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	0	0	0	0
2	Lower Kikuletwa	1	25	0	0	26	68
3	Upper Ruvu	0	0	0	0	0	0
4	Lower Ruvu	-20	0	0	0	0	0
6	Pangani at Kirua	500	800	500	800	0	0
7	Lower Mkomazi	0	0	1	25	0	0
8	Lower Luengera	0	0	1	25	1	25
9	Lower Pangani	0	0	0	0	0	0

A4.4.1.6 Overall condition

The changes in overall river condition associated with thisscenario are provided in Addendum Table 29. There is a mild improvement in condition at most sites, with a noticeable improvement at the Kirua Swamp area.

Addendum Table 29 Overall condition at each river site for the Optimise Present Day with Agriculture scenario

Site No.	Name	Present Day River Health Category	Change from Present Day ecological integrity	River Health Category for the scenario
1	Upper Kikuletwa	B/C	0	B/C
2	Lower Kikuletwa	D	0.055	D
3	Upper Ruvu	C/D	0	C/D
4	Lower Ruvu	D	0.010	D
6	Pangani at Kirua	C	0.319	B/C
7	Lower Mkomazi	C/D	0.050	C/D
8	Lower Luengera	C	0.036	C
9	Lower Pangani	C	0	C

A4.4.2 Summary of biophysical condition in NyM

A4.4.2.1 Water level change

The FA Tool assesses likely change in two parameters associated with NyM Dam – fish catch and reed area. These parameters are affected by water area (volume) of the lake and the variation in area, which are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under the Optimise Present Day with Agriculture scenario are presented in Addendum Table 30 and discussed in the respective sections below.

Addendum Table 30 Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in NyM under the Optimise Present Day with Agriculture scenario relative to the Present Day, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario

	Present Day	This Scenario	% Change
Mean lake area (ha)	103.8	67.6	-35%
Std dev of lake area (m)	1.24	1.86	49%
Max lake area (ha)	137.1	114.1	-17%
Reed area (ha)	33.3	46.5	40%
Mean lake level (m)	15.9	12	-25%
Std dev of lake level (m)	1.2	1.9	58%
Fish catch (tonnes)	3538.8	2604.4	-26%

A4.4.2.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surround NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under this scenario, lake area shrinks significantly by 35%, variability increases significantly by 49%, and maximum area inundated decreases by 17% (Addendum Table 30). The net result of this is that total reed area is expected to expand by 40%.

A4.4.2.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the present day we expect fish populations to expand in responses to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under this scenario, variability in lake level increases significantly by 49% but average area declines by 35% (Addendum Table 30). As a result, fish catches are expected to decline by 26%.

A4.4.3 Summary of biophysical condition in Kirua Swamp

The largest improvement in condition associated with the Optimise Present Day scenarios occurs at Kirua Swamp. The reinstated flood regime results in greater inundation of the swamp, with concomitant improvements of its condition. Under present day condition swamp inundation is *c.* 4% of natural. This will increase to c. 24% under the Optimise Present Day with Agriculture scenario.

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to present day. Under this scenario, fish abundances are predicted to increase to 458% of present day (608 tonnes) and floodplain vegetation to increase to 480%.

A4.4.4 Summary of biophysical condition in the Estuary

A4.4.4.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under this scenario freshwater flows reaching the estuary are higher than the Present Day during all four seasons, but only significantly so during the Long Rains (increase in flow = 27.4%, other seasons all <2% increase) (Addendum Table 31). Agricultural return flows, as a proportion of the total flow, decrease in all seasons except the Long Rains where no change is expected (Addendum Table 31). The number of months where flow exceeds 250 Mm^3 increases by 38%.

Addendum Table 31 Change in freshwater flows reaching the estuary under the Optimise Present Day with Agriculture scenario relative to the Present Day

		Short rains	Dry 1	Long rains	Dry 2	All months
Average monthly flows	Present Day (Mm^3)	91.3	72.7	186.9	80.7	102.1
	Opt PD (Agric) (Mm^3)	91.9	73.8	238.2	80.7	113.3
	% Change	0.7	1.6	27.4	0.0	11.0
Agricultural monthly return flows	Present Day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	Opt PD (Agric) (Mm^3)	18.2	21.6	20.3	16.2	22.8
	% Change	-27.1	-26.0	0.0	-34.3	-16.6
No. months flow >250 Mm^3	Present Day	8.0				
	Opt PD (Agric) (Mm^3)	11.0				
	% Change	37.5				

Addendum Table 32 Health scores for the estuary as a whole and the component parameters under the Optimise Present Day with Agriculture scenario

	Present Day	This scenario	% change from PD (+/-)
Geomorphology	40%	43%	6%
Water Quality	53%	54%	2%
Micro-algae	40%	40%	0%
Vegetation	60%	62%	3%
Inverts	60%	62%	3%
Fish	50%	51%	2%
Birds	40%	42%	5%
Overall health score	57%	61	7%

A4.4.4.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the Present Day status of the mouth, which is both wide and deep. Thus, only the extreme high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significantly affect geomorphological conditions in the estuary such as channel width and depth, and intertidal area, albeit on a relative small scale due to the large size of the tidal prism.

The high flows have increased by 38% from the Present Day under this scenario (Addendum Table 32) but, as they do not contribute as much to the existing mouth status as the tidal flow, the resulting change in geomorphological conditions in the estuary can be expected to be small – an improvement of about 6% (Addendum Table 32).

A4.4.4.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Reduced flow volumes have a reduced capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under this scenario, mean monthly flows are higher while the contributions by agricultural return flows decrease. The combined effect of these two influences is predicted to lead to a small improvement in water quality in the estuary – i.e. decreased nutrients, higher dissolved oxygen concentrations, and increased water clarity (lower turbidity). Water quality health score has increased to 56% (up by 2%).

A4.4.4.4 Micro-algae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient level) with the result that phytoplankton concentrations in the system are extremely high. Changes in water quality under this scenario are very modest and are unlikely to have a noticeable effect on the micro-algae health score for the estuary.

A4.4.4.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As existing mean monthly flows are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the contribution from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production). The effect of increased flow and reduced agricultural return flow volumes anticipated under this scenario, is expected to have a minor positive influence on vegetation communities associated with the estuary, translating to an improvement in the health score by 3% (Addendum Table 32).

A4.4.4.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes from natural in the geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality (reduced water clarity and oxygen levels, increased nutrients). While existing geomorphological conditions are not expected to change significantly under this scenario, the anticipated improvement in water quality will result in a modest improvement of macroinvertebrate health of 3% (Addendum Table 32).

A4.4.4.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geomorphological characteristics and water quality as well as by the decline of their main food supply (invertebrates). As such, the current health score is low (50%) and is expected to improve only marginally under this scenario to 51% (Addendum Table 32).

A4.4.4.8 Birds

Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the estuary and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). The predicted improvements in invertebrate and fish abundance are likely to be translated into a modest improvement from 40% to 42% in the numbers and species of birds frequenting the estuary (Addendum Table 32).

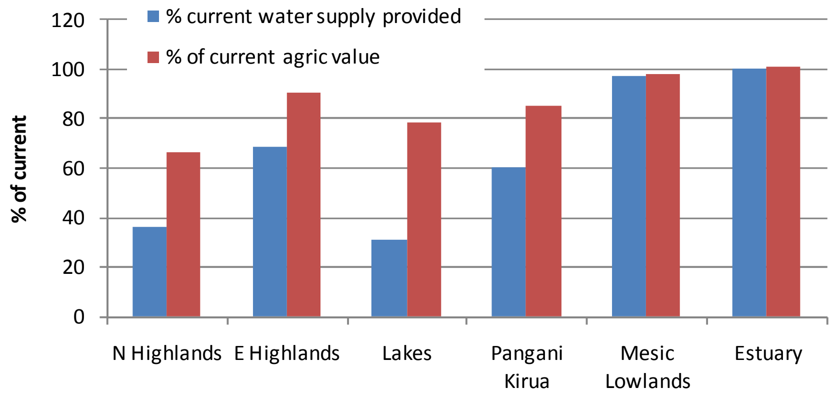
A4.4.4.9 Overall condition

All measured health parameters in the estuary show a modest improvement under this scenario, translating to a modest improvement in overall health from 57 to 61%. There is a predicted increase in health status from a D class to a C class – i.e. a change from a highly modified to a moderately modified system.

A4.5 Effects on livelihoods

A4.5.1 Income from small-scale agriculture

Addendum Figure 30 shows aggregate net income from agriculture to rural households within 5 km of rivers under the scenario as a percentage of current value. In this scenario, income is reduced in all zones except the Estuary, particularly in the Northern Highlands and Lakes zones (Addendum Figure 30). Change in aggregate income is concentrated in the Northern Highlands, but significant losses are also incurred in the Eastern Highlands (Figure 9.1).



Addendum Figure 30 **Area under small-scale irrigation under the Optimise Present Day with Agriculture scenario as compared with the Present Day**

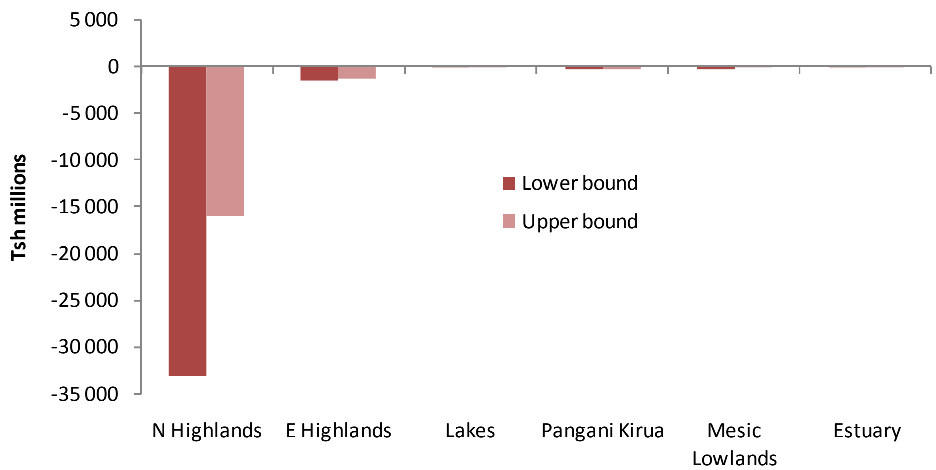
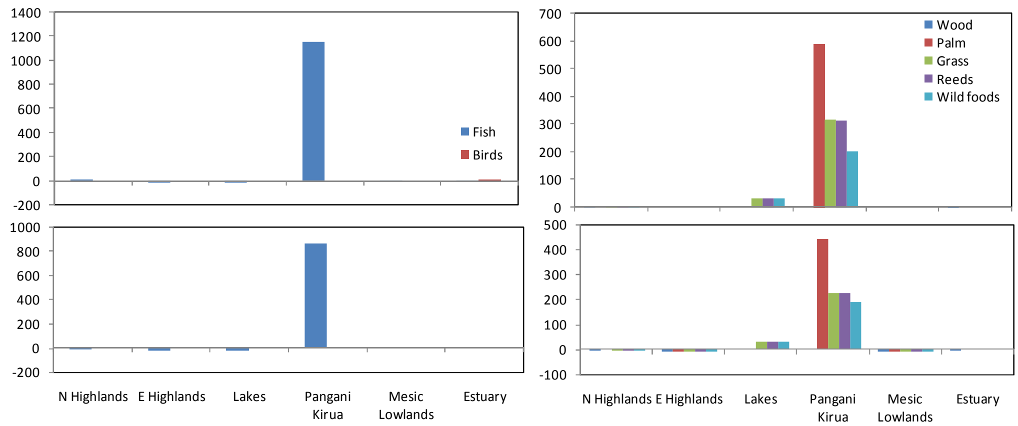


Figure 9.1 **Lower and upper bound estimates of the aggregate change in income from small-scale agriculture under the Optimise Present Day with Agriculture scenario**

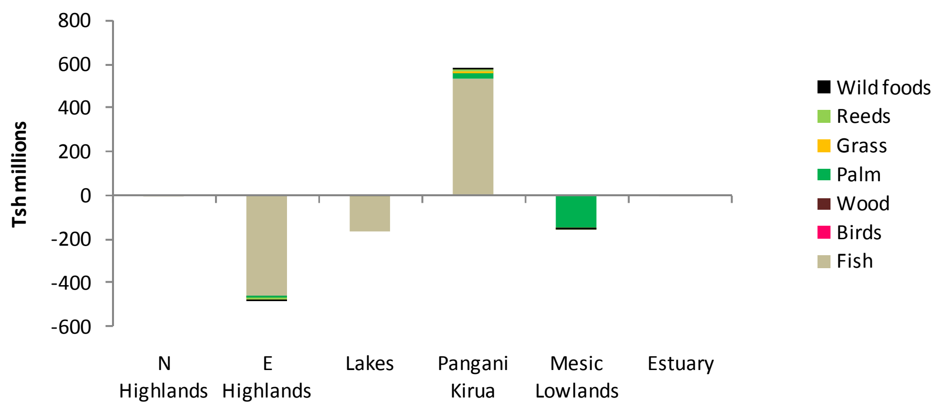
A4.5.2 Income from natural resources

Changes in fish stocks are minor in all zones apart from Pangani-Kirua, which sees an approximately 10-fold increase in fish as a result of restoration of the wetland. Bird numbers increase slightly. Plant resources are little affected apart from at the Lakes, where there are significant increases, and in Pangani-Kirua, where very large increases are expected (Addendum Figure 31).



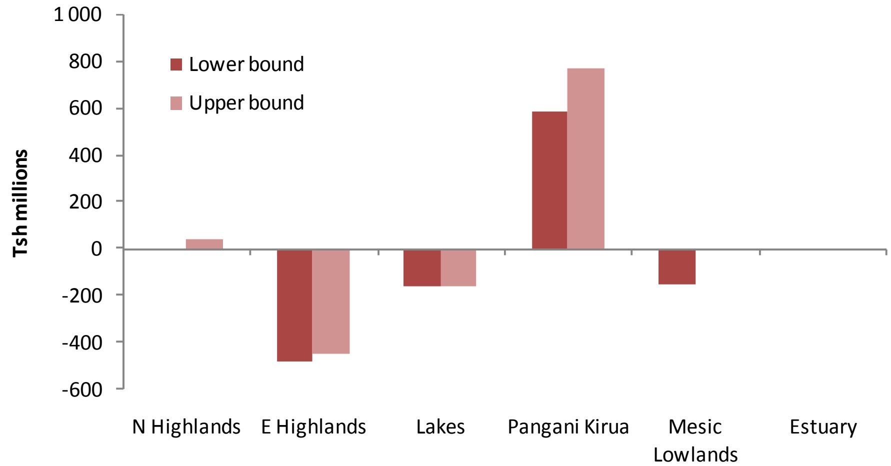
Addendum Figure 31 **Best and worst case estimates of the percentage change from Present Day in the abundance of natural resources used by households, under the Optimise Present Day with Agriculture scenario**

Impacts of these changes on income to households are shown in Addendum Figure 32.



Addendum Figure 32 **Worst-case estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under the Optimise Present Day with Agriculture scenario**

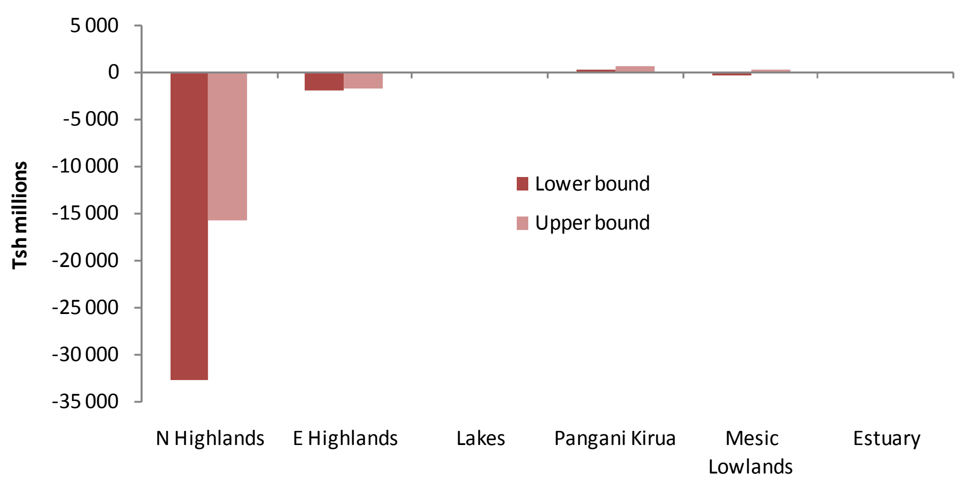
Aggregate income is expected to increase significantly in Pangani-Kirua, but there are also significant decreases in income in other zones, particularly the Eastern Highlands (Addendum Figure 33).



Addendum Figure 33 Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under the Optimise Present Day with Agriculture scenario

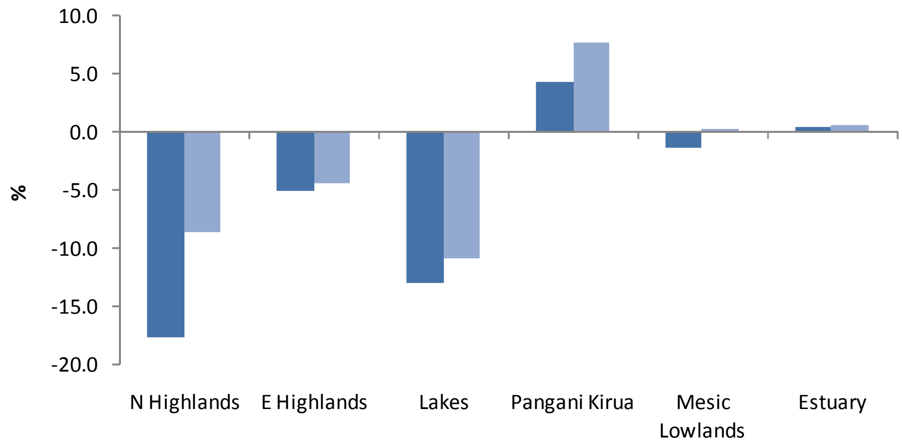
A4.5.3 Overall household income

There are major losses in aggregate household income in the Northern Highlands, slight losses in the Eastern Highlands, and relatively minor changes elsewhere (Addendum Figure 34).



Addendum Figure 34 Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, under the Optimise Present Day with Agriculture scenario

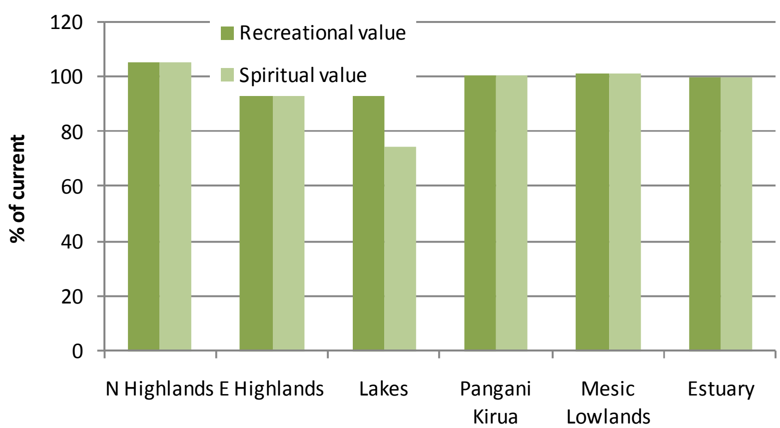
Aggregate household income increases by about 5% in the Pangani-Kirua areas and very slightly in the Estuary zone, but decreases in all other zones, with losses of over 10% in the Northern Highlands and Lakes (Addendum Figure 35).



Addendum Figure 35 **Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under the Optimise Present Day with Agriculture scenario**

A4.5.4 Intangible values

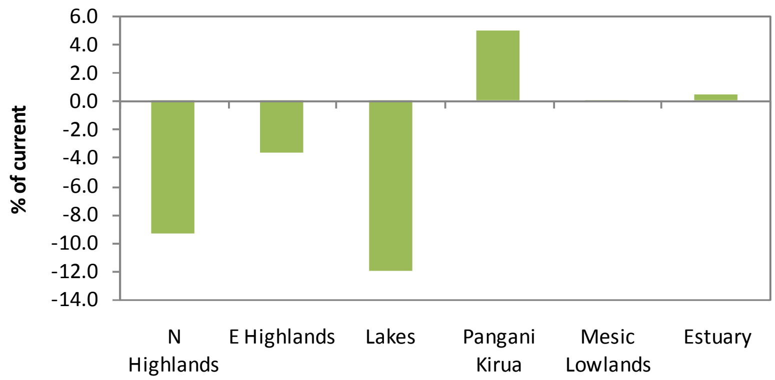
There is a slight increase in recreational and spiritual well-being among households in the Northern Highlands, decreases in the Eastern Highlands and Lake areas, and no changes in the zones below these (Addendum Figure 36).



Addendum Figure 36 **Overall recreational and spiritual well-being (derived from rivers and other sources) under the Optimise Present Day with Agriculture scenarios as percentage of current well-being**

A4.5.5 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 37. Overall well-being declines markedly in the highlands and Lakes, but improves significantly in Pangani-Kirua.



Addendum Figure 37 **Percentage change in overall well-being of households within 5 km of rivers under the Optimise Present Day with Agriculture scenario**

A4.6 Effects on economic value

Under this scenario, changes in environmental quality and function lead to a gain in the value of ecosystem regulating services, but a slight loss in terms of direct value added by the natural resources sector. Much larger losses are incurred in terms of direct value added by the agricultural sector. These losses are larger than the gains in the energy sector (Addendum Table 33).

Addendum Table 33 **Gains and losses in the value (Tsh millions per year) of HEP, Agriculture, Natural Resources and Ecosystem regulating services under the Optimise Present Day with Agriculture scenario**

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
31 962	-59 008	-1	296	-26 752

A5 OPTIMISE PRESENT DAY WITH HEP

NB: This scenario prioritised water allocation for environmental maintenance through optimising Present Day volumes into a new pattern of flows. This became the second priority after Basin Human Needs

A5.1 Description of the scenario

The Optimise Present Day with HEP scenario comprised the following (in order of priority):

- Supply of water for BHN
- Supply of present day volumes of river flow in a revised pattern of flows to improve ecosystem condition, at river sites 1, 2, 3, 4, 6, 7, 8 and 9, and at Kirua Swamps and the estuary.
- Allocation of water to Arusha and Moshi towards the 2025 Urban/Industrial demands.
- The resulting river flows used to generate HEP
- Any remaining water abstracted at a 75% level of assurance for agriculture.

A5.2 Hydrological implications

A5.2.1 Water allocated per sector

Urban/industrial 53.6 Mcm a^{-1} (PD = 31.1)
Irrigation 435 Mcm a^{-1} (PD = 1042), but see Section A5.3 for area irrigated
HEP 784 235 MW h^{-1} (PD = 602 647)

A5.2.2 Changes in the flow regime relative to present day

The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 34. There were two main kinds of change relative to Present Day:

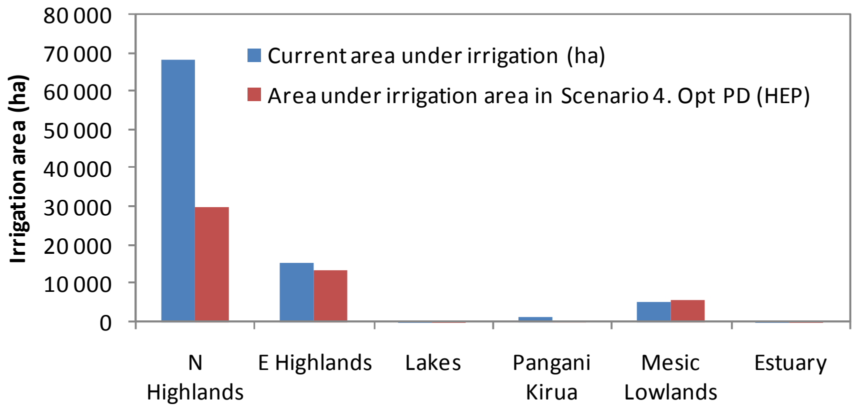
- low flows re-instated, particularly in the dry season (Sites 1-4 at top of the catchment and at Site 7 in the Mkomazi River);
- floods re-instated downstream of NyM at Site 6 - Pangani River at Kirua Swamp).

Addendum Table 34 DRIFT flow summary data for the optimised present day with HEP scenario

Location	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 6**	**Site 7**	**Site 8**	**Site 9**
Scenario MAR (MCM)	62.0	604.4	206.0	733.8	800.0	38.0	105.0	1276.6
WSLF - Volumes (MCM)	23.0	278.0	96.0	388.0	316.0	9.0	39.2	574.0
DSLF - Volumes (MCM)	26.0	262.0	86.0	242.0	258.0	12.5	40.3	498.6
Class 1 - Annual Frequency	5	2	0	2	0	1	2	0
Class 2 - Annual Frequency	3	3	0	3	2	4	7	1
Class 3 - Annual Frequency	2	2	3	3	2	4	4	2
Class 4 - Annual Frequency	1	4	3	3	4	1	2	2
1:2	P	P	P	P	A	P	P	P
1:5	P	P	P	P	A	P	P	P
1:10	P	P	P	P	A	P	P	P
1:20	P	P	P	P	P	P	P	P

A5.3 Effects on irrigated agriculture

There are significant decreases in irrigated agriculture by more than 50% in the Northern Highlands. The Eastern Highlands, Pangani Kirua and Mesic Lowlands experience a slight increase (Addendum Figure 38).



Addendum Figure 38 Area under irrigation under the Optimise Present Day with HEP scenario as compared with the Present Day

A5.4 Effects on HEP production

HEP output is increased to 784 235 MWh which is 130% of current output.

A5.5 Effects on environmental condition

The effects on the river and Kirua Swamp are the same as for Optimise Present Day with agriculture scenario (Appendix 4).

A5.5.1 Summary of biophysical condition in NyM

A5.5.1.1 Water level change

The FA Tool assesses likely change in two parameters associated with NyM Dam – fish catch and reed area. These parameters are affected by water area (volume) of the lake and the variation in area, which are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under the Optimise Present Day with HEP scenario are presented in Addendum Table 35 and discussed in the respective sections below.

Addendum Table 35 Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in NyM under the Optimise Present Day with HEP scenario relative to the Present Day, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario

	Present Day	This Scenario	% Change
Mean lake area (ha)	103.8	58.4	-44%
Std dev of lake area (m)	1.24	1.36	9%
Max lake area (ha)	137.1	101	-26%
Reed area (ha)	33.3	42.7	28%
Mean lake level (m)	15.9	10.8	-32%
Std dev of lake level (m)	1.2	1.4	17%
Fish catch (tonnes)	3538.8	2349.1	-34%

A5.5.1.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surround NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under the Optimise Present Day with HEP scenario, lake area shrinks significantly by 44%, variability increases marginally by 9%, while maximum area inundated decreases by 26% (Addendum Table 35). The net result of this is that total reed area is expected to expand by 28%.

A5.5.1.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the Present Day we expect fish populations to expand in responses to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under the Optimise Present Day with HEP scenario, variability in lake level increases marginally by 9% but the average area declines markedly by 44% (Addendum Table 35). Fish catches as a result, are expected to decline by 34%.

A5.5.2 Summary of biophysical condition in Kirua Swamp

The largest improvement in condition associated with the Optimise Present Day scenarios occurs at Kirua Swamp. The reinstated flood regime results in greater inundation of the swamp, with concomitant improvements of its condition. Under present day condition swamp inundation is *c.* 4% of natural. This will increase to *c.* 24% under the Optimise Pesent Day with Agriculture scenario.

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to present day. Under this scenario, fish abundances are predicted to increase to 458% of present day (608 tonnes) and floodplain vegetation to increase to 480%.

A5.5.3 Summary of biophysical condition in the Estuary

A5.5.3.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under this scenario, freshwater flows reaching the estuary are higher in all four seasons, with an average increase in flow of 37.5% (Addendum Table 36). Agricultural return flows, as a proportion of the total flow, decrease in all seasons except the Long Rains where no change is expected (Addendum Table 36). The number of months where flow exceeds 250 Mm^3 increases by 38%.

Addendum Table 36 Change in freshwater flows reaching the estuary under the Optimise Present Day with HEP scenario relative to the Present Day

		Short rains	Dry 1	Long rains	Dry 2	All months
Average monthly flows	Present Day (Mm^3)	91.3	72.7	186.9	80.7	102.1
	Opt PD (HEP) (Mm^3)	125.2	113.1	238.7	118.2	140.4
	% Change	37.1	55.6	27.7	46.6	37.5
Agricultural monthly return flows	Present Day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	Opt PD (HEP) (Mm^3)	12.9	17.1	20.3	13.4	19.7
	% Change	-36.7	-40.2	0.0	-43.0	-22.6
No. months flow >250 Mm^3	Present Day	8.0				
	Opt PD (HEP) (Mm^3)	11.0				
	% Change	37.5				

Addendum Table 37 Change in health scores for the estuary as a whole and the component parameters under the Optimise Present Day with HEP scenario

	Present Day	This scenario	Change (+/-)
Geomorphology	40%	43%	6%
Water Quality	53%	61%	15%
Micro-algae	40%	41%	4%
Vegetation	60%	64%	6%
Inverts	60%	67%	12%
Fish	50%	55%	9%
Birds	40%	46%	16%
Overall health score	57%	70%	24%

A5.5.3.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the Present Day status of the mouth, which is both wide and deep. Thus, only the extreme high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significantly affect geomorphological conditions in the estuary such as channel width and depth, and intertidal area, albeit on a relative small scale due to the large size of the tidal prism.

These high flows have increased by 38% from the Present Day under this scenario (Addendum Table 36) but as they do not contribute as much to the current mouth status as the tidal flow, the resulting change in geomorphological conditions in the estuary can be expected to be small (up by 6%, Addendum Table 37).

A5.5.3.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Reduced flow volumes have a reduced capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under this scenario, mean monthly flows are substantially higher while the contributions by agricultural return flows decrease. The combined effect of these two influences is predicted to lead to a significant improvement in water quality in the estuary – i.e. decreased nutrients, higher dissolved oxygen concentrations, and increased water clarity (lower turbidity). The water-quality health score increases to 61% (up by 15%).

A5.5.3.4 Micro-algae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient level) with the result that phytoplankton concentrations in the system are extremely high. Increases in mean monthly runoff and reduced contribution by agricultural return flows are likely to reduce (dilute) nutrient concentrations in the estuary and have a net positive effect on microalgae health (i.e. a reduction in phytoplankton concentrations). Health scores under this scenario increase from the Present Day by 4% to 41%.

A5.5.3.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As mean monthly flows under the Present Day scenario are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the contribution from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production).

The effects of increased flow and reduced agricultural return flow volumes anticipated under this scenario are expected to have a minor positive influence on vegetation communities associated with the estuary, translating to an improvement in the health score by 6% (Addendum Table 37).

A5.5.3.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes in the geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality (reduced water clarity and oxygen levels, increased nutrients) between the natural and Present Day situations.

While existing geomorphological conditions are not expected to change significantly under this scenario, the anticipated improvement in water quality will have a beneficial impact on macroinvertebrates populations in the estuary (12% increase, Addendum Table 37), with concomitant improvements in catches of shrimp and crab as well.

A5.5.3.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geomorphological characteristics and water quality as well as by the decline of their main food supply (invertebrates). As such the current health score is low (50%) but is expected to improve somewhat under this scenario to 55% (Addendum Table 37).

A5.5.3.8 Birds

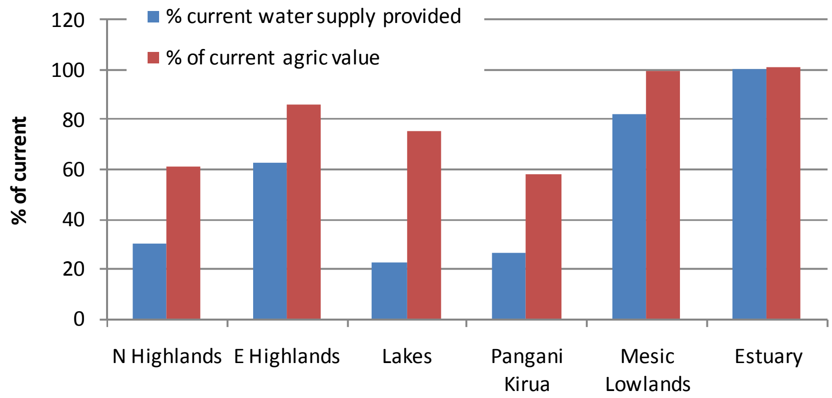
Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the estuary and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). The predicted improvements in invertebrate and fish abundance are likely to be translated into a modest improvement in the numbers and species of birds frequenting the estuary, with a health score increasing from 40 to 46% (Addendum Table 37).

A5.5.3.9 Overall condition

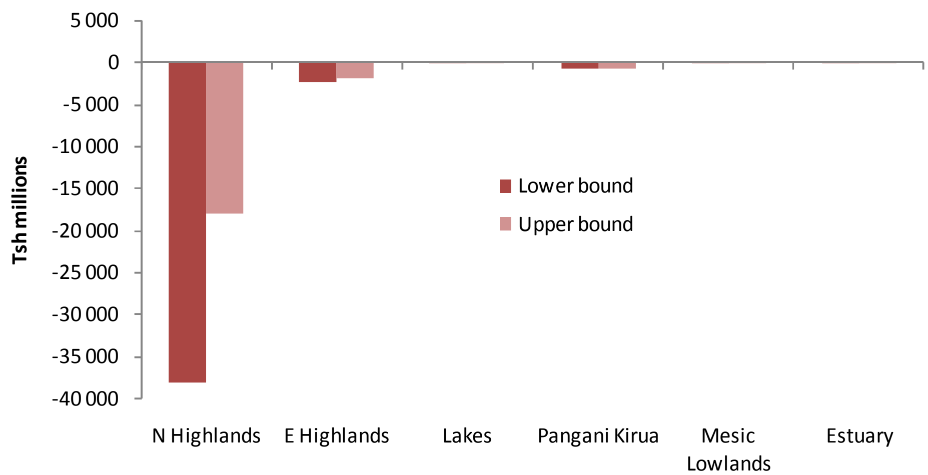
All measured health parameters in the estuary show an improvement under this scenario, translating to a significant improvement in overall health from 57% to 70%. The health category increases from a D to a C class.

A5.5.4 Income from small-scale agriculture

Addendum Figure 39 shows aggregate net income from agriculture to rural households within 5 km of rivers under the scenario as a percentage of current value. In this scenario, income decreases across almost all regions, most notably in Pangani-Kirua. Significant losses are seen in the Northern Highlands (Addendum Figure 40).



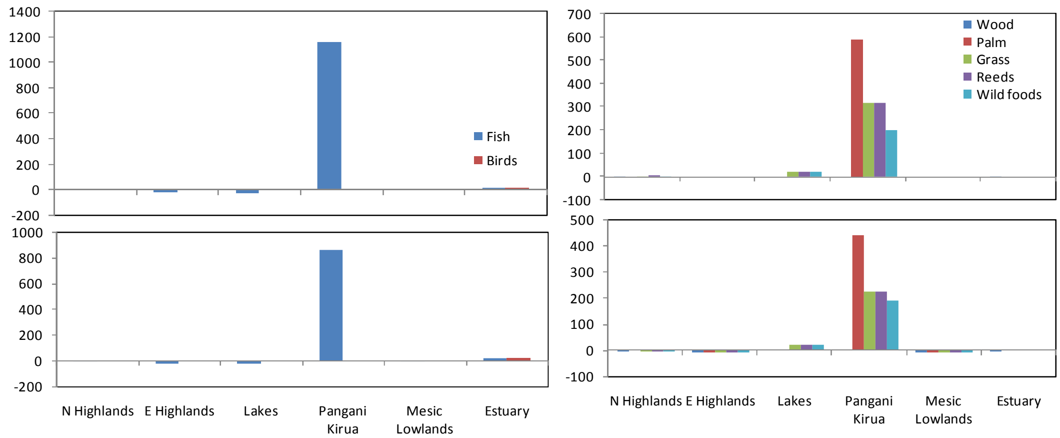
Addendum Figure 39 Area under small-scale irrigation under the Optimise Present Day with HEP scenario as compared with the Present Day



Addendum Figure 40 Lower and upper bound estimates of the aggregate change in income from small-scale agriculture under the Optimise Present Day with HEP scenario

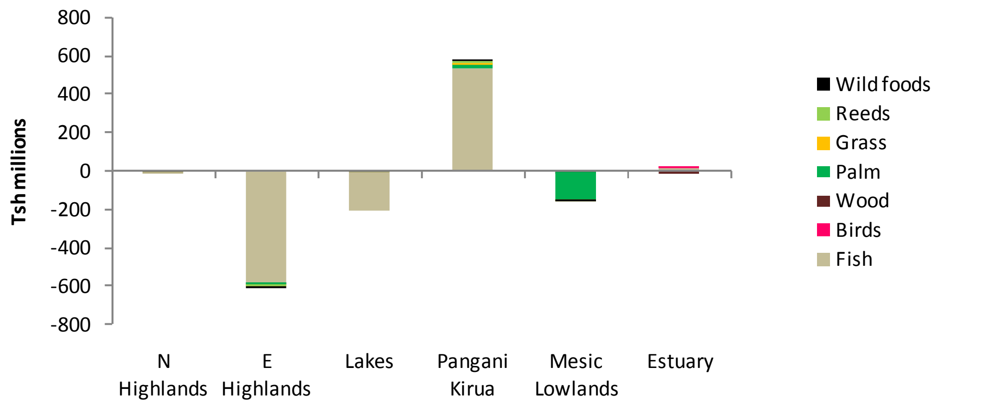
A5.5.5 Income from natural resources

Fish increase in abundance in Pangani-Kirua under this scenario, with gains of around 1000%. Losses or gains (only Estuary) are minimal for other areas. Changes in plant resources are also negligible, although again Pangani-Kirua is the exception, with significant increases in resources, most notably in palms, which increase by up to 600%.



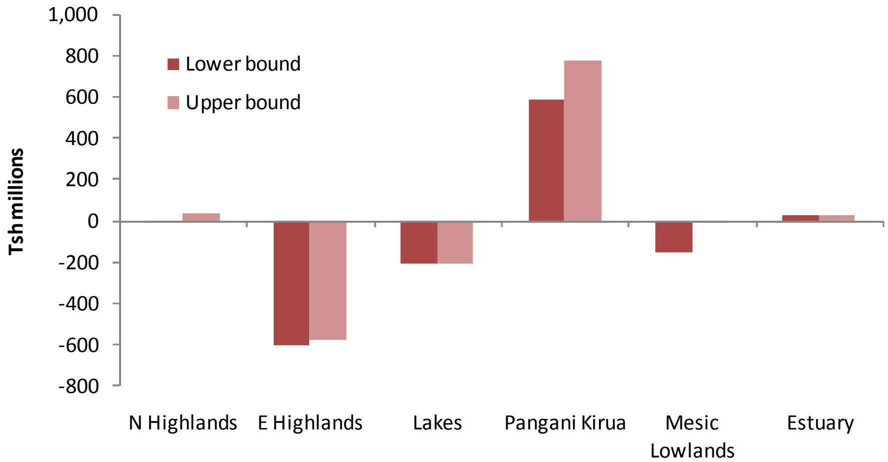
Addendum Figure 41 **Best and worst case estimates of the percentage change from Present Day in the abundance of natural resources used by households, under the Optimise Present Day with HEP scenario**

Impacts of these changes on income to households are shown in Addendum Figure 42.



Addendum Figure 42 **Worst-case estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under the Optimise Present Day with HEP scenario**

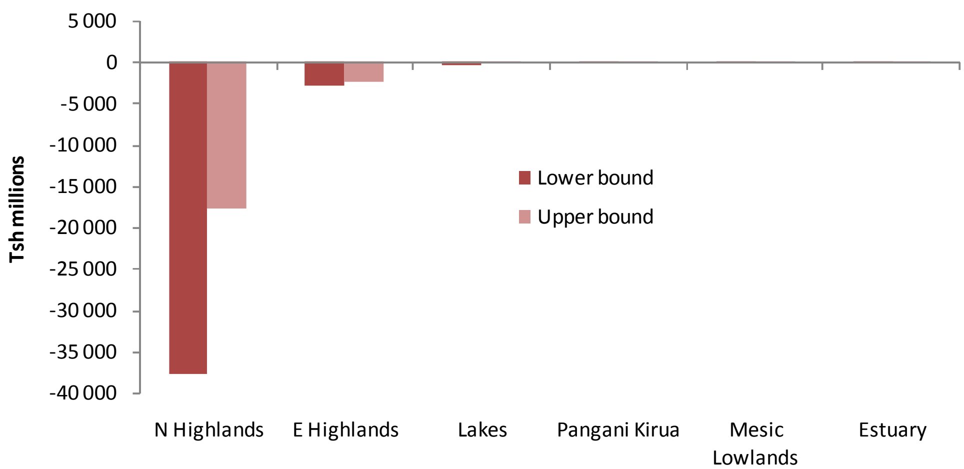
Aggregate income increases significantly in Pangani-Kirua mainly due to rises in fishing. Eastern Highlands shows a decrease of similar proportions. Lakes and Mesic Lowlands show smaller, but still significant decreases, while the remaining zones show negligible change.



Addendum Figure 43 Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under the Optimise Present Day with HEP scenario

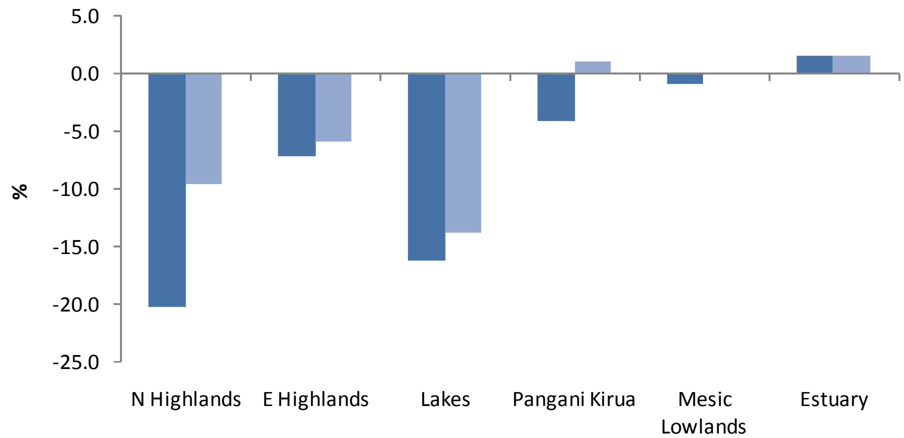
A5.5.6 Overall household income

There are significant losses to overall household income in Northern Highlands, and a slight loss in the Eastern Highlands. There are negligible changes in the remaining zones (Addendum Figure 44).



Addendum Figure 44 Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, under the Optimise Present Day with HEP scenario

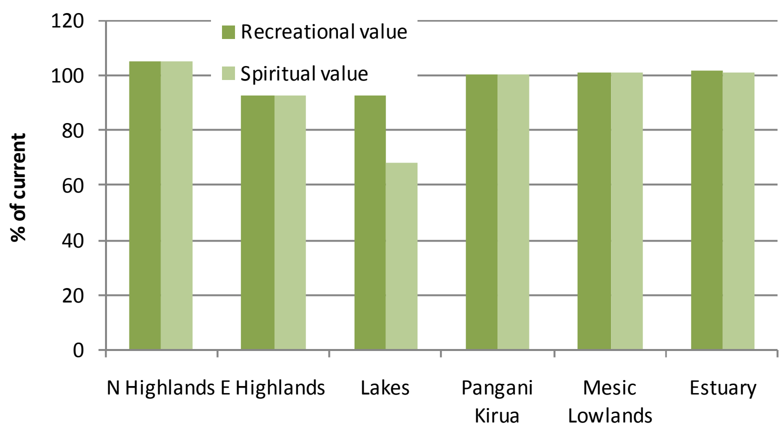
Aggregate household income increases marginally in the Estuary by around 2%. Changes in Pangani Kirua could be positive or negative. In the remaining zones there is a decrease in income, particularly in the Northern Highlands and Lakes zone where income decreases by up to 20% (Addendum Figure 45).



Addendum Figure 45 Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under the Optimise Present Day with HEP scenario

A5.5.7 Intangible values

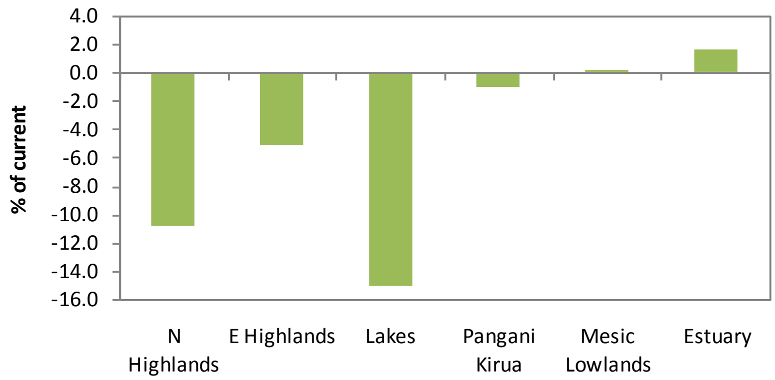
There is a marked decline in recreational and spiritual well-being among households in the Eastern Highlands and particularly the Lake area (Addendum Figure 46). A slight increase in utility is enjoyed in Northern Highlands, and there is very little change in the remaining three zones.



Addendum Figure 46 Overall recreational and spiritual well-being (derived from rivers and other sources) under the Optimise Present Day with HEP scenario as a percentage of current well-being

A5.5.8 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 47. In general the percentage change in well-being is small in the lower zones, whereas households suffer a significant loss of well-being in the upper zones.



Addendum Figure 47 Percentage change in overall well-being of households within 5 km of rivers under the Optimise Present Day with HEP scenario

A5.6 Effects on economic value

Under this scenario, agriculture sees significant losses, while natural resources display a slight loss. Ecosystem regulating services increase by a small amount. HEP has very substantial gains that far outweigh the other sectors leading to a significant overall gain (Addendum Table 38).

Addendum Table 38 Gains and losses in the value of HEP, Agriculture, Natural Resources and Ecosystem regulating services (Tsh millions per year) under the Optimise Present Day with HEP scenario

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
552 605	-69 370	-157	338	483 417

A6 HIGH ENVIRONMENT WITH AGRICULTURE

NB: This scenario prioritised water allocation for environmental maintenance at a high level. This became the second priority after Basin Human Needs

A6.1 Description of the scenario

The High Environment with Agriculture scenario comprised the following (in order of priority):

- Supply of water for BHN
- Supply of an increased volume of water in a pattern of flows for high environmental condition at river sites 1, 2, 3, 4, 6, 7, 8 and 9, and at Kirua Swamps and the estuary.
- Allocation of water to Arusha and Moshi towards the 2025 Urban/Industrial demands.
- Any remaining water abstracted at a 75% level of assurance for agriculture.
- The resulting river flows used to generate HEP.

A6.2 Hydrological implications

A6.2.1 Water allocated per sector

Urban/industrial 50.9 Mcm a^{-1} (PD = 31.1).
Irrigation 497 Mcm a^{-1} (PD = 1042) but see Section A6.3 for area irrigated.
HEP 601 411 MW h^{-1} (PD = 602 647).

A6.2.2 Changes in the flow regime relative to present day

The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 39. There were two main kinds of change relative to present day:

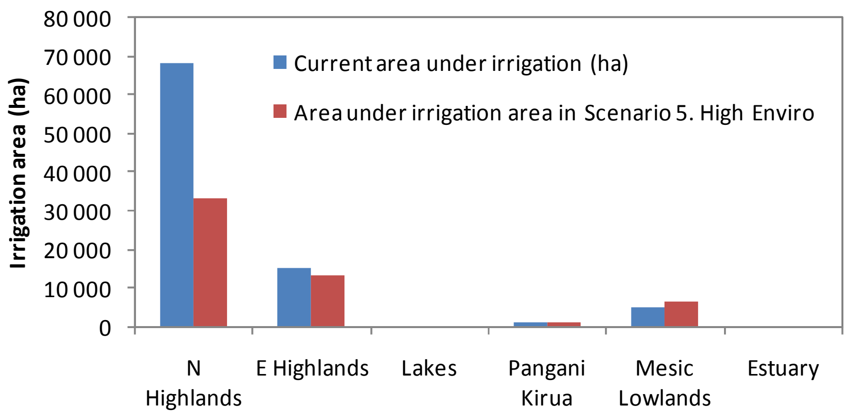
- low flows partially re-instated, particularly in the dry season (Sites 1-4 at top of the catchment and at Site 7 in the Mkomazi River);
- floods re-instated downstream of NyM at Site 6 - Pangani River at Kirua Swamp) – to a greater extent than for the Optimise Present Day scenarios.

Addendum Table 39 DRIFT flow summary data for the High Environment with Agriculture scenario

Location	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario MAR (MCM)	102.0	604.4	206.0	733.8	953.1	50.3	105.0	1276.6
WSLF - Volumes (MCM)	30.1 - adjusted to 29.3	278.0	96.0	388.0	368.6	25.5	39.2	574.0
DSLF - Volumes (MCM)	56.4 - adjusted to 54.7	262.0	86.0	242.0	413.8	12.5	40.3	498.6
Class 1 - Annual Frequency	5	2	0	2	0	1	2	0
Class 2 - Annual Frequency	3	3	0	3	2	4	7	1
Class 3 - Annual Frequency	3	2	3	3	2	3	4	2
Class 4 - Annual Frequency	1	4	3	3	4	3	2	2
1:2	P	P	P	P	P	P	P	P
1:5	P	P	P	P	P	P	P	P
1:10	P	P	P	P	P	P	P	P
1:20	P	P	P	P	A	P	P	P

A6.3 Effects on irrigated agriculture

In this scenario the area under irrigation will halve in the Northern Highlands. The Eastern Highlands will see a slight decrease and the Mesic Lowlands will see a slight increase, which is a significant proportion to the small area irrigated there currently.



Addendum Figure 48 Area under irrigation under the High Environment with Agriculture scenario as compared with the Present Day

A6.4 Effects on HEP production

HEP output is reduced to 99.8% of current output, resulting in an output of 601 411 MWh.

A6.5 Effects on environmental condition

A6.5.1 Summary of biophysical condition in the river

The influence of the requested environmental flows on the condition of the rivers is described in two ways:

- as percentage change relative to present day for key indicators representing each of geomorphology, water quality, riparian vegetation, macroinvertebrates and fish;
- in terms of change in overall river condition as denoted by the integrity score

Note: The Present Day levels of the indicators have not been quantified, thus the reported change is relative to an unknown quantity.

A6.5.1.1 Geomorphology

Most of the beneficial geomorphological changes associated with this scenario are concentrated in Pangani River at Kirua and lower Mkomazi River (Addendum Table 40). At the other sites many of the impacts on condition are non-flow related and hence condition cannot be restored with flow alone. The changes can be summarised as follows:

- minor improvements in pool condition, and increased coarse sediments and reduced fine sediments at most sites;
- significant improvements in physical habitat and floodplain inundation at Pangani River at Kirua.

Addendum Table 40 Estimated percentage change from Present Day for geomorphological features under the High Environment with Agriculture scenario

Site No.	Name	Riffles and rapids		Pools		Fine sediments		Coarse sediments		Bank erosion		Floodplain inundation	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	1	25	1	25	-20	0	1	25	0	0	0	0
2	Lower Kikuletwa	0	0	1	25	0	0	0	0	1	25	0	0
3	Upper Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
4	Lower Ruvu	0	0	1	25	0	0	0	0	0	0	0	0
6	Pangani at Kirua	500	800	500	800	1	25	0	0	0	0	500	800
7	Lower Mkomazi	251	500	68	250	-40	-20	0	0	0	0	1	25
8	Lower Luengera	1	25	1	25	-20	0	0	0	0	0	0	0
9	Lower Pangani	0	0	0	0	0	0	0	0	0	0	0	0

A6.5.1.2 Water Quality

The water quality changes associated with this scenario are minor (Addendum Table 41). The changes can be summarised as follows:

- reduction in conductivity and nutrient levels in the Upper Kikuletwa and the Lower Mkomazi Rivers.

Addendum Table 41 Estimated percentage change from Present Day for water quality under the High Environment with Agriculture scenario

Site No.	Name	Turbidity/TSS		Conductivity/TDS		Phosphorus		Nitrogen	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	1	25	-40	-20	-20	0	1	25
2	Lower Kikuletwa	-20	0	0	0	0	0	0	0
3	Upper Ruvu	0	0	0	0	0	0	0	0
4	Lower Ruvu	0	0	0	0	0	0	0	0
6	Pangani at Kirua	0	0	0	0	0	0	0	0
7	Lower Mkomazi	1	25	-40	-20	-40	-20	-20	0
8	Lower Luengera	0	0	0	0	0	0	0	0
9	Lower Pangani	0	0	0	0	0	0	0	0

A6.5.1.3 Vegetation

Most of the beneficial vegetation changes associated with this scenario are concentrated in Pangani River at Kirua (Addendum Table 42). At the other sites many of the impacts on condition are non-flow related and hence condition cannot be restored by flow changes alone. The changes in riparian vegetation associated with the scenario can be summarised as follows:

- dramatically increased wet bank vegetation in the Pangani at Kirua;
- slight improvements in wetbank vegetation in the Lower Mkomazi River;
- slight improvements to the dry bank vegetation in the Lower Kikuletwa.

Addendum Table 42 Estimated percentage change from Present Day for vegetation under the High Environment with Agriculture scenario

Site No.	Name	Dry Bank Trees		Dry Bank Herbs & Shrubs		Dry Bank Grasses		Wetbank Trees		Wetbank Herbs		Wetbank grasses and reeds	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	0	0	0	0	0	0	1	25	-20	0
2	Lower Kikuletwa	1	25	0	0	0	0	0	0	1	25	1	25
3	Upper Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
4	Lower Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
6	Pangani at Kirua	0	0	0	0	0	0	500	800	68	250	500	800
7	Lower Mkomazi	0	0	0	0	0	0	1	25	26	68	26	68
8	Lower Luengera	0	0	0	0	0	0	0	0	0	0	0	0
9	Lower Pangani	0	0	0	0	0	0	0	0	0	0	0	0

A6.5.1.4 Macroinvertebrates

The changes in macroinvertebrates associated with this scenario (Addendum Table 43) can be summarised as follows:

- dramatic increase in sensitive and tolerant species in the Pangani at Kirua due to increased habitat from floodplain inundation, and milder increase in the Lower Mkomazi;
- a reduction in the likelihood of proliferations of simuliid black flies.

Addendum Table 43 Estimated percentage change from Present Day for macro-invertebrates under the High Environment with Agriculture scenario

Site No.	Name	Sensitive species		Tolerant species (e.g., Dysticidae, Chironominae and Culicidae)		Pest Simuliidae	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	1	25	-20	0	1	25
2	Lower Kikuletwa	1	25	-20	0	0	0
3	Upper Ruvu	0	0	0	0	0	0
4	Lower Ruvu	0	0	0	0	0	0
6	Pangani at Kirua	251	500	-60	-40	0	0
7	Lower Mkomazi	26	68	-20	0	0	0
8	Lower Luengera	1	25	-20	0	0	0
9	Lower Pangani	0	0	0	0	0	0

A6.5.1.5 Fish

The changes in fish associated with this scenario (Addendum Table 44) can be summarised as follows:

- significant increase in *Clarias* and *Tilapia* in the Pangani at Kirua and in the Mkomazi River;
- significant increases in the *Labeo* group in the Lower Mkomazi and to a lesser extent in the Lower Kikuletwa;
- slight to moderate increases elsewhere.

Addendum Table 44 Estimated percentage change from Present Day for fish under the High Environment with Agriculture scenario

Site No.	Name	*Clarias* group		*Tilapia* group		*Labeo* group	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	1	25	0	0	0	0
2	Lower Kikuletwa	1	25	0	0	26	68
3	Upper Ruvu	0	0	0	0	0	0
4	Lower Ruvu	-20	0	0	0	0	0
6	Pangani at Kirua	500	800	500	800	0	0
7	Lower Mkomazi	26	68	251	500	251	500
8	Lower Luengera	0	0	1	25	1	25
9	Lower Pangani	0	0	0	0	0	0

A6.5.1.6 Overall condition

The changes in overall river condition associated with this scenario are provided in Addendum Table 45. All sites but Lower Pangani improve in condition, with a substantial improvement in the Pangani at Kirua and the Lower Mkomazi.

Addendum Table 45 Overall condition at each river site for the High Environment with Agriculture scenario

Site No.	Name	Present Day River Health Category	Change from Present Day ecological integrity	River Health Category for the scenario
1	Upper Kikuletwa	B/C	0.072	B/C
2	Lower Kikuletwa	D	0.055	D
3	Upper Ruvu	C/D	0.000	C/D
4	Lower Ruvu	D	0.010	C
6	Pangani at Kirua	C	0.515	B
7	Lower Mkomazi	C/D	0.204	C
8	Lower Luengera	C	0.036	C
9	Lower Pangani	C	0.000	C

A6.5.2 Summary of biophysical condition in NyM

A6.5.2.1 Water level change

The FA Tool assesses likely change in two parameters associated with NM Dam – fish catch and reed area. These parameters are affected by water area (volume) of the lake and the variation in area, which are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under the High Environment with Agriculture scenario are presented in Addendum Table 46 and discussed in the respective sections below.

Addendum Table 46 Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in NyM under the High Environment with Agriculture scenario relative to the Present Day, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario

	Present Day	This Scenario	% Change
Mean lake area (ha)	103.8	64.3	-38%
Std dev of lake area (m)	1.24	1.88	51%
Max lake area (ha)	137.1	117.3	-14%
Reed area (ha)	33.3	53.1	59%
Mean lake level (m)	15.9	11.5	-28%
Std dev of lake level (m)	1.2	1.9	+58%
Fish catch (tonnes)	3538.8	2516.4	-29%

A6.5.2.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surround NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under the High Environment with Agriculture scenario, lake area shrinks by 38%, variability increases by 51%, and maximum area inundated decreases by 14% (Addendum Table 46). The net result of this is that total reed area is expected to expand by 59%.

A6.5.2.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and by the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the present day we expect fish populations to expand in responses to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under the High Environment with Agriculture scenario, variability in lake level increases markedly by 51% but average area declines by 38% (Addendum Table 46). Fish catches as a result, are expected to decline by 29%.

A6.5.3 Summary of biophysical condition in Kirua Swamp

As was the case with the Optimise Present Day scenarios, the largest improvement in condition associated with the High Environment with Agriculture scenario occurs at

Kirua Swamp. The reinstated flood regime results in greater inundation of the swamp, with concomitant improvements of its condition. Under Present Day swamp inundation is *c.* 4% of natural, and this will increase to *c.* 25% under the high environment scenario.

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to present day. Under this scenario, fish abundances are predicted to increase to 485% of present day (643 tonnes) and floodplain vegetation to increase to 509%.

A6.5.4 Summary of biophysical condition in the Estuary

A6.5.4.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under this scenario, freshwater flows reaching the estuary are lower in all four seasons except the Long Rains (Addendum Table 47). Agricultural return flows, as a proportion of the total flow, decrease in all seasons (Addendum Table 47). Number of months where flow exceeds 250 Mm^3 is up by 100%.

Addendum Table 47 Change in freshwater flows reaching the estuary under the High Environment with Agriculture scenario relative to the Present Day.

		Short rains	Dry 1	Long rains	Dry 2	All month s
Average monthly flows	Present Day (Mm^3)	91.3	72.7	186.9	80.7	102.1
	High Env. (Agric) (Mm^3)	87.9	71.3	254.4	71.5	115.7
	% Change	-3.8	-1.9	36.1	-11.3	13.3
Agricultural monthly return flows	Present Day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	High Env. (Agric) (Mm^3)	16.9	21.5	19.1	15.5	22.0
	% Change	-27.7	-25.2	-1.0	-32.6	-17.7
No. months flow >250 Mm^3	Present Day	8.0				
	High Env. (Agric) (Mm^3)	16.0				
	% Change	100.0				

Addendum Table 48 Health scores for the estuary as a whole and the component parameters under the High Environment with Agriculture scenario.

	Present Day	This scenario	% change from PD (+/-)
Geomorphology	40%	46%	14%
Water Quality	53%	55%	4%
Micro-algae	40%	40%	1%
Vegetation	60%	62%	3%
Inverts	60%	61%	2%
Fish	50%	51%	1%
Birds	40%	42%	5%
Overall health score	57%	62%	9%

A6.5.4.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the Present Day status of the mouth, which is both wide and deep. Thus, only the extreme high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significantly affect geomorphological conditions in the estuary such as channel width and depth, and intertidal area, albeit on a relative small scale due to the large size of the tidal prism.

These high flows increase by 100% from the Present Day under this scenario (Addendum Table 47) but as they do not contribute as much to the current mouth status as the tidal flow, the resulting change in geomorphological conditions in the estuary can be expected to be a small increase of 14% (Addendum Table 48).

A6.5.4.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Reduced flow volumes have a reduced capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under the High Environment with Agriculture scenario, mean monthly flows increase, while the contributions by agricultural return flows decrease. The combined effect of these two influences is predicted to lead to a modest improvement in water quality in the estuary – i.e. decreased nutrients, higher dissolved oxygen concentrations, and increased water clarity (lower turbidity). The water-quality health score increases by 4% to 55%.

A6.5.4.4 Micro-algae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient level) with the result that phytoplankton concentrations in the system are extremely high. Increases in mean monthly runoff and reduced contribution by agricultural return flows are likely to reduce (dilute) nutrient concentrations in the estuary and have a net positive effect on microalgae health (i.e. a reduction in phytoplankton concentrations). Health scores under this scenario increase from the present day by 1% to 40%.

A6.5.4.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As mean monthly flows under the Present Day scenario are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the contribution from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production)

The effect of increased flow and reduced agricultural return flow volumes anticipated under this scenario are expected to have a minor positive influence on vegetation communities associated with the estuary, translating to an improvement in the health score by 3% (Addendum Table 48).

A6.5.4.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes in the geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality (reduced water clarity and oxygen levels, increased nutrients) between the natural and Present Day situations.

While geomorphological conditions are not expected to change significantly from the present day under High Environment with Agriculture scenario, the anticipated improvement in water quality will have a mild beneficial impact on macroinvertebrate populations in the estuary (Addendum Table 48) with a 2% increase in catches of shrimp and crab as well.

A6.5.4.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geomorphological characteristics and water quality as well as by the decline of their main food supply (invertebrates). As such the current health score is low 50% but is expected to improve marginally to 51% under this scenario (Addendum Table 48).

A6.5.4.8 Birds

Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the estuary and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). The predicted improvements in invertebrate and fish abundance are likely to be translated into a modest improvement in the numbers and species of birds frequenting the estuary, with their health score increasing from 40 to 42% (Addendum Table 48).

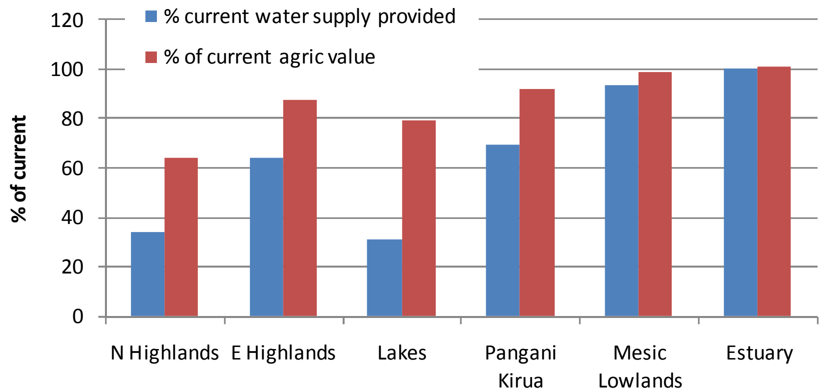
A6.5.4.9 Overall condition

All measured health parameters in the estuary show a modest improvement under the High Environment with Agriculture scenario, translating to a modest improvement in overall health from 57 to 62%. The health class is predicted to change from D to C (highly modified to moderately modified).

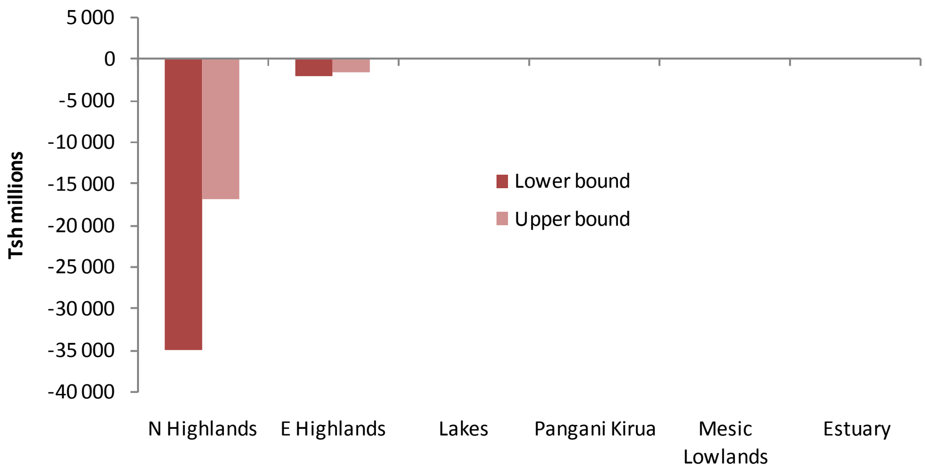
A6.6 Effects on livelihoods and well-being

A6.6.1 Income from small-scale agriculture

Addendum Figure 49 shows aggregate net income from agriculture to rural households within 5 km of rivers under the scenario as a percentage of current value. In this scenario, income in the Northern Highlands, Lakes and Eastern Highlands decreases substantially. There is less change in the lower zones. Due to the large population in Northern Highlands, the change in aggregate income is very significant (Addendum Figure 49).



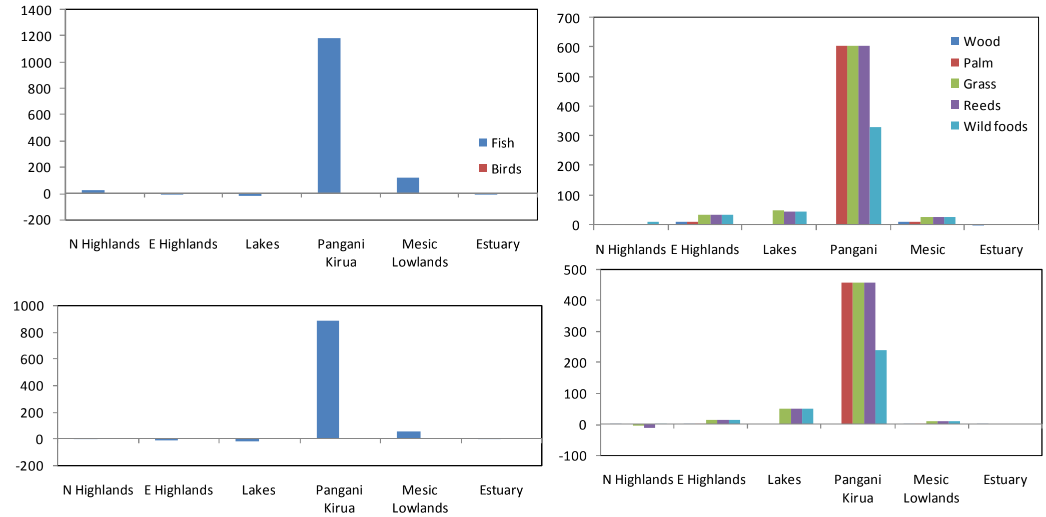
Addendum Figure 49 **Area under small-scale irrigation under High Environment with Agriculture scenario as compared with the Present Day**



Addendum Figure 50 **Lower and upper bound estimates of the aggregate change in income from small-scale agriculture under High Environment with Agriculture scenario**

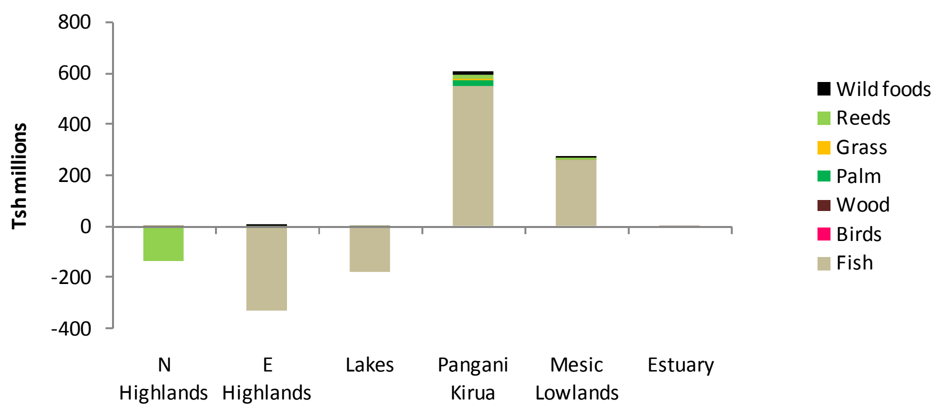
A6.6.2 Income from natural resources

Fish increase significantly in Pangani Kirua under this scenario, with also a slight increase in Mesic Lowlands. Changes in other areas are negligible. Pangani Kirua shows a substantial increase in Wood, Palm and Grass production, with other regions showing slight increases in plant resources. The exceptions are Northern Highlands and Estuary where change is minimal.



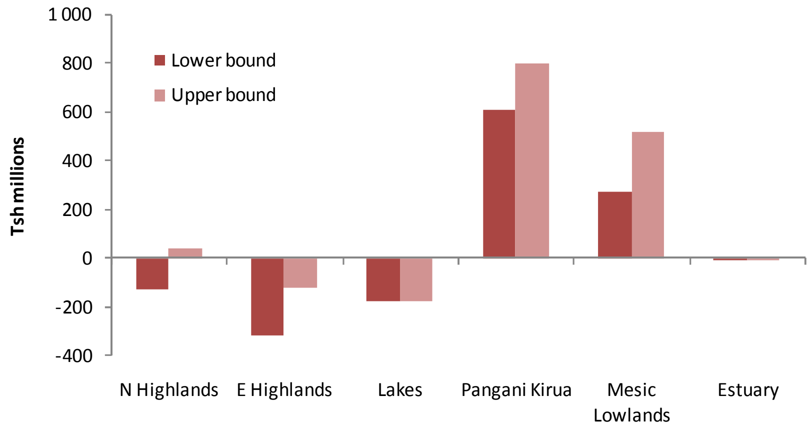
Addendum Figure 51 Best and worst case estimates of the percentage change from Present Day in the abundance of natural resources used by households, under High Environment with Agriculture scenario

Impacts of these changes on income to households are shown in Addendum Figure 52.



Addendum Figure 52 Worst-case estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under High Environment with Agriculture scenario

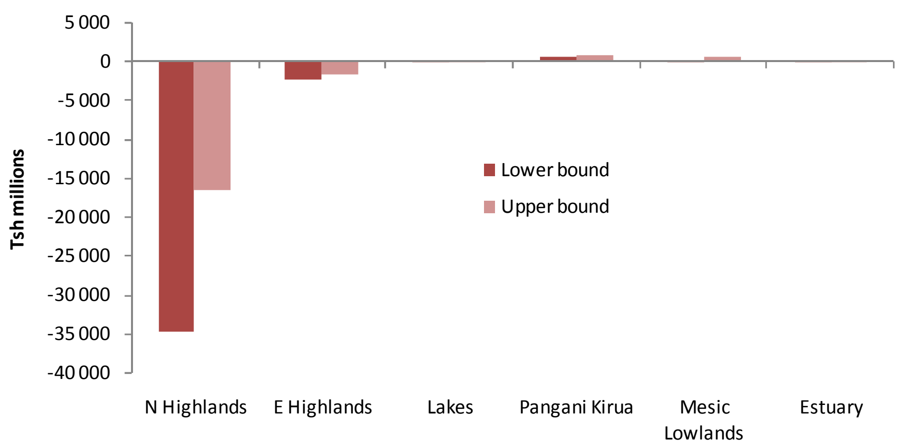
Aggregate income is expected to increase somewhat in the Pangani-Kirua and Mesic Lowlands, but decrease in the upper zones. The Estuary will experience minimal change.



Addendum Figure 53 Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under High Environment with Agriculture scenario

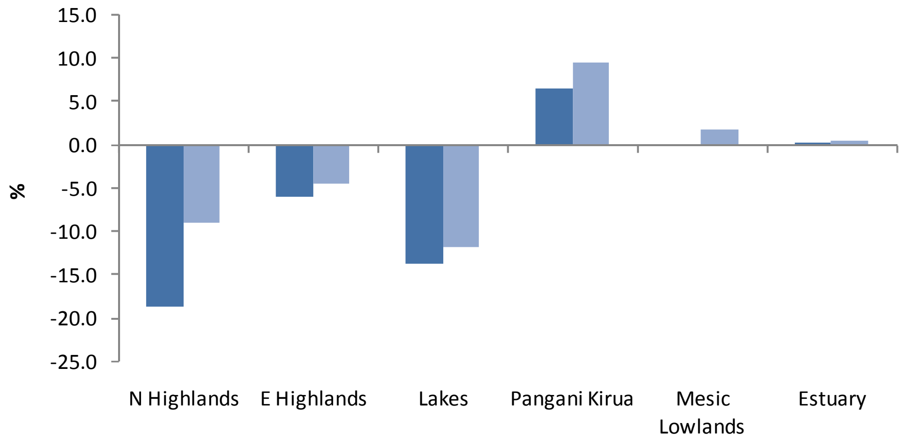
A6.6.3 Overall household income

Overall impacts on household income are expected to be negative in the Northern Highlands and less so in the Eastern Highlands. There are negligible changes in the remaining zones (Addendum Figure 54).



Addendum Figure 54 Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, under High Environment with Agriculture scenario

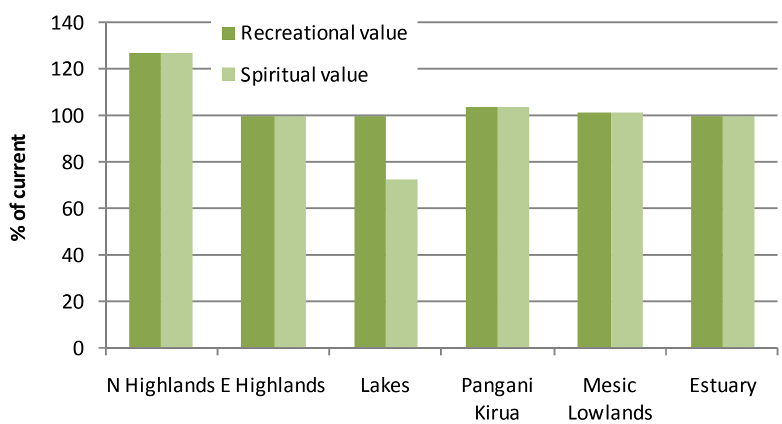
Aggregate household income decreases by up to 19% in the higher zones and a slight increase is expected in the Mesic Lowlands. In the remaining zones there is an increase in income, particularly in the Pangani Kirua zone where income increases by up to 9%, while the others show less marginal increases (Addendum Figure 55).



Addendum Figure 55 Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under High Environment with Agriculture scenario

A6.6.4 Intangible values

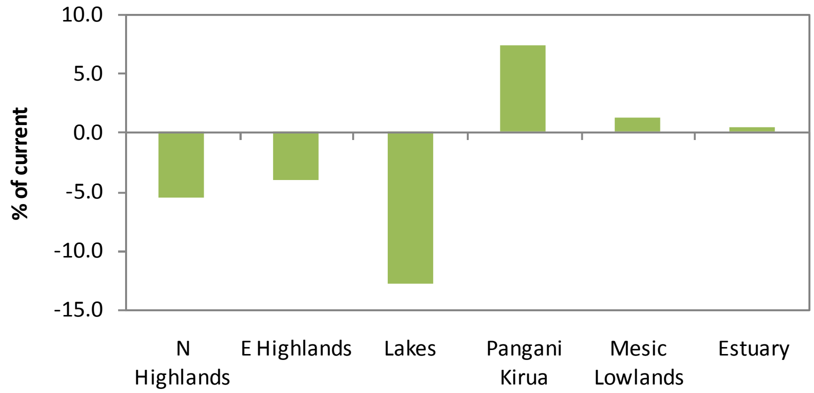
There is a large increase in the recreational and spiritual well-being experienced by households in the Northern Highlands, and little or no change elsewhere apart from a decline in spiritual well-being in the Lakes zone (Addendum Figure 56).



Addendum Figure 56 Overall recreational and spiritual well-being (derived from rivers and other sources) under High Environment with Agriculture scenario as a percentage of current well-being

A6.6.5 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 57. Northern Highlands and Eastern Highlands experience a decline in well-being. The most significant decline occurs in the Lakes zone at almost 15%. Pangani-Kirua experiences an increase of 7%. The remaining areas experience minimal change.



Addendum Figure 57 Percentage change in overall well-being of households within 5 km of rivers under High Environment with Agriculture scenario

A6.7 Effects on economic value

Under this scenario, changes in environmental quality and function lead to a slight gain of value in terms of ecosystem regulating services and the natural resources sector. However, there are significant losses for HEP and agriculture, which outweigh these gains. The overall impact is a substantial loss mainly because of the decline in agriculture (Addendum Table 49).

Addendum Table 49 Gains and losses in the value (Tsh millions per year) of HEP, agriculture, natural resources, and ecosystem regulating services under High Environment with Agriculture scenario

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
-4 037	-62 798	661	322	-65 852

A7 PRESENT DAY WITH CLIMATE CHANGE

A7.1 Description of the scenario

The Present Day with Climate Change scenario comprised the following (in order of priority):

- Using the predicted changes in rainfall (Table 3.9), rainfall-runoff models used to predict change in flows in the rivers.
- Allocation of present day water demands for BHN, Urban and Industrial to Arusha and Moshi.
- Allocation towards present day agricultural demands.
- Allocation towards present day HEP demands.
- Available flows in the river were used to generate HEP. Is this not 4?
- Environment received whatever water was left.

A7.2 Hydrological implications

A7.2.1 Water allocated per sector

Urban/industrial 54.7 Mcm a^{-1} (PD = 31.1)
Irrigation 1016 Mcm a^{-1} (PD = 1042) but see Section A7.3 for area irrigated
HEP 472 371 MW h^{-1} (PD = 602 647)

A7.2.2 Changes in the flow regime relative to present day

The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 50. There were two main kinds of change relative to present day:

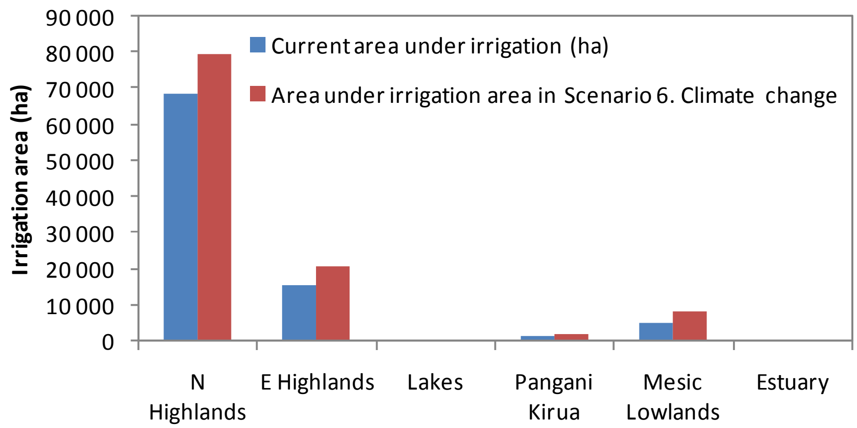
- drastically reduced low flows, particularly in the dry season (Sites 1-4 in upper catchment and Site 7 in the Mkomazi River).
- slight increase in intra-annual floods at Site 6 Pangani River at Kirua Swamp.
- Increased frequency of large floods.

Addendum Table 50 DRIFT flow summary data for the Present Day with Climate Change scenario

Location	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario MAR (MCM)	53.6	395.4	145.9	882.3	653.6	27.1	97.4	995.9
WSLF - Volumes (MCM)	18.2	267.9	68.1	578.4	255.1	4.1	36.2	448.1
DSLF - Volumes (MCM)	23.4	47.2	53.2	122.3	372.5	8.6	39.4	381.0
Class 1 - Annual Frequency	3	0	0	3	0	1	2	0
Class 2 - Annual Frequency	3	2	1	2	4	1	6	2
Class 3 - Annual Frequency	2	4	2	2	0	1	4	3
Class 4 - Annual Frequency	1	3	3	3	0	0	2	1
1:2	P	P	P	P	A	A	P	P
1:5	P	P	P	P	A	A	P	X2
1:10	P	P	P	P	A	X2	A	X3
1:20	P	P	P	P	A	X5	A	X4

A7.3 Effects on irrigated agriculture

Under this scenario, there are increases in all irrigated areas. In proportion to the Present Day, the most substantial is in the Mesic Lowlands.



Addendum Figure 58 Area under irrigation under the Present Day with Climate Change as compared with the Present Day

A7.4 Effects on HEP production

HEP output is reduced to 78.4% of current output, resulting in an output of 472 371 MWh.

A7.5 Effects on environmental condition

A7.5.1 Summary of biophysical condition in the river

The influence of the residual flows on the condition of the rivers is described in two ways:

- as percentage change relative to present day for key indicators representing each of geomorphology, water quality, riparian vegetation, macroinvertebrates and fish;
- in terms of change in overall river condition as denoted by the integrity score

Note: The present-day levels of the indicators have not been quantified, thus the reported change is relative to an unknown quantity.

A7.5.1.1 Geomorphology

The geomorphological changes associated with this scenario are concentrated in the upper portion of the catchment, i.e., upstream of NyM and in the Mkomazi River (Addendum Table 51). The changes can be summarised as follows:

- noticeable reduction in habitat quality, particularly in the Kikuletwa, Mkomazi and Luengera Rivers, through loss of riffles, rapids and pools;
- slight improvement in the floodplain in the Pangani River at Kirua, as a result of expected increase in Class 2 intra-annual floods.

Addendum Table 51 Estimated percentage change from Present Day for geomorphological features under Present Day with Climate Change scenario

Site No.	Name	Riffles and rapids		Pools		Fine sediments		Coarse sediments		Bank erosion		Floodplain inundation	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	-20	0	0	0	0	0	1	25	0	0
2	Lower Kikuletwa	-60	-40	-60	-40	0	0	0	0	0	0	0	0
3	Upper Ruvu	-20	0	0	0	1	25	0	0	0	0	0	0
4	Lower Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
6	Pangani at Kirua	0	0	1	25	1	25	0	0	0	0	26	68
7	Lower Mkomazi	-100	-100	-100	-100	500	800	0	0	0	0	-100	-100
8	Lower Luengera	-60	-40	-20	0	1	25	0	0	0	0	-100	-80
9	Lower Pangani	0	0	0	0	-20	0	0	0	1	25	0	0

A7.5.1.2 Water Quality

The water-quality changes associated with this scenario are concentrated in the Lower Kikuletwa and Mkomazi Rivers (Addendum Table 52). The changes can be summarised as follows:

- noticeable increase in turbidity, conductivity and nutrient in the Kikuletwa and Mkomazi Rivers, due to increased irrigation efficiency and thus larger agricultural areas.

Addendum Table 52 Estimated percentage change from Present Day for water quality under Present Day with Climate Change scenario

Site No.	Name	Turbidity/TSS		Conductivity/TDS		Phosphorus		Nitrogen	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	1	25	0	0	0	0
2	Lower Kikuletwa	1	25	251	500	26	68	-20	0
3	Upper Ruvu	0	0	1	25	1	25	0	0
4	Lower Ruvu	0	0	0	0	0	0	0	0
6	Pangani at Kirua	0	0	0	0	0	0	0	0
7	Lower Mkomazi	1	25	68	250	68	250	1	25
8	Lower Luengera	0	0	0	0	0	0	0	0
9	Lower Pangani	0	0	0	0	0	0	1	25

A7.5.1.3 Vegetation

The changes in riparian vegetation associated with this scenario (Addendum Table 53) can be summarised as follows:

- increase of wet bank trees in upper and lower Kikuletwa, upper Ruvu (i.e., in the upper catchment);
- noticeable increase in wet bank vegetation in the Lower Mkomazi and Luengera Rivers as a result of increased flow variability.

Addendum Table 53 Estimated percentage change from Present Day for vegetation under Present Day with Climate Change scenario

Site No.	Name	Dry Bank Trees		Dry Bank Herbs & Shrubs		Dry Bank Grasses		Wetbank Trees		Wetbank Herbs		Wetbank grasses and reeds	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-20	0	0	0	0	0	0	0	-20	0	0	0
2	Lower Kikuletwa	-20	0	0	0	0	0	0	0	-80	-60	-40	-20
3	Upper Ruvu	0	0	0	0	0	0	0	0	-20	0	26	68
4	Lower Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
6	Pangani at Kirua	-	-	-	-	-	-	26	68	1	25	1	25
7	Lower Mkomazi	-	-	-	-	-	-	251	500	68	250	68	250
8	Lower Luengera	-	-	-	-	-	-	26	68	26	68	26	68
9	Lower Pangani	1	25	1	25	0	0	0	0	0	0	0	0

A7.5.1.4 Macroinvertebrates

The changes in macroinvertebrates associated with this scenario (Addendum Table 54) can be summarised as follows:

- Severe decline in sensitive species and a modest decline in tolerant species across almost the whole basin.

Addendum Table 54 Estimated percentage change from Present Day for macroinvertebrates under Present Day with Climate Change scenario

Site No.	Name	Sensitive species		Tolerant species (e.g., Dysticidae, Chironominae and Culicidae)		Pest Simuliidae	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	0	0	-40	-20
2	Lower Kikuletwa	-100	-100	-60	-40	-20	0
3	Upper Ruvu	-60	-40	-20	0	0	0
4	Lower Ruvu	-40	-20	1	25	0	0
6	Pangani at Kirua	-20	0	-20	0	1	25
7	Lower Mkomazi	-100	-80	0	0	0	0
8	Lower Luengera	-20	0	-40	-20	0	0
9	Lower Pangani	0	0	0	0	0	0

A7.5.1.5 Fish

The changes in fish associated with this scenario (Addendum Table 55) can be summarised as follows:

- low to severe declines in fish across most of the basin, except at the Pangani River at Kirua, where slightly increased variability could result in a slight improvement in conditions.

Addendum Table 55 Estimated percentage change from Present Day for fish under Present Day with Climate Change scenario

Site No.	Name	*Clarias* group		*Tilapia* group		*Labeo* group	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	0	0	0	0
2	Lower Kikuletwa	-60	-40	0	0	-100	-80
3	Upper Ruvu	0	0	0	0	-80	-60
4	Lower Ruvu	-20	0	0	0	-40	-20
6	Pangani at Kirua	1	25	1	25	0	0
7	Lower Mkomazi	-40	-20	-100	-100	-100	-100
8	Lower Luengera	0	0	-20	0	-60	-40
9	Lower Pangani	0	0	-60	-40	0	0

A7.5.1.6 Overall condition

The changes in overall river condition associated with this scenario are provided in Addendum Table 56. There is a widespread decline in ecosystem condition, which is most noticeable in the Kikuletwa, with a slight overall improvement in the Pangani at Kirua.

Addendum Table 56 Overall condition at each river site for the Present Day with Climate Change scenario

Site No.	Name	Present Day River Health Category	Change from Present Day ecological integrity	River Health Category for the scenario
1	Upper Kikuletwa	B/C	-0.149	C
2	Lower Kikuletwa	D	-0.227	D
3	Upper Ruvu	C/D	-0.131	D
4	Lower Ruvu	D	-0.055	D
6	Pangani at Kirua	C	0.047	C
7	Lower Mkomazi	C/D	-0.583	D
8	Lower Luengera	C	-0.095	C
9	Lower Pangani	C	-0.044	C

A7.5.2 Summary of biophysical condition in NyM

A7.5.2.1 Water level change

The FA Tool assesses likely change in two parameters associated with NyM Dam – fish catch and reed area. These parameters are affected by water area (volume) of the lake and the variation in area that are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under this scenario are presented in Addendum Table 57 and discussed in the respective sections below.

Addendum Table 57 Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in NyM under the Present Day with Climate Change scenario relative to the Present Day, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario

	Present Day	This Scenario	% Change
Mean lake area (ha)	103.8	73	-30%
Std dev of lake area (m)	1.24	1.67	34%
Max lake area (ha)	137.1	137.1	0%
Reed area (ha)	33.3	64.1	92%
Mean lake level (m)	15.9	12.5	-21%
Std dev of lake level (m)	1.2	1.4	17%
Fish catch (tonnes)	3538.8	2755.5	-22%

A7.5.2.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surround NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under this scenario, lake area shrinks by 30%, variability increases by 34%, while maximum area is not expected to change (Addendum Table 57). The net result of this is that total reed area is expected to expand considerably by up to 92%.

A7.5.2.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the present day we expect fish populations to expand in responses to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under the Present Day with Climate Change scenario, variability in lake level increases by 34% but average area declines by 30% (Addendum Table 57). Fish catches as a result, are expected to decline by 22%.

A7.5.3 Summary of biophysical condition in Kirua Swamp

This scenario will result in a further decline in the condition of the Kirua Swamp because of reduced flooding relative to Present Day. Swamp inundation is presently *c*. 4% of natural and this will drop to *c*. 3%.

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to present day. Under this scenario, fish abundances are predicted to decrease to 62% of present day (82 tonnes) and floodplain vegetation decrease to 61%.

A7.5.4 Summary of biophysical condition in the Estuary

A7.5.4.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under this scenario freshwater flows reaching the estuary are lower than at present during all four seasons (average reduction = 18.1%) but are most severely reduced during the Short Rains (37.4% reduction) and both Dry Seasons (-14.7% and -18.1% respectively, Addendum Table 58). Agricultural return flows, as a proportion of the total flow, increase markedly in all seasons (average increase = 37.7%) due to increased irrigation efficiency and thus area and are most marked during Short Rains and Dry 1 and 2 (36.3%, 39.9%, and 39.8%, respectively). Number of months where flow exceeds 250 Mm^3 is down by 12.5%.

Addendum Table 58 Change in freshwater flows reaching the estuary under the PD with Climate Change scenario relative to the Present Day

		Short rains	Dry 1	Long rains	Dry 2	All months
Average monthly flows	Present Day (Mm^3)	91.3	72.7	186.9	80.7	102.1
	Climate change	57.2	62.0	170.8	66.0	83.7
	% Change	-37.4	-14.7	-8.7	-18.1	-18.1
Agricultural monthly return flows	Present Day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	Climate change	36.3	39.9	21.7	39.8	37.7
	% Change	16.5	9.1	4.2	5.9	8.4
No. months flow >250 Mm^3	Present Day	8.0				
	Climate change	9.0				
	% Change	12.5				

Addendum Table 59 Health scores for the estuary as a whole and the component parameters under the PD with Climate Change scenario

	This scenario	Present Day	% change from PD (+/-)
Geomorphology	40%	41%	2%
Water Quality	53%	49%	-8%
Micro-algae	40%	38%	-5%
Vegetation	60%	59%	-2%
Inverts	60%	55%	-8%
Fish	50%	47%	-6%
Birds	40%	38%	-4%
Overall health score	57%	51%	--11%

A7.5.4.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the Present Day status of the mouth, which is both wide and deep. Thus, only the extreme high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significantly affect geomorphological conditions in the estuary such as channel width and depth, and intertidal area, albeit on a relative small scale due to the large size of the tidal prism.

These high flows are elevated by 12.5% relative to the Present Day under this scenario (Addendum Table 58) but as they do not contribute as much to the current mouth status as the tidal flow, the resulting change in geomorphological conditions in the estuary can be expected to be a small 2% increase in channel condition (Addendum Table 59).

A7.5.4.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Reduced flow volumes have a reduced capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under this scenario, mean monthly flows are lower while the contributions by agricultural return flows increase. The combined effect of these two negative influences is predicted to lead to increased concentrations of nutrients, lower dissolved oxygen concentrations, and reduced water clarity (higher turbidity). Water quality health score is down by 8% to 49%.

A7.5.4.4 Micro-algae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient level) with the result that phytoplankton concentrations in the system are extremely high. Further increases in nutrient concentration through the process described above will almost certainly give rise to further increases in the phytoplankton abundance in the estuary with a concomitant reduction in health score associated with this parameters from 40% to 38%.

A7.5.4.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As mean monthly flows under the Present Day scenario are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the contribution from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production)

The effect of reductions in flow and increases in agricultural return flows anticipated under this scenario, are consequently anticipated to have a minor negative influence on vegetation communities associated with the estuary, translating to a reduction in the health score of 2% (Addendum Table 59).

A7.5.4.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes in the geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality (reduced water clarity and oxygen levels, increased nutrients) between the natural and Present Day situations.

While existing geomorphological conditions are not expected to change significantly under the Present Day with Climate Change scenario, the anticipated reduction in water quality will have a significant impact on macroinvertebrates. The concomitant reduction in health score is anticipated to be in the region of 8%, from a present day score of 60% to 55% (Addendum Table 59). This will manifest as a further reduction in catches of shrimp and possibly mangrove crabs from the estuary.

A7.5.4.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geomorphological characteristics and water quality as well as by the decline of their main food supply (invertebrates). As such the current health score is low (50%) and is expected to decline even further under this scenario (to 47%, Addendum Table 59). Effects of this will be manifest as a reduction in abundance and species richness of the fish fauna in the estuary, with a corresponding reduction in fish landings derived from the estuary.

A7.5.4.8 Birds

Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the estuary and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). The predicted reductions in invertebrate and fish abundance are likely to be translated into a further reduction in the numbers and species of birds frequenting the estuary albeit not as severe as for the fish and invertebrates (Addendum Table 59).

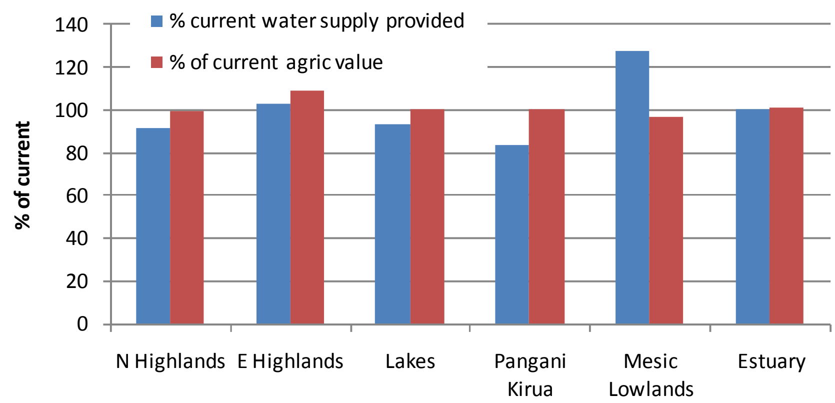
A7.5.4.9 Overall condition

All measured health parameters in the estuary show a decline under the Present Day with Climate Change scenario, with the result that the overall health of the system can be expected to decline severely as well. Overall health score declines from 57 to 51%, but remains in a D class (i.e. largely modified).

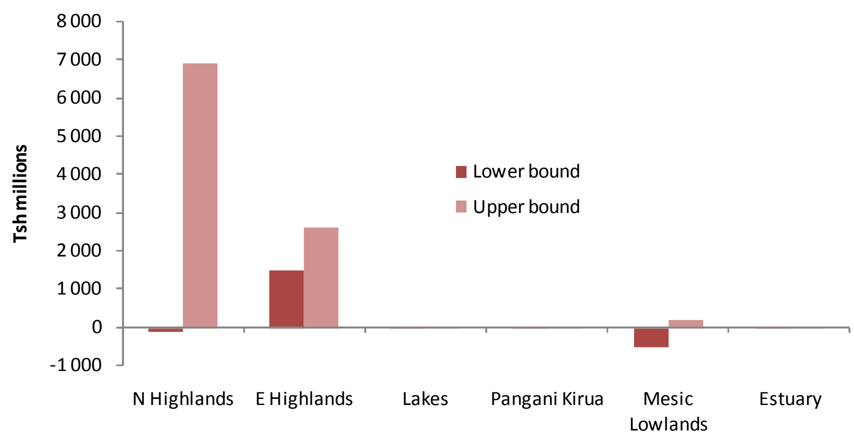
A7.6 Effects on livelihoods

A7.6.1 Income from small-scale agriculture

Addendum Figure 59 shows aggregate net income from agriculture to rural households within 5 km of rivers under the scenario as a percentage of current value. In this scenario, income in the Eastern Highlands increases, and there is little change in the other zones. Significant overall gains are seen in the highland zones with a probable decrease in the Mesic Lowlands (Addendum Figure 60).



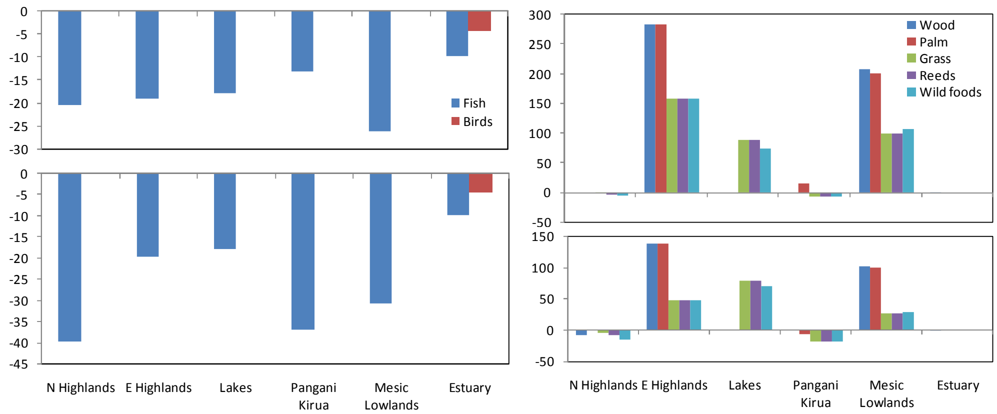
Addendum Figure 59 Area under small-scale irrigation under the Present Day with Climate Change scenario compared with the Present Day



Addendum Figure 60 Lower and upper bound estimates of the aggregate change in income from small-scale agriculture under the Present Day with Climate Change scenario

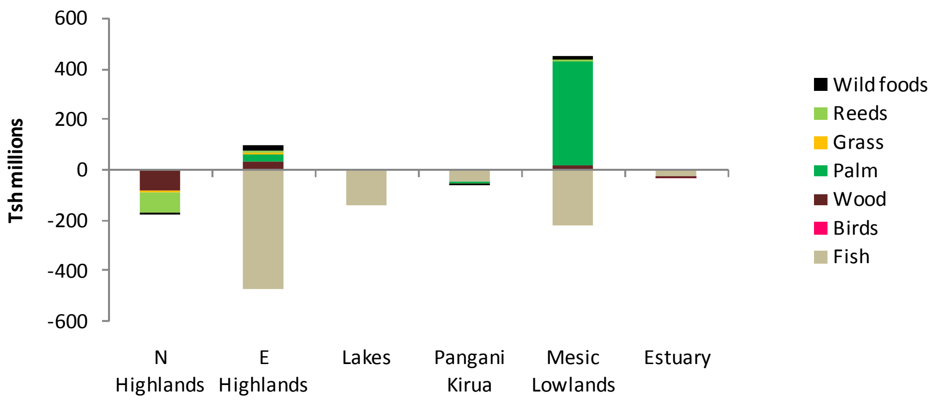
A7.6.2 Income from natural resources

Fish decrease in abundance in all zones under this scenario, with losses in the order of 15% to 40% of current stocks. Bird numbers also decrease. Plant resources are expected to increase in most areas under this scenario, especially in the Eastern Highlands, because of increased flow variability. In the Northern Highlands and Pangani-Kirua decreases of up to 20% are expected (Addendum Figure 61).



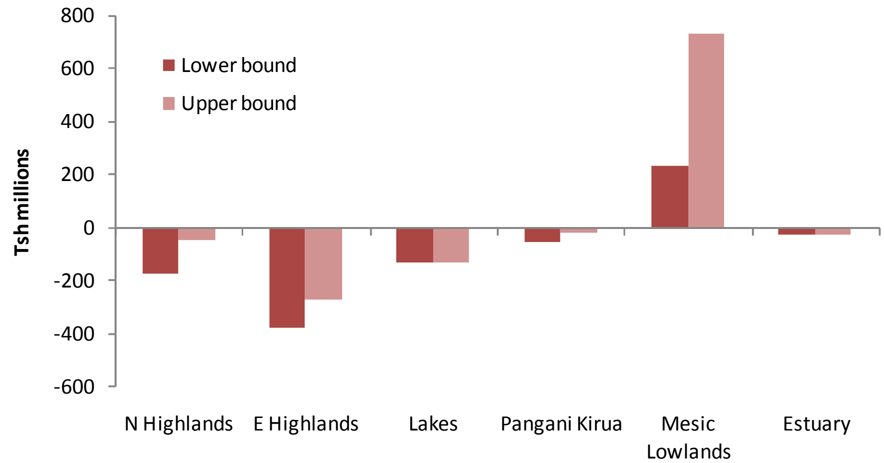
Addendum Figure 61 **Best and worst case estimates of the percentage change from Present Day in the abundance of natural resources used by households, under the Present Day with Climate Change scenario**

Impacts of these changes on income to households are shown in Addendum Figure 62.



Addendum Figure 62 **Worst-case estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under the PD with Climate Change scenario**

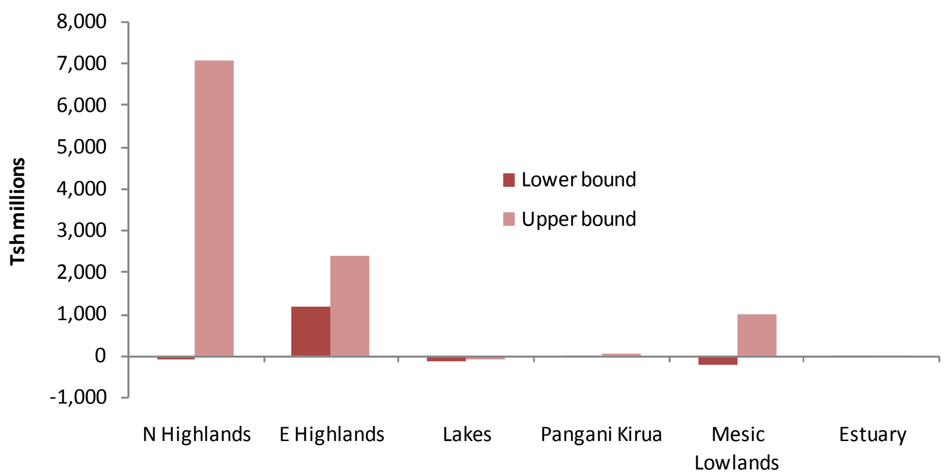
Aggregate income losses are expected for the Lakes, Pangani Kirua and Estuary regions based mainly on Fish losses. Northern Highlands will see even greater losses as a result of mainly Reeds and Wild foods decline. Eastern Highlands will see gains in all sectors, except Fish that will offset those gains dramatically. Mesic Lowlands, which also sees large Fish losses, contrarily has that offset by major gains in Palm income.



Addendum Figure 63 Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under the Present Day with Climate Change scenario

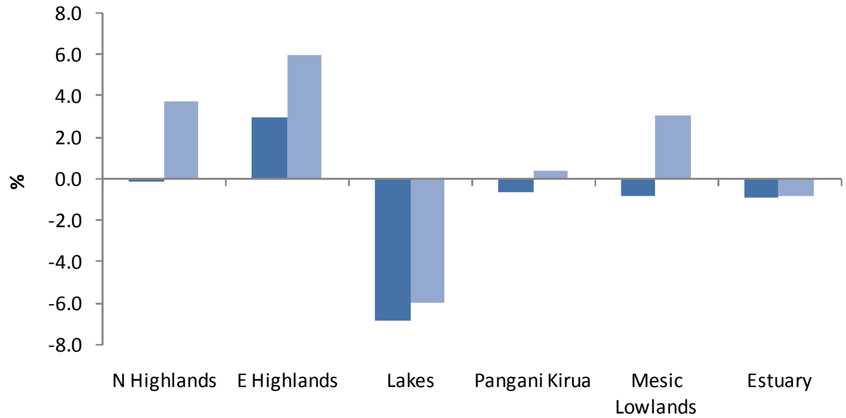
A7.6.3 Overall household income

Overall impacts on household income are expected to be positive in the highlands and Mesic Lowlands. There are negligible losses in the remaining zones (Addendum Figure 64).



Addendum Figure 64 Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, under the Present Day with Climate Change scenario

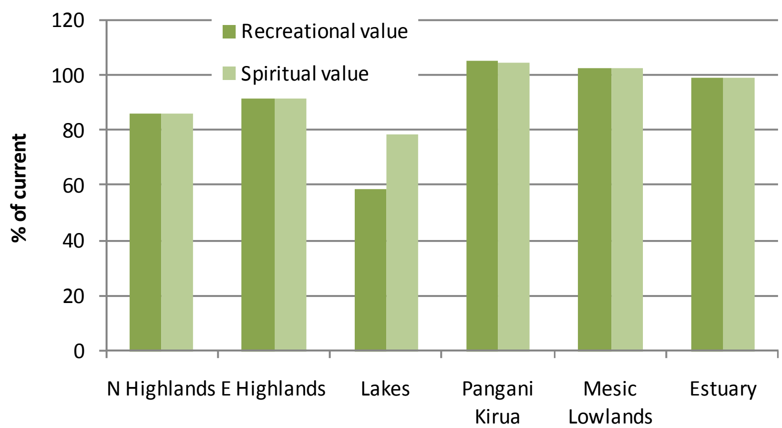
Aggregate household income increases by up to 6% in the highland areas and a slight increase is expected in the Mesic Lowlands. In the remaining zones there is a decrease in income, particularly in the Lakes zone where income decreases by up to 9% (Addendum Figure 65).



Addendum Figure 65 Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under the Present Day with Climate Change scenario

A7.6.4 Intangible values

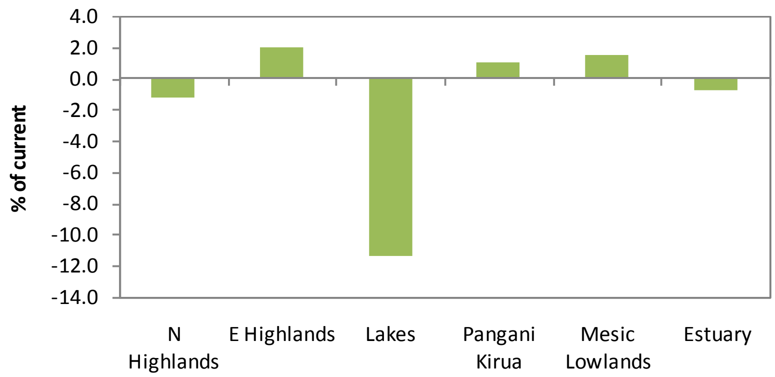
There is a marked decline in recreational and spiritual well-being among households in the highlands and lake area (Addendum Figure 66). A slight increase in well-being is enjoyed in Pangani-Kirua, and there is very little change in the last two zones.



Addendum Figure 66 Overall recreational and spiritual well-being (derived from rivers and other sources) under the Present Day with Climate Change scenario as a percentage of current well-being

A7.6.5 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 67. In general the percentage change in well-being is small, apart from in the Lakes area, where households suffer a significant loss of well-being.



Addendum Figure 67 Percentage change in overall well-being of households within 5 km of rivers under the PD with Climate Change scenario

A7.7 Effects on economic value

Under the Present Day with Climate Change scenario, agriculture will see substantial gains. However, other sectors, particularly HEP, will offset these gains as they are all losses, and there is a significant overall decline (Addendum Table 60).

Addendum Table 60 Gains and losses in the value of HEP, agriculture, natural resources, and ecosystem regulating services (Tsh millions per year) under the Present Day with Climate Change scenario.

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
-445 989	10 933	-136	-56	-435 248

A8 MAXIMISE AGRICULTURE LESS 20%

A8.1 Description of the scenario

The Maximise Agriculture with 20% Less Rainfall scenario comprised the following (in order of priority):

- Selecting 20% across the catchment reduction in wet season rainfall, rainfall-runoff models used to predict change in flows in the rivers.
- Allocation of 2025 BHN and Urban/Industrial water demands to Arusha and Moshi.
- Allocation towards 2025 agricultural demands.
- Allocation towards 2025 HEP demands.
- Environment received whatever water was left.

A8.2 Hydrological implications

A8.2.1 Water allocated per sector

Urban/industrial 54.7 Mcm a^{-1} (PD = 31.1)
Irrigation 873 Mcm a^{-1} (PD = 1042), but see Section A8.3 for area irrigated
HEP 225 815 MW h^{-1} (PD = 602 647)

A8.2.2 Changes in the flow regime relative to present day

The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 61. There were two main kinds of change relative to present day:

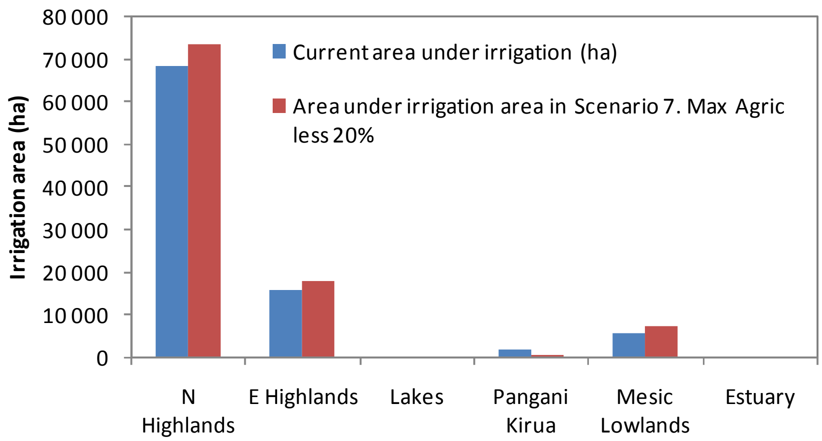
- drastically reduced low flows, particularly in the dry season (Sites 1-4 in upper catchment and Site 7 in the Mkomazi River).
- reduced variability due to lower inflows to NyM and thus storage of floods (Site 6 Pangani River at Kirua Swamp).

Addendum Table 61 DRIFT flow summary data for the Maximise Agriculture with 20% Less Rainfall scenario

Location	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario MAR	32.6	258.7	107.5	573.3	282.5	2.7	61.2	487.7
WSLF - Volumes (MCM)	7.4	160.0	70.6	338.7	189.2	0.4	18.4	247.8
DSLF - Volumes (MCM)	19.2	50.2	58.4	114.1	79.7	1.9	33.1	155.8
Class 1 - Annual Frequency	2	1	0	2	1	1	2	1
Class 2 - Annual Frequency	2	4	1	2	2	0	9	2
Class 3 - Annual Frequency	1	3	2	3	0	0	3	2
Class 4 - Annual Frequency	1	2	3	2	0	0	0	1
1:2	A	A	A	A	A	A	A	P
1:5	P	A	P	A	A	A	A	P
1:10	A	A	P	A	A	A	A	A
1:20	A	A	P	A	A	A	A	P

A8.3 Effects on irrigated agriculture

Under this scenario, there are increases in the irrigation area in all zones relative to present day.



Addendum Figure 68 Area under irrigation under the Maximise Agriculture with 20% Less Rainfall scenario as compared with the Present Day

A8.4 Effects on HEP production

HEP output is reduced to 37.5% of current output, resulting in an output of 225 815 MWh.

A8.5 Effects on environmental condition

A8.5.1 Summary of biophysical condition in the river

The influence of the residual flows on the condition of the rivers is described in two ways:

- as percentage change relative to present day for key indicators representing each of geomorphology, water quality, riparian vegetation, macroinvertebrates and fish;
- in terms of change in overall river condition as denoted by the integrity score

Note: The present day levels of the indicators have not been quantified, thus the reported change is relative to an unknown quantity.

A8.5.1.1 Geomorphology

The geomorphological changes associated with this scenario are most obvious in the upper portion of the catchment, i.e., upstream of NyM and in the Mkomazi and Luengera Rivers (Addendum Table 62). The changes can be summarised as follows:

- severe and possibly total loss of quality physical habitat in all of the rivers;
- severe loss of remaining floodplains, especially in the Lower Kikuletwa and Ruvu Rivers, and the Mkomazi and Luengera Rivers.

Addendum Table 62 Estimated percentage change from Present Day for geomorphological features under the Maximise Agriculture with 20% Less Rainfall scenario

Site No.	Name	Riffles and rapids		Pools		Fine sediments		Coarse sediments		Bank erosion		Floodplain inundation	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-100	-100	-100	-100	500	800	-80	-60	0	0	0	0
2	Lower Kikuletwa	-100	-100	-100	-100	26	68	-60	-40	-40	-20	-100	-100
3	Upper Ruvu	-40	-20	-20	0	26	68	-20	0	0	0	0	0
4	Lower Ruvu	-80	-60	-100	-100	1	25	-40	-20	-40	-20	-100	-100
6	Pangani at Kirua	-80	-60	-60	-40	1	25	0	0	1	25	26	68
7	Lower Mkomazi	-100	-100	-100	-100	500	800	0	0	0	0	-100	-100
8	Lower Luengera	-100	-100	-80	-60	500	800	0	0	0	0	-100	-100
9	Lower Pangani	-60	-40	-100	-80	0	0	0	0	1	25	0	0

A8.5.1.2 Water Quality

The water-quality changes associated with this scenario are concentrated in the Lower Kikuletwa and Mkomazi Rivers (Addendum Table 63). The changes can be summarised as follows:

- noticeable increase in conductivity and nutrient levels in all the rivers but especially in the Kikuletwa, Ruvu and Mkomazi Rivers.

Addendum Table 63 Estimated percentage change from Present Day for water quality under the Maximise Agriculture with 20% Less Rainfall scenario

Site No.	Name	Turbidity/TSS		Conductivity/TDS		Phosphorus		Nitrogen	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	68	250	1	25	1	25
2	Lower Kikuletwa	1	25	68	250	26	68	-40	-20
3	Upper Ruvu	0	0	1	25	1	25	0	0
4	Lower Ruvu	0	0	68	250	26	68	-20	0
6	Pangani at Kirua	0	0	0	0	0	0	0	0
7	Lower Mkomazi	0	0	500	800	251	500	0	0
8	Lower Luengera	0	0	1	25	1	25	0	0
9	Lower Pangani	-20	0	1	25	1	25	26	68

A8.5.1.3 Vegetation

The changes in riparian vegetation associated with this scenario (Addendum Table 64) can be summarised as follows:

- Increase in dry-bank vegetation in Lower Kikuletwa and Lower Ruvu Rivers;
- increase of wet bank trees in Upper and Lower Kikuletwa, Lower Ruvu (i.e., in the upper catchment) and slight changes in understory vegetation cover at some sites;
- noticeable increase in wet bank vegetation in the Lower Mkomazi and Luengera Rivers.

Addendum Table 64 Estimated percentage change from Present Day for vegetation under the Maximise Agriculture with 20% Less Rainfall scenario

Site No.	Name	Dry Bank Trees		Dry Bank Herbs & Shrubs		Dry Bank Grasses		Wetbank Trees		Wetbank Herbs		Wetbank grasses and reeds	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-20	0	0	0	0	0	26	68	-20	0	68	250
2	Lower Kikuletwa	68	250	251	500	251	500	26	68	-40	-20	-20	0
3	Upper Ruvu	0	0	0	0	0	0	0	0	0	0	26	68
4	Lower Ruvu	251	500	251	500	251	500	26	68	0	0	0	0
6	Pangani at Kirua	-	-	-	-	-	-	0	0	-40	-20	-40	-20
7	Lower Mkomazi	-	-	-	-	-	-	500	800	68	250	68	250
8	Lower Luengera	-	-	-	-	-	-	26	68	26	68	26	68
9	Lower Pangani	1	25	0	0	1	25	0	0	0	0	0	0

A8.5.1.4 Macroinvertebrates

The changes in macroinvertebrates associated with this scenario (Addendum Table 65) can be summarised as follows:

- drastic decline in sensitive species across almost the whole basin.some increases in tolerant species, e.g., in the Lower Kikuletwa and Ruvu Rivers, but declines elsewhere;
- conditions in the Pangani River at Kirua may support a noticeable increase in pest Simuliidae.

Addendum Table 65 Estimated percentage change from Present Day for macroinvertebrates under the Maximise Agriculture with 20% Less Rainfall scenario

Site No.	Name	Sensitive species		Tolerant species (e.g., Dysticidae, Chironominae and Culicidae)		Pest Simuliidae	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-100	-100	-20	0	-100	-100
2	Lower Kikuletwa	-100	-100	1	25	-20	0
3	Upper Ruvu	-60	-40	-20	0	0	0
4	Lower Ruvu	-100	-80	251	500	0	0
6	Pangani at Kirua	-100	-80	-80	-60	251	500
7	Lower Mkomazi	-100	-100	-100	-80	0	0
8	Lower Luengera	-100	-80	-40	-20	0	0
9	Lower Pangani	0	0	0	0	0	0

A8.5.1.5 Fish

The changes in fish associated with this scenario (Addendum Table 66) can be summarised as follows:

- low to severe declines in fish in all parts of the basin.

Addendum Table 66 Estimated percentage change from Present Day for fish under the Maximise Agriculture with 20% Less Rainfall scenario

Site No.	Name	*Clarias* group		*Tilapia* group		*Labeo* group	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-100	-80	0	0	0	0
2	Lower Kikuletwa	-80	-60	0	0	-100	-100
3	Upper Ruvu	0	0	0	0	-80	-60
4	Lower Ruvu	-40	-20	0	0	-100	-100
6	Pangani at Kirua	-20	0	-60	-40	0	0
7	Lower Mkomazi	-100	-100	-100	-100	-100	-80
8	Lower Luengera	-20	0	-100	-100	-100	-100
9	Lower Pangani	-80	-60	-100	-100	0	0

A8.5.1.6 Overall condition

The changes in overall river condition associated with this scenario are provided in Addendum Table 67. There is a basin-wide decline in river condition, in most areas dropping the river down to a lower condition class or at that threshold.

Addendum Table 67 Overall condition at each river site for the Maximise Agriculture with 20% Less Rainfall scenario

Site No.	Name	Present Day River Health Category	Change from Present Day ecological integrity	River Health Category for the scenario
1	Upper Kikuletwa	B/C	-0.587	C
2	Lower Kikuletwa	D	-0.558	D/E
3	Upper Ruvu	C/D	-0.155	D
4	Lower Ruvu	D	-0.274	D
6	Pangani at Kirua	C	-0.204	C/D
7	Lower Mkomazi	C/D	-1.124	E
8	Lower Luengera	C	-0.509	D
9	Lower Pangani	C	-0.200	C/D

A8.5.2 Summary of biophysical condition in NyM

A8.5.2.1 Water level change

The FA Tool assesses likely change in two parameters associated with NyM Dam – fish catch and reed area. These parameters are affected by water area (volume) of the lake and the variation in area, which are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under this scenario are presented in Addendum Table 68 and discussed in the respective sections below.

Addendum Table 68 Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in NyM under the Maximise Agriculture with 20% Less Rainfall scenario relative to Present Day, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario

	Present Day	This Scenario	% Change
Mean lake area (ha)	103.8	50.6	-51%
Std dev of lake area (m)	1.24	0.68	-45%
Max lake area (ha)	137.1	91.1	-34%
Reed area (ha)	33.3	40.5	21%
Mean lake level (m)	15.9	9.9	-38%
Std dev of lake level (m)	1.2	0.7	-42%
Fish catch (tonnes)	3538.8	2101.2	-41%

A8.5.2.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surround NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under this scenario, lake area shrinks by 51%, variability decreases by 45%, and the maximum area decreases (down by 34%) (Addendum Table 68). The net result of this is that total reed area is expected to expand marginally by about 21%.

A8.5.2.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the present day we expect fish populations to expand in responses to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under this scenario, the loss of variability and declining average area of lake level (Addendum Table 68) is expected to result in a 41% decline in fish catches.

A8.5.3 Summary of biophysical condition in Kirua Swamp

This scenario will all but eliminate the last vestiges of the Kirua Swamp as a result of reduced flooding relative to present day. Under Present Day condition the area of swamp inundation is *c*. 4% of natural and this is predicted to decrease to *c*. 1%.

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to present day. Under this scenario, fish abundances are predicted to decrease to 18% of present day (23 tonnes) and floodplain vegetation decrease to 17%.

A8.5.4 Summary of biophysical condition in the Estuary

A8.5.4.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under this scenario freshwater flows reaching the estuary are markedly lower than the Present Day during all four seasons (average reduction = 60.2%) but are most markedly lower during Dry 1, Dry 2 and the Short Rains (70.4%, 72.3% and 67.7%, respectively) (Addendum Table 69). Agricultural return flows, as a proportion of the total flow, increase in all seasons (average increase = 46.2%) as would be expected under this scenario and are most marked during Dry 1, Dry 2 and the Short Rains (114.9%, 106.6% and 75.0%, respectively). The number of months where flow exceeds 250 Mm^3 is down by 87.5%.

Addendum Table 69 Change in freshwater flows reaching the estuary under the Maximise Agriculture with 20% Less Rainfall scenario relative to the Present Day

		Short Rains	Dry 1	Long Rains	Dry 2	All months
Average monthly flows	Present Day (Mm^3)	91.3	72.7	186.9	80.7	102.1
	Max Agric less 20%	29.5	21.5	98.4	22.3	40.6
	% Change	-67.7	-70.4	-47.4	-72.3	-60.2
Agricultural monthly return flows	Present Day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	Max Agric less 20%	35.9	36.6	17.5	35.9	33.7
	% Change	75.0	114.9	9.3	106.6	46.2
No. months flow >250 Mm^3	Present Day	8.0				
	Max Agric less 20%	1.0				
	% Change	-87.5				

Addendum Table 70 Health scores for the estuary as a whole and the component parameters under the Maximise Agriculture with 20% Less Rainfall scenario

	Present Day	This scenario	% change from PD (+/-)
Geomorphology	40%	35%	-12%
Water Quality	53%	41%	-23%
Micro-algae	40%	33%	-18%
Vegetation	60%	57%	-6%
Invertebrates	60%	43%	-28%
Fish	50%	39%	-22%
Birds	40%	34%	-15%
Overall health score	57%	34%	-41%

A8.5.4.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the Present Day status of the mouth, which is both wide and deep. Thus, only the extreme high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significantly affect geomorphological conditions in the estuary such as channel width and depth, and intertidal area, albeit on a relative small scale due to the large size of the tidal prism.

These high flows change considerably from the Present Day under this scenario (down by 87.5%, Addendum Table 69) but as they do not contribute as much to the current mouth status as the tidal flow, the resulting change in geomorphological conditions in the estuary can be expected to be relative modest (a 12% move away from natural, Addendum Table 70).

A8.5.4.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Reduced flow volumes have a reduced capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under this scenario, mean monthly flows are lower while the contributions by agricultural return flows increase. The combined effect of these two negative influences is predicted to be a significant reduction in water quality in the estuary – i.e. increased nutrients, lower dissolved oxygen concentrations, and reduced water clarity (higher turbidity). The water quality health score declines by 23% to 41%.

A8.5.4.4 Micro-algae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient levels) with the result that phytoplankton concentrations in the system are extremely high. Further increases in nutrient concentration through the process described above will almost certainly give rise to further increases in the phytoplankton abundance in the estuary with a concomitant reduction in health score associated with these parameters, from 40% to 33%.

A8.5.4.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As mean monthly flows under the Present Day scenario are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the contribution from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production).

The effect of further reductions in flow and increases in agricultural return flows anticipated under this scenario, are consequently anticipated to have a minor negative influence on vegetation communities associated with the estuary, translating to a reduction in the health score of 6%, Addendum Table 70).

A8.5.4.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes in the geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality (reduced water clarity and oxygen levels, increased nutrients) between the natural and Present Day situations.

While geomorphological conditions are not expected to change significantly from the Present Day under this scenario, the anticipated reduction in water quality will have a significant impact on macroinvertebrates. The concomitant reduction in health score is anticipated to be in the region of 28% (i.e. from a present day score of 60% to 43%, Addendum Table 70), and will be manifest as a further reduction in catches of shrimp and possibly mangrove crabs from the estuary.

A8.5.4.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geomorphological characteristics and water quality as well as by the decline of their main food supply (invertebrates). As such the current health score is low (50%) and is expected to decline even further under this scenario to 39% (Addendum Table 70). The effects of this will manifest as a further reduction in abundance and species richness of the fish fauna in the estuary, with a corresponding reduction in fish landings derived from the estuary.

A8.5.4.8 Birds

Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the estuary and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). The predicted reductions in invertebrate and fish abundance are likely to be translated into a further reduction in the numbers and species of birds frequenting the estuary albeit not as severe as for the fish and invertebrates (down from 40 to 34%, Addendum Table 70).

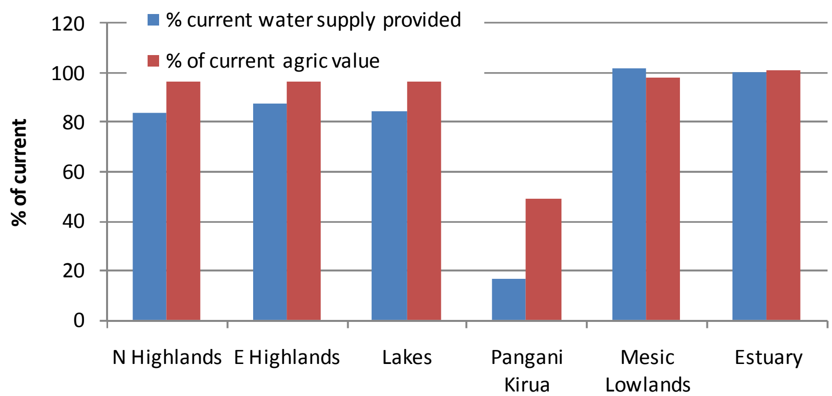
A8.5.4.9 Overall condition

All measured health parameters in the estuary show a decline under the High Agriculture scenario, mostly a severe decline, with the result that the overall health of the system can be expected to decline severely as well. Overall health score declines from 57 to 34% and the estuary drops in health status from a highly modified system (“D” class) to a highly degraded system (“E” class).

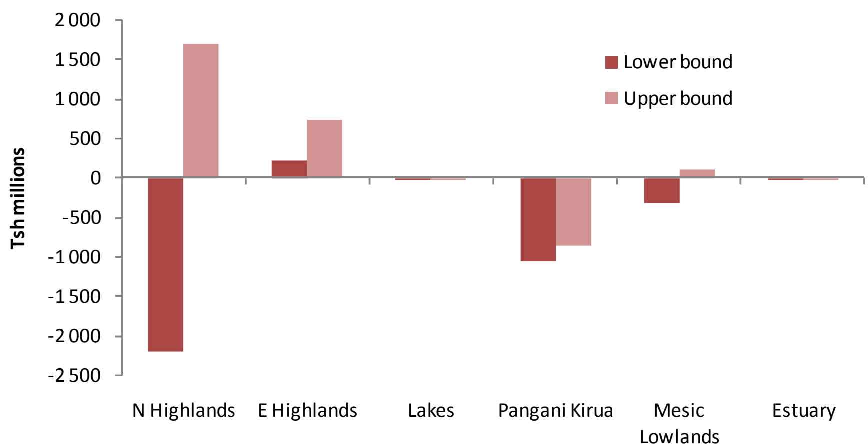
A8.6 Effects on livelihoods

A8.6.1 Income from small-scale agriculture

Addendum Figure 69 shows aggregate net income from agriculture to rural households within 5 km of rivers under the scenario as a percentage of current value. There is little change in any of the zones apart form Pangani-Kirua where income is predicted to be very much lower. However, the range of possible gains and losses in the Northern Highlands is large (Addendum Figure 70) making clear predictions difficult.



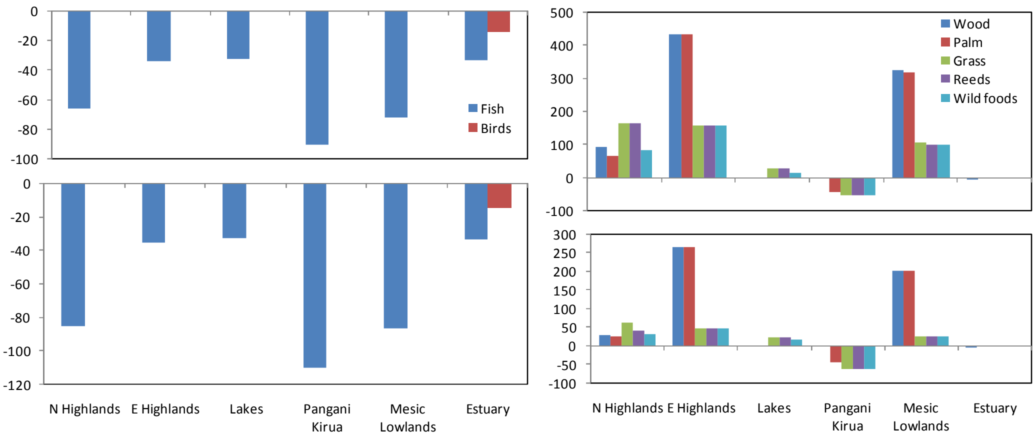
Addendum Figure 69 **Area under small-scale irrigation under Maximise Agriculture with 20% Less Rainfall scenario as compared with the Present Day**



Addendum Figure 70 **Lower and upper bound estimates of the aggregate change in income from small-scale agriculture under Maximise Agriculture with 20% Less Rainfall scenario**

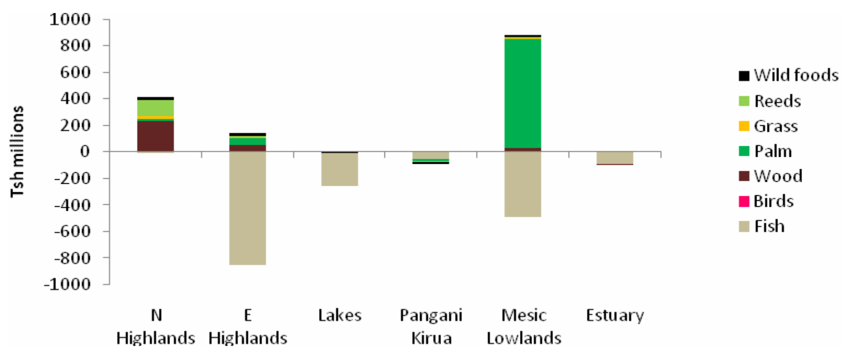
A8.6.2 Income from natural resources

Fish decrease in abundance in all zones under this scenario, with losses ranging from 30% to total absence in the worst case for Pangani Kirua. Bird numbers also decrease in the estuary. Plant resources are little affected in the Estuary and Lakes, but there are significant losses in Pangani Kirua. The other regions see significant increases.



Addendum Figure 71 **Best and worst case estimates of the percentage change from Present Day in the abundance of natural resources used by households, under the Maximise Agriculture with 20% Less Rainfall scenario**

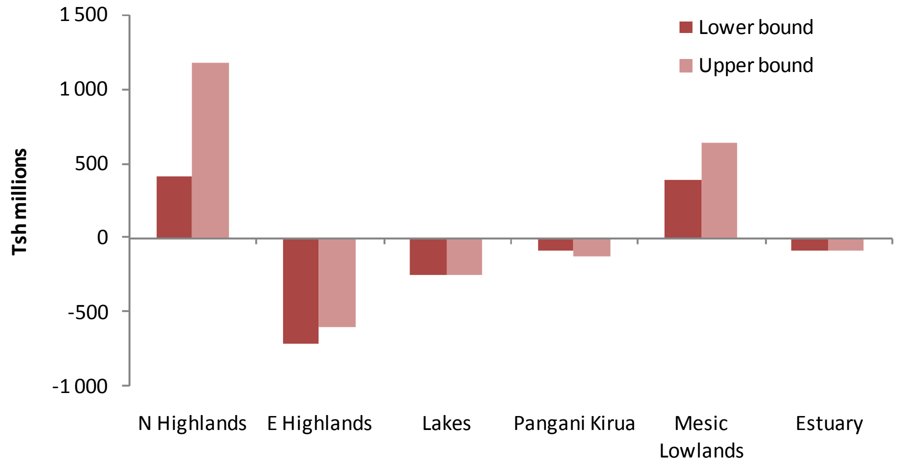
Impacts of these changes on income to households are shown in Addendum Figure 72.



Addendum Figure 72 **Worst-case estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under the Maximise Agriculture with 20% Less Rainfall scenario**

Aggregate income is expected to increase somewhat in the Northern Highlands by about Tsh 400. Mesic Lowlands will see some loss in fisheries, but overall gains due to a strong increase in palm income. Eastern Highlands will see a slight gain in most sectors nullified by extremely high losses in fish income. Other regions will see declines.

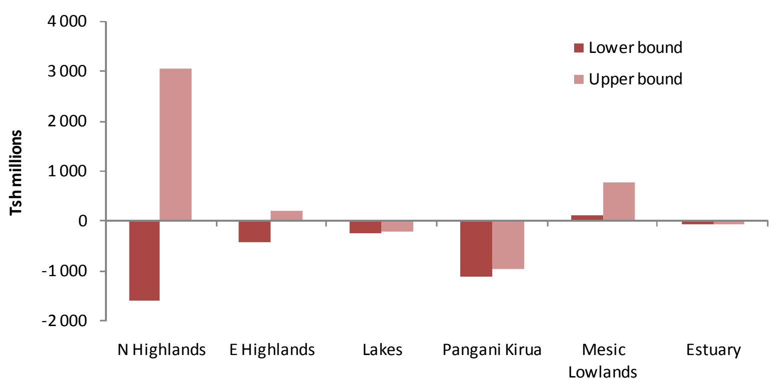
Overall income from natural resources is expected to increase in the Northern Highlands and Mesic Lowlands, but decrease in the other zones (Addendum Figure 73).



Addendum Figure 73 **Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under the Maximise Agriculture with 20% Less Rainfall scenario**

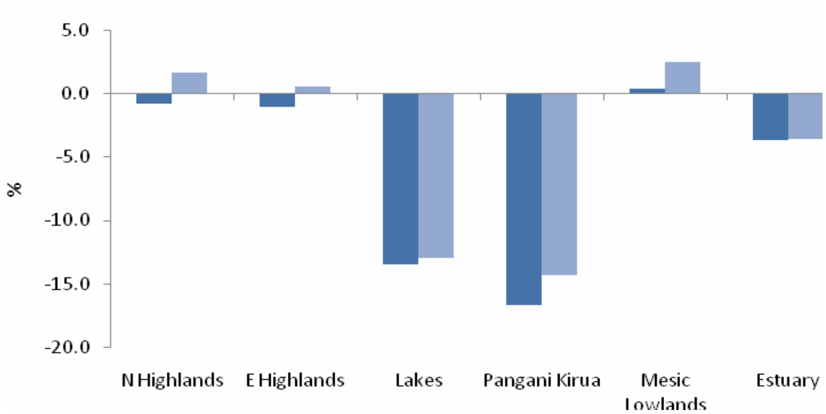
A8.6.3 Overall household income

Overall impacts on household income are expected to be negative in the Lakes and Pangani Kirua. The Mesic Lowlands will see an increase. The two Highland regions show a split in prediction. There are negligible losses in the remaining zones (Addendum Figure 74).



Addendum Figure 74 **Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, Maximise Agriculture with 20% Less Rainfall scenario**

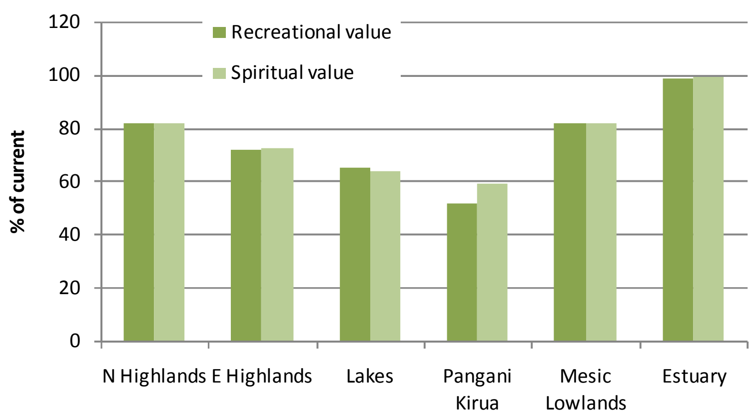
Aggregate household income increase is expected in the Mesic Lowlands. The two highland areas see minimal change. In the remaining zones there is a decrease in income, particularly in the Lakes zone and Pangani Kirua where income decreases by more than 15% (Addendum Figure 75).



Addendum Figure 75 **Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under the Maximise Agriculture with 20% Less Rainfall scenario.**

A8.6.4 Intangible values

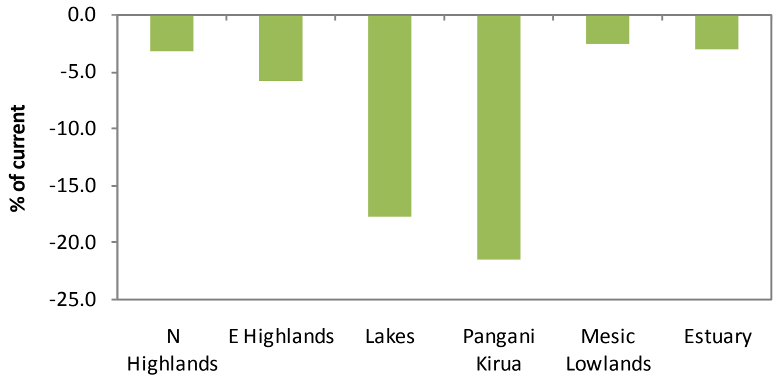
There is a marked decline in recreational and spiritual well-being among households in all areas excepting the Estuary where change is minimal (Addendum Figure 76). The most affected area is Pangani-Kirua, which is predicted to have a 50% decline in recreational well-being.



Addendum Figure 76 **Overall recreational and spiritual well-being (derived from rivers and other sources) under the Maximise Agriculture with 20% Less Rainfall scenario as a percentage of current well-being**

A8.6.5 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 77. There is a decrease in well-being across all regions with the worst affected being Lakes and Pangani-Kirua, which experiences over 20% decline.



Addendum Figure 77 Percentage change in overall well-being of households within 5 km of rivers under the Maximise Agriculture with 20% Less Rainfall scenario

A8.7 Effects on economic value

Under this scenario, there are gains in the natural resources sector. However, there are losses in the three other sectors, particularly for HEP, which dominates the overall loss in economic value (Addendum Table 71).

Addendum Table 71 Gains and losses in the value of HEP, agriculture, natural resources, and ecosystem regulating services (Tsh millions per year) under the Maximise Agriculture with 20% Less Rainfall scenario

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
-1 403 326	-1 420	230	-164	-1 404 680

A9 MAXIMISE AGRICULTURE LESS 30%

A9.1 Description of the scenario

The Maximise Agriculture with 30% Less Rainfall scenario comprised the following (in order of priority):

- Selecting 30% across the catchment reduction in wet season rainfall, rainfall-runoff models used to predict change in flows in the rivers.
- Allocation of 2025 BHN and Urban/Industrial water demands to Arusha and Moshi.
- Allocation towards 2025 agricultural demands.
- Allocation towards 2025 HEP demands.
- Environment received whatever water was left.

A9.2 Hydrological implications

A9.2.1 Water allocated per sector

Urban/industrial 54.7 Mcm a^{-1} (PD = 31.1)
Irrigation 807 Mcm a^{-1} (PD = 1042), but see Section A9.3 for area irrigated
HEP 141 347 MW h^{-1} (PD = 602 647)

A9.2.2 Changes in the flow regime relative to Present Day

The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 72. There were two main kinds of change relative to present day:

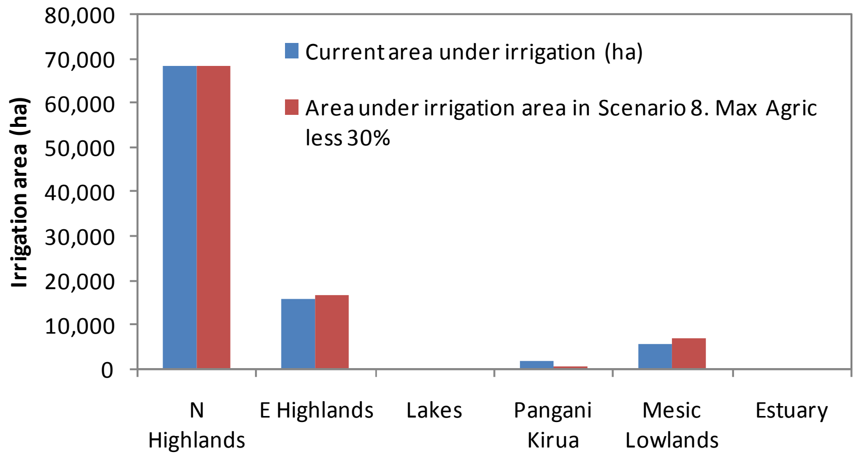
- drastically reduced low flows, particularly in the dry season (Sites 1-4 in upper catchment and Site 7 in the Mkomazi River).
- reduced variability due to lower inflows to NyM and thus storage of floods (Site 6 Pangani River at Kirua Swamp).

Addendum Table 72 DRIFT flow summary data for the Maximise Agriculture with 30% Less Rainfall scenario

Location	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario MAR	27.4	207.0	92.4	491.0	154.9	2.0	50.8	344.5
WSLF - Volumes (MCM)	5.6	117.9	42.6	281.0	100.7	0.2	13.9	161.1
DSLF - Volumes (MCM)	18.0	53.7	40.8	108.8	46.1	1.3	26.0	131.4
Class 1 - Annual Frequency	2	2	0	2	0	0	4	1
Class 2 - Annual Frequency	2	4	1	3	1	0	7	2
Class 3 - Annual Frequency	1	3	3	3	0	0	1	1
Class 4 - Annual Frequency	0	1	2	2	0	0	0	0
1:2	A	A	A	A	A	A	A	A
1:5	A	A	A	A	A	A	A	A
1:10	A	A	A	A	A	A	A	A
1:20	A	A	A	A	A	A	A	P

A9.3 Effects on irrigated agriculture

Under this scenario, there is very little change in overall irrigation area with very slight increases in the Eastern Highlands and Mesic Lowlands, and a decrease in Pangani-Kirua.



Addendum Figure 78 Area under irrigation under the Maximise Agriculture with 30% Less Rainfall scenario compared with the Present Day

A9.4 Effects on HEP production

HEP output is reduced to 23.5% of current output, resulting in an output of 141 347 MWh.

A9.5 Effects on environmental condition

A9.5.1 Summary of biophysical condition in the river

This is the most severe scenario in terms of its impact on the river ecosystems.

The influence of the residual flows on the condition of the rivers is described in two ways:

- as percentage change relative to present day for key indicators representing each of geomorphology, water quality, riparian vegetation, macroinvertebrates and fish;
- in terms of change in overall river condition as denoted by the integrity score (see Section 4.4.1).

Note: The present day levels of the indicators have not been quantified, thus the reported change is relative to an unknown quantity.

A9.5.1.1 Geomorphology

The geomorphological changes associated with this scenario are severe throughout the system (Addendum Table 73). The changes can be summarised as follows:

- severe and possibly total loss of high-quality rocky and pool habitat in all of the rivers with a bud up of fine sediments;
- severe loss of remaining floodplains, especially at the Lower Kikuletwa and Ruvu Rivers, and the Mkomazi and Luengera Rivers.

Addendum Table 73 Estimated percentage change from Present Day for geomorphological features under the Maximise Agriculture with 30% Less Rainfall scenario

Site No.	Name	Riffles and rapids		Pools		Fine sediments		Coarse sediments		Bank erosion		Floodplain inundation	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-100	-100	-100	-100	500	800	-100	-100	-20	0	0	0
2	Lower Kikuletwa	-100	-100	-100	-100	68	250	-60	-40	-40	-20	-100	-100
3	Upper Ruvu	-100	-80	-60	-40	68	250	-60	-40	0	0	0	0
4	Lower Ruvu	-100	-80	-100	-100	1	25	-40	-20	-40	-20	-100	-100
6	Pangani at Kirua	-100	-100	-100	-80	26	68	0	0	1	25	0	0
7	Lower Mkomazi	-100	-100	-100	-100	500	800	0	0	0	0	-100	-100
8	Lower Luengera	-100	-100	-100	-100	500	800	0	0	0	0	-100	-100
9	Lower Pangani	-80	-60	-100	-100	26	68	0	0	1	25	0	0

A9.5.1.2 Water Quality

The detrimental water quality changes associated with this scenario are concentrated in the Lower Kikuletwa and Mkomazi Rivers (Addendum Table 74). The changes can be summarised as follows:

- severe increase in nutrient levels in all the rivers but especially in the Kikuletwa, Ruvu and Mkomazi rivers.
- Increased TDS in the upper catchment and Mkomazi River.

Addendum Table 74 Estimated percentage change from Present Day for water quality under the Maximise Agriculture with 30% Less Rainfall scenario

Site No.	Name	Turbidity/TSS		Conductivity/TDS		Phosphorus		Nitrogen	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	68	250	1	25	1	25
2	Lower Kikuletwa	1	25	68	250	68	250	-40	-20
3	Upper Ruvu	0	0	68	250	68	250	0	0
4	Lower Ruvu	0	0	68	250	26	68	-20	0
6	Pangani at Kirua	0	0	0	0	0	0	0	0
7	Lower Mkomazi	0	0	500	800	251	500	0	0
8	Lower Luengera	0	0	1	25	1	25	0	0
9	Lower Pangani	0	0	1	25	1	25	68	250

A9.5.1.3 Vegetation

The changes in riparian vegetation associated with this scenario (Addendum Table 75) can be summarised as follows:

- increase in wet bank trees in Upper and Lower Kikuletwa, Lower Ruvu (i.e., in the upper catchment) and changes in understory vegetation cover at some sites;
- noticeable increase in wet bank vegetation in the Lower Mkomazi and Luengera Rivers;increase in dry bank vegetation trees in the riparian zone of the Lower Kikuletwa, Lower Ruvu and Lower Pangani Rivers.

Addendum Table 75 Estimated percentage change from Present Day for water quality under the Maximise Agriculture with 30% Less Rainfall scenario

Site No.	Name	Dry Bank Trees		Dry Bank Herbs & Shrubs		Dry Bank Grasses		Wetbank Trees		Wetbank Herbs		Wetbank grasses and reeds	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-20	0	0	0	0	0	68	250	0	0	500	800
2	Lower Kikuletwa	68	250	251	500	251	500	68	250	-60	-40	-20	0
3	Upper Ruvu	0	0	0	0	0	0	1	25	0	0	26	68
4	Lower Ruvu	251	500	251	500	251	500	26	68	-20	0	0	0
6	Pangani at Kirua	-	-	-	-	-	-	0	0	-80	-60	-80	-60
7	Lower Mkomazi	-	-	-	-	-	-	500	800	68	250	68	250
8	Lower Luengera	-	-	-	-	-	-	68	250	68	250	68	250
9	Lower Pangani	68	250	1	25	26	68	26	68	26	68	26	68

A9.5.1.4 Macroinvertebrates

The changes in macroinvertebrates associated with this scenario (Addendum Table 76) can be summarised as follows:

- decline in sensitive species across the basin;decline in tolerant species at most sites, but some increase in the lower Kikuletwa and Ruvu Rivers;
- conditions in the Pangani River at Kirua may favour Simuliidae.

Addendum Table 76 Estimated percentage change from Present Day for macroinvertebrates under the Maximise Agriculture with 30% Less Rainfall scenario

Site No.	Name	Sensitive species		Tolerant species (e.g., Dysticidae, Chironominae and Culicidae)		Pest Simuliidae	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-100	-100	-60	-40	-100	-100
2	Lower Kikuletwa	-100	-100	1	25	-40	-20
3	Upper Ruvu	-100	-100	-80	-60	-20	0
4	Lower Ruvu	-100	-80	251	500	0	0
6	Pangani at Kirua	-100	-100	-100	-80	500	800
7	Lower Mkomazi	-100	-100	-100	-80	0	0
8	Lower Luengera	-100	-100	-40	-20	0	0
9	Lower Pangani	0	0	0	0	0	0

A9.5.1.5 Fish

The changes in fish associated with this scenario (Addendum Table 77) can be summarised as follows:

- low to severe declines, perhaps to local extinction, in fish across most of the basin.

Addendum Table 77 Estimated percentage change from Present Day for fish under the Maximise Agriculture with 30% Less Rainfall scenario

Site No.	Name	*Clarias* group		*Tilapia* group		*Labeo* group	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-100	-100	0	0	0	0
2	Lower Kikuletwa	-100	-80	0	0	-100	-100
3	Upper Ruvu	-20	0	0	0	-100	-100
4	Lower Ruvu	-40	-20	0	0	-100	-100
6	Pangani at Kirua	-80	-60	-100	-100	0	0
7	Lower Mkomazi	-100	-100	-100	-100	-100	-80
8	Lower Luengera	-40	-20	-100	-100	-100	-100
9	Lower Pangani	-100	-100	-100	-100	0	0

A9.5.1.6 Overall condition

The changes in overall river condition associated with this scenario are provided in Addendum Table 78. A noticeable decline in condition is predicted across the basin, with most sites slipping to a lower condition category.

Addendum Table 78 Overall condition at each river site for the Maximise Agriculture with 30% Less Rainfall scenario

Site No.	Name	Present Day River Health Category	Change from Present Day ecological integrity	River Health Category for the scenario
1	Upper Kikuletwa	B/C	-0.726	C
2	Lower Kikuletwa	D	-0.610	E
3	Upper Ruvu	C/D	-0.412	D
4	Lower Ruvu	D	-0.289	D
6	Pangani at Kirua	C	-0.377	D
7	Lower Mkomazi	C/D	-1.143	E
8	Lower Luengera	C	-0.663	D
9	Lower Pangani	C	-0.388	C/D

A9.5.2 Summary of biophysical condition in NyM

A9.5.2.1 Water level change

The FA Tool assesses likely change in two parameters associated with NyM – fish catch and reed area. These parameters are affected by water area (volume) of the lake and the variation in area that are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under the maximise HEP scenario are presented in Addendum Table 79 and discussed in the respective sections below.

Addendum Table 79 Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in NyM under the Maximise Agriculture with 30% Less Rainfall scenario relative to Present Day, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario

	Present Day	This Scenario	% Change
Mean lake area (ha)	103.8	48.1	-54%
Std dev of lake area (m)	1.24	0.43	-65%
Max lake area (ha)	137.1	90.0	-34%
Reed area (ha)	33.3	41.9	26%
Mean lake level (m)	15.9	9.5	-40%
Std dev of lake level (m)	1.2	0.4	-67%
Fish catch (tonnes)	3538.8	2011.6	-43%

A9.5.2.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surround NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under this scenario, lake area shrinks by 54%, variability decreases markedly by 65% and maximum area also decreases by 34% (Addendum Table 79). The net result of this is that total reed area is expected to expand marginally by 26%.

A9.5.2.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the present day we expect fish populations to expand in responses to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under this scenario, variability in lake level decreases markedly by 65% and average area declines markedly by 54% (Addendum Table 79). Fish catches as a result, are expected to decline by 43%.

A9.5.3 Summary of biophysical condition in Kirua Swamp

This scenario will all but eliminate the last vestiges of the Kirua Swamp as a result of reduced flooding relative to Present Day. Under present conditions the swamp inundation is *c*. 4% of natural and this will drop to *c*. 0.5%. This is the most severe scenario in terms of its impact on the Kirua Swamp.

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to present day. Under this scenario, fish abundances are predicted to decrease to 12% of present day (16 tonnes) and floodplain vegetation decrease to 11%.

A9.5.4 Summary of biophysical condition in the Estuary

A9.5.4.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under this scenario freshwater flows reaching the estuary are markedly lower than the Present Day during all four seasons (average reduction = 71.9%) (Addendum Table 80). Agricultural return flows, as a proportion of the total flow, increase markedly in all seasons (average increase = 72.4%) as would be expected under this scenario. The number of months where flow exceeds 250 Mm^3 decline by 88%.

Addendum Table 80 Change in freshwater flows reaching the estuary under the Maximise Agriculture with 30% Less Rainfall scenario relative to the Present Day

		Short rains	Dry 1	Long rains	Dry 2	All months
Average monthly flows	Current day (Mm^3)	91.3	72.7	186.9	80.7	102.1
	Max Agric less 30% (Mm^3)	26.5	18.3	64.1	16.9	28.7
	% Change	-71.0	-74.9	-65.7	-79.1	-71.9
Agricultural monthly return flows	Current day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	Max Agric less 30% (Mm^3)	34.0	35.4	15.4	33.7	31.3
	% Change	81.2	138.1	15.5	145.2	72.4
No. months flow >250 Mm^3	Current day	8.0				
	Max Agric less 30% (Mm^3)	1.0				
	% Change	-87.5				

Addendum Table 81 Health scores for the estuary as a whole and the component parameters under the Maximise Agriculture with 30% Less Rainfall scenario

	Present day	This scenario	% change from PD (+/-)
Geomorphology	40%	35%	-12%
Water Quality	53%	40%	-25%
Micro-algae	40%	32%	-19%
Vegetation	60%	56%	-6%
Invertebrates	60%	41%	-32%
Fish	50%	38%	-25%
Birds	40%	34%	-16%
Overall health score	57%	32%	-45%

A9.5.4.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the Present Day status of the mouth, which is both wide and deep. Thus, only the extreme high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significantly affect geomorphological conditions in the estuary such as channel width and depth, and intertidal area, albeit on a relative small scale due to the large size of the tidal prism.

These high flows have changed markedly from the present day under this scenario (down by 88%, Addendum Table 80) but as they do not contribute as much to the current mouth status as the tidal flow, the resulting change in geomorphological conditions in the estuary can be expected to be small (-12%, Addendum Table 81).

A9.5.4.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Reduced flow volumes have a reduced capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under this scenario, mean monthly flows are lower while the contributions by agricultural return flows increase. The combined effect of these two negative influences is predicted to lead to a significant reduction in water quality in the estuary through increased nutrients, lower dissolved oxygen concentrations, and reduced water clarity (higher turbidity). Water quality health score is down by 25 percentage points to 40%.

A9.5.4.4 Micro-algae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient level) with the result that phytoplankton concentrations in the system are extremely high. Further increases in nutrient concentration through the process described above will almost certainly give rise to further increases in the phytoplankton abundance in the estuary with a concomitant reduction in health score from 40 to 32%.

A9.5.4.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As mean monthly flows under the Present Day scenario are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the contribution from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production).

The effect of further reductions in flow and increases in agricultural return flows anticipated under this scenario are consequently anticipated to have a minor negative influence on vegetation communities associated with the estuary (translating to a reduction in the health score of 6%, Addendum Table 81).

A9.5.4.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes in the geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality (reduced water clarity and oxygen levels, increased nutrients) between the natural and Present Day situations.

While geomorphological conditions are not expected to change significantly from the Current Day under this scenario, the anticipated reduction in water quality will have a significant impact on macroinvertebrates. The concomitant reduction in health score is anticipated to be in the region of 32% (i.e. from a percent score of 60% to 41%, Addendum Table 81), and will be manifest as a further reduction in catches of shrimp and possibly mangrove crabs from the estuary.

A9.5.4.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geomorphological characteristics and water quality as well as by the decline of their main food supply (invertebrates). As such the current health score is low (50%) and is expected to decline even further under this scenario to 38%, Addendum Table 81). Effects of this will manifest as a reduction in abundance and species richness of the fish fauna in the estuary, with a corresponding reduction in fish landings derived from the estuary.

A9.5.4.8 Birds

Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the estuary and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). The predicted reductions in invertebrate and fish abundance are likely to be translated into a further reduction in the numbers and species of birds frequenting the estuary albeit not as severe as for the fish and invertebrates (Addendum Table 81).

A9.5.4.9 Overall condition

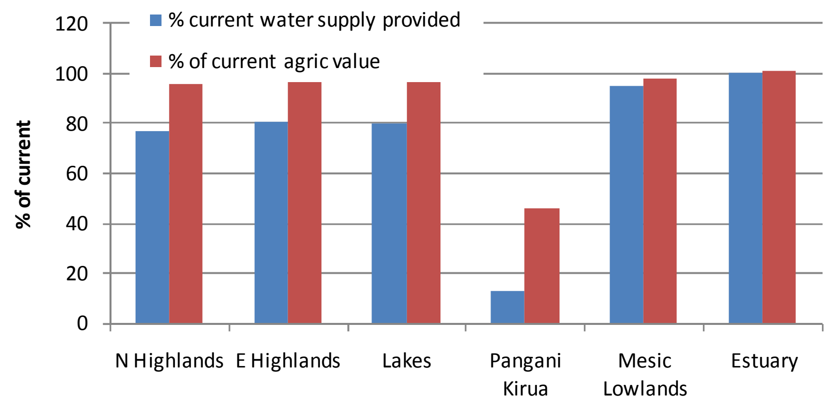
All measured health parameters in the estuary show a decline under this scenario, mostly a severe decline, with the result that the overall health of the system can be expected to decline severely as well. Overall estuarine health score declines from 57 to 32% and the estuary drops in health status from a highly modified system (D class) to a highly degraded system (E class).

A9.6 Effects on livelihoods

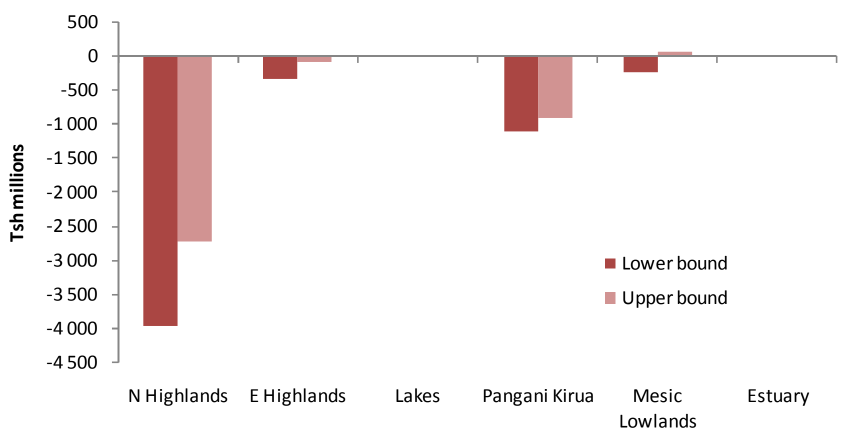
A9.6.1 Income from small-scale agriculture

Addendum Figure 79 shows aggregate net income from agriculture to rural households within 5 km of rivers under the scenario as a percentage of current value. In this scenario, there is a slight reduction in the income from agriculture relative to Present Day, apart from at Pangani-Kirua, where there is a major reduction.

Significant overall losses are incurred in the Northern Highlands and Pangani-Kirua (Addendum Figure 80).



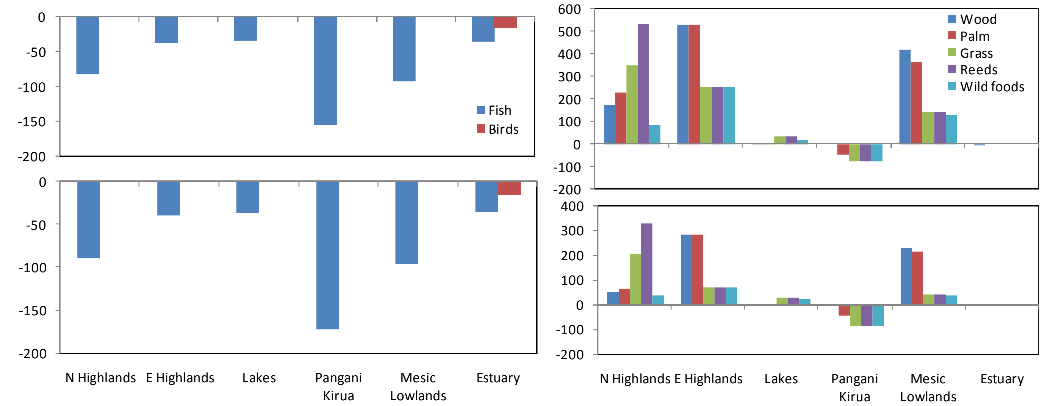
Addendum Figure 79 Area under small-scale irrigation under the Maximise Agriculture with 30% Less Rainfall scenario as compared with the Present Day



Addendum Figure 80 Lower and upper bound estimates of the aggregate change in income from small-scale agriculture under the Maximise Agriculture with 30% Less Rainfall scenario

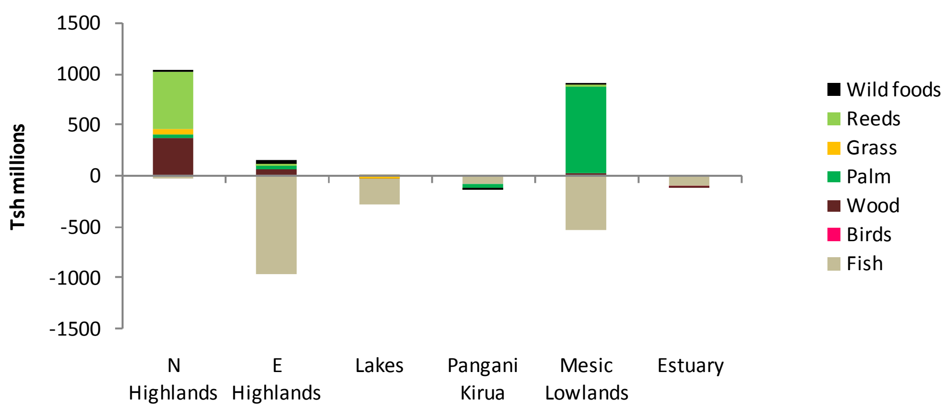
A9.6.2 Income from natural resources

Fish decrease in abundance in all zones under this scenario, with near-total losses expected in Pangani Kirua and the Mesic Lowlands. Bird numbers also decrease in the estuary. Plant resources increase in all areas except Pangani-Kirua and the Estuary (Addendum Figure 81).



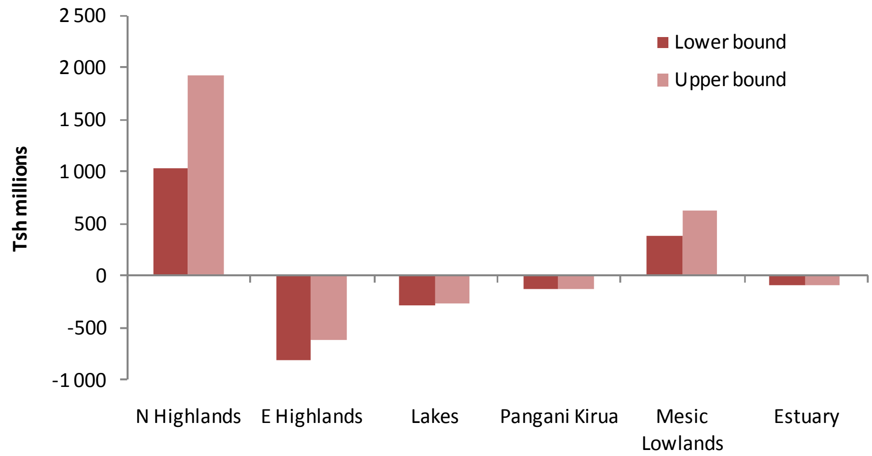
Addendum Figure 81 **Best and worst case estimates of the percentage change from Present Day in the abundance of natural resources used by households, under the Maximise Agriculture with 30% Less Rainfall scenario**

Impacts of these changes on income to households are shown in Addendum Figure 92.



Addendum Figure 82 **Worst-case estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under the Maximise Agriculture with 30% Less Rainfall scenario**

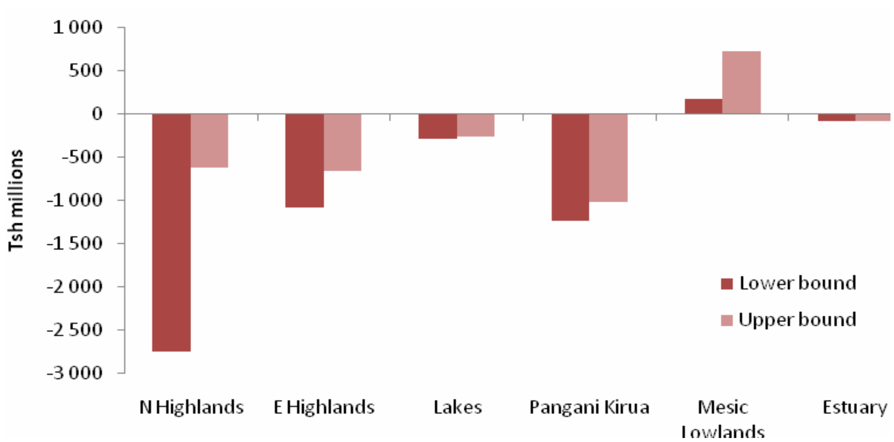
Aggregate income is expected to increase in the Northern Highlands by about Tsh 1000 - 2000 million and to a lesser extent in the Mesic Lowlands, but there are substantial losses in the Eastern Highlands (Addendum Figure 83).



Addendum Figure 83 Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under the Maximise Agriculture with 30% Less Rainfall scenario

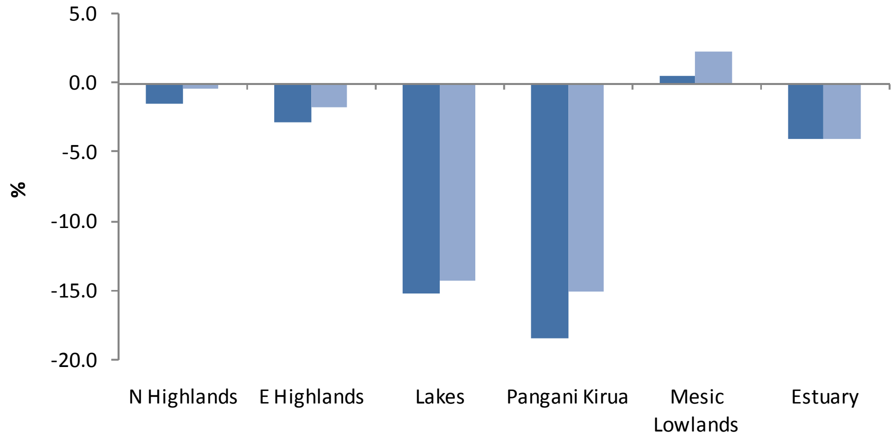
A9.6.3 Overall household income

Overall impacts on household income are expected to be negative in all zones apart from the Mesic Lowlands where there is an increase in income (Addendum Figure 84).



Addendum Figure 84 Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, under the Maximise Agriculture with 30% Less Rainfall scenario

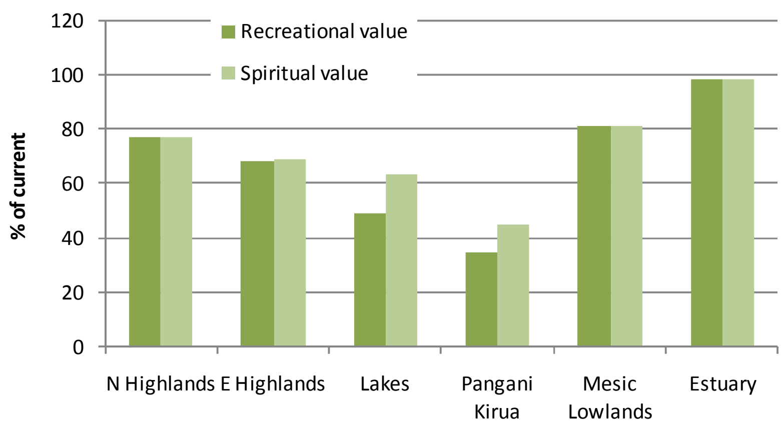
The percentage change in income is less than 5% in most zones, apart from the Lakes and Pangani-Kirua where income decreases by more than 15% (Addendum Figure 85).



Addendum Figure 85 Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under the Maximise Agriculture with 30% Less Rainfall scenario

A9.6.4 Intangible values

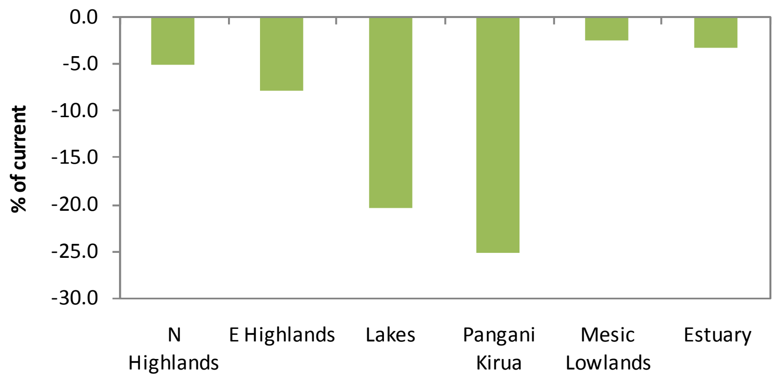
There is a marked decline in recreational and spiritual well-being among households in all areas excepting the Estuary where the impact is minimal (Addendum Figure 86). The most affected is Pangani-Kirua, which could see a 50% decline in recreational well-being.



Addendum Figure 86 Overall recreational and spiritual well-being (derived from rivers and other sources) under the Maximise Agriculture with 30% Less Rainfall scenario as a percentage of current well-being

A9.6.5 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 87. There is a decrease in well-being across all regions with the worst affected being Lakes and Pangani-Kirua, which experience declines of over 20%.



Addendum Figure 87 Percentage change in overall well-being of households within 5 km of rivers under the Maximise Agriculture with 30% Less Rainfall scenario

A9.7 Effects on economic value

Under this scenario, there are gains in the natural resources sector. However, there are losses in the three other sectors, particularly HEP, which accounts for most of the overall loss (Addendum Table 82).

Addendum Table 82 Gains and losses in the value of HEP, agriculture, natural resources and ecosystem regulating services (Tsh millions per year) under the Maximise Agriculture with 30% Less Rainfall scenario

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
-1 765 391	-10 500	806	-178	-1 775 263

A10 MAXIMISE HEP LESS 20%

A10.1 Description of the scenario

The Maximise HEP with 20% Less Rainfall scenario comprised the following (in order of priority):

- Selecting 20% across the catchment reduction in wet season rainfall, rainfall-runoff models used to predict change in flows in the rivers.
- Allocation of 2025 BHN and Urban/Industrial water demands to Arusha and Moshi.
- Abstraction for agriculture restricted, particularly in the upper catchment, in order to maximise the amount of water that could be released from NyM and Kalemawe dams for HEP generation. This water released in a pattern as close as possible to optimum for the operation of the HEP stations.
- Water that could not be used for HEP generation allocated to agriculture.
- Environment received whatever water was left.

A10.2 Hydrological implications

A10.2.1 Water allocated per sector

Urban/industrial 54.7 Mcm a^{-1} (PD = 31.1)
Irrigation 286 Mcm a^{-1} (PD = 1042), but see Section A10.3 for area irrigated
HEP 755 227 MW h^{-1} (PD = 602 647)

A10.2.2 Changes in the flow regime relative to present day

The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 83. There were three main kinds of change relative to present day:

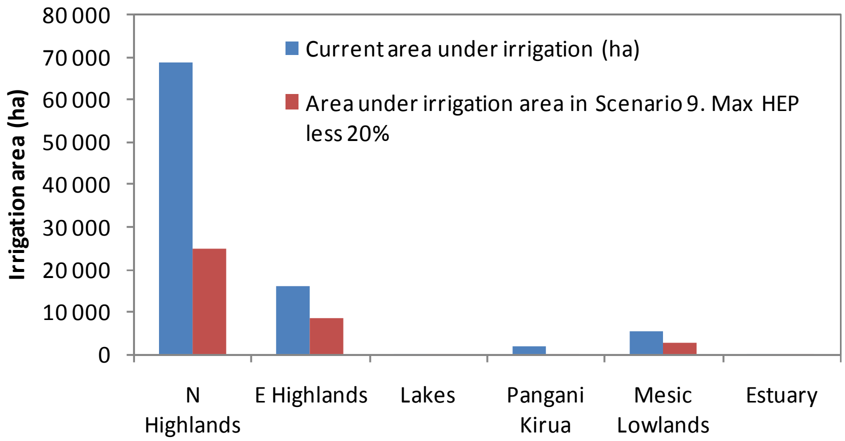
- reduced low flows at all sites;
- some increased intra-annual flood variation;
- loss of inter-annual floods.

Addendum Table 83 DRIFT flow summary data for the Maximise HEP with 20% Less Rainfall scenario

Location	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario MAR	52.4	454.8	143.8	666.6	782.6	42.2	72.2	1375.0
WSLF - Volumes (MCM)	106	194.4	51.2	348.8	277.5	4.1	19.2	529.6
DSLF - Volumes (MCM)	34.42	207.3	73.5	187.2	455.2	24.4	41.7	731.6
Class 1 - Annual Frequency	4	2	0	2	5	2	1	0
Class 2 - Annual Frequency	3	6	0	3	9	5	9	1
Class 3 - Annual Frequency	1	4	4	3	1	4	4	9
Class 4 - Annual Frequency	1	2	4	2	0	1	0	1
1:2	A	A	A	A	A	A	A	P
1:5	P	A	P	A	A	A	A	P
1:10	A	A	A	A	A	A	A	P
1:20	A	A	A	A	A	A	A	P

A10.3 Effects on irrigated agriculture

Under this scenario, the irrigation area in the Northern Highlands is severely reduced, and in the Eastern Highlands is reduced to almost half of present. Irrigation area is also reduced in the Mesic Lowlands (Addendum Figure 88).



Addendum Figure 88 Area under irrigation under for the Maximise HEP with 20% Less Rainfall scenario as compared with the Present Day

A10.4 Effects on HEP production

HEP output is increased to 125% of current output, resulting in an output of 755 227 MWh.

A10.5 Effects on environmental condition

A10.5.1 Summary of biophysical condition in the river

The influence of the residual flows on the condition of the rivers is described in two ways:

- as percentage change relative to present day for key indicators representing each of geomorphology, water quality, riparian vegetation, macroinvertebrates and fish;
- in terms of change in overall river condition as denoted by the integrity score

Note: The Present Day levels of the indicators have not been quantified, thus the reported change is relative to an unknown quantity.

A10.5.1.1 Geomorphology

The geomorphological changes associated with this scenario are most severe in the upper portion of the catchment, i.e., upstream of NyM and in the Mkomazi and Luengera Rivers (Addendum Table 84). The changes can be summarised as follows:

- noticeable reduction in rocky areas, and thus fish habitat in the Kikuletwa, Ruvu and Mkomazi and Luengera Rivers;
- loss of pools, and thus fish refuge, at the same sites;
- build up of fine sediments especially in the Upper Kikuletwa, Mkomazi and Luengera Rivers;
- severe loss of remaining floodplains in the Lower Kikuletwa and Ruvu, and Mkomazi and Luengera Rivers, but a low to moderate restoration of the floodplains along the Pangani River at Kirua.

Addendum Table 84 Estimated percentage change from Present Day for geomorphological features under the Maximise HEP with 20% Less Rainfall scenario

Site No.	Name	Riffles and rapids		Pools		Fine sediments		Coarse sediments		Bank erosion		Floodplain inundation	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-100	-100	-100	-100	251	500	-80	-60	-20	0	0	0
2	Lower Kikuletwa	-80	-60	-100	-100	1	25	-20	0	-40	-20	-100	-100
3	Upper Ruvu	-60	-40	-40	-20	26	68	-40	-20	0	0	0	0
4	Lower Ruvu	-80	-60	-100	-100	1	25	-40	-20	-40	-20	-100	-100
6	Pangani at Kirua	26	68	26	68	1	25	0	0	0	0	68	250
7	Lower Mkomazi	-100	-100	-40	-20	68	250	0	0	0	0	-100	-100
8	Lower Luengera	-100	-100	-80	-60	500	800	0	0	0	0	-100	-100
9	Lower Pangani	0	0	1	25	-20	0	0	0	1	25	0	0

A10.5.1.2 Water Quality

The noticeable water-quality changes associated with this scenario are mostly in the Ruvu and Mkomazi Rivers (Addendum Table 85). The changes can be summarised as follows:

- noticeable increase in conductivity in the Kikuletwa, Ruvu and Mkomazi Rivers;
- noticeably increased phosphorus levels in the Ruvu and to a lesser extent in the Luengera River.

Addendum Table 85 Estimated percentage change from Present Day for water quality under the Maximise HEP with 20% Less Rainfall scenario

Site No.	Name	Turbidity/TSS		Conductivity/TDS		Phosphorus		Nitrogen	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	1	25	26	68	0	0	1	25
2	Lower Kikuletwa	0	0	1	25	0	0	0	0
3	Upper Ruvu	0	0	26	68	26	68	0	0
4	Lower Ruvu	0	0	26	68	26	68	-20	0
6	Pangani at Kirua	0	0	0	0	0	0	0	0
7	Lower Mkomazi	0	0	26	68	0	0	-20	0
8	Lower Luengera	0	0	1	25	1	25	-20	0
9	Lower Pangani	1	25	0	0	-20	0	-20	0

A10.5.1.3 Vegetation

The changes in riparian vegetation associated with this (Addendum Table 86) can be summarised as follows:

- noticeable increase in wet bank vegetation throughout the basin;
- increase in dry bank vegetation in the Lower Kikuletwa and Lower Ruvu.

Addendum Table 86 Estimated percentage change from Present Day for vegetation under the Maximise HEP with 20% Less Rainfall scenario

Site No.	Name	Dry Bank Trees		Dry Bank Herbs & Shrubs		Dry Bank Grasses		Wetbank Trees		Wetbank Herbs		Wetbank grasses and reeds	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	0	0	0	0	26	68	1	25	26	68
2	Lower Kikuletwa	251	500	251	500	251	500	26	68	0	0	1	25
3	Upper Ruvu	0	0	0	0	0	0	1	25	1	25	26	68
4	Lower Ruvu	251	500	251	500	251	500	26	68	1	25	0	0
6	Pangani at Kirua	0	0	0	0	0	0	26	68	26	68	26	68
7	Lower Mkomazi	0	0	0	0	0	0	26	68	1	25	1	25
8	Lower Luengera	0	0	0	0	0	0	26	68	26	68	26	68
9	Lower Pangani	1	25	1	25	0	0	-20	0	-20	0	-20	0

A10.5.1.4 Macro-invertebrates

The changes in macroinvertebrates associated with this scenario (Addendum Table 87) can be summarised as follows:

- low decline of sensitive species over all the catchment except the Pagan at Kirua and Lower Pangani;
- negligible to small loss of tolerant species at some sites, but significant increase in the Lower Kikuletwa and Lower Ruvu.

Addendum Table 87 Estimated percentage change from Present Day for macroinvertebrates under the Maximise HEP with 20% Less Rainfall scenario

Site No.	Name	Sensitive species		Tolerant species (e.g., Dysticidae, Chironominae and Culicidae)		Pest Simuliidae	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-100	-100	-20	0	-80	-60
2	Lower Kikuletwa	-80	-60	68	250	0	0
3	Upper Ruvu	-60	-40	-40	-20	-20	0
4	Lower Ruvu	-80	-60	251	500	0	0
6	Pangani at Kirua	0	0	0	0	0	0
7	Lower Mkomazi	-40	-20	-60	-40	0	0
8	Lower Luengera	-80	-60	-60	-40	0	0
9	Lower Pangani	0	0	0	0	0	0

A10.5.1.5 Fish

The changes in fish associated with this scenario (Addendum Table 88) can be summarised as follows:

- decrease in *Clarias* and *Labeo* in the upper catchment;
- increase in *Clarias* and *Tilapia* in the Pangani at Kirua;
- decline of all fish groups in the Lower Mkomazi and Luengera Rivers;
- moderate increase in *Clarias* and *Tilapia* in the lower Pangani River.

Addendum Table 88 Estimated percentage change from Present Day for fish under the Maximise HEP with 20% Less Rainfall scenario

Site No.	Name	*Clarias* group		*Tilapia* group		*Labeo* group	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-60	-40	0	0	0	0
2	Lower Kikuletwa	0	0	0	0	-80	-60
3	Upper Ruvu	0	0	0	0	-80	-60
4	Lower Ruvu	-20	0	0	0	-100	-80
6	Pangani at Kirua	251	500	68	250	0	0
7	Lower Mkomazi	-20	0	-60	-40	-100	-100
8	Lower Luengera	-20	0	-100	-80	-100	-100
9	Lower Pangani	1	25	26	68	0	0

A10.5.1.6 Overall condition

The changes in overall river condition associated with this scenario are provided in Addendum Table 89. There is a moderate decline in condition at most sites but a slight improvement in the Kirua area.

Addendum Table 89 Overall condition at each river site for the Maximise HEP with 20% Less Rainfall scenario

Site No.	Name	Present Day River Health Category	Change from Present Day ecological integrity	River Health Category for the scenario
1	Upper Kikuletwa	B/C	-0.38	C
2	Lower Kikuletwa	D	-0.27	D/E
3	Upper Ruvu	C/D	-0.20	D
4	Lower Ruvu	D	-0.24	D
6	Pangani at Kirua	C	0.17	C
7	Lower Mkomazi	C/D	-0.31	D
8	Lower Luengera	C	-0.47	D
9	Lower Pangani	C	0.06	C

A10.5.2 Summary of biophysical condition in NyM

A10.5.2.1 Water level change

The FA Tool assesses likely change in two parameters associated with NyM Dam – fish catch and reed area. These parameters are affected by water area (volume) of the lake and the variation in area that are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under this scenario are presented in Addendum Table 90 and discussed in the respective sections below.

Addendum Table 90 Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in NyM under the Maximise HEP with 20% Less Rainfall scenario relative to the Present Day, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario

	Present Day	This Scenario	% Change
Mean lake area (ha)	103.8	48.7	-53%
Std dev of lake area (m)	1.24	0.36	-71%
Max lake area (ha)	137.1	75.4	-45%
Reed area (ha)	33.3	26.6	-20%
Mean lake level (m)	15.9	9.6	-40%
Std dev of lake level (m)	1.2	0.4	-67%
Fish catch (tonnes)	3538.8	2050.8	-42%

A10.5.2.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surround NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under this scenario, lake area shrinks by 53%, variability decreases markedly by 71%, and the maximum lake area decreases by 45% (Addendum Table 90). The net result of this is that total reed area is expected to decrease by 20%.

A10.5.2.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the present day we expect fish populations to expand in responses to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under this, variability in lake level decreases by 71% and average area declines by 53% (Addendum Table 90). Fish catches as a result, are expected to decline by 42%.

A10.5.3 Summary of biophysical condition in Kirua Swamp

The Maximise HEP with 20% Less Rainfall scenario will result in an improvement in the condition of the Kirua Swamp as a result of increased flooding relative to Present Day. Under current conditions swamp inundation is c. 4% of natural, and this will increase to c. 8%.

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to Present Day. Under this scenario, fish abundances are predicted to increase to 150% of present day (199 tonnes) and floodplain vegetation increase to 152%.

A10.5.4 Summary of biophysical condition in the Estuary

A10.5.4.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under this scenario freshwater flows reaching the estuary are higher than Present Day during all four seasons except the Long Rains (Addendum Table 91). A concomitant reduction is evident in agricultural return flows in all seasons except the Long Rains. The number of months where flow exceeds 250 Mm^3 decreases by 88%.

Addendum Table 91 Change in freshwater flows reaching the estuary under the Maximise HEP with 20% Less Rainfall scenario relative to PD.

		Short rains	Dry 1	Long rains	Dry 2	All months
Average monthly flows	(Mm^3)	91.3	72.7	186.9	80.7	102.1
	Max HEP less 20% (Mm^3)	112.4	106.4	125.7	113.1	114.7
	% Change	23.2	46.5	-32.7	40.2	12.3
Agricultural monthly return flows	Current day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	Max HEP less 20% (Mm^3)	11.0	17.1	16.7	8.0	17.3
	% Change	-37.2	-39.2	4.8	-47.2	-21.6
No. months flow >250 Mm^3	Current day	8.0				
	Max HEP less 20% (Mm^3)	1.0				
	% Change	-87.5				

Addendum Table 92 Health scores for the estuary as a whole and the component parameters under the Maximise HEP with 20% Less Rainfall scenario

	Present day	This scenario	% change from PD (+/-)
Geomorphology	40%	35%	-12%
Water Quality	53%	57%	8%
Micro-algae	40%	41%	2%
Vegetation	60%	61%	1%
Invertebrates	60%	61%	2%
Fish	50%	51%	2%
Birds	40%	42%	6%
Overall health score	57%	58%	2%

A10.5.4.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the Present Day status of the mouth, which is both wide and deep. Thus, only the extreme high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significantly affect geomorphological conditions in

the estuary such as channel width and depth, and intertidal area, albeit on a relative small scale due to the large size of the tidal prism.

These high flows have changed somewhat from the Present Day under this scenario (down by 88%, Addendum Table 91) but as they do not contribute as much to the current mouth status as the tidal flow, the resulting change in geomorphological conditions in the estuary can be expected to be a small decrease of about 12% (Addendum Table 92).

A10.5.4.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Reduced flow volumes have a reduced capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under this scenario, mean monthly flows are higher and contributions by agricultural return flows decrease in all seasons except the Long Rains. The combined effect of this is a predicted improvement in water quality in all seasons except the Long Rains, with an overall positive effect on water quality (score increases from 53 to 57%).

A10.5.4.4 Micro-algae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient level) with the result that phytoplankton concentrations in the system are extremely high. Changes in water quality are not consistent throughout the year but are expected to give rise to a net reduction in phytoplankton abundance with a concomitant improvement in health score associated with this parameter from 40 to 41%.

A10.5.4.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As mean monthly flows under the Present Day scenario are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the contribution from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production).

The effect of a net increase in flow and a net decrease in agricultural return flows anticipated under this scenario, is anticipated to be a net positive influence on vegetation communities associated with the estuary, translating into an improvement in the health score of 1% (Addendum Table 92).

A10.5.4.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes in the

geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality (reduced water clarity and oxygen levels, increased nutrients) between the natural and Present Day situations.

While geomorphological conditions are not expected to change significantly from the Present Day under this scenario, the anticipated net improvement in water quality will manifest itself as a negligible net increase in macroinvertebrate abundance from 60% to 61% (Addendum Table 92).

A10.5.4.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geomorphological characteristics and water quality as well as by the decline of their main food supply (invertebrates). As such, the current health score is low (50%) and is expected to improve slightly under this scenario by 2% (Addendum Table 92).

A10.5.4.8 Birds

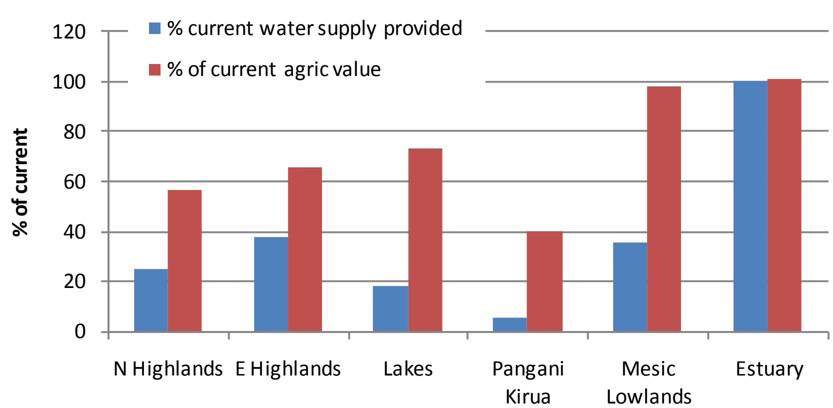
Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the estuary and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). The predicted net increase in invertebrate and fish abundance is likely to be translated into a mild net increase in the numbers and species of birds frequenting the estuary from 40% to 42% (Addendum Table 92).

A10.5.4.9 Overall condition

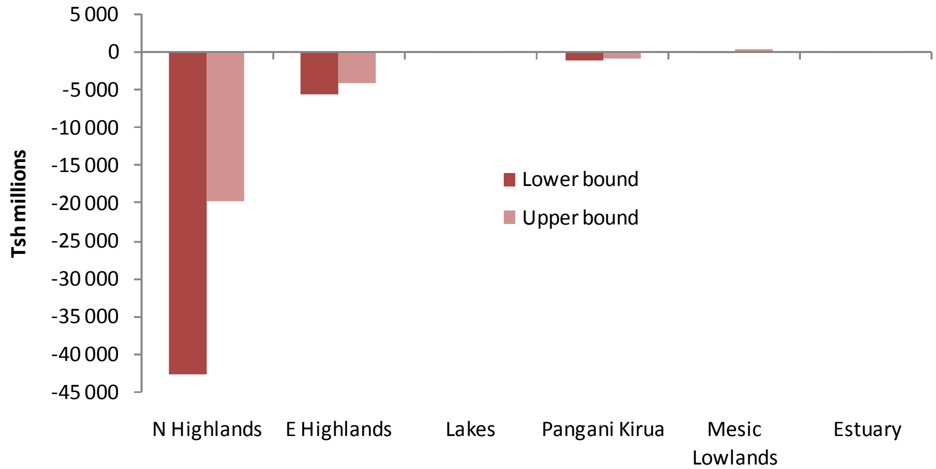
All measured health parameters in the estuary show a net improvement under this scenario, except geomorphology, with the result that the overall health of the system can be expected to improve slightly. Overall health score increases from 57 to 58%. No change in health class is expected.

A10.5.5 Income from small-scale agriculture

Addendum Figure 89 shows aggregate net income from agriculture to rural households within 5 km of rivers under the scenario as a percentage of current value. In this scenario, compared with the Present Day, income is severely reduced in the upper zone and Pangani-Kirua, but remains relatively unchanged in the Mesic Lowlands and Estuary. There is a dramatic loss of income overall, concentrated in the Northern Highlands (Addendum Figure 89).



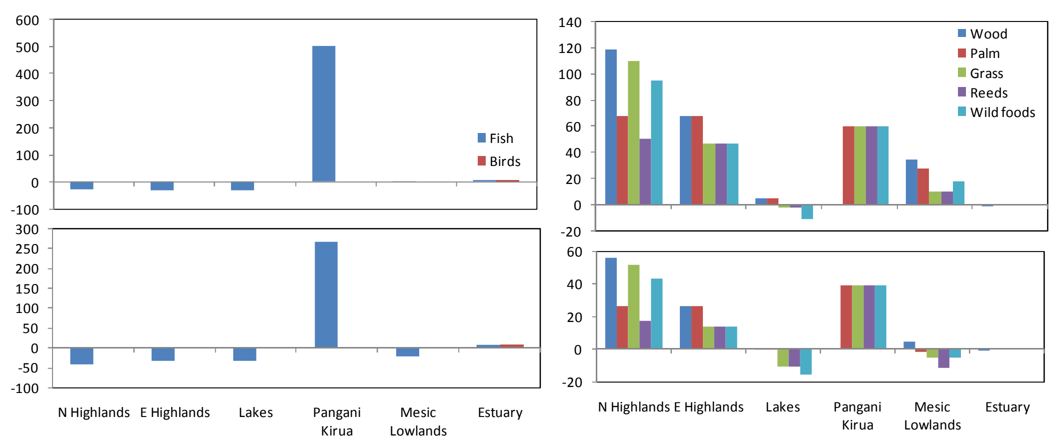
Addendum Figure 89 Area under small-scale irrigation under the Maximise HEP with 20% Less Rainfall scenario compared with Present Day



Addendum Figure 90 Lower and upper bound estimates of the aggregate change in income from small-scale agriculture Maximise HEP with 20% Less Rainfall scenario

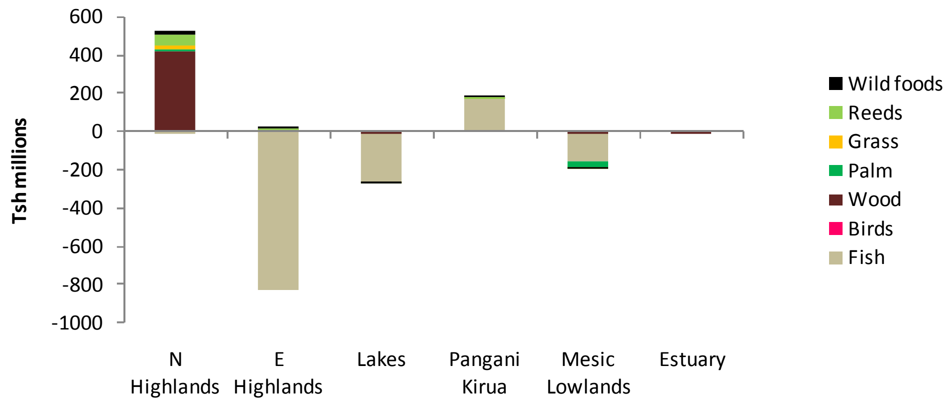
A10.5.6 Income from natural resources

Fish decrease in abundance in the upper zones but increase in Pangani-Kirua and the Estuary. Birds also increase at the Estuary. Plant resources increase in abundance generally, but particularly in the Northern Highlands (Addendum Figure 91).



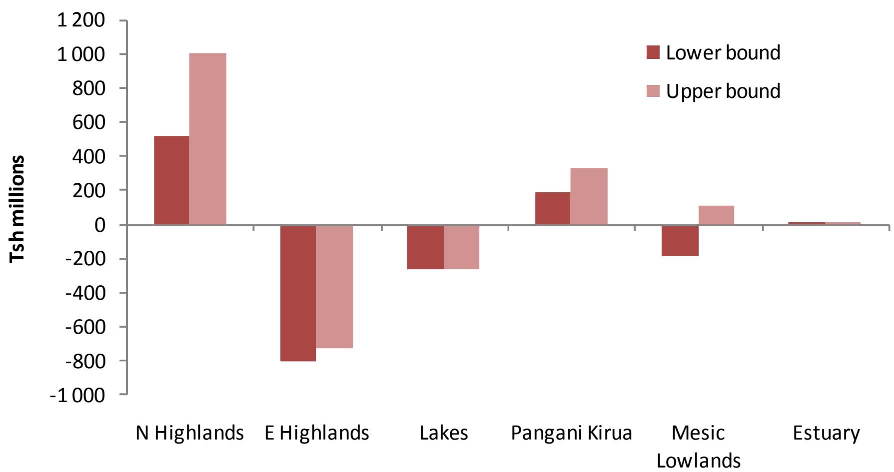
Addendum Figure 91 Best and worst case estimates of the percentage change from Present Day in the abundance of natural resources used by households, under the Maximise HEP with 20% Less Rainfall scenario

Impacts of these changes on income to households are shown in Addendum Figure 92.



Addendum Figure 92 Worst-case estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under the Maximise HEP with 20% Less Rainfall scenario

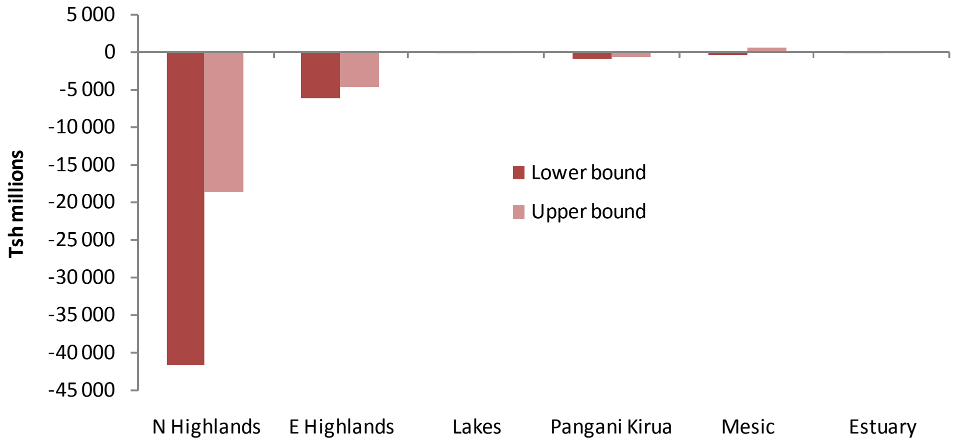
There is an increase in income from natural resources in the Northern Highlands and Pangani-Kirua, but decreases in the rest of the upper zones (Addendum Figure 93).



Addendum Figure 93 Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under the Maximise HEP with 20% Less Rainfall scenario

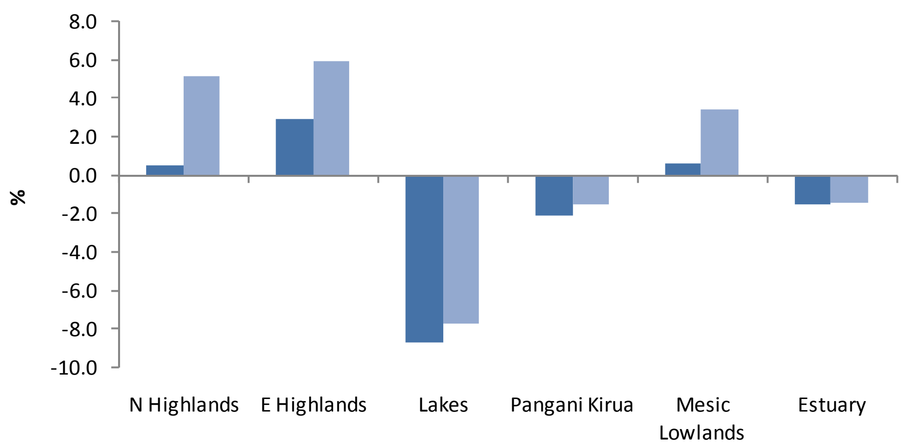
A10.5.7 Overall household income

Aggregate income decreases throughout the basin, but particularly in the Northern Highlands (Addendum Figure 94).



Addendum Figure 94 **Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, under the Maximise HEP with 20% Less Rainfall scenario**

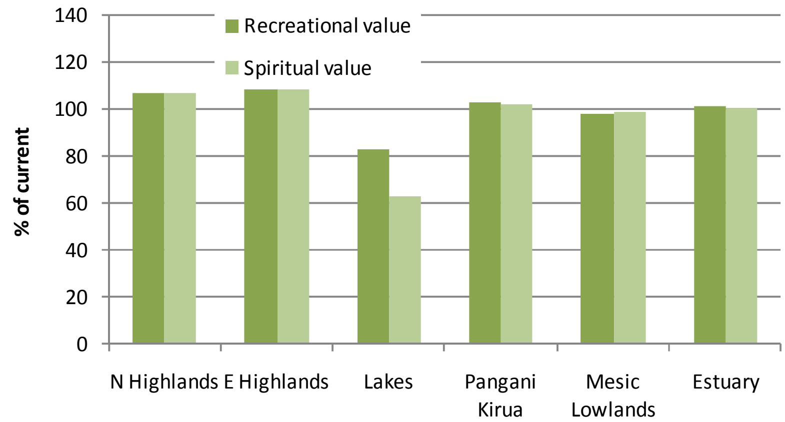
Aggregate household income increases by around 5% in the highlands, but decreases by more than 8% in the Lakes. Changes in the lower zones are relatively small (Addendum Figure 95).



Addendum Figure 95 **Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under the Maximise HEP with 20% Less Rainfall scenario**

A10.5.8 Intangible values

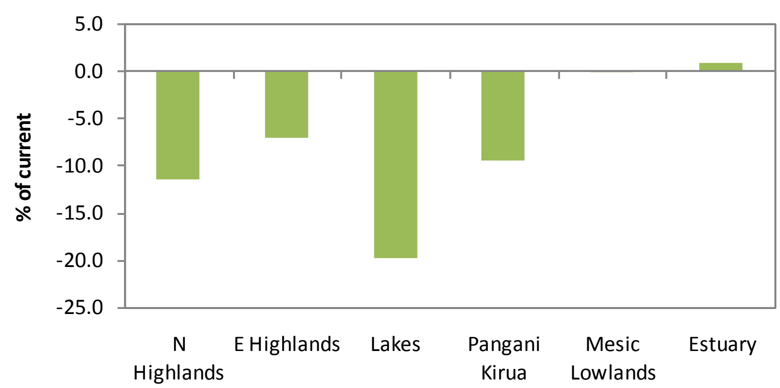
There is an increase in recreational and spiritual well-being among households in the highlands and, to a lesser extent, Pangani-Kirua, but a marked decrease in the Lakes zone (Addendum Figure 96).



Addendum Figure 96 Overall recreational and spiritual well-being (derived from rivers and other sources) under the maximise HEP less 20% scenario as a percentage of current well-being

A10.5.9 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 97. There is a strongly negative impact on well-being in all of the upper zones and Pangani-Kirua, but little impact on the lowest two zones.



Addendum Figure 97 Percentage change in overall well-being of households within 5 km of rivers under the Maximise HEP with 20% Less Rainfall scenario

A10.6 Effects on economic value

Under this scenario, changes in environmental quality and function lead to a small increase in value in terms of ecosystem regulating services, and a similar loss in natural resources. Larger losses are incurred through direct value added by the agricultural sector, but these are overwhelmingly offset by gains in the energy sector (Addendum Table 93).

Addendum Table 93 Gains and losses in the value of HEP, Agriculture, Natural Resources and Ecosystem regulating services (Tsh millions per year) under the Maximise HEP with 20% Less Rainfall scenario

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
469 726	-80 879	-48	44	388 848

A11 MAXIMISE HEP LESS 30%

A11.1 Description of the scenario

The Maximise HEP with 30% Less Rainfall scenario comprised the following (in order of priority):

- Selecting 30% across the catchment reduction in wet season rainfall, rainfall-runoff models used to predict change in flows in the rivers.
- Allocation of 2025 BHN and Urban/Industrial water demands to Arusha and Moshi.
- Abstraction for agriculture restricted, particularly in the upper catchment, in order to maximise the amount of water that could be released from NyM and Kalemawe dams for HEP generation. This water was released in a pattern as close as possible to optimum for the operation of the HEP stations.
- Water that could not be used for HEP generation allocated to agriculture.
- Environment received whatever water was left.

A11.2 Hydrological implications

A11.2.1 Water allocated per sector

Urban/industrial 54.7 Mcm a^{-1} (PD = 31.1)
Irrigation 203 Mcm a^{-1} (PD = 1042), but see Section A11.3 for area irrigated
HEP 614 810 MW h^{-1} (PD = 602 647)

A11.2.2 Changes in the flow regime relative to present day

The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 94. There were three main kinds of change relative to present day:

- reduced low flows at all sites;
- some increased intra-annual flood variation;
- loss of inter-annual floods.

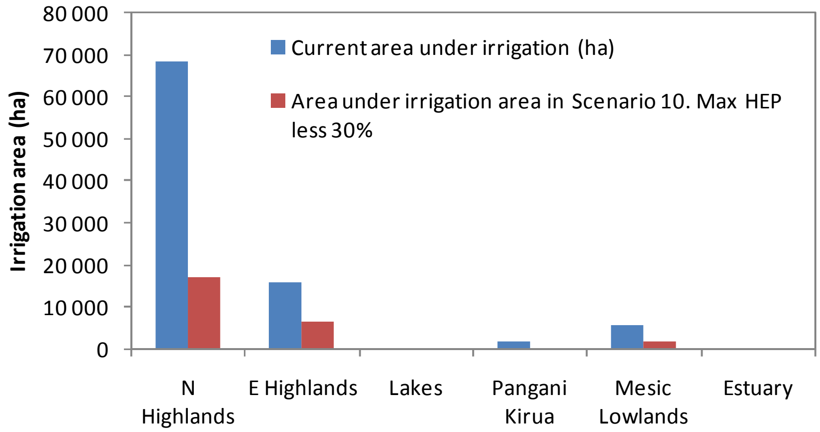
Addendum Table 94 DRIFT flow summary data for the Maximise HEP with 30% Less Rainfall scenario

Location	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario (MAR)	50.2	437.6	132.7	591.8	729.9	53.4	64.2	1330.0
WSLF - Volumes (MCM)	9.8	171.6	46.6	299.9	251.3	4.62	15.4	523.0
DSLF - Volumes (MCM)	35.2	224.0	73.2	179.8	436.1	29.1	39.7	708.9
Class 1 - Annual Frequency	5	3	0	1	5	2	2	0
Class 2 - Annual Frequency	3	7	0	4	8	6	9	1
Class 3 - Annual Frequency	1	3	5	3	0	4	3	9
Class 4 - Annual Frequency	0	1	4	2	0	3	0	1
1:2	A	A	A	A	A	P	A	A
1:5	A	A	A	A	A	A	A	A
1:10	A	A	A	A	A	A	A	P
1:20	A	A	A	A	A	A	A	P

A11.3 Effects on irrigated agriculture

Under this scenario, the irrigation area in the Northern Highlands is dramatically reduced, and in the Eastern Highlands is reduced to less than 50% of present.

Irrigation area is also noticeably reduced in the Mesic Lowlands (Addendum Figure 98).



Addendum Figure 98 Area under irrigation under the Maximise HEP with 30% Less Rainfall scenario compared with the Present Day

A11.4 Effects on HEP production

HEP output is very slightly increased to 102% of current output, resulting in an output of 602 647 MWh.

A11.5 Effects on environmental condition

A11.5.1 Summary of biophysical condition in the river

The influence of the residual flows on the condition of the rivers is described in two ways:

- as percentage change relative to present day for key indicators representing each of geomorphology, water quality, riparian vegetation, macroinvertebrates and fish;
- in terms of change in overall river condition as denoted by the integrity score (see Section 4.4.1).

Note: The Present Day levels of the indicators have not been quantified, thus the reported change is relative to an unknown quantity.

A11.5.1.1 Geomorphology

The geomorphological changes associated with this scenario are concentrated in the upper portion of the catchment, i.e., upstream of NyM and in the Mkomazi and Luengera Rivers (Addendum Table 95). The changes are similar but slightly more severe than they were for the Maximise HEP with 20% Less Rainfall scenario and can be summarised as follows:

- noticeable reduction in rocky areas, and thus fish habitat in the Kikuletwa, Ruvu, Mkomazi and Luengera Rivers;
- loss of pools, and thus fish refuge, at the same sites except Mkomazi;
- build up of fine sediments especially in the Upper Kikuletwa and Luengera Rivers;

- severe loss of remaining floodplains in the Lower Kikuletwa, Lower Ruvu, Mkomazi and Luengera Rivers, but a very mild restoration of the floodplains along the Pangani River at Kirua.

Addendum Table 95 Estimated percentage change from Present Day for geomorphological features under the Maximise HEP with 30% Less Rainfall scenario

Site No.	Name	Riffles and rapids		Pools		Fine sediments		Coarse sediments		Bank erosion		Floodplain inundation	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-100	-100	-100	-100	500	800	-100	-100	-40	-20	0	0
2	Lower Kikuletwa	-100	-80	-100	-100	26	68	-60	-40	-40	-20	-100	-100
3	Upper Ruvu	-80	-60	-40	-20	68	250	-40	-20	0	0	0	0
4	Lower Ruvu	-100	-80	-100	-100	1	25	-40	-20	-40	-20	-100	-100
6	Pangani at Kirua	1	25	1	25	0	0	0	0	0	0	26	68
7	Lower Mkomazi	-60	-40	0	0	26	68	0	0	0	0	-100	-100
8	Lower Luengera	-100	-100	-80	-60	500	800	0	0	0	0	-100	-100
9	Lower Pangani	0	0	-40	-20	-20	0	0	0	1	25	0	0

A11.5.1.2 Water Quality

The water quality changes associated with this scenario are almost identical to those associated with the Maximise HEP less 20% Rainfall scenario (Addendum Table 96). The changes can be summarised as follows:

- slight increase in conductivity in the Ruvu River and negligible increase in the Kikuletwa, Mkomazi and Luengera Rivers;
- negligible to slight increase in phosphorus levels in the upper catchment and Luengera River, and a decline in this and nitrogen levels in the Mkomazi.

Addendum Table 96 Estimated percentage change from Present Day for water quality under the Maximise HEP with 30% Less Rainfall scenario

Site No.	Name	Turbidity/TSS		Conductivity/TDS		Phosphorus		Nitrogen	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	1	25	1	25	0	0	1	25
2	Lower Kikuletwa	1	25	1	25	1	25	0	0
3	Upper Ruvu	0	0	26	68	26	68	0	0
4	Lower Ruvu	0	0	26	68	26	68	-20	0
6	Pangani at Kirua	0	0	0	0	0	0	0	0
7	Lower Mkomazi	0	0	1	25	-40	-20	-40	-20
8	Lower Luengera	0	0	1	25	1	25	0	0
9	Lower Pangani	1	25	0	0	-20	0	-20	0

A11.5.1.3 Vegetation

The changes in riparian vegetation associated with this scenario (Addendum Table 86) can be summarised as follows:

- noticeable increase in wet bank vegetation across the basin
- noticeable increase in dry bank vegetation in the Lower Kikuletwa and Ruvu Rivers, and a milder increase in the Lower Pangani.

Addendum Table 97 Estimated percentage change from Present Day for vegetation under the Maximise HEP with 30% Less Rainfall scenario

Site No.	Name	Dry Bank Trees		Dry Bank Herbs & Shrubs		Dry Bank Grasses		Wetbank Trees		Wetbank Herbs		Wetbank grasses and reeds	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	0	0	0	0	68	250	26	68	251	500
2	Lower Kikuletwa	251	500	251	500	251	500	68	250	0	0	1	25
3	Upper Ruvu	0	0	0	0	0	0	26	68	1	25	68	250
4	Lower Ruvu	251	500	251	500	251	500	26	68	0	0	0	0
6	Pangani at Kirua	0	0	0	0	0	0	26	68	1	25	1	25
7	Lower Mkomazi	0	0	0	0	0	0	1	25	26	68	26	68
8	Lower Luengera	0	0	0	0	0	0	26	68	26	68	26	68
9	Lower Pangani	26	68	1	25	1	25	1	25	1	25	1	25

A11.5.1.4 Macroinvertebrates

The changes in macroinvertebrates associated with this scenario (Addendum Table 87) can be summarised as follows:

- Low to severe decline in sensitive species throughout the catchment, with possible local extinction in places. A decline in tolerant species also, except in the Lower Kikuletwa and Lower Ruvu where they are expected to increase.

Addendum Table 98 Estimated percentage change from Present Day for macroinvertebrates under the Maximise HEP with 30% Less Rainfall scenario

Site No.	Name	Sensitive species		Tolerant species (e.g., Dysticidae, Chironominae and Culicidae)		Pest Simuliidae	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-100	-100	-60	-40	-100	-100
2	Lower Kikuletwa	-60	-40	251	500	0	0
3	Upper Ruvu	-80	-60	-60	-40	-20	0
4	Lower Ruvu	-100	-100	500	800	0	0
6	Pangani at Kirua	-20	0	-20	0	1	25
7	Lower Mkomazi	0	0	-60	-40	0	0
8	Lower Luengera	-100	-80	-40	-20	0	0
9	Lower Pangani	0	0	0	0	0	0

A11.5.1.5 Fish

The changes in fish associated with this (Addendum Table 88) can be summarised as follows:

- decrease in *Clarias* and *Labeo* in the upper catchment, possibly to local extinction for the latter in places;
- increase in *Clarias* and *Tilapia* in the Pangani at Kirua;
- decline of all fish groups in the Mkomazi and Luengera Rivers;
- moderate increase in *Clarias* in the middle and lower Pangani River.

Addendum Table 99 Estimated percentage change from Present Day for fish under the Maximise HEP with 30% Less Rainfall scenario

Site No.	Name	*Clarias* group		*Tilapia* group		*Labeo* group	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-60.0	-40.0	0.0	0.0	0.0	0.0
2	Lower Kikuletwa	0.0	0.0	0.0	0.0	-100.0	-100.0
3	Upper Ruvu	0.0	0.0	0.0	0.0	-100.0	-80.0
4	Lower Ruvu	-20.0	0.0	0.0	0.0	-100.0	-100.0
6	Pangani at Kirua	1.0	25.0	1.0	25.0	0.0	0.0
7	Lower Mkomazi	-20.0	0.0	-20.0	0.0	-100.0	-80.0
8	Lower Luengera	-20.0	0.0	-100.0	-80.0	-100.0	-100.0
9	Lower Pangani	1.0	25.0	0.0	0.0	0.0	0.0

A11.5.1.6 Overall condition

The changes in overall river condition associated with this scenario are provided in Addendum Table 100. There is a slight to moderate decline in overall condition at different sites, except for a negligible improvement at Kirua. There is a very mild shift toward lower condition classes.

Addendum Table 100 Overall condition at each river site for the Maximise HEP with 30% Less Rainfall scenario

Site number	Site name	Present Day River Health Category	Change from Present Day ecological integrity	River Health Category for the scenario
1	Upper Kikuletwa	B/C	-0.47	C
2	Lower Kikuletwa	D	-0.34	D/E
3	Upper Ruvu	C/D	-0.28	D
4	Lower Ruvu	D	-0.28	D
6	Pangani at Kirua	C	0.06	C
7	Lower Mkomazi	C/D	-0.15	C
8	Lower Luengera	C	-0.50	D
9	Lower Pangani	C	-0.01	C

A11.5.2 Summary of biophysical condition in NyM

A11.5.2.1 Water level change

The FA Tool assesses likely change in two parameters associated with NyM Dam – fish catch and reed area. These parameters are affected by water area (volume) of the lake and the variation in area, which are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under the maximise HEP scenario are presented in Addendum Table 101 and discussed in the respective sections below.

Addendum Table 101 Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in NyM under the Maximise HEP with 30% Less Rainfall scenario relative to Present Day, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario.

	Present Day	This Scenario	% Change
Mean lake area (ha)	103.8	47.4	-54%
Std dev of lake area (m)	1.24	0.11	-91%
Max lake area (ha)	137.1	68.2	-50%
Reed area (ha)	33.3	20.8	-38%
Mean lake level (m)	15.9	9.4	-41%
Std dev of lake level (m)	1.2	0.1	-92%
Fish catch (tonnes)	3538.8	2000.9	-43%

A11.5.2.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surround NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under this scenario, lake area shrinks by 54%, variability decreases markedly by 91%, and maximum area decreases by 50% (Addendum Table 101). The net result of this is that total reed area is expected to decrease by 38%.

A11.5.2.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the present day we expect fish populations to expand in responses to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under this scenario, variability in lake level decreases markedly by 91% and average area declines by 54% (Addendum Table 101). Fish catches as a result, are expected to decline by 43%.

A11.5.3 Summary of biophysical condition in Kirua Swamp

There is no significant change the condition of the Kirua Swamp relative to present day under the maximise HEP less 20% rainfall scenario.

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to present day. Under this scenario, fish abundances are predicted to decrease to 86% of present day (113 tonnes) and floodplain vegetation decrease to 85%.

A11.5.4 Summary of biophysical condition in the Estuary

A11.5.4.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under this scenario freshwater flows reaching the estuary are higher than Present Day during all four seasons except the Long Rains (Addendum Table 102). A concomitant reduction is evident in agricultural return flows in all seasons except the long rains. Number of months where flow exceeds 250 Mm^3 is down by 88%.

Addendum Table 102 Change in freshwater flows reaching the estuary under the Maximise HEP with 30% Less Rainfall scenario relative to PD.

		Short rains	Dry 1	Long rains	Dry 2	All months
Average monthly flows	Current day (Mm^3)	91.3	72.7	186.9	80.7	102.1
	Max HEP less 30% (Mm^3)	108.2	103.5	120.3	106.7	110.8
	% Change	18.5	42.4	-35.6	32.3	8.5
Agricultural monthly return flows	Current day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	Max HEP less 30% (Mm^3)	9.6	15.2	13.7	4.8	13.6
	% Change	-38.0	-40.6	2.9	-49.9	-24.4
No. months flow >250 Mm^3	Current day	8.0				
	Max HEP less 30% (Mm^3)	1.0				
	% Change	-87.5				

Addendum Table 103 Health scores for the estuary as a whole and the component parameters under the Maximise HEP with 30% Less Rainfall scenario relative to Present Day

	Present day	This scenario	% change from PD (+/-)
Geomorphology	40%	35%	-12%
Water Quality	53%	57%	7%
Micro-algae	40%	41%	1%
Vegetation	60%	60%	1%
Invertebrates	60%	61%	1%
Fish	50%	51%	1%
Birds	40%	42%	4%
Overall health score	57%	57%	0%

A11.5.4.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the Present Day status of the mouth, which is both wide and deep. Thus, only the extreme high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significantly affect geomorphological conditions in

the estuary such as channel width and depth, and intertidal area, albeit on a relative small scale due to the large size of the tidal prism.

These high flows have changed somewhat from the present day under this scenario (down by 88%, Addendum Table 102) but as they do not contribute as much to the current mouth status as the tidal flow, the resulting change in geomorphological conditions in the estuary can be expected to be a small decline of 12% (Addendum Table 103).

A11.5.4.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Reduced flow volumes have a reduced capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under this scenario, mean monthly flows are higher and contributions by agricultural return flows have decreased in all seasons except the Long Rains. The combined effect of this is predicted to lead to an improvement in water quality in all seasons except the Long Rains, with an overall net positive effect on water quality (score increases from 53 to 57%).

A11.5.4.4 Microalgae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient level) with the result that phytoplankton concentrations in the system are extremely high. Changes in water quality are not consistent throughout the year but will give rise to a net reduction in phytoplankton abundance with a concomitant improvement in health score associated with this parameters from 40 to 41%.

A11.5.4.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As mean monthly flows under the Present Day scenario are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the contribution from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production).

The effect of a net increase in flow and a net decrease in agricultural return flows anticipated under this scenario, are anticipated to have a net positive influence on vegetation communities associated with the estuary, translating to a improvement in the health score of 1% (Addendum Table 103).

A11.5.4.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes in the geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality (reduced water clarity and oxygen levels, increased nutrients) between the natural and Present Day situations.

While geomorphological conditions are not expected to change significantly from the present day under this scenario, the anticipated net improvement in water quality will manifest itself as a mild increase in macroinvertebrate abundance from 50% to 51% (Addendum Table 103).

A11.5.4.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geo-morphological characteristics and water quality as well as by the decline of their main food supply (invertebrates). As such the current health score is low (50%) but is expected to improvement slightly under this scenario by 1% (Addendum Table 103).

A11.5.4.8 Birds

Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the estuary and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). The predicted net increase in invertebrate and fish abundance is likely to be translated into a mild increase in the numbers and species of birds frequenting the estuary from 40% tp 42% (Addendum Table 103).

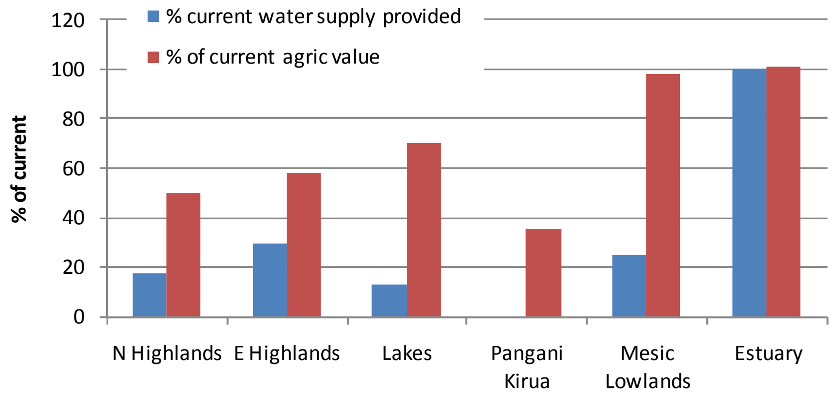
A11.5.4.9 Overall condition

Most measured health parameters in the estuary show little change from the present day under this scenario except geomorphology (+) and water quality (-). The net result of this is that no change is expected in the overall health score of the estuary.

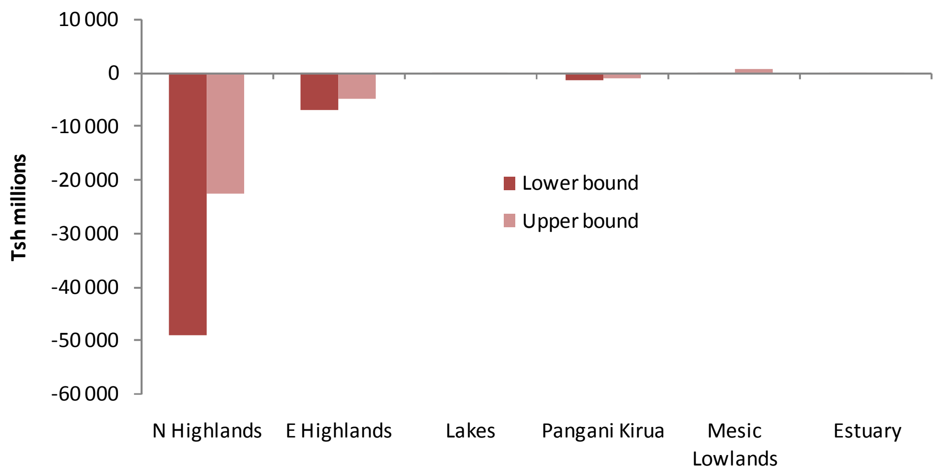
A11.6 Effects on livelihoods

A11.6.1 Income from small-scale agriculture

Addendum Figure 99 shows aggregate net income from agriculture to rural house-holds within 5 km of rivers under the scenario as a percentage of current value. In the Maximise HEP with 30% Less Rainfall scenario, income is severely reduced in the upper zones and Pangani-Kirua, but remains relatively unchanged in the Mesic Lowlands and Estuary. There is a loss of income overall, concentrated in the Northern Highlands (Addendum Figure 100).



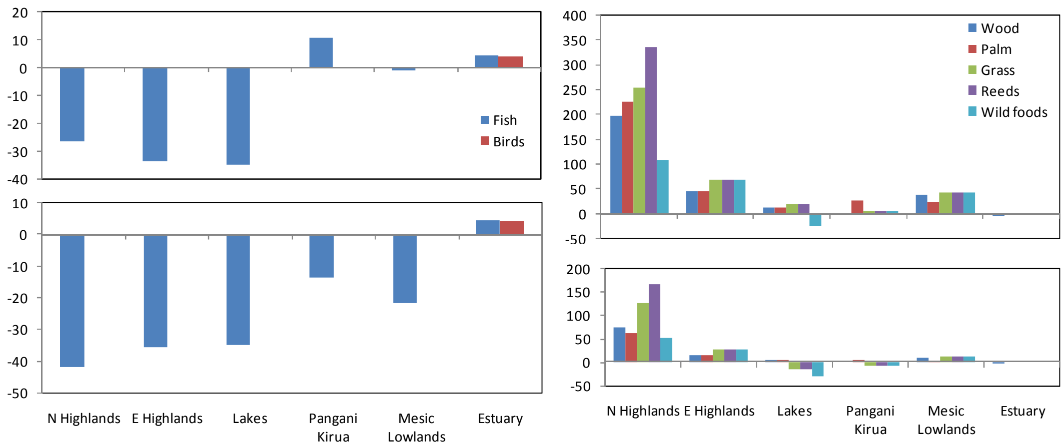
Addendum Figure 99 Area under small-scale irrigation under the Maximise HEP with 30% Less Rainfall scenario compared with the Present Day



Addendum Figure 100 Lower and upper bound estimates of the aggregate change in income from small-scale agriculture under the Maximise HEP with 30% Less Rainfall scenario

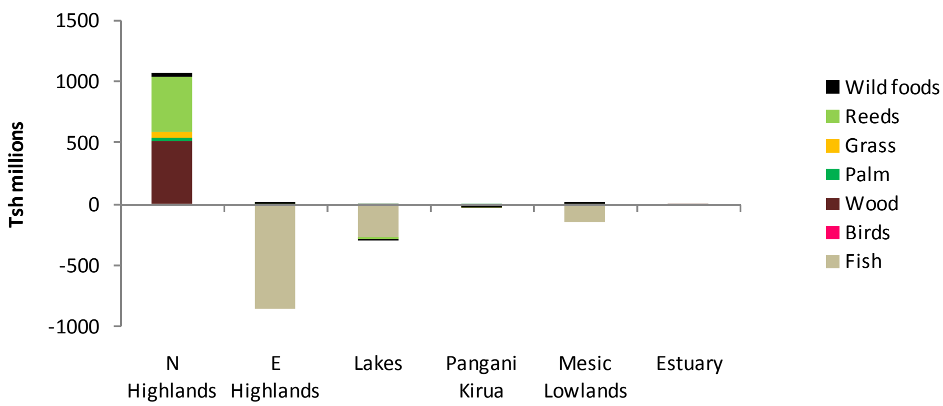
A11.6.2 Income from natural resources

Fish decrease in abundance in the upper zones but may increase or decrease in Pangani-Kirua; there is a decrease in the Mesic Lowlands. Birds and fish increase at the Estuary. Plant resources increase in abundance generally in the Highlands, particularly the Northern Highlands, and may increase or decrease slightly elsewhere (Addendum Figure 101).



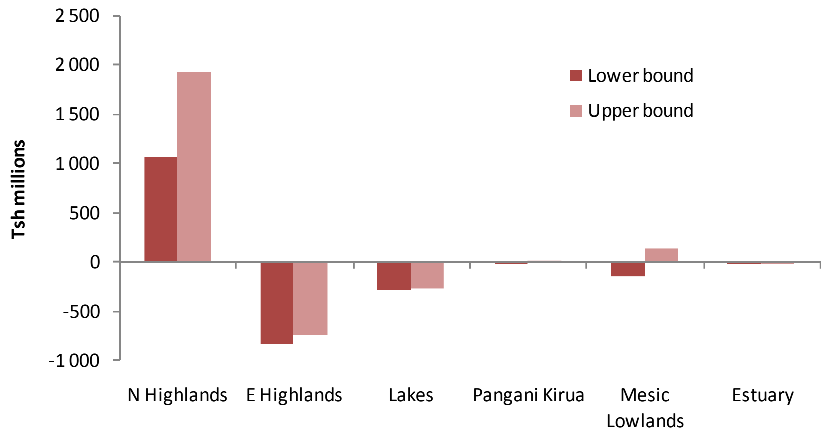
Addendum Figure 101 Lower and upper bound estimates of the percentage change from present day in the abundance of natural resources used by households, Maximise HEP with 30% Less Rainfall scenario

Impacts of these changes on income to households are shown in Addendum Figure 102.



Addendum Figure 102 Lower-bound estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under the Maximise HEP with 30% Less Rainfall scenario

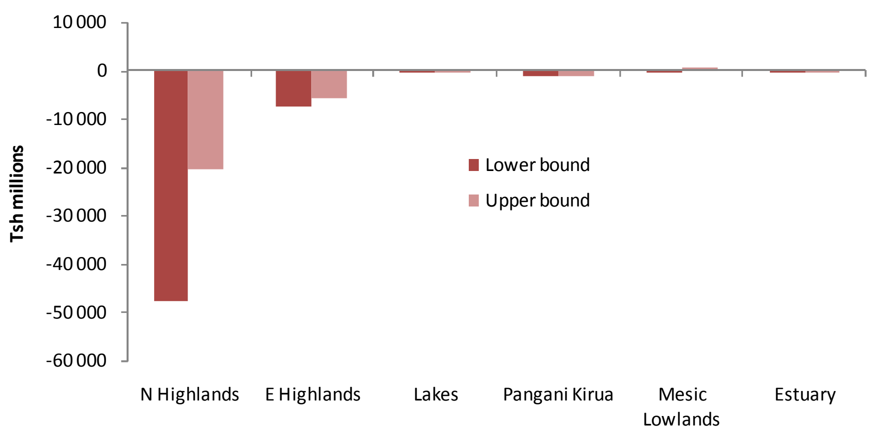
There is an increase in income from natural resources in the Northern Highlands, but decreases in the rest of the upper zones and little change in the lower zones (Addendum Figure 103).



Addendum Figure 103 Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under the Maximise HEP with 30% Less Rainfall scenario

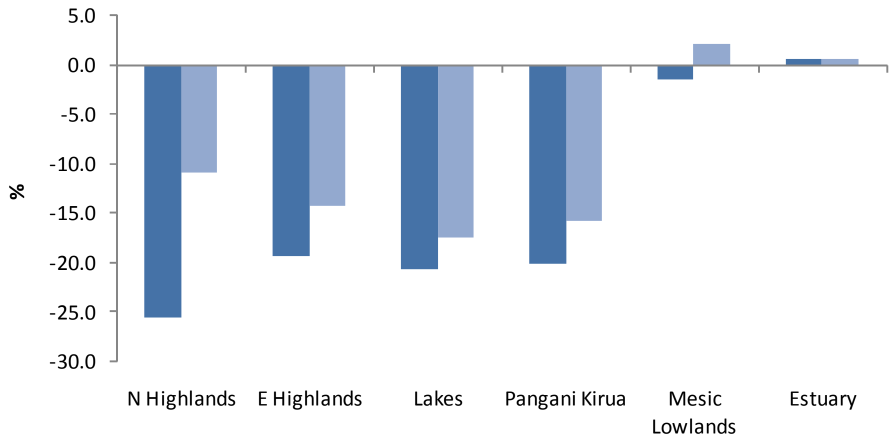
A11.6.3 Overall household income

Aggregate income is expected to decreases throughout the basin, but particularly in the Northern Highlands (Addendum Figure 104).



Addendum Figure 104 Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, under the Maximise HEP with 30% Less Rainfall scenario

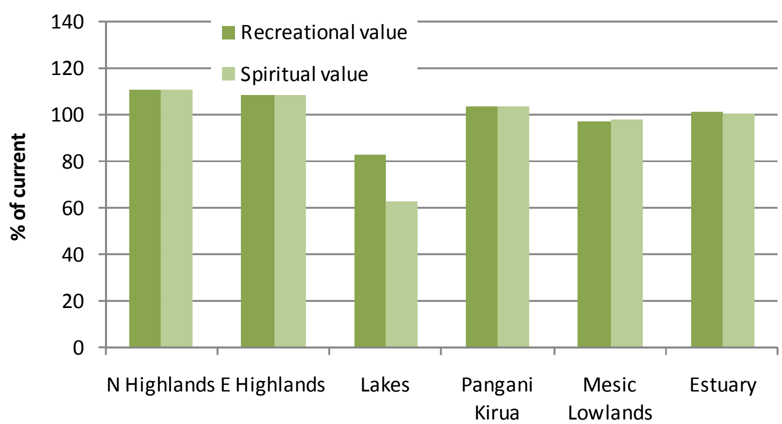
Aggregate household income decreases by up to 20% or more in all the upper zones and Pangani-Kirua (Addendum Figure 105).



Addendum Figure 105 Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under the Maximise HEP with 30% Less Rainfall scenario

A11.6.4 Intangible values

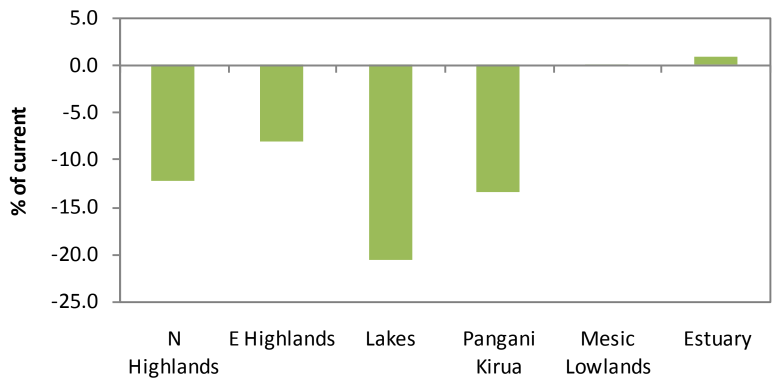
There is an increase in recreational and spiritual well-being among households in the highlands and, to a lesser extent, Pangani-Kirua, but a marked decrease in the Lakes zone (Addendum Figure 106).



Addendum Figure 106 Overall recreational and spiritual well-being (derived from rivers and other sources) under the Maximise HEP with 30% Less Rainfall scenario as a percentage of current well-being

A11.6.5 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 107. There is a very strongly negative impact on well-being in all of the upper zones and Pangani-Kirua, but little impact on the lowest two zones.



Addendum Figure 107 Percentage change in overall well-being of households within 5 km of rivers under the Maximise HEP with 30% Less Rainfall scenario

A11.7 Effects on economic value

Under this scenario, changes in environmental quality and function lead to a small loss of value in terms of ecosystem regulating services, but a larger gain in terms of direct value added by the natural resources sector. Much larger losses are incurred through direct value added by the agricultural sector. These losses are offset to a significant extent by gains in the energy sector (Addendum Table 104).

Addendum Table 104 Gains and losses in the value of HEP, agriculture, natural resources and ecosystem regulating services (Tsh millions per year) under the Maximise HEP with 30% Less Rainfall scenario

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
39 527	-94 457	430	-10	-54 509

A12 STORAGE U/S NYM WITH MAXIMISE AGRICULTURE

A12.1 Description of the scenario

The Storage upstream of NyM, with Maximise Agriculture scenario comprised the following (in order of priority):

- Basic Human Needs
- Allocation of water for Urban/Industrial to Arusha and Moshi towards the 2025 demands.
- 56 MCM storage in the Kikuletwa catchment and 10 MCM storage in the Ruvu catchment to store some wet-season flows. As much water as can be abstracted at a 75% level of assurance allocated to agriculture.
- The remaining water used to generate HEP.
- Environment received whatever water was left.

A12.2 Hydrological implications

A12.2.1 Water allocated per sector

Urban/industrial 54.7 Mcm a^{-1} (PD = 31.1)
Irrigation 1 031 Mcm a^{-1} (PD = 1042)
HEP 420 688 MW h^{-1} (PD = 602 647)

A12.2.2 Changes in the flow regime relative to present day

The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 105. There were three main kinds of change relative to present day:

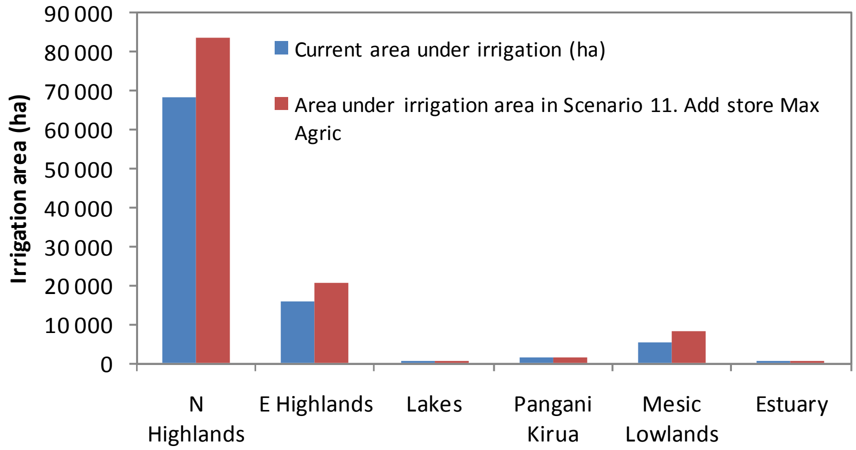
- reduced low flows at all sites;
- some increased intra-annual flood variation;
- loss of inter-annual floods.

Addendum Table 105 DRIFT flow summary data for Storage upstream of NyM with Maximise Agriculture scenario

Location	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario (MAR)	50.49	390	155.93	777.62	579.68	9.1	101.03	892.03
WSLF - Volumes (MCM)	16.56	261.67	77.3	499.79	244.26	1.21	36.65	414.44
DSLF - Volumes (MCM)	22.6	62.92	60.65	150.18	314.9	4.5	41.6	334.24
Class 1 - Annual Frequency	4.47	0.32	0	1.47	0.16	1.47	1.16	0.21
Class 2 - Annual Frequency	2.11	1.53	1.11	2.16	2.95	0.84	7.53	2
Class 3 - Annual Frequency	1.74	4.21	1.89	2.58	0	0.16	4	3.79
Class 4 - Annual Frequency	1.42	3.05	3.47	3.32	0	0.26	1.84	1.05
1:2	P	P	A	P	A	A	A	A
1:5	P	P	P	P	A	A	P	P
1:10	P	P	P	P	A	A	A	P
1:20	P	P	P	P	A	A	A	P

A12.3 Effects on irrigated agriculture

Under this scenario, the irrigation area is increased by about 25% in most zones, apart from the Lakes area, where there is little change, and the relatively small irrigation area in the Mesic Lowlands increases by 50%. Overall irrigation area increases by 25% (Addendum Figure 108).



Addendum Figure 108 Area under irrigation under Storage upstream of NyM with Maximise Agriculture scenario compared with the Present Day

A12.4 Effects on HEP production

HEP decreases to 70% of current output, or 420 688 MWh.

A12.5 Effects on environmental condition

A12.5.1 Summary of biophysical condition in the river

The influence of the residual flows on the condition of the rivers is described in two ways:

- as percentage change relative to present day for key indicators representing each of geomorphology, water quality, riparian vegetation, macroinvertebrates and fish;
- in terms of change in overall river condition as denoted by the integrity score

Note: The Present Day levels of the indicators have not been quantified, thus the reported change is relative to an unknown quantity.

A12.5.1.1 Geomorphology

The geomorphological changes associated with this scenario are concentrated in the upper portion of the catchment, i.e., upstream of NyM and in the Mkomazi and Luengera Rivers (Addendum Table 106). The changes are similar to those for the Maximise Agriculture scenario and can be summarised as follows:

- noticeable reduction in rocky areas, and thus fish habitat in the Kikuletwa, Ruvu, Mkomazi and Luengera Rivers;
- loss of pools, and thus fish refuge, at the same sites;
- build up of fine sediments especially in the Upper Kikuletwa, Lower Mkomazi and Luengera Rivers.

Addendum Table 106 Estimated percentage change from Present Day for geomorphological features under Storage upstream of NyM with Maximise Agriculture scenario

Site No.	Name	Riffles and rapids		Pools		Fine sediments		Coarse sediments		Bank erosion		Floodplain inundation	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	-20	0	1	25	0	0	0	0	0	0
2	Lower Kikuletwa	-60	-40	-60	-40	0	0	0	0	0	0	0	0
3	Upper Ruvu	-20	0	-20	0	26	68	-20	0	0	0	0	0
4	Lower Ruvu	0	0	-20	0	0	0	0	0	0	0	0	0
6	Pangani at Kirua	0	0	0	0	1	25	0	0	0	0	26	68
7	Lower Mkomazi	-100	-100	-100	-100	500	800	0	0	0	0	-100	-100
8	Lower Luengera	-80	-60	-40	-20	26	68	0	0	0	0	-100	-100
9	Lower Pangani	-20	0	-20	0	-40	-20	0	0	1	25	0	0

A12.5.1.2 Water Quality

The water quality changes associated with this scenario (Addendum Table 107) are almost identical to those associated with the Maximise Agriculture scenario (Addendum Table 3). The changes can be summarised as follows:

- noticeable increase in conductivity in the Lower Kikuletwa and Mkomazi rivers;
- slightly increased phosphorus levels in the upper catchment, and severely increased levels in the Mkomazi River.

Addendum Table 107 Estimated percentage change from Present Day for water quality under Storage upstream of NyM with Maximise Agriculture scenario

Site No.	Name	Turbidity/TSS		Conductivity/TDS		Phosphorus		Nitrogen	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	1	25	0	0	0	0
2	Lower Kikuletwa	1	25	251	500	26	68	-20	0
3	Upper Ruvu	0	0	1	25	1	25	0	0
4	Lower Ruvu	0	0	1	25	0	0	-20	0
6	Pangani at Kirua	0	0	0	0	0	0	0	0
7	Lower Mkomazi	0	0	500	800	251	500	0	0
8	Lower Luengera	0	0	0	0	0	0	0	0
9	Lower Pangani	0	0	0	0	0	0	1	25

A12.5.1.3 Vegetation

The changes in riparian vegetation associated with this scenario (Addendum Table 108) can be summarised as follows:

- moderate decline in wet bank vegetation in the Kikuletwa River;
- noticeable increase in wet bank vegetation in the Mkomazi and Luengera Rivers;
- negligible to low increase in dry bank vegetation in the Lower Pangani.

Addendum Table 108 Estimated percentage change from Present Day for vegetation under Storage upstream of NyM with Maximise Agriculture scenario

Site No.	Name	Dry Bank Trees		Dry Bank Herbs & Shrubs		Dry Bank Grasses		Wetbank Trees		Wetbank Herbs		Wetbank grasses and reeds	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-20	0	0	0	0	0	0	0	-20	0	0	0
2	Lower Kikuletwa	-20	0	0	0	0	0	0	0	-80	-60	-40	-20
3	Upper Ruvu	0	0	0	0	0	0	0	0	0	0	26	68
4	Lower Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
6	Pangani at Kirua	0	0	0	0	0	0	1	25	0	0	0	0
7	Lower Mkomazi	0	0	0	0	0	0	500	800	251	500	251	500
8	Lower Luengera	0	0	0	0	0	0	26	68	26	68	26	68
9	Lower Pangani	1	25	1	25	1	25	0	0	0	0	0	0

A12.5.1.4 Macroinvertebrates

The changes in macroinvertebrates associated with this scenario (Addendum Table 109) can be summarised as follows:

- low to severe decline in sensitive species throughout the catchment, with possible local extinction in places.
- a decline in tolerant species also, except in the Upper Kikuletwa and Lower Ruvu.

Addendum Table 109 Estimated percentage change from Present Day for macroinvertebrates under Storage upstream of NyM with Maximise Agriculture scenario

Site No.	Name	Sensitive species		Tolerant species (e.g., Dysticidae, Chironominae and Culicidae)		Pest Simuliidae	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	1	25	-40	-20
2	Lower Kikuletwa	-100	-100	-60	-40	-20	0
3	Upper Ruvu	-60	-40	-20	0	0	0
4	Lower Ruvu	-40	-20	1	25	0	0
6	Pangani at Kirua	-20	0	-20	0	1	25
7	Lower Mkomazi	-100	-100	-60	-40	0	0
8	Lower Luengera	-40	-20	-40	-20	0	0
9	Lower Pangani	0	0	0	0	0	0

A12.5.1.5 Fish

The changes in fish associated with this (Addendum Table 110) can be summarised as follows:

- decrease in fish species throughout the catchment.

Addendum Table 110 Estimated percentage change from Present Day for fish under Storage upstream of NyM with Maximise Agriculture scenario

Site No.	Name	*Clarias* group		*Tilapia* group		*Labeo* group	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	0	0	0	0
2	Lower Kikuletwa	-60	-40	0	0	-100	-80
3	Upper Ruvu	0	0	0	0	-60	-40
4	Lower Ruvu	-20	0	0	0	-40	-20
6	Pangani at Kirua	1	25	0	0	0	0
7	Lower Mkomazi	-80	-60	-100	-100	-100	-100
8	Lower Luengera	0	0	-40	-20	-100	-80
9	Lower Pangani	0	0	-80	-60	0	0

A12.5.1.6 Overall condition

The changes in overall river condition associated with this scenario are provided in Addendum Table 111. There is a slight to moderate decline in overall condition at different sites, except for a significant decline at Mkomazi River and a negligible improvement in the river at Kirua. There is a very mild shift toward lower condition classes.

Addendum Table 111 Overall condition at each river site for the Storage upstream of NyM with Maximise Agriculture scenario

Site No.	Name	Present Day River Health Category	Change from Present Day ecological integrity	River Health Category for the scenario
1	Upper Kikuletwa	B/C	-0.138	C
2	Lower Kikuletwa	D	-0.227	D
3	Upper Ruvu	C/D	-0.132	D
4	Lower Ruvu	D	-0.053	D
6	Pangani at Kirua	C	0.014	C
7	Lower Mkomazi	C/D	-0.971	D/E
8	Lower Luengera	C	-0.169	C
9	Lower Pangani	C	-0.061	C

A12.5.2 Summary of biophysical condition in NyM

A12.5.2.1 Water level change

The FA Tool assesses likely change in two parameters associated with NyM Dam – fish catch and reed area. These parameters are affected by water area (volume) of the lake and the variation in area, which are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under the maximise HEP scenario are presented in Addendum Table 112 and discussed in the respective sections below.

Addendum Table 112 Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in NyM under Storage upstream of NyM with Maximise Agriculture scenario relative to PD, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario

	Present Day	This Scenario	% Change
Mean lake area (ha)	103.8	64	-38%
Std dev of lake area (m)	1.24	1.53	23%
Max lake area (ha)	137.1	120.5	-12%
Mean lake level (m)	15.9	11.5	-28%
Std dev of lake level (m)	1.2	1.5	+25%
Reed area (ha)	33.3	56.5	70%
Fish catch (tonnes)	3538.8	2509.1	-29%

A12.5.2.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surround NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under this scenario, average lake area shrinks by 38%, variability increases slightly by 23%, and maximum area decreases by 12% (Addendum Table 112). The net result of this is that total reed area is expected to increase by 70%.

A12.5.2.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the present day we expect fish populations to expand in responses to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under this scenario, variability in lake level increases by 25% but average area declines by 38% (Addendum Table 112). Fish catches as a result, are expected to decline by 29%.

A12.5.3 Summary of biophysical condition in Kirua Swamp

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to present day.

Under this scenario, fish abundances are predicted to decrease to 33% of present day (31 tonnes) and floodplain vegetation to decrease to 22% of its present day extent.

A12.5.4 Summary of biophysical condition in the Estuary

A12.5.4.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under this scenario freshwater flows reaching the estuary are substantially lower than Present Day during all four seasons except the Long Rains (Addendum Table 113; Addendum Table 114). Agricultural return flows are moderately reduced in all seasons except the long rains where these are essentially the same as in the Present Day. Number of months where flow exceeds 250 Mm^3 is down by 25%.

Addendum Table 113 Change in freshwater flows reaching the estuary under the Storage upstream of NyM with Maximise Agriculture scenario relative to Present Day

		Short rains	Dry 1	Long rains	Dry 2	All months
Average monthly flows	Current day (Mm^3)	91.3	72.7	186.9	80.7	102.1
	Storage upstream of NyM with Maximise Agriculture (Mm^3)	59.7	33.3	166.1	56.8	74.3
	% Change	-34.7	-54.2	-11.1	-29.5	-27.2
Agricultural monthly return flows	Current day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	Storage upstream of NyM with Maximise Agriculture (Mm^3)	39.1	38.6	21.0	42.6	38.8
	% Change	18.5	60.7	4.1	20.7	15.5
No. months flow >250 Mm^3	Current day	8.0				
	Storage upstream of NyM with Maximise Agriculture (Mm^3)	6.0				
	% Change	-25.0				

Addendum Table 114 Health scores for the estuary as a whole and the component parameters under Storage upstream of NyM with Maximise Agriculture scenario relative to Present Day

	Present day	This scenario	% change from PD (+/-)
Geomorphology	40%	37%	-3%
Water Quality	53%	39%	-14%
Micro-algae	40%	29	-11%
Vegetation	60%	57%	-3%
Invertebrates	60%	47%	-13%
Fish	50%	40%	-10%
Birds	40%	33%	-7%
Overall health score	57%	46%	-11%

A12.5.4.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the Present Day status of the mouth, which is both wide and deep. Thus, only the extreme high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significantly affect geomorphological conditions in

the estuary such as channel width and depth, and intertidal area, albeit on a relative small scale due to the large size of the tidal prism.

These high flows have changed a little from the present day under this scenario (down by 25%, Addendum Table 113) and given that their contribution to maintaining the current mouth status is small relative to tidal flow; the resulting change in geomorphological conditions in the estuary can be expected to be a small decline of 3% (Addendum Table 114).

A12.5.4.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Reduced flow volumes have a reduced capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under this scenario, mean monthly flows are around 25% lower and contributions by agricultural return flows have increased significantly in all seasons (up by 20-40%). The combined effect of this is predicted to lead to a reduction in water quality (score decreases from 53 to 39%).

A12.5.4.4 Microalgae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient level) with the result that phytoplankton concentrations in the system are extremely high. The overall reductions in water quality expected under this scenario is expected to give rise to a further increase in phytoplankton abundance (increased eutrophication) with a concomitant reduction in health score associated with this parameters from 40 to 29% (Addendum Table 114).

A12.5.4.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As mean monthly flows under the Present Day scenario are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the contribution from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production).

The effect of a net reduction in flow and a net increase in agricultural return flows anticipated under this scenario, are anticipated to have a small negative influence on vegetation communities associated with the estuary, translating to a reduction in the health score of 3% (Addendum Table 114).

A12.5.4.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes in the

geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality (reduced water clarity and oxygen levels, increased nutrients) between the natural and Present Day situations.

While geomorphological conditions are not expected to change significantly from the present day under this scenario, the anticipated net reduction in water quality will manifest itself as a net reduction in macroinvertebrate abundance from 60% to 47% (Addendum Table 114).

A12.5.4.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geomorphological characteristics and water quality as well as by the decline of their main food supply (invertebrates). As such, the current health score is low (50%) and is expected to decrease even further under this scenario (down by 10%, Addendum Table 114).

A12.5.4.8 Birds

Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the estuary and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). The predicted net reduction in invertebrate and fish abundance is likely to be translated into a further decrease in the numbers and species of birds frequenting the estuary from 40% tp 33% (Addendum Table 114).

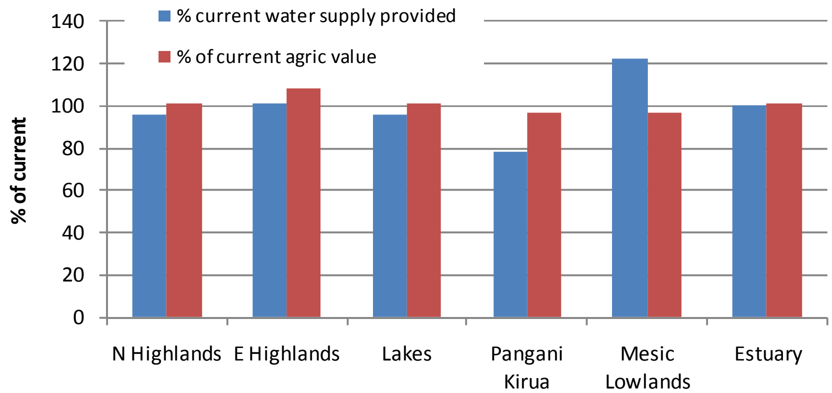
A12.5.4.9 Overall condition

Most measured health parameters in the estuary are expected to decline significantly from the present day under this scenario, with a concomitant reduction in overall health expected for the estuary (down by 11% to 46%).

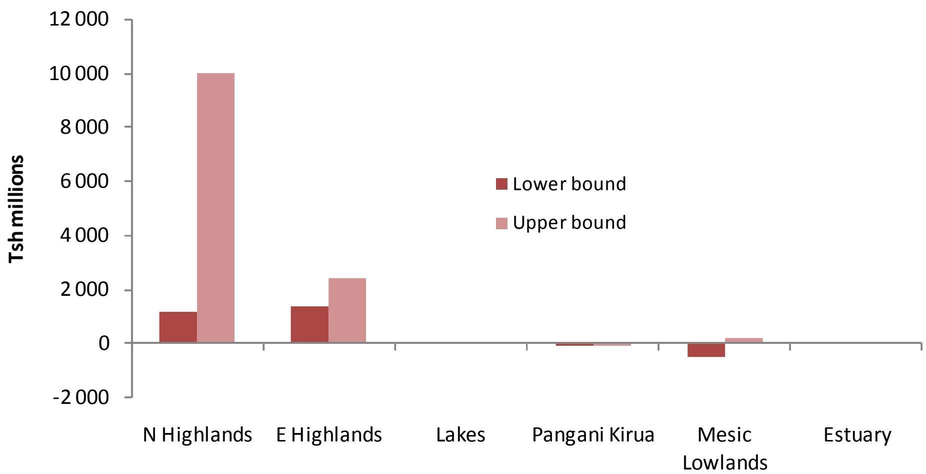
A12.6 Effects on livelihoods

A12.6.1 Income from small-scale agriculture

Addendum Figure 109 shows aggregate net income from agriculture to rural households within 5 km of rivers under the scenario as a percentage of current value. Under this scenario, income is slightly increased in the Northern and Eastern Highlands and remains relatively unchanged in the other zones (Addendum Figure 110).



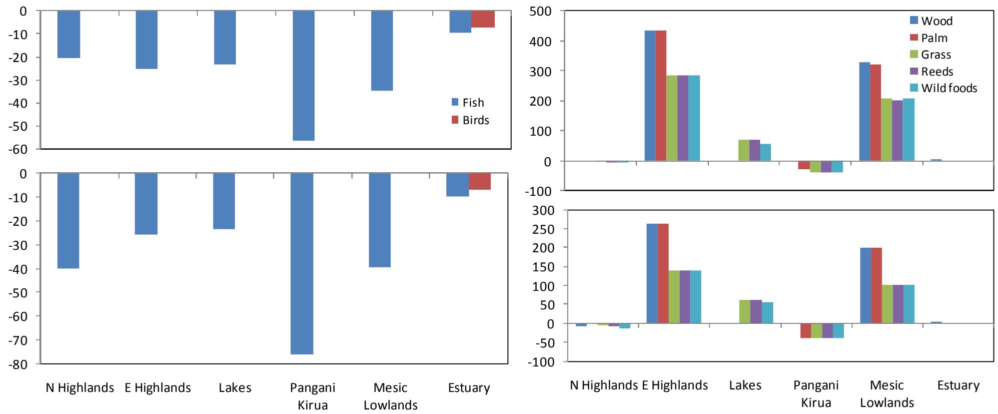
Addendum Figure 109 Area under small-scale irrigation under Storage upstream of NyM with Maximise Agriculture scenario compared with the Present Day



Addendum Figure 110 Lower and upper bound estimates of the aggregate change in income from small-scale agriculture under Storage upstream of NyM with Maximise Agriculture scenario

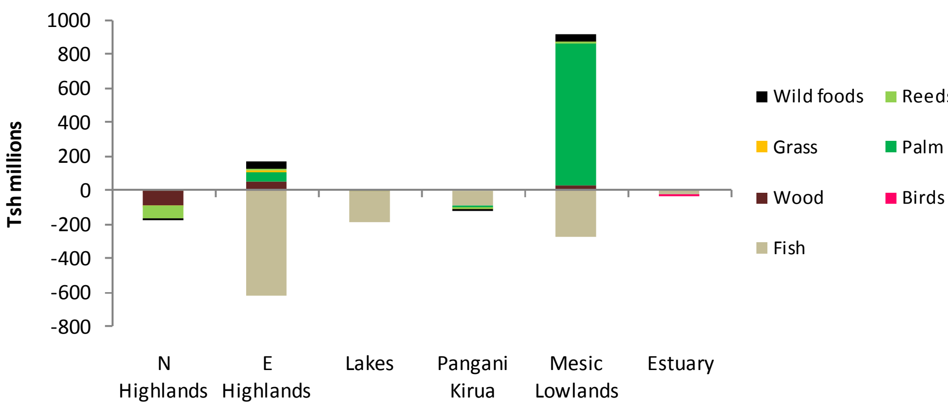
A12.6.2 Income from natural resources

Fish decrease in abundance in the all the zones under this scenario, and bird numbers decrease at the estuary. Plant resources increase in the Eastern Highlands and Mesic Lowlands (Addendum Figure 111).



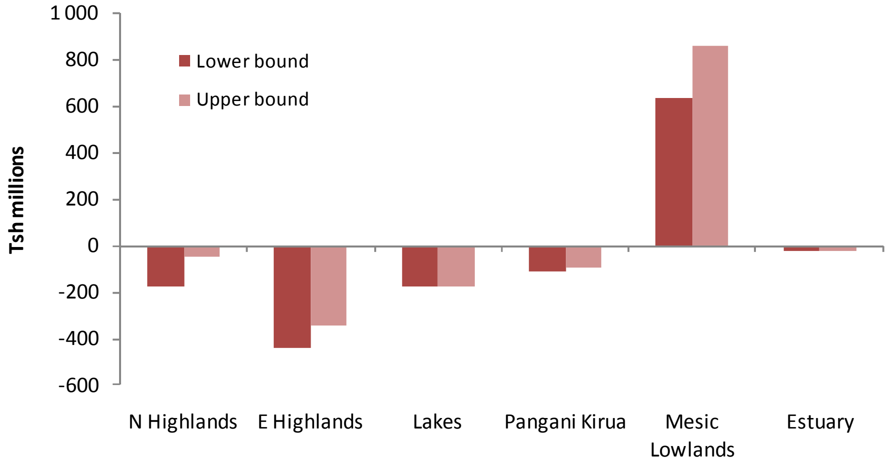
Addendum Figure 111 Lower and upper bound estimates of the percentage change from present day in the abundance of natural resources used by households, Storage upstream of NyM with Maximise Agriculture scenario

Impacts of these changes on income to households are shown in Addendum Figure 112.



Addendum Figure 112 Lower-bound estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under Storage upstream of NyM with Maximise Agriculture scenario

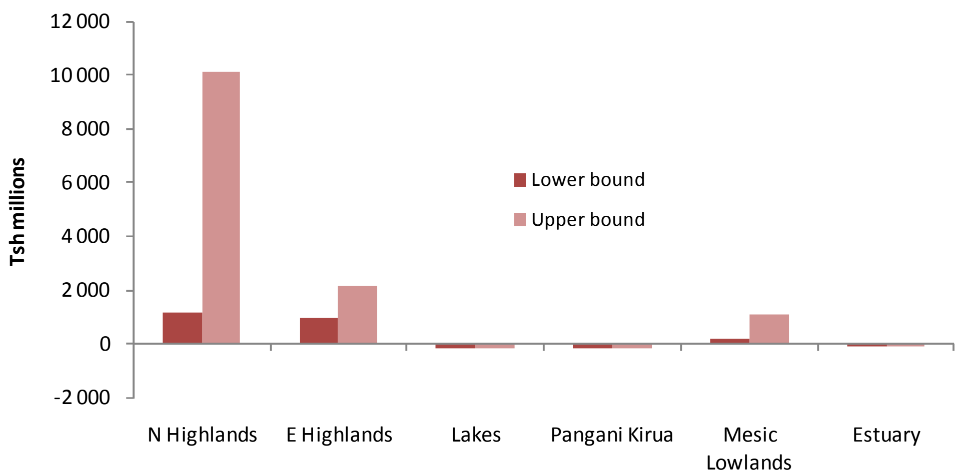
There is an increase in income from natural resources in the Mesic Lowlands, but decreases in the rest of the zones, although this is negligible in the Estuary zone (Addendum Figure 113).



Addendum Figure 113 Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under Storage upstream of NyM with Maximise Agriculture scenario

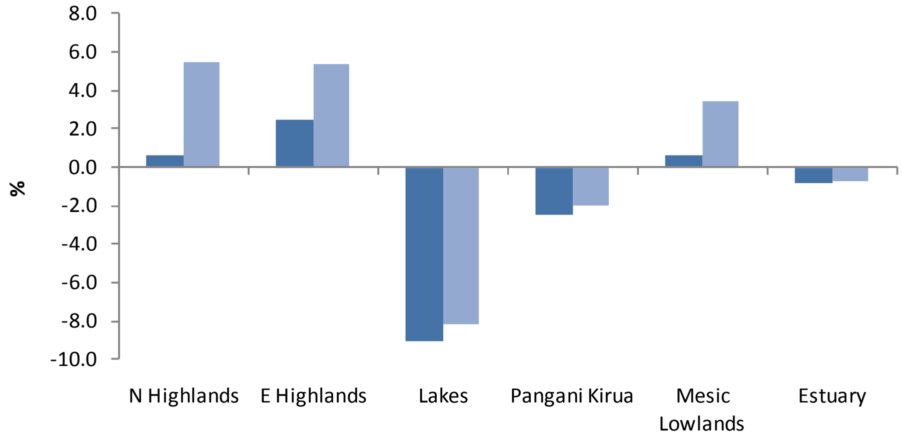
A12.6.3 Overall household income

Aggregate household income is expected to increase in the Highland areas. Changes are negligible in the remaining zones (Addendum Figure 114).



Addendum Figure 114 Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, under the Storage upstream of NyM with Maximise Agriculture scenario

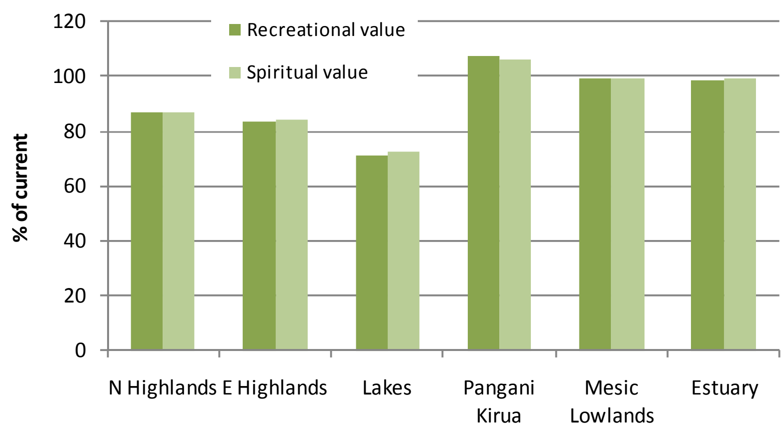
The percentage change in aggregate household income is very small in most zones and largest in the Lakes zone, where the decrease represents about 8% of current income (Addendum Figure 115).



Addendum Figure 115 Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under Storage upstream of NyM with Maximise Agriculture scenario

A12.6.4 Intangible values

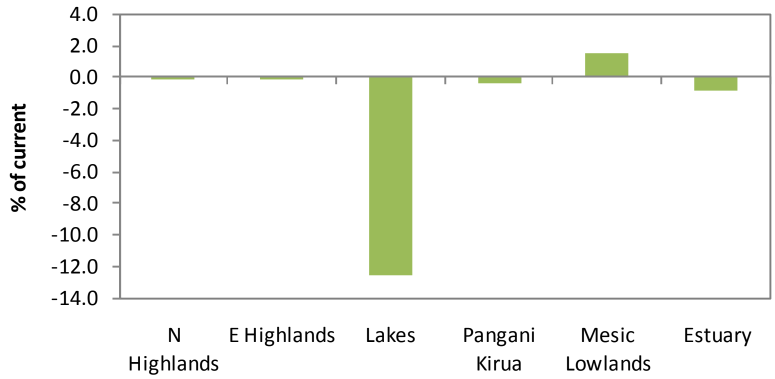
There is a decrease in recreational and spiritual well-being among households in the Highlands and Lakes, while scores remain similar to the present day in the remaining zones (Addendum Figure 116).



Addendum Figure 116 Overall recreational and spiritual well-being (derived from rivers and other sources) under Storage upstream of NyM with Maximise Agriculture scenario as a percentage of current well-being

A12.6.5 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 117. There is a relatively strongly negative impact on well-being in the Lakes zones and no significant change in any other zone.



Addendum Figure 117 Percentage change in overall well-being of households within 5 km of rivers under Storage upstream of NyM with Maximise Agriculture scenario

A12.7 Effects on economic value

Under this scenario, there is a gain in Agricultural output value of some Tshs 16.5 billion, but this is an order of magnitude smaller than the loss of HEP value. Small losses are also incurred in terms of natural resources and ecosystem services (Addendum Table 115).

Addendum Table 115 Gains and losses in the value of HEP, agriculture, natural resources and ecosystem regulating services (Tsh millions per year) under the Storage upstream of NyM with Maximise Agriculture scenario

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
-634 385	16 576	-62	-106	-617 977

A13 STORAGE D/S NYM WITH MAXIMISE HEP

A13.1 Description of the scenario

The purpose of providing storage downstream of NyM (Luengera) is to supplement HEP flows that have been reduced by agricultural development in the upstream catchments. The scenario comprised the following (in order of priority):

- Basic Human Needs
- Allocation of water for Urban/Industrial to Arusha and Moshi towards the 2025 demands.
- In the upper basin: As much water as can be abstracted at a 75% level of assurance allocated to agriculture.
- In the lower basin: 20 MCM storage in the lower Luengera to regulate water for HEP. Abstraction for agriculture restricted, to increase the amount of water that is available for HEP generation.
- Environment received whatever water was left.

A13.2 Hydrological implications

A13.2.1 Water allocated per sector

Urban/industrial 54.7 Mcm a^{-1} (PD = 31.1)
Irrigation 934 Mcm a^{-1} (PD = 1042)
HEP 478 802 MW h^{-1} (PD = 602 647)

A13.2.2 Changes in the flow regime relative to present day

The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 116. There were three main kinds of change relative to present day:

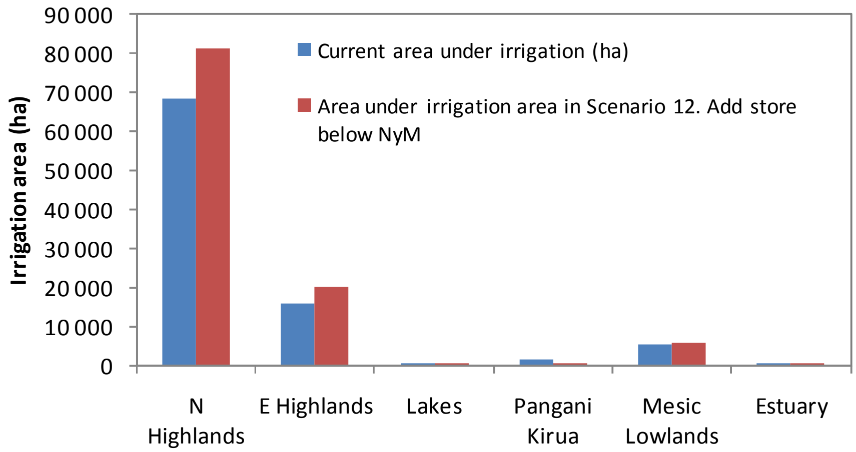
- reduced low flows in the upper catchment, Mkomazi and Lower Pangani Rivers;
- a loss of intra-annual floods in the Lower Pangani River
- increased low flows and a loss of intra-annual floods in the Luengera River; increased flows in the Pangani at Kirua.

Addendum Table 116 DRIFT flow summary data for Storage downstream of NyM with Maximise HEP scenario

Location	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario (MAR)	51.67	408.61	157.01	783.59	623.21	10.5	104.27	986.33
WSLF - Volumes (MCM)	16.51	271.7	72.38	499.08	306.34	1.41	32.8	491.99
DSLF - Volumes (MCM)	23.66	63.49	61.83	147.74	301.82	5.13	50.99	371.07
Class 1 - Annual Frequency	5.47	0.26	0	1.58	0	0.21	0.68	0.11
Class 2 - Annual Frequency	2.16	1.58	1.74	2.26	0.63	0.79	5.79	0.58
Class 3 - Annual Frequency	1.74	4.05	2.37	2.68	0.42	0.32	5.95	4.26
Class 4 - Annual Frequency	1.42	3.11	3.58	3.37	0	0.32	1.16	1.47
1:2	P	P	A	P	A	A	A	A
1:5	P	P	P	P	A	A	P	P
1:10	P	P	P	P	A	A	A	P
1:20	P	P	P	P	A	A	A	P

A13.3 Effects on irrigated agriculture

Under this scenario, the irrigation area is increased by about 27% and 17% in the Northern and Eastern Highlands, respectively, and decreases to about 22% of current in Pangani-Kirua. There is little change in the other zones. Overall irrigation area increases by 17% (Addendum Figure 118).



Addendum Figure 118 Area under irrigation under Storage downstream of NyM with Maximise HEP scenario compared with the Present Day

A13.4 Effects on HEP production

HEP decreases to 79% of current output, or 478 802 MWh.

A13.5 Effects on environmental condition

A13.5.1 Summary of biophysical condition in the river

The influence of the residual flows on the condition of the rivers is described in two ways:

- as percentage change relative to present day for key indicators representing each of geomorphology, water quality, riparian vegetation, macroinvertebrates and fish;
- in terms of change in overall river condition as denoted by the integrity score

Note: The Present Day levels of the indicators have not been quantified, thus the reported change is relative to an unknown quantity.

A13.5.1.1 Geomorphology

The geomorphological changes associated with this scenario occur throughout the catchment, with the exception of the Lower Ruvu and Lower Pangani Rivers (Addendum Table 117). The changes are similar but slightly more severe than they were for the Maximise HEP scenario and can be summarised as follows:

- noticeable reduction in rocky areas and loss of pools, and thus fish habitat and refuge in the Kikuletwa, Ruvu, Mkomazi and Luengera Rivers;
- build up of fine sediments especially in the Mkomazi and Luengera Rivers.

Addendum Table 117 Estimated percentage change from Present Day for geomorphological features under Storage downstream of NyM with Maximise HEP scenario

Site No.	Name	Riffles and rapids		Pools		Fine sediments		Coarse sediments		Bank erosion		Floodplain inundation	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	-20	0	1	25	0	0	0	0	0	0
2	Lower Kikuletwa	-60	-40	-60	-40	0	0	0	0	0	0	0	0
3	Upper Ruvu	-20	0	-20	0	26	68	-20	0	0	0	0	0
4	Lower Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
6	Pangani at Kirua	-20	0	-20	0	1	25	0	0	0	0	0	0
7	Lower Mkomazi	-100	-100	-100	-100	500	800	0	0	0	0	-100	-100
8	Lower Luengera	-100	-80	-60	-40	68	250	0	0	0	0	-100	-100
9	Lower Pangani	0	0	-20	0	-20	0	0	0	1	25	0	0

A13.5.1.2 Water Quality

The water quality changes associated with this scenario are similar but more pronounced than those associated with Maximise HEP scenario (Addendum Table 118). The changes can be summarised as follows:

- increase in conductivity in the Lower Kikuletwa and Mkomazi Rivers River and negligible increase in the Upper Kikuletwa and Ruvu Rivers;
- slight increase in phosphorus levels in the upper catchment and, slightly more pronounced increase in the Mkomazi River,
- negligible decline in nitrogen in the upper catchment and Luengera River.

Addendum Table 118 Estimated percentage change from Present Day for water quality under Storage downstream of NyM with Maximise HEP scenario

Site No.	Name	Turbidity/TSS		Conductivity/TDS		Phosphorus		Nitrogen	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	1	25	0	0	0	0
2	Lower Kikuletwa	1	25	251	500	26	68	-20	0
3	Upper Ruvu	0	0	1	25	1	25	0	0
4	Lower Ruvu	0	0	1	25	0	0	-20	0
6	Pangani at Kirua	0	0	0	0	0	0	0	0
7	Lower Mkomazi	0	0	500	800	251	500	0	0
8	Lower Luengera	0	0	0	0	1	25	-20	0
9	Lower Pangani	0	0	0	0	0	0	1	25

A13.5.1.3 Vegetation

The changes in riparian vegetation associated with this scenario (Addendum Table 119) can be summarised as follows:

- noticeable increase in wet bank vegetation in the Mkomazi and Luengera Rivers;
- negligible to slight decrease in wet bank herbs and grasses in the Kikuletwa River;
- negligible to slight decrease in dry bank vegetation in the Lower Pangani.

Addendum Table 119 Estimated percentage change from Present Day for vegetation under Storage downstream of NyM with Maximise HEP scenario

Site No.	Name	Dry Bank Trees		Dry Bank Herbs & Shrubs		Dry Bank Grasses		Wetbank Trees		Wetbank Herbs		Wetbank grasses and reeds	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-20	0	0	0	0	0	0	0	-20	0	0	0
2	Lower Kikuletwa	-20	0	0	0	0	0	0	0	-80	-60	-40	-20
3	Upper Ruvu	0	0	0	0	0	0	0	0	0	0	26	68
4	Lower Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
6	Pangani at Kirua	0	0	0	0	0	0	0	0	0	0	0	0
7	Lower Mkomazi	0	0	0	0	0	0	500	800	251	500	251	500
8	Lower Luengera	0	0	0	0	0	0	68	250	68	250	68	250
9	Lower Pangani	1	25	1	25	1	25	0	0	0	0	0	0

A13.5.1.4 Macroinvertebrates

The changes in macroinvertebrates associated with this scenario (Addendum Table 120) can be summarised as follows:

- low to severe decline in sensitive species throughout the catchment, with the exception of the Lower Pangani River;
- a decline in tolerant species also, except in the Lower Ruvu and Lower Pangani Rivers.

Addendum Table 120 Estimated percentage change from Present Day for macro-invertebrates under Storage downstream of NyM with Maximise HEP scenario

Site No.	Name	Sensitive species		Tolerant species (e.g., Dysticidae, Chironominae and Culicidae)		Pest Simuliidae	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	1	25	-40	-20
2	Lower Kikuletwa	-100	-100	-60	-40	-20	0
3	Upper Ruvu	-60	-40	-20	0	0	0
4	Lower Ruvu	-20	0	0	0	0	0
6	Pangani at Kirua	-20	0	-20	0	1	25
7	Lower Mkomazi	-100	-100	-60	-40	0	0
8	Lower Luengera	-60	-40	-40	-20	0	0
9	Lower Pangani	0	0	0	0	0	0

A13.5.1.5 Fish

The changes in fish associated with this (Addendum Table 121) can be summarised as follows:

- decrease in *Clarias* and *Labeo* in the upper catchment, possibly to local extinction for the latter in places;
- decline of all fish groups in the Mkomazi River, and *Tilapia* and *Labeo* in the Luengera River;
- moderate decrease in *Tilapia* in the Lower Pangani River.

Addendum Table 121 Estimated percentage change from Present Day for fish under Storage downstream of NyM with Maximise HEP scenario

Site No.	Name	*Clarias* group		*Tilapia* group		*Labeo* group	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	0	0	0	0
2	Lower Kikuletwa	-60	-40	0	0	-100	-80
3	Upper Ruvu	0	0	0	0	-60	-40
4	Lower Ruvu	-20	0	0	0	-20	0
6	Pangani at Kirua	0	0	0	0	0	0
7	Lower Mkomazi	-80	-60	-100	-100	-100	-100
8	Lower Luengera	0	0	-60	-40	-100	-100
9	Lower Pangani	0	0	-80	-60	0	0

A13.5.1.6 Overall condition

The changes in overall river condition associated with this scenario are provided in Addendum Table 122. There is a slight to moderate decline in overall condition all sites and a shift toward lower condition classes.

Addendum Table 122 Overall condition at each river site for the Storage downstream of NyM with Maximise HEP scenario

Site No.	Name	Present Day River Health Category	Change from Present Day ecological integrity	River Health Category for the scenario
1	Upper Kikuletwa	B/C	-0.132	C
2	Lower Kikuletwa	D	-0.227	D
3	Upper Ruvu	C/D	-0.141	D
4	Lower Ruvu	D	-0.027	D
6	Pangani at Kirua	C	-0.043	C
7	Lower Mkomazi	C/D	-0.990	D/E
8	Lower Luengera	C	-0.266	D
9	Lower Pangani	C	-0.044	C

A13.5.2 Summary of biophysical condition in NyM

A13.5.2.1 Water level change

The FA Tool assesses likely change in two parameters associated with NyM Dam – fish catch and reed area. These parameters are affected by water area (volume) of the lake and the variation in area, which are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under the maximise HEP scenario are presented in Addendum Table 123 and discussed in the respective sections below.

Addendum Table 123 Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in NyM under Storage downstream of NyM with Maximise HEP scenario relative to Present Day, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario

	Present Day	This Scenario	% Change
Mean lake area (ha)	103.8	60.1	-42%
Std dev of lake area (m)	1.24	1.37	10%
Max lake area (ha)	137.1	123.8	-10%
Mean lake level (m)	15.9	11	-31%
Std dev of lake level (m)	1.2	1.4	17%
Reed area (ha)	33.3	63.7	91%
Fish catch (tonnes)	3538.8	2409.8	-32%

A13.5.2.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surround NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under this scenario, lake area shrinks by 42%, variability increases slightly (up by 10%), and maximum area decreases by 10% (Addendum Table 123). The net result of this is that total reed area is expected to increase by 91%.

A13.5.2.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the present day we expect fish populations to expand in responses to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under this scenario, variability in lake level increases by 10% but average area declines by 10% (Addendum Table 123). Fish catches as a result, are expected to decline by 32%.

A13.5.3 Summary of biophysical condition in Kirua Swamp

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to present day.

Under this scenario, fish abundances are predicted to increase to 153% of present day (334 tonnes) and floodplain vegetation to increase to 159% of its present day extent.

A13.5.4 Summary of biophysical condition in the Estuary

A13.5.4.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under this scenario freshwater flows reaching the estuary are substantially lower than the Present Day during all four seasons (Addendum Table 124). The relative contribution by agricultural return flows is higher under this scenario, particularly during the short rains and Dry 1. Number of months where flow exceeds 250 Mm^3 is down by 25%.

Addendum Table 124 Change in freshwater flows reaching the estuary under the Storage downstream of NyM with Maximise HEP scenario relative to Present Day

		Short rains	Dry 1	Long rains	Dry 2	All months
Average monthly flows	Current day (Mm^3)	91.3	72.7	186.9	80.7	102.1
	Storage downstream of NyM with Maximise HEP (Mm^3)	57.9	38.6	164.1	70.3	48.6
	% Change	-36.6	-46.9	-12.2	-12.9	-52.4
Agricultural monthly return flows	Current day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	Storage downstream of NyM with Maximise HEP (Mm^3)	36.0	35.0	20.7	38.6	35.9
	% Change	15.3	35.3	4.1	0.5	37.2
No. months flow >250 Mm^3	Current day	8.0				
	Storage downstream of NyM with Maximise HEP (Mm^3)	6.0				
	% Change	-25.0				

Addendum Table 125 Health scores for the estuary as a whole and the component parameters under Storage downstream of NyM with Maximise HEP scenario relative to Present Day

	Present day	This scenario	% change from PD (+/-)
Geomorphology	40%	37%	-3%
Water Quality	53%	43%	-10%
Micro-algae	40%	33%	-7%
Vegetation	60%	57%	-3%
Invertebrates	60%	50%	-10%
Fish	50%	43%	-7%
Birds	40%	34%	-6%
Overall health score	57%	48%	-9%

A13.5.4.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the Present Day status of the mouth, which is both wide and deep. Thus, only the extreme high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significantly affect geomorphological conditions in

the estuary such as channel width and depth, and intertidal area, albeit on a relative small scale due to the large size of the tidal prism.

These high flows have changed only slightly from the present day under this scenario (down by 25%, Addendum Table 124) and given that they do not contribute as much to the current mouth status as the tidal flow, the resulting change in geomorphological conditions in the estuary can be expected to be small (down by 3%, Addendum Table 125).

A13.5.4.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Reduced flow volumes have a reduced capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under this scenario, mean monthly flows are lower and relative contributions by agricultural return flows have increased, particularly during the short rains and Dry 1. The combined effect of this is predicted to lead to a significant reduction in water quality (score decreases from 53 to 43%).

A13.5.4.4 Microalgae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient level) with the result that phytoplankton concentrations in the system are extremely high. Changes in water quality are mostly negative under this scenario and will give rise to a net increase in phytoplankton abundance with a concomitant reduction in health score associated with this parameter from 40 to 33%.

A13.5.4.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As mean monthly flows under the Present Day scenario are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the contribution from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production).

The effect of a net reduction in flow and a net increase in agricultural return flows anticipated under this scenario, are anticipated to have a negative influence on vegetation communities associated with the estuary, translating to a reduction in the health score of 3% (Addendum Table 125).

A13.5.4.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes in the geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality (reduced water clarity and oxygen levels, increased nutrients) between the natural and Present Day situations.

While geomorphological conditions are not expected to change significantly from the present day under this scenario, the anticipated reduction in water quality and increased eutrophication will manifest itself as a significant decrease in macroinvertebrate abundance from 60% to 50% (Addendum Table 125).

A13.5.4.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geomorphological characteristics and water quality as well as by the decline of their main food supply (invertebrates). As such the current health score is low (50%) and is expected to decline under this scenario by 7% (Addendum Table 125).

A13.5.4.8 Birds

Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the estuary and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). The predicted decrease in invertebrate and fish abundance is likely to be translated into a net decrease in the numbers and species of birds frequenting the estuary from 40% tp 34% (Addendum Table 125).

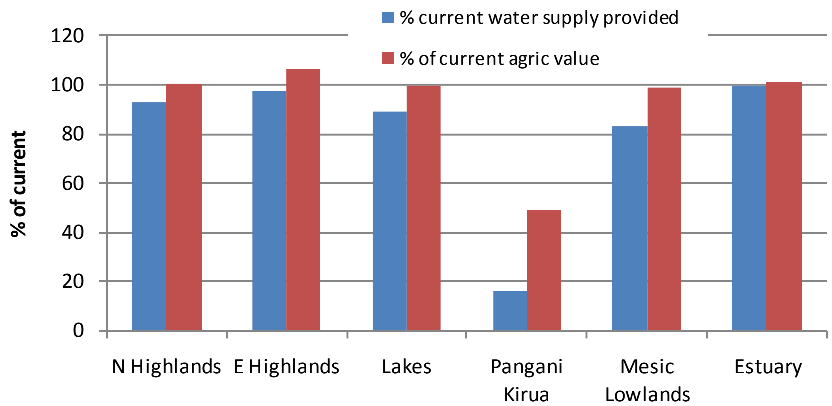
A13.5.4.9 Overall condition

Most measured health parameters in the estuary are expected to decline relative to the present day under this scenario with the result overall health score of the estuary is also expected to decline (down by 9% to 48%).

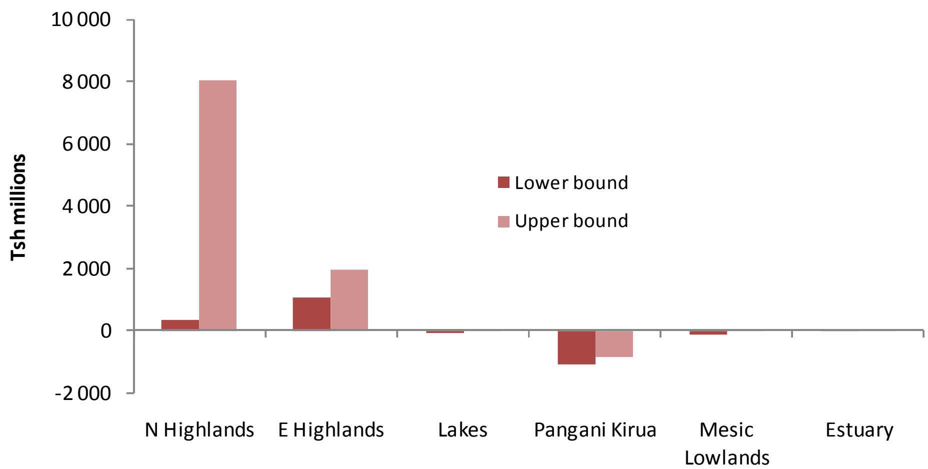
A13.6 Effects on livelihoods

A13.6.1 Income from small-scale agriculture

Addendum Figure 119 shows aggregate net income from agriculture to rural households within 5 km of rivers under the scenario as a percentage of current value. Under this scenario, income is slightly increased in the Eastern Highlands, is very much reduced in Pangani-Kirua, and remains relatively unchanged in the other zones. Because of the large proportion of the population being in the Northern Highlands, the absolute change in value is highest in this zone (Addendum Figure 120).



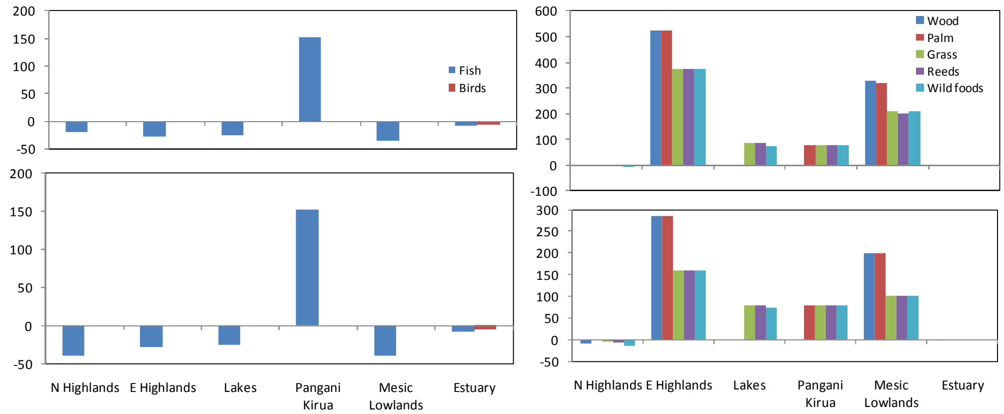
Addendum Figure 119 Area under small-scale irrigation under Storage downstream of NyM with Maximise HEP scenario compared with the Present Day



Addendum Figure 120 Lower and upper bound estimates of the aggregate change in income from small-scale agriculture under Storage downstream of NyM with Maximise HEP scenario

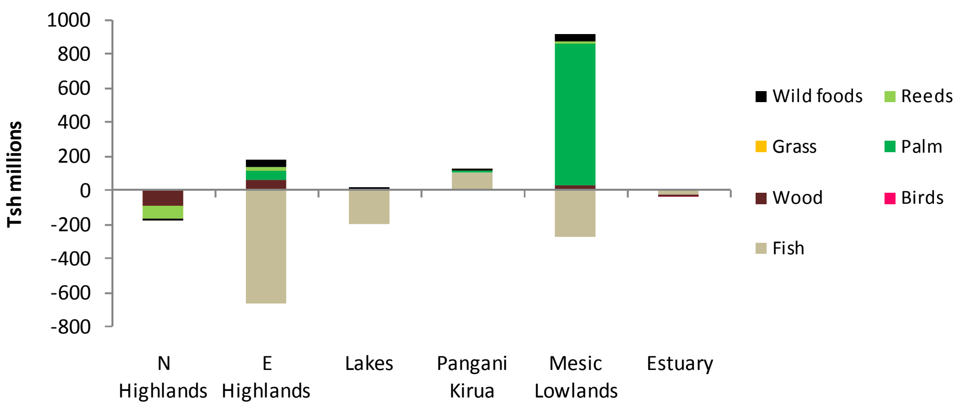
A13.6.2 Income from natural resources

Fish increase markedly in abundance in the Pangani-Kirua zone, but decrease slightly in all the other zones. Plant resources increase by up to several fold in all but the Northern Highlands and Estuary (Addendum Figure 121).



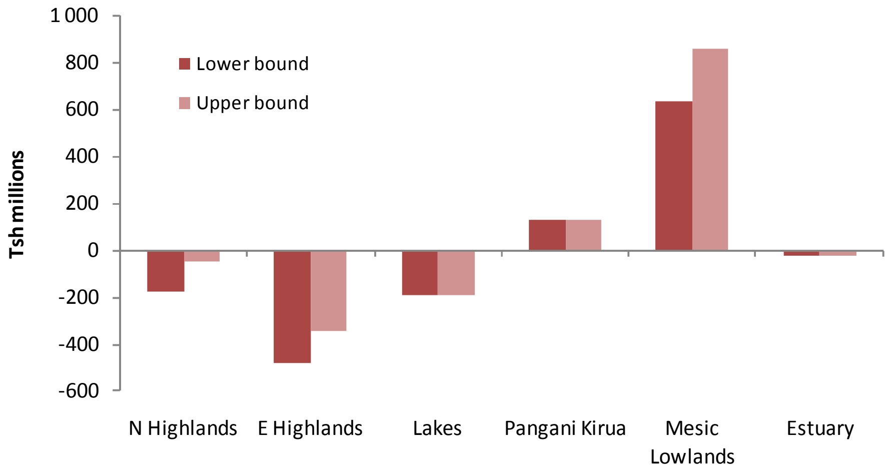
Addendum Figure 121 Lower and upper bound estimates of the percentage change from present day in the abundance of natural resources used by households, Storage downstream of NyM with Maximise HEP scenario

Impacts of these changes on income to households are shown in Addendum Figure 102.



Addendum Figure 122 Lower-bound estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under Storage downstream of NyM with Maximise HEP scenario

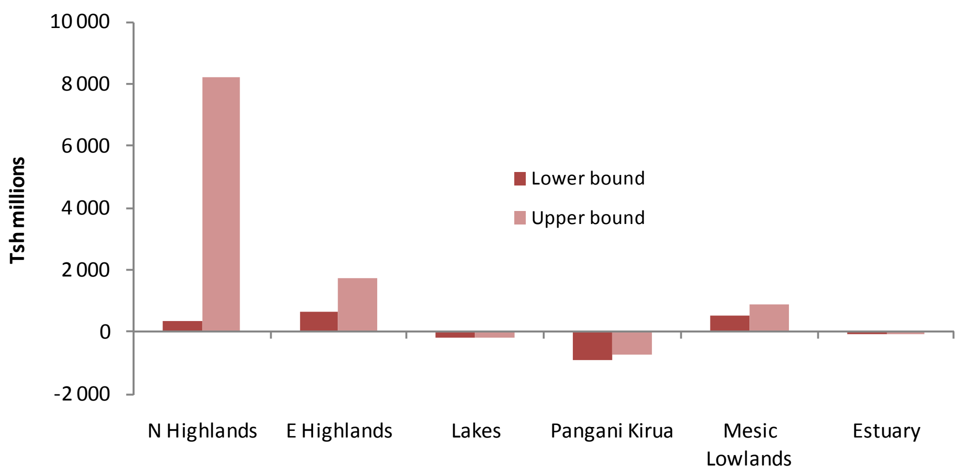
There is an increase in income from natural resources in Pangani-Kirua and particularly the Mesic Lowlands, but decreases in the remaining zones (Addendum Figure 123).



Addendum Figure 123 Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under Storage downstream of NyM with Maximise HEP scenario

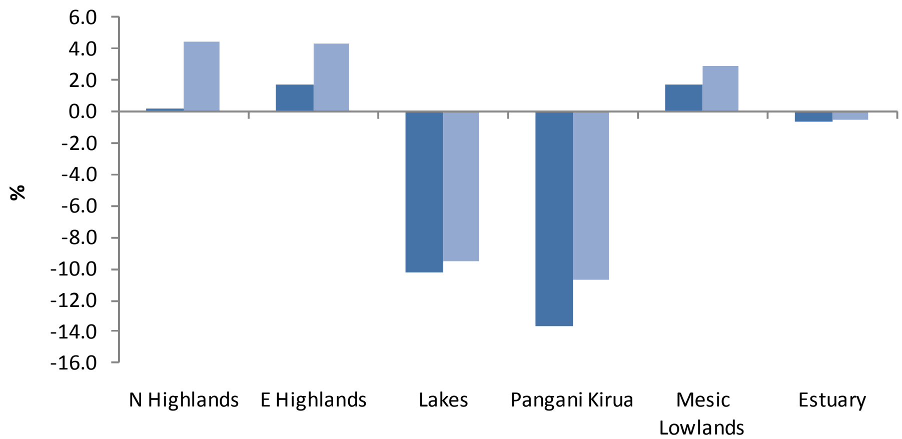
A13.6.3 Overall household income

Aggregate income is expected to increase in the Highland areas and Mesic lowlands, and to decrease slightly in Pangani-Kirua (Addendum Figure 124).



Addendum Figure 124. Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, under the Storage downstream of NyM with Maximise HEP scenario

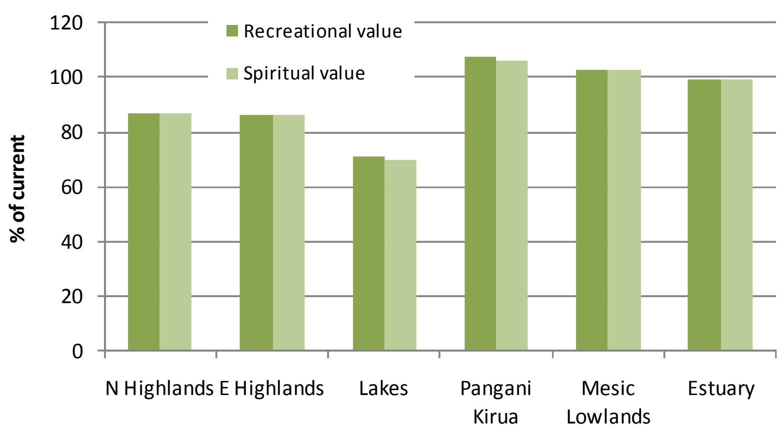
Aggregate household income decreases by about 10 - 12% in the Lakes and Pangani-Kirua and Pangani-Kirua (Addendum Figure 125), but increases slightly in the remaining zones apart from the Estuary.



Addendum Figure 125 Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under Storage downstream of NyM with Maximise HEP scenario

A13.6.4 Intangible values

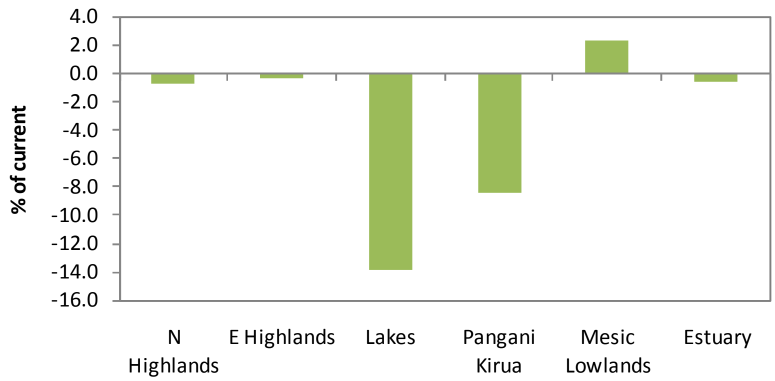
There is a decrease in recreational and spiritual well-being among households in the Highlands and Lakes, while scores remain similar to the present day in the remaining zones (Addendum Figure 126).



Addendum Figure 126 Overall recreational and spiritual well-being (derived from rivers and other sources) under Storage downstream of NyM with Maximise HEP scenario as a percentage of current well-being

A13.6.5 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 127. There is a relatively strongly negative impact on well-being in the Lakes and Pangani-Kirua and no significant change in any other zone.



Addendum Figure 127 Percentage change in overall well-being of households within 5 km of rivers under Storage downstream of NyM with Maximise HEP scenario

A13.7 Effects on economic value

Under this scenario, changes in environmental quality and function lead to gains in value of natural resources and ecosystem regulating services, and much larger gains in agricultural output. These gains are offset by much larger losses in the HEP sector (Addendum Table 126).

Addendum Table 126 Gains and losses in the value of HEP, agriculture, natural resources and ecosystem regulating services (Tsh millions per year) under the Storage downstream of NyM with Maximise HEP scenario

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
-423 001	11 743	136	78	-411 045

A14 COMBINATION OF U/S AND D/S STORAGE

A14.1 Description of the scenario

The Combination of storage upstream of NyM, with Maximise Agriculture AND storage downstream of NyM (Luengera), with Maximise HEP scenario comprised the following (in order of priority):

- Basic Human Needs
- Allocation of water for Urban/Industrial to Arusha and Moshi towards the 2025 demands.
- In the upper basin: 56 MCM storage in the Kikuletwa catchment and 10 MCM storage in the Ruvu catchment to store some wet-season flows. As much water as can be abstracted at a 75% level of assurance allocated to agriculture.
- In the lower basin: 20 MCM storage in the lower Luengera to regulate water for HEP. Abstraction for agriculture restricted, to increase the amount of water that is available for HEP generation.
- Environment received whatever water was left.

A14.2 Hydrological implications

A14.2.1 Water allocated per sector

Urban/industrial 54.7 Mcm a^{-1} (PD = 31.1)
Irrigation 950 Mcm a^{-1} (PD = 1042)
HEP 472 745 MW h^{-1} (PD = 602 647)

A14.2.2 Changes in the flow regime relative to present day

The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 127. There were three main kinds of change relative to present day:

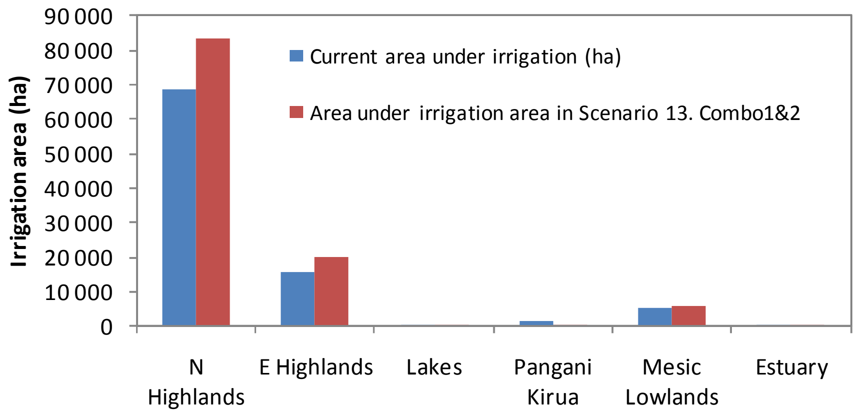
- reduced low flows in upper catchment and Mkomazi River;Kirua (Site 6): 2x flooding of PD;
- increased low flows and reduced Class 1 floods in the Luengera River.

Addendum Table 127 DRIFT flow summary data for the Combination of u/s and d/s Storage scenario

Location	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario (MAR)	50.72	393.74	157	782.26	611.8	10.5	104.42	975.78
WSLF - Volumes (MCM)	16.46	263.61	75.69	500.98	292.2	1.65	32.94	477.57
DSLF - Volumes (MCM)	22.88	64.41	61.62	155.41	279.38	5.16	51.8	361.25
Class 1 - Annual Frequency	4.47	0.37	0	1.63	0.11	1	0.84	0
Class 2 - Annual Frequency	2.11	1.63	0.89	2.11	3.47	0.89	6.53	0.47
Class 3 - Annual Frequency	1.72	4.26	2.26	2.47	0.68	0.53	5.68	3.63
Class 4 - Annual Frequency	1.42	3.05	3.63	3.26	0	0.21	1.32	1.26
1:2	P	P	A	P	A	A	A	A
1:5	P	P	P	P	A	A	P	P
1:10	P	P	P	P	A	A	A	P
1:20	P	P	P	P	A	A	A	P

A14.3 Effects on irrigated agriculture

Under this scenario, the irrigation area is increased by about 27% and 19% in the Northern and Eastern Highlands, respectively, and decreases to about 22% of current in Pangani-Kirua. There is little change in the other zones. Overall irrigation area increases by 18% (Addendum Figure 128).



Addendum Figure 128 Area under irrigation under the Combination of u/s and d/s Storage scenario compared with the Present Day

A14.4 Effects on HEP production

HEP decreases to 78% of current output, or 472 745 MWh.

A14.5 Effects on environmental condition

A14.5.1 Summary of biophysical condition in the river

The influence of the residual flows on the condition of the rivers is described in two ways:

- as percentage change relative to present day for key indicators representing each of geomorphology, water quality, riparian vegetation, macroinvertebrates and fish;
- in terms of change in overall river condition as denoted by the integrity score.

Note: The Present Day levels of the indicators have not been quantified, thus the reported change is relative to an unknown quantity.

A14.5.1.1 Geomorphology

The geomorphological changes associated with this scenario are concentrated in the upper portion of the catchment, i.e., upstream of NyM and in the Mkomazi and Luengera Rivers (Addendum Table 128). The changes are similar to those for the Storage upstream of NyM with Maximise Agriculture scenario and can be summarised as follows:

- noticeable reduction in rocky areas, and thus fish habitat in the Kikuletwa, Ruvu, Mkomazi and Luengera Rivers;
- loss of pools, and thus fish refuge, at the same sites;
- build up of fine sediments at the same sites;

- severe loss of remaining floodplains in the Mkomazi and Luengera Rivers, but a very mild restoration of the floodplains along the Pangani River at Kirua.

Addendum Table 128 Estimated percentage change from Present Day for geomorphological features under the Combination of u/s and d/s Storage scenario

Site No.	Name	Riffles and rapids		Pools		Fine sediments		Coarse sediments		Bank erosion		Floodplain inundation	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	-20	0	1	25	0	0	0	0	0	0
2	Lower Kikuletwa	-60	-40	-60	-40	0	0	0	0	0	0	0	0
3	Upper Ruvu	-20	0	-20	0	26	68	-20	0	0	0	0	0
4	Lower Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
6	Pangani at Kirua	0	0	0	0	1	25	0	0	0	0	26	68
7	Lower Mkomazi	-100	-100	-100	-100	500	800	0	0	0	0	-100	-100
8	Lower Luengera	-100	-80	-60	-40	68	250	0	0	0	0	-100	-100
9	Lower Pangani	0	0	-20	0	-20	0	0	0	1	25	0	0

A14.5.1.2 Water Quality

The water quality changes associated with this scenario (Addendum Table 129) can be summarised as follows:

- slight to moderate increase in conductivity in the Kikuletwa and Mkomazi Rivers;
- slight to moderate increase in phosphorus in the Lower Kikuletwa and Mkomazi Rivers, and a negligible to slight increase in phosphorus levels in the upper Ruvu, Luengera and lower Pangani River.

Addendum Table 129 Estimated percentage change from Present Day for water quality under the Combination of u/s and d/s Storage scenario

Site No.	Name	Turbidity/TSS		Conductivity/TDS		Phosphorus		Nitrogen	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	1	25	0	0	0	0
2	Lower Kikuletwa	1	25	251	500	26	68	-20	0
3	Upper Ruvu	0	0	1	25	1	25	0	0
4	Lower Ruvu	0	0	0	0	0	0	0	0
6	Pangani at Kirua	0	0	0	0	0	0	0	0
7	Lower Mkomazi	0	0	251	500	251	500	0	0
8	Lower Luengera	0	0	0	0	1	25	-20	0
9	Lower Pangani	0	0	1	25	1	25	1	25

A14.5.1.3 Vegetation

The changes in riparian vegetation associated with this scenario (Addendum Table 130) can be summarised as follows:

- noticeable increase in wet bank vegetation across in the Ruvu, Pangani at Kirua, Luengera and Mkomazi Rivers;
- noticeable decrease in wet bank vegetation in the Lower Kikuletwa River.

Addendum Table 130 Estimated percentage change from Present Day for vegetation under the Combination of u/s and d/s Storage scenario

Site No.	Name	Dry Bank Trees		Dry Bank Herbs & Shrubs		Dry Bank Grasses		Wetbank Trees		Wetbank Herbs		Wetbank grasses and reeds	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-20	0	0	0	0	0	0	0	-20	0	0	0
2	Lower Kikuletwa	-20	0	0	0	0	0	0	0	-80	-60	-40	-20
3	Upper Ruvu	0	0	0	0	0	0	0	0	0	0	26	68
4	Lower Ruvu	0	0	0	0	0	0	0	0	1	25	0	0
6	Pangani at Kirua	0	0	0	0	0	0	1	25	0	0	0	0
7	Lower Mkomazi	0	0	0	0	0	0	251	500	68	250	68	250
8	Lower Luengera	0	0	0	0	0	0	26	68	26	68	26	68
9	Lower Pangani	1	25	1	25	1	25	0	0	0	0	0	0

A14.5.1.4 Macroinvertebrates

The changes in macroinvertebrates associated with this scenario (Addendum Table 131) can be summarised as follows:

- low to severe decline in sensitive species throughout the catchment, with possible local extinction in places;
- a decline in tolerant species, except in the Upper Kikuletwa and Lower Ruvu where they are expected to increase but negligibly;
- a decline in pest species in the Upper Kikuletwa River.

Addendum Table 131 Estimated percentage change from Present Day for macroinvertebrates under the Combination of u/s and d/s Storage scenario.

Site No.	Name	Sensitive species		Tolerant species (e.g., Dysticidae, Chironominae and Culicidae)		Pest Simuliidae	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	1	25	-40	-20
2	Lower Kikuletwa	-100	-100	-60	-40	-20	0
3	Upper Ruvu	-60	-40	-20	0	0	0
4	Lower Ruvu	-20	0	1	25	0	0
6	Pangani at Kirua	-20	0	-20	0	1	25
7	Lower Mkomazi	-100	-100	-80	-60	0	0
8	Lower Luengera	-40	-20	-40	-20	0	0
9	Lower Pangani	0	0	0	0	0	0

A14.5.1.5 Fish

The changes in fish associated with this (Addendum Table 132) can be summarised as follows:

- decrease in *Clarias* and *Labeo* in the upper catchment, possibly to local extinction for the latter in places;
- increase in *Clarias* in the Pangani at Kirua;
- decline of all fish groups in the Mkomazi River;
- decrease in *Tilapia* and *Labeo* in the Luengera River, possibly to local extinction for the latter in places;
- decrease in *Tilapia* in the Lower Pangani River.

Addendum Table 132 Estimated percentage change from Present Day for fish under the Combination of u/s and d/s Storage scenario

Site No.	Name	*Clarias* group		*Tilapia* group		*Labeo* group	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	0	0	0	0
2	Lower Kikuletwa	-60	-40	0	0	-100	-80
3	Upper Ruvu	0	0	0	0	-60	-40
4	Lower Ruvu	-20	0	0	0	-20	0
6	Pangani at Kirua	1	25	0	0	0	0
7	Lower Mkomazi	-80	-60	-100	-100	-100	-100
8	Lower Luengera	0	0	-60	-40	-100	-100
9	Lower Pangani	0	0	-80	-60	0	0

A14.5.1.6 Overall condition

The changes in overall river condition associated with this scenario are provided in Addendum Table 133. There is a slight to moderate decline in overall condition at different sites, except for a negligible improvement at Kirua. There is a mild shift toward lower condition classes.

Addendum Table 133 Overall condition at each river site for the Combination of u/s and d/s Storage scenario

Site No.	Name	Present Day River Health Category	Change from Present Day ecological integrity	River Health Category for the scenario
1	Upper Kikuletwa	B/C	-0.138	C
2	Lower Kikuletwa	D	-0.227	D
3	Upper Ruvu	C/D	-0.132	D
4	Lower Ruvu	D	-0.041	D
6	Pangani at Kirua	C	0.014	D
7	Lower Mkomazi	C/D	-0.915	D/E
8	Lower Luengera	C	-0.245	D
9	Lower Pangani	C	-0.040	C

A14.5.2 Summary of biophysical condition in NyM

A14.5.2.1 Water level change

The FA Tool assesses likely change in two parameters associated with NyM Dam – fish catch and reed area. These parameters are affected by water area (volume) of the lake and the variation in area, which are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under the maximise HEP scenario are presented in Addendum Table 134 and discussed in the respective sections below.

Addendum Table 134 Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in NyM under the Combination of u/s and d/s Storage scenario relative to Present Day, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario

	Present Day	This Scenario	% Change
Mean lake area (ha)	103.8	59	-43%
Std dev of lake area (m)	1.24	1.3	4%
Max lake area (ha)	137.1	119.8	-13%
Mean lake level (m)	15.9	10.9	-31%
Std dev of lake level (m)	1.2	1.3	8%
Reed area (ha)	33.3	60.6	82%
Fish catch (tonnes)	3538.8	2382.4	-33%

A14.5.2.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surround NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under this scenario, lake area shrinks by 43%, but variability changes little and maximum area decreases by 11% (Addendum Table 134). The net result of this is that total reed area is expected to increase by 82%.

A14.5.2.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the present day we expect fish populations to expand in responses to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under this scenario, variability in lake level decreases markedly by 31% and average area declines by 13% (Addendum Table 134). Fish catches as a result, are expected to decline (down by 33%).

A14.5.3 Summary of biophysical condition in Kirua Swamp

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to present day.

Under this scenario, fish abundances are predicted to increase by 94% from present day (257 tonnes) and floodplain vegetation to increase by 98% from its present day extent.

A14.5.4 Summary of biophysical condition in the Estuary

A14.5.4.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under this scenario freshwater flows reaching the estuary are substantially lower than Present Day during all four seasons but particularly during the short rains and Dry 1 (Addendum Table 135). The contribution by agricultural return flows increase however, particularly during the short rains and Dry 1. Number of months where flow exceeds 250 Mm^3 is down by 25%.

Addendum Table 135 Change in freshwater flows reaching the estuary under the Combination of u/s and d/s Storage scenario relative to PD

		Short rains	Dry 1	Long rains	Dry 2	All months
Average monthly flows	Current day (Mm^3)	91.3	72.7	186.9	80.7	102.1
	Combination of u/s and d/s Storage (Mm^3)	56.8	38.6	164.1	70.3	48.6
	% Change	-37.8	-46.9	-12.2	-12.9	-52.4
Agricultural monthly return flows	Current day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	Combination of u/s and d/s Storage (Mm^3)	35.8	35.0	20.7	40.1	36.4
	% Change	16.1	35.3	4.1	2.7	38.2
No. months flow >250 Mm^3	Current day	8.0				
	Combination of u/s and d/s Storage (Mm^3)	6.0				
	% Change	-25.0				

Addendum Table 136 Health scores for the estuary as a whole and the component parameters under the Combination of u/s and d/s Storage scenario relative to PD

	Present day	This scenario	% change from PD (+/-)
Geomorphology	40%	37%	-3%
Water Quality	53%	42%	-11%
Micro-algae	40%	33%	-7%
Vegetation	60%	57%	-3%
Invertebrates	60%	49%	-11%
Fish	50%	42%	-8%
Birds	40%	34%	-6%
Overall health score	57%	48%	-9%

A14.5.4.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the Present Day status of the mouth, which is both wide and deep. Thus, only the extreme high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significantly affect geomorphological conditions in

the estuary such as channel width and depth, and intertidal area, albeit on a relative small scale due to the large size of the tidal prism.

These high flows have changed little from the present day under this scenario (down by 25%, Addendum Table 102) and given that they do not contribute as much to the current mouth status as the tidal flow, the resulting change in geomorphological conditions in the estuary can be expected to be a small (down by 3%,Addendum Table 136).

A14.5.4.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Reduced flow volumes have a reduced capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under this scenario, mean monthly flows are lower and contributions by agricultural return flows have increased, particularly during the short rains and Dry 1. The combined effect of this is predicted to lead to a net reduction in water quality (score decreases from 53 to 42%).

A14.5.4.4 Microalgae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient level) with the result that phytoplankton concentrations in the system are extremely high. Further reductions in water quality anticipated under this scenario (increased nutrient concentrations) are expected to give rise to a net increase in phytoplankton abundance with a concomitant decrease in health score associated with this parameters from 40 to 33%.

A14.5.4.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As mean monthly flows under the Present Day scenario are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the contribution from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production).

The effect of a decrease in flow and a net increase in agricultural return flows anticipated under this scenario, are anticipated to have a negative impact on vegetation communities associated with the estuary, translating to a reduction in the health score of 3% (Addendum Table 136).

A14.5.4.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes in the

geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality (reduced water clarity and oxygen levels, increased nutrients) between the natural and Present Day situations.

While geomorphological conditions are not expected to change significantly from the present day under this scenario, the anticipated reduction in water quality will manifest itself as a decrease in macroinvertebrate abundance from 60% to 49% (Addendum Table 136).

A14.5.4.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geomorphological characteristics and water quality as well as by the decline of their main food supply (invertebrates). As such the current health score is low (50%) and is expected to decline further still under this scenario (down by *%, Addendum Table 136).

A14.5.4.8 Birds

Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the estuary and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). The predicted decrease in invertebrate and fish abundance is likely to be translated into a further decline in the numbers and species of birds frequenting the estuary from 40% tp 34% of pristine (Addendum Table 136).

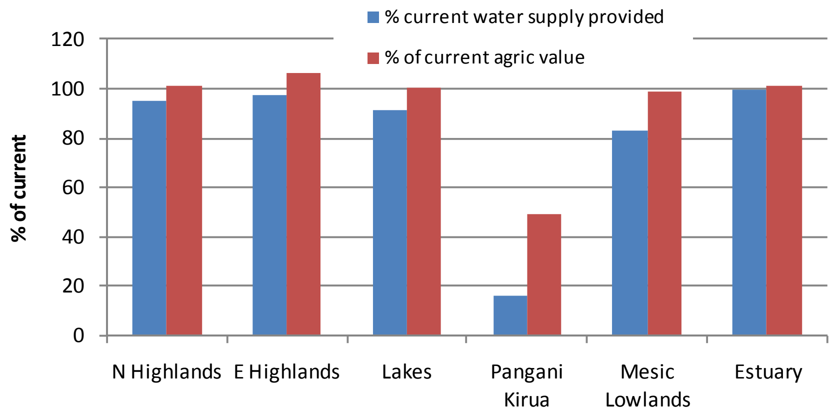
A14.5.4.9 Overall condition

Most measured health parameters in the estuary decline markedly from the present day under this scenario with the result that overall health score of the estuary is expected to decline markedly too (down to 48%).

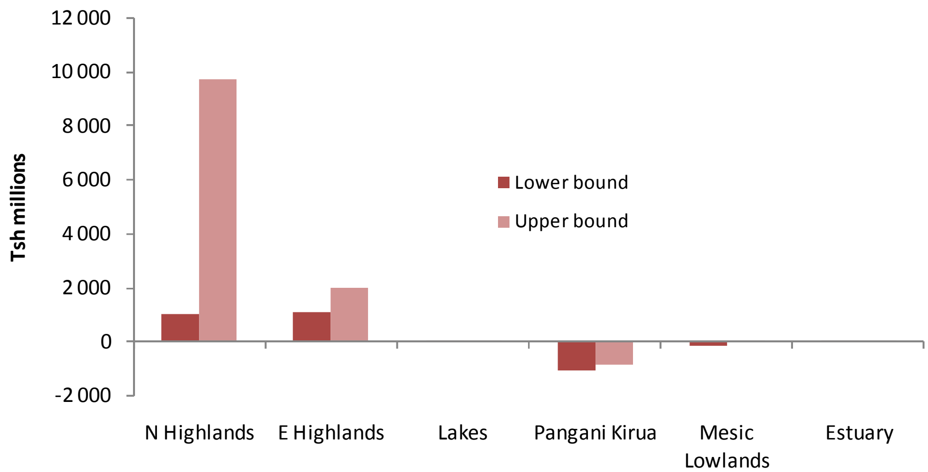
A14.6 Effects on livelihoods

A14.6.1 Income from small-scale agriculture

Addendum Figure 129 shows aggregate net income from agriculture to rural households within 5 km of rivers under the scenario as a percentage of current value. Under this scenario, income is slightly increased in the Eastern Highlands, is very much reduced in Pangani-Kirua, and remains relatively unchanged in the other zones. Because of the large proportion of the population being in the Northern Highlands, the absolute change in value is potentially highest in this zone, with a slightly greater increase than in the previous scenario (Addendum Figure 130).



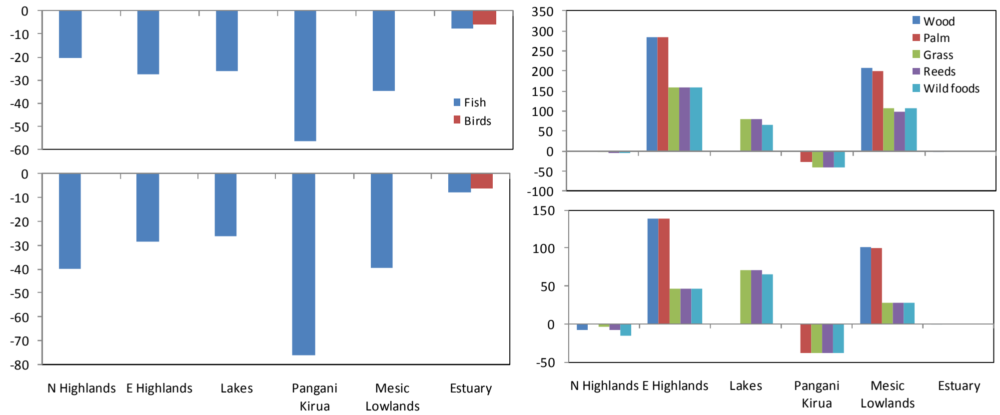
Addendum Figure 129 Area under small-scale irrigation under the Combination of u/s and d/s Storage scenario compared with the Present Day



Addendum Figure 130 Lower and upper bound estimates of the aggregate change in income from small-scale agriculture under the Combination of u/s and d/s Storage scenario

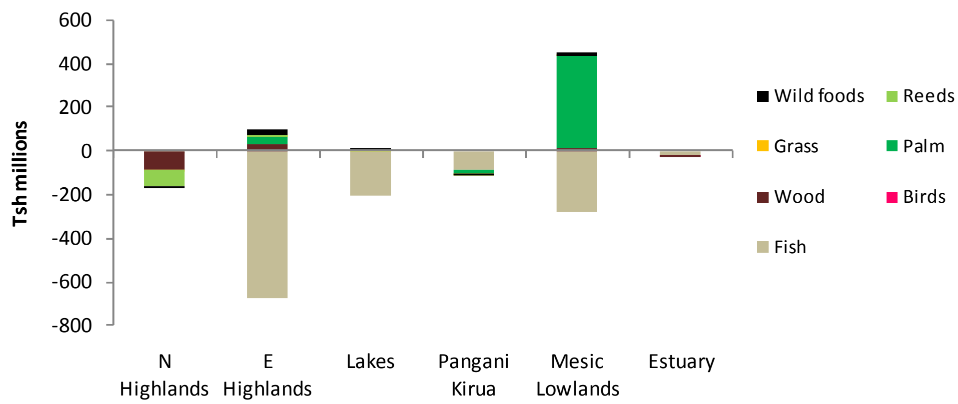
A14.6.2 Income from natural resources

Fish decrease in abundance in all the zones, with the greatest impact in Pangani-Kirua and smallest at the Estuary. Plant resources substantially increase in abundance in the Eastern Highlands, Lakes and Mesic Lowlands, and decrease slightly in Pangani-Kirua (Addendum Figure 131).



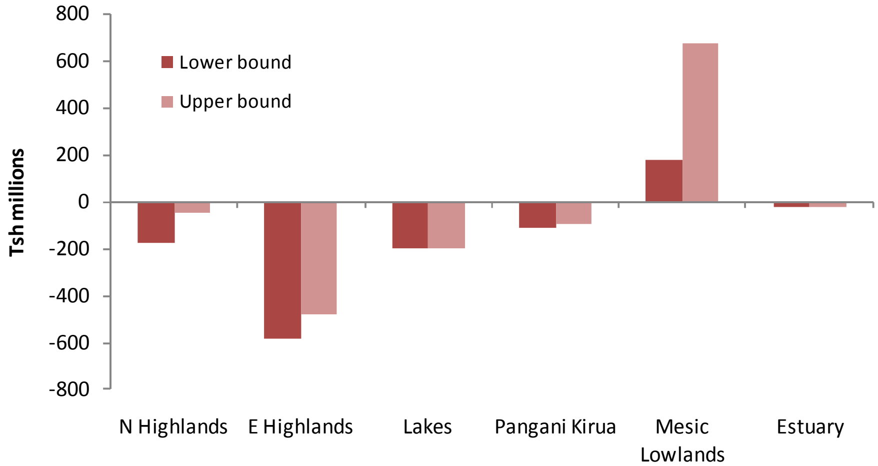
Addendum Figure 131 Lower and upper bound estimates of the percentage change from PD in the abundance of natural resources used by households, under the Combination of u/s and d/s Storage scenario

Impacts of these changes on income to households are shown in Addendum Figure 132.



Addendum Figure 132 Lower-bound estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under the Combination of u/s and d/s Storage scenario

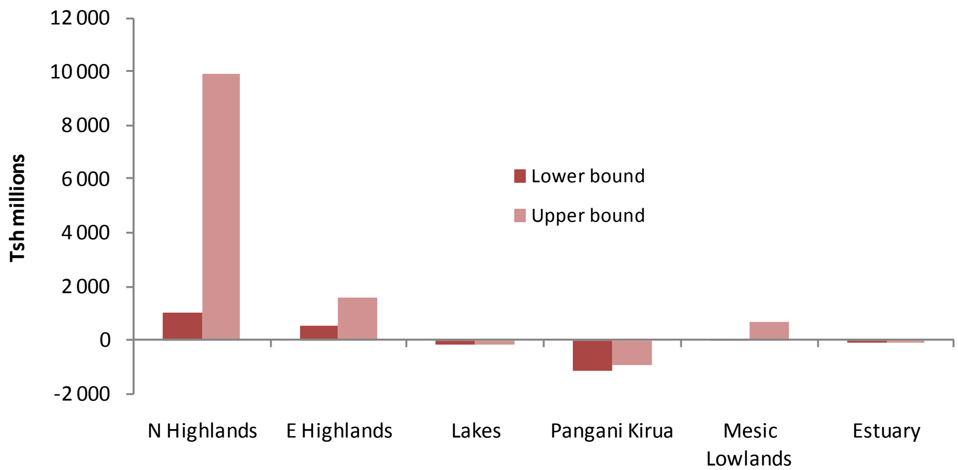
There is an increase in income from natural resources in the Mesic Lowlands, but decreases in all the other zones (Addendum Figure 133).



Addendum Figure 133 Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under the Combination of u/s and d/s Storage scenario

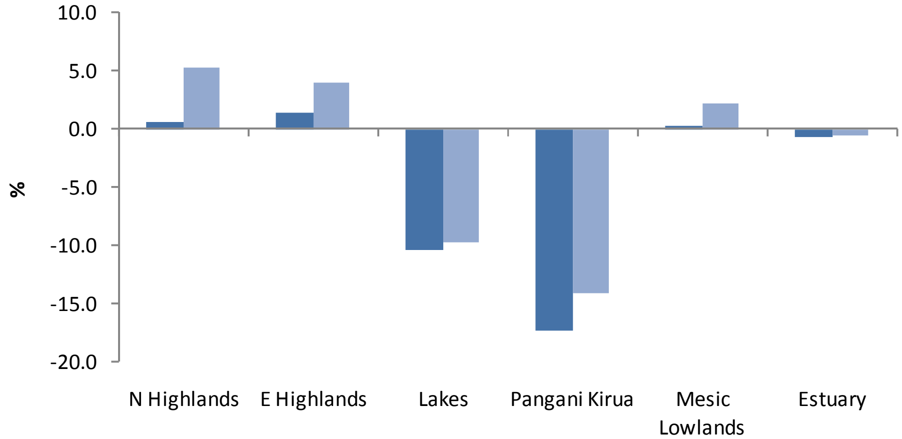
A14.6.3 Overall household income

Aggregate income is expected to increase in the Highland areas and Mesic lowlands, and to decrease slightly in Pangani-Kirua (Addendum Figure 134).



Addendum Figure 134 Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, under the Combination of u/s and d/s Storage scenario

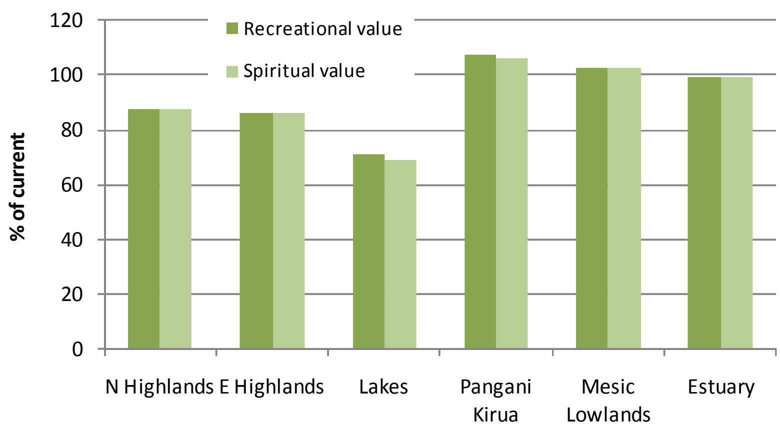
Aggregate household income decreases by about 10 - 15% in the Lakes and Pangani-Kirua and Pangani-Kirua (Addendum Figure 135), but increases slightly in the remaining zones apart from the Estuary.



Addendum Figure 135 Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under the Combination of u/s and d/s Storage scenario

A14.6.4 Intangible values

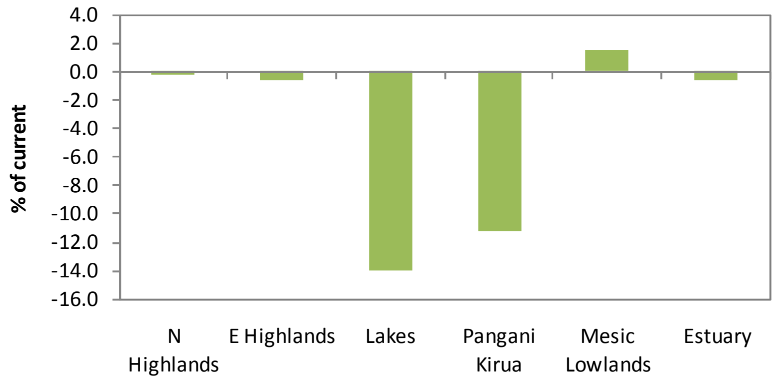
There is a decrease in recreational and spiritual well-being among households in the Highlands and Lakes, while scores remain similar to the present day in the remaining zones (Addendum Figure 136).



Addendum Figure 136 Overall recreational and spiritual well-being (derived from rivers and other sources) under the Combination of u/s and d/s Storage scenario as a percentage of current well-being

A14.6.5 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 137. There is a relatively strongly negative impact on well-being in the Lakes and Pangani-Kirua and no significant change in any other zone.



Addendum Figure 137 Percentage change in overall well-being of households within 5 km of rivers under the Combination of u/s and d/s Storage scenario

A14.7 Effects on economic value

Under this scenario, changes in environmental quality and function lead to a small loss of value in terms of natural resources and ecosystem regulating services, but a larger gain in terms of agricultural outputs. Very much larger losses are incurred in the energy sector (Addendum Table 137).

Addendum Table 137 Gains and losses in the value of HEP, agriculture, natural resources and ecosystem regulating services (Tsh millions per year) under the Combination of u/s and d/s Storage scenario

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
-444 648	14 909	-542	-98	-430 379

A15 MIXED BENEFITS

A15.1 Description of the scenario

The Mixed Benefits scenario comprised the following (in order of priority):

- Basic Human Needs
- Allocation of water for Urban/Industrial to Arusha and Moshi towards the 2025 demands.
- In the upper basin: As much water as can be abstracted at a 75% level of assurance allocated to agriculture.
- In the lower basin: Supply of present day volumes of river flow in a revised pattern of flows to improve ecosystem condition at Kirua Swamps. Abstraction for agriculture restricted, to increase the amount of water that is available for HEP generation.
- Environment received whatever water was left.

A15.2 Hydrological implications

A15.2.1 Water allocated per sector

Urban/industrial 54.7 Mcm a^{-1} (PD = 31.1)
Irrigation 932 Mcm a^{-1} (PD = 1042)
HEP 436 558 MW h^{-1} (PD = 602 647)

A15.2.2 Changes in the flow regime relative to present day

The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 138. There were four main kinds of change relative to present day:

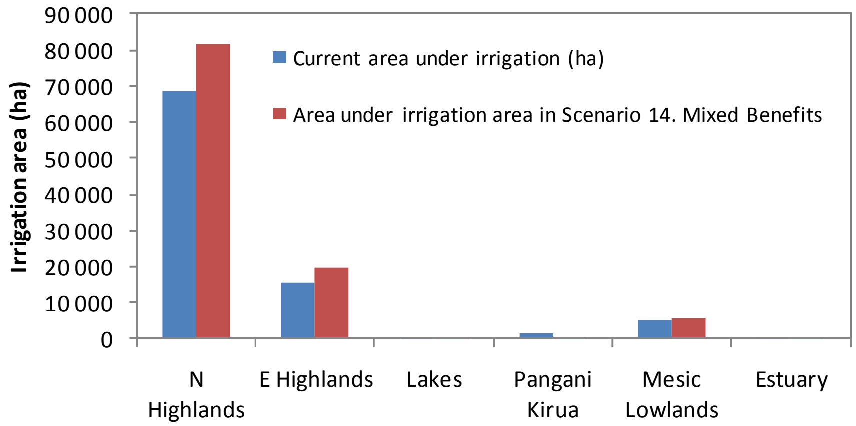
- reduced low flows in the upper catchment, Mkomazi River and Lower Pangani River;
- increased low flows in the Luengera River, with the loss of some intra-annual floods;
- five-fold increased in inundation of Kirua Swamps;
- loss of inter-annual floods.

Addendum Table 138 DRIFT flow summary data for Mixed Benefits scenario

Location	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario (MAR)	50.76	393.7	157	782.3	644.9	10.5	105.2	1012.1
WSLF - Volumes (MCM)	16.47	263.3	75.68	501.1	295.2	1.65	30.16	523.38
DSLF - Volumes (MCM)	22.8	64.49	61.49	155.6	288.1	5.16	55.26	314.14
Class 1 - Annual Frequency	5.42	0.32	0	1.37	0.11	1	0.89	0.16
Class 2 - Annual Frequency	2.53	1.68	1	2.11	2.89	0.89	5.47	0.47
Class 3 - Annual Frequency	1.79	4.37	2.37	2.47	0.63	0.53	5.16	3.47
Class 4 - Annual Frequency	1.42	3.05	3.68	3.26	0	0.21	1.74	2.26
1:2	P	P	A	P	A	A	A	A
1:5	P	P	P	P	A	A	A	P
1:10	P	P	P	P	A	A	P	P
1:20	P	P	P	P	A	A	P	P

A15.3 Effects on irrigated agriculture

Under this scenario, the irrigation area is increased by about 19% and 25% in the Northern and Eastern Highlands, respectively, and decreases to about 22% of current in Pangani-Kirua. There is little change in the other zones. Overall irrigation area increases by 20% (Addendum Figure 138).



Addendum Figure 138 Area under irrigation under Mixed Benefits scenario compared with the Present Day

A15.4 Effects on HEP production

HEP decreases to 72% of current output, or 436 558 MWh.

A15.5 Effects on environmental condition

A15.5.1 Summary of biophysical condition in the river

The influence of the residual flows on the condition of the rivers is described in two ways:

- as percentage change relative to present day for key indicators representing each of geomorphology, water quality, riparian vegetation, macroinvertebrates and fish;
- in terms of change in overall river condition as denoted by the integrity score

Note: The Present Day levels of the indicators have not been quantified, thus the reported change is relative to an unknown quantity.

A15.5.1.1 Geomorphology

The geomorphological changes associated with this scenario (Addendum Table 139) can be summarised as follows:

- noticeable reduction in rocky areas, and thus fish habitat in the Kikuletwa, Mkomazi and Luengera Rivers;
- loss of pools, and thus fish refuge, at the same sites;
- increase in rocky habitats and pools in the Pangani River at Kirua;
- build up of fine sediments especially in the Upper Ruvu, Mkomazi and Luengera Rivers;
- severe loss of remaining floodplains in the Mkomazi and Luengera Rivers, but a partial restoration of the floodplains along the Pangani River at Kirua.

Addendum Table 139 Estimated percentage change from Present Day for geomorphological features under Mixed Benefits scenario

Site No.	Name	Riffles and rapids		Pools		Fine sediments		Coarse sediments		Bank erosion		Floodplain inundation	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	-20	0	0	0	0	0	0	0	0	0
2	Lower Kikuletwa	-60	-40	-60	-40	0	0	0	0	0	0	0	0
3	Upper Ruvu	-20	0	-20	0	26	68	-20	0	0	0	0	0
4	Lower Ruvu	0	0	-20	0	0	0	0	0	0	0	0	0
6	Pangani at Kirua	1	25	26	68	1	25	0	0	0	0	68	250
7	Lower Mkomazi	-100	-100	-100	-100	500	800	0	0	0	0	-100	-100
8	Lower Luengera	-60	-40	-20	0	26	68	0	0	0	0	-100	-80
9	Lower Pangani	-20	0	-20	0	0	0	0	0	0	0	0	0

A15.5.1.2 Water Quality

The water quality changes associated with this scenario are presented in Addendum Table 140. The changes can be summarised as follows:

- slight increase in conductivity in the Lower Kikuletwa and Mkomazi Rivers and nil to negligible increases elsewhere;
- low to slight increase in phosphorus levels in the Lower Kikuletwa and Mkomazi Rivers and negligible increases elsewhere.

Addendum Table 140 Estimated percentage change from Present Day for water quality under the Mixed Benefits scenario

Site No.	Name	Turbidity/TSS		Conductivity/TDS		Phosphorus		Nitrogen	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	1	25	0	0	0	0
2	Lower Kikuletwa	1	25	251	500	26	68	-20	0
3	Upper Ruvu	0	0	1	25	1	25	0	0
4	Lower Ruvu	0	0	0	0	0	0	0	0
6	Pangani at Kirua	0	0	0	0	0	0	0	0
7	Lower Mkomazi	0	0	251	500	251	500	0	0
8	Lower Luengera	0	0	0	0	1	25	-20	0
9	Lower Pangani	0	0	1	25	1	25	1	25

A15.5.1.3 Vegetation

The changes in riparian vegetation associated with this scenario (Addendum Table 141) can be summarised as follows:

- noticeable increase in wet bank vegetation in the lower catchment and Mkomazi and Luengera Rivers;
- slight decrease in wet bank vegetation in the Kikuletwa River.

Addendum Table 141 Estimated percentage change from Present Day for vegetation under the Mixed Benefits scenario

Site No.	Name	Dry Bank Trees		Dry Bank Herbs & Shrubs		Dry Bank Grasses		Wetbank Trees		Wetbank Herbs		Wetbank grasses and reeds	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-20	0	0	0	0	0	0	0	-20	0	0	0
2	Lower Kikuletwa	-20	0	0	0	0	0	0	0	-80	-60	-40	-20
3	Upper Ruvu	0	0	0	0	0	0	0	0	0	0	26	68
4	Lower Ruvu	0	0	0	0	0	0	0	0	1	25	0	0
6	Pangani at Kirua	0	0	0	0	0	0	26	68	1	25	1	25
7	Lower Mkomazi	0	0	0	0	0	0	251	500	68	250	68	250
8	Lower Luengera	0	0	0	0	0	0	26	68	26	68	26	68
9	Lower Pangani	1	25	1	25	1	25	1	25	1	25	1	25

A15.5.1.4 Macroinvertebrates

The changes in macroinvertebrates associated with this scenario (Addendum Table 142) can be summarised as follows:

- Low to severe decline in sensitive species throughout the catchment, except Lower Pangani, with possible local extinction in places.
- A decline in tolerant species also, except in the Lower Ruvu where they are expected to increase.

Addendum Table 142 Estimated percentage change from Present Day for macroinvertebrates under the Mixed Benefits scenario

Site No.	Name	Sensitive species		Tolerant species (e.g., Dysticidae, Chironominae and Culicidae)		Pest Simuliidae	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	0	0	-40	-20
2	Lower Kikuletwa	-100	-100	-60	-40	-20	0
3	Upper Ruvu	-60	-40	-20	0	0	0
4	Lower Ruvu	-60	-40	26	68	0	0
6	Pangani at Kirua	-20	0	-20	0	1	25
7	Lower Mkomazi	-100	-100	-80	-60	0	0
8	Lower Luengera	-40	-20	-40	-20	0	0
9	Lower Pangani	0	0	0	0	0	0

A15.5.1.5 Fish

The changes in fish associated with this (Addendum Table 143) can be summarised as follows:

- decrease in *Clarias* and/or *Labeo* in the upper catchment;
- decrease in *Clarias*, *Labeo* and *Tilapia* in the Mkomazi River;
- increase in *Clarias* and *Labeo* in the Pangani River at Kirua;
- decrease in *Labeo* and/or *Tilapia* in the Luengera and Lower Pangani Rivers.

Addendum Table 143 Estimated percentage change from Present Day for fish under the Mixed Benefits scenario

Site No.	Name	*Clarias* group		*Tilapia* group		*Labeo* group	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	-40	-20	0	0	0	0
2	Lower Kikuletwa	-60	-40	0	0	-100	-80
3	Upper Ruvu	0	0	0	0	-60	-40
4	Lower Ruvu	-20	0	0	0	-40	-20
6	Pangani at Kirua	251	500	26	68	0	0
7	Lower Mkomazi	-80	-60	-100	-100	-100	-100
8	Lower Luengera	0	0	-40	-20	-60	-40
9	Lower Pangani	0	0	-80	-60	0	0

A15.5.1.6 Overall condition

The changes in overall river condition associated with this scenario are provided in Addendum Table 144. There is a slight to moderate decline in overall condition at different sites, except for a significant improvement at Kirua.

Addendum Table 144 Overall condition at each river site for the Mixed Benefits scenario

Site No.	Name	Present Day River Health Category	Change from Present Day ecological integrity	River Health Category for the scenario
1	Upper Kikuletwa	B/C	-0.121	C
2	Lower Kikuletwa	D	-0.227	D
3	Upper Ruvu	C/D	-0.132	D
4	Lower Ruvu	D	-0.067	D
6	Pangani at Kirua	C	0.115	C/B
7	Lower Mkomazi	C/D	-0.915	D/E
8	Lower Luengera	C	-0.215	D
9	Lower Pangani	C	-0.044	C

A15.5.2 Summary of biophysical condition in NyM

A15.5.2.1 Water level change

The FA Tool assesses likely change in two parameters associated with NyM Dam – fish catch and reed area. These parameters are affected by water area (volume) of the lake and the variation in area, which are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under the Mixed Benefits scenario are presented in Addendum Table 145 and discussed in the respective sections below.

Addendum Table 145 Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in NyM under the Mixed Benefits scenario relative to Present Day, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario

	Present day	This Scenario	% Change
Mean lake area (ha)	103.8	55	-47%
Std dev of lake area (m)	1.24	1.12	-10%
Max lake area (ha)	137.1	111.2	-19%
Mean lake level (m)	15.9	10.4	-35%
Std dev of lake level (m)	1.2	1.1	-8%
Reed area (ha)	33.3	56.2	69%
Fish catch (tonnes)	3538.8	2260.7	-36%

A15.5.2.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surround NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under this scenario, lake area shrinks by 47%, variability decreases by 10%, and maximum area decreases by 19% (Addendum Table 145). The net result of this is that total reed area is expected to increase by 69%.

A15.5.2.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the present day we expect fish populations to expand in responses to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under this scenario, variability in lake level decreases markedly by 10% and average area declines by 47% (Addendum Table 145). Fish catches as a result, are expected to decline by 36%

A15.5.3 Summary of biophysical condition in Kirua Swamp

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to present day.

Under this scenario, fish abundances are predicted to increase to 385% of present day (643 tonnes) and floodplain vegetation to increase to 409% of its present day extent.

A15.5.4 Summary of biophysical condition in the Estuary

A15.5.4.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under this scenario freshwater flows reaching the estuary are markedly lower than Present Day during all four seasons except the Long Rains (Addendum Table 146). A concomitant increase is evident in agricultural return flows in all seasons except the long rains. Number of months where flow exceeds 250 Mm^3 remains the same as for the present day.

Addendum Table 146 Change in freshwater flows reaching the estuary under the Mixed Benefits scenario relative to Present Day

		Short rains	Dry 1	Long rains	Dry 2	All months
Average monthly flows	Current day (Mm^3)	91.3	72.7	186.9	80.7	102.1
	Mixed Benefits (Mm^3)	52.5	39.4	208.2	50.0	49.7
	% Change	-42.5	-45.8	11.4	-38.0	-51.3
Agricultural monthly return flows	Current day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	Mixed Benefits (Mm^3)	34.8	34.9	20.8	38.8	35.9
	% Change	19.3	33.3	1.5	23.1	35.5
No. months flow >250 Mm^3	Current day	8.0				
	Mixed Benefits (Mm^3)	8.0				
	% Change	0.0				

Addendum Table 147 Health scores for the estuary as a whole and the component parameters under the Mixed Benefits scenario relative to Present Day

	Present day	This scenario	% change from PD (+/-)
Geomorphology	40%	40%	0%
Water Quality	53%	42%	-11%
Micro-algae	40%	31%	-9%
Vegetation	60%	59%	-1%
Invertebrates	60%	50%	-10%
Fish	50%	42%	-8%
Birds	40%	36%	-4%
Overall health score	57%	49%	-8%

A15.5.4.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the Present Day status of the mouth, which is both wide and deep. Thus, only the extreme high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significantly affect geomorphological conditions in the estuary such as channel width and depth, and intertidal area, albeit on a relative small scale due to the large size of the tidal prism.

These high flows have not changed from the present day under this scenario thus no change is expected in geomorphological conditions in the estuary (Addendum Table 103).

A15.5.4.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Reduced flow volumes have a reduced capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under this scenario, mean monthly flows are lower while contributions by agricultural return flows have increased in all seasons. The combined effect of this is predicted to lead to a major reduction in water quality in the estuary (down from 52 to 42%).

A15.5.4.4 Microalgae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient level) with the result that phytoplankton concentrations in the system are extremely high. The anticipated reduction in water quality (increased eutrophication) is expected to give rise to a significant increase in phytoplankton abundance with a concomitant reduction in health score for this parameter (down from 40 to 31%.

A15.5.4.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As mean monthly flows under the Present Day scenario are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the contribution from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production).

The effect of a net decrease in flow and a net increase in agricultural return flows anticipated under this scenario, are anticipated to have a negative influence on vegetation communities associated with the estuary, translating to a reduction in the health score of 1% (Addendum Table 147).

A15.5.4.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes in the geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality (reduced water clarity and oxygen levels, increased nutrients) between the natural and Present Day situations.

While geomorphological conditions are not expected to change significantly from the present day under this scenario, the anticipated reduction in water quality will manifest itself as a significant decrease in macroinvertebrate abundance from 60% to 50% (Addendum Table 147).

A15.5.4.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geomorphological characteristics and water quality as well as by the decline of their main food supply (invertebrates). As such the current health score is low (50%) and is expected to decline further still under this scenario (down by 8%, Addendum Table 147).

A15.5.4.8 Birds

Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the estuary and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). The predicted decline in invertebrate and fish abundance is likely to be translated into a further decrease in the numbers and species of birds frequenting the estuary from 40% tp 36% (Addendum Table 147).

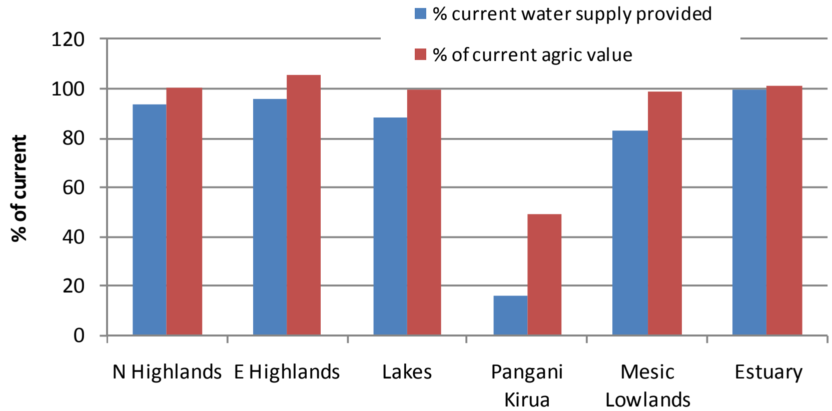
A15.5.4.9 Overall condition

Most measured health parameters in the estuary show a marked decline from the present day under this scenario with the result that overall health score of the estuary is also expected to drop – down to 49%.

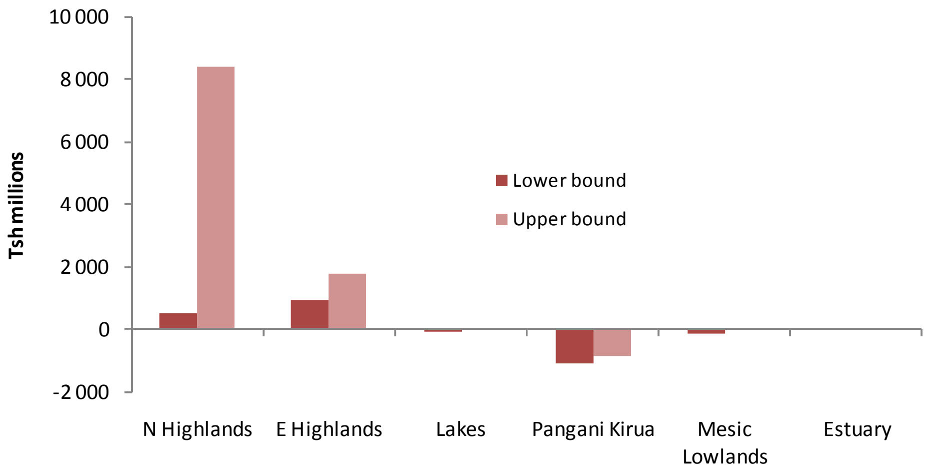
A15.6 Effects on livelihoods

A15.6.1 Income from small-scale agriculture

Addendum Figure 139 shows aggregate net income from agriculture to rural households within 5 km of rivers under the scenario as a percentage of current value. Under this scenario, income is slightly increased in the Eastern Highlands, is very much reduced in Pangani-Kirua, and remains relatively unchanged in the other zones. Because of the large proportion of the population being in the Northern Highlands, the absolute change in value is potentially highest in this zone, with a slightly greater increase than in the previous scenario (Addendum Figure 140).



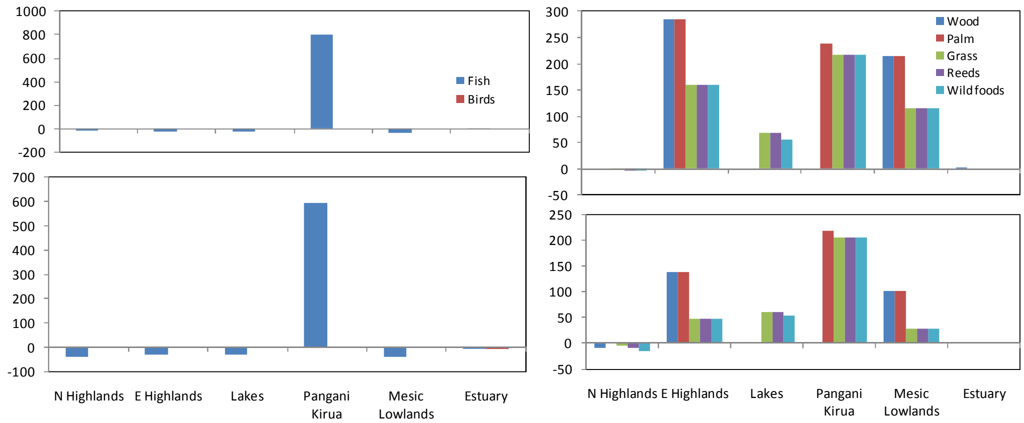
Addendum Figure 139 Area under small-scale irrigation under the Mixed Benefits scenario compared with the Present Day



Addendum Figure 140 Lower and upper bound estimates of the aggregate change in income from small-scale agriculture under the Mixed Benefits scenario

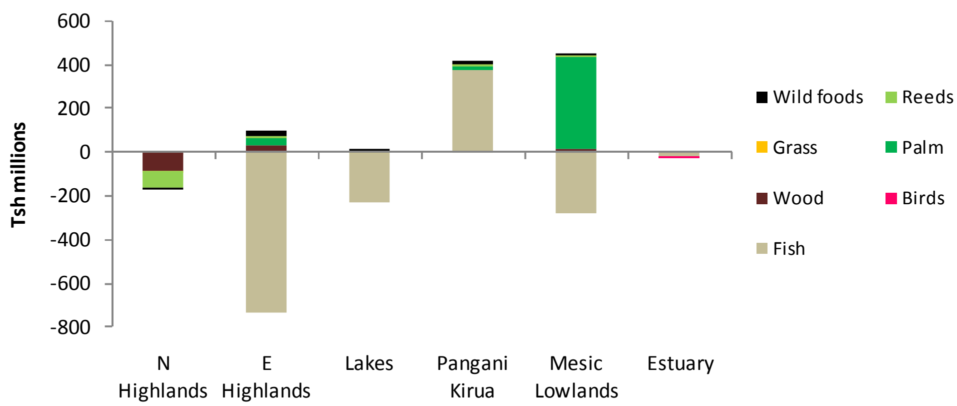
A15.6.2 Income from natural resources

Fish decrease in abundance in all the zones apart from Pangani-Kirua where there is a manifold increase in abundance. Plant resources substantially increase in all zones apart from the Northern Highlands and Estuary (Addendum Figure 141).



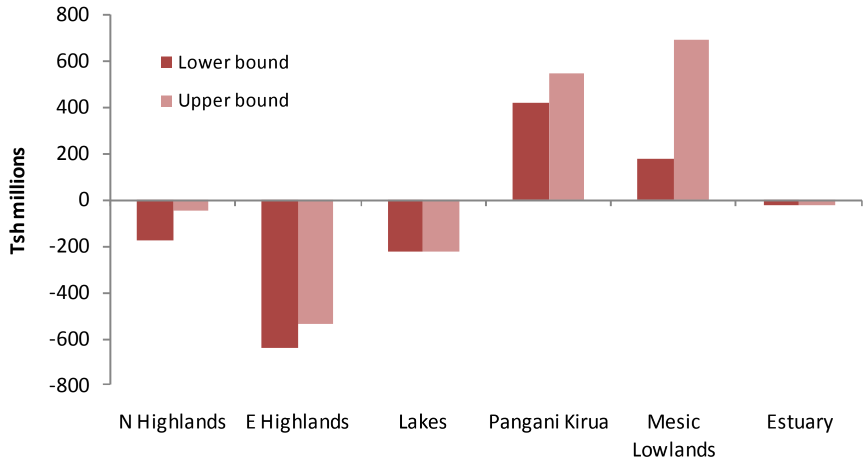
Addendum Figure 141 Lower and upper bound estimates of the percentage change from present day in the abundance of natural resources used by households, under the Mixed Benefits scenario

Impacts of these changes on income to households are shown in Addendum Figure 142.



Addendum Figure 142 Lower-bound estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under the Mixed Benefits scenario

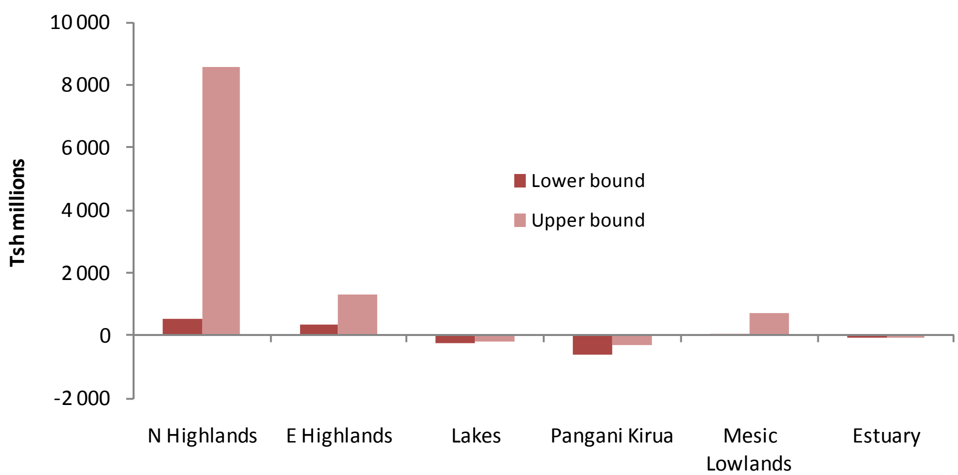
There is an increase in income from natural resources in Pangani-Kirua and the Mesic Lowlands, but decreases in all the other zones (Addendum Figure 143).



Addendum Figure 143 Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under the Mixed Benefits scenario

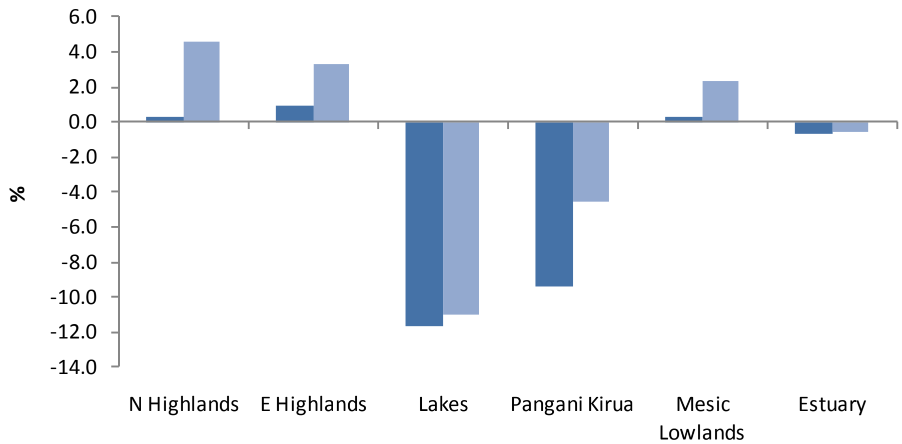
A15.6.3 Overall household income

Aggregate income is expected to decreases throughout the basin, but particularly in the Northern Highlands (Addendum Figure 144).



Addendum Figure 144 Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, under the Mixed Benefits scenario

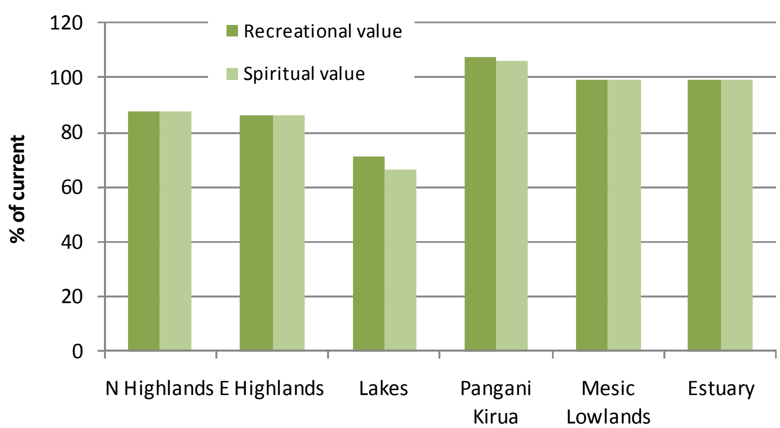
Aggregate household income decreases by about 7 - 10% in the Lakes and Pangani-Kirua (Addendum Figure 145), but increases slightly in the remaining zones apart from the Estuary.



Addendum Figure 145 Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under the Mixed Benefits scenario

A15.6.4 Intangible values

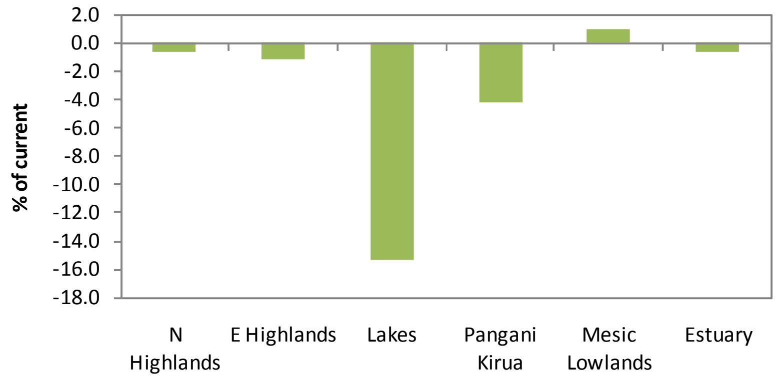
There is a decrease in recreational and spiritual well-being among households in the Highlands and Lakes, while scores remain similar to the present day in the remaining zones (Addendum Figure 146).



Addendum Figure 146 Overall recreational and spiritual well-being (derived from rivers and other sources) under the Mixed Benefits scenario as a percentage of current well-being

A15.6.5 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 147. There is a relatively strongly negative impact on well-being in the Lakes and slightly negative impact in Pangani-Kirua and no significant change in any other zone.



Addendum Figure 147 Percentage change in overall well-being of households within 5 km of rivers under the Mixed Benefits scenario

A15.7 Effects on economic value

Under this scenario, changes in environmental quality and function lead to a very small loss of value in terms of natural resources and a larger gain in terms of ecosystem regulating services, and much larger gain in terms of agricultural outputs. Very much larger losses are incurred in the energy sector (Addendum Table 148).

Addendum Table 148 Gains and losses in the value of HEP, agriculture, natural resources and ecosystem regulating services (Tsh millions per year) under the Mixed Benefits scenario

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
-575 842	12 225	-23	265	-563 376

A16 OPTIMISE PRESENT DAY WITH AGRICULTURE AND STORAGE

A16.1 Description of the scenario

The Optimise Present Day with Agriculture and Storage scenario comprised the following (in order of priority):

- Basic Human Needs
- Supply of present day volumes of river flow in a revised pattern of flows to improve ecosystem condition at river sites 1, 2, 3, 4, 6, 7, 8 and 9, and at Kirua Swamps and the estuary.
- 56 MCM storage in the Kikuletwa catchment to store some wet-season flows.
- MCM storage in the Ruvu catchment to store some wet-season flows.
- Allocation of water for Urban/Industrial to Arusha and Moshi towards the 2025 demands.
- Any remaining water abstracted at a 75% level of assurance allocated to agriculture.
- The river flows (made up primarily of environmental flows) were used to generate HEP.

A16.2 Hydrological implications

A16.2.1 Water allocated per sector

Urban/industrial 53.6 Mcm a^{-1} (PD = 31.1)
Irrigation 545 Mcm a^{-1} (PD = 1042)
HEP 610 424 MW h^{-1} (PD = 602 647)

A16.2.2 Changes in the flow regime relative to present day

The distribution of flows between the DRIFT flow classes at each of the sites is provided in Addendum Table 149. There were three main kinds of change relative to present day:

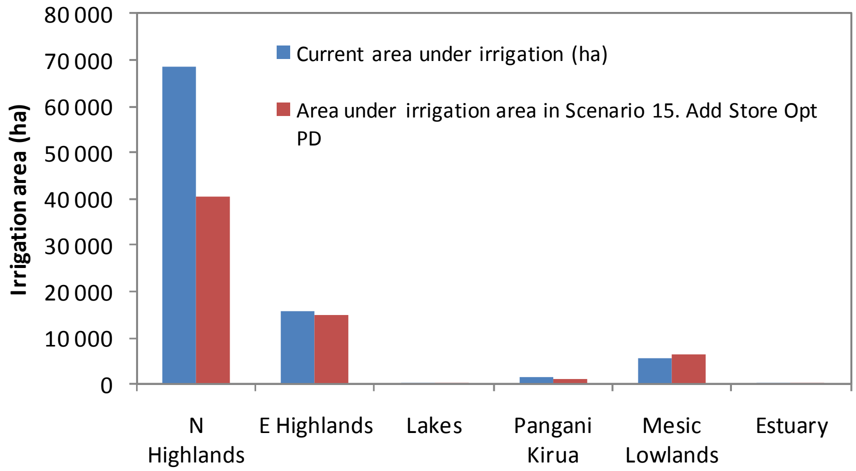
- low flows re-instated, particularly in the dry season (Sites 1-4 at top of the catchment and at Site 7 in the Mkomazi River);
- floods re-instated downstream of NyM at Site 6 - Pangani River at Kirua Swamp).

Addendum Table 149 DRIFT flow summary data for the Optimise Present Day with Agriculture and Storage scenario

Location	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
Scenario (MAR)	77.84	636.19	213.58	884.27	898.98	38.71	106.7	1235.31
WSLF - Volumes (MCM)	22.08	312.5	88.2	514.78	365.05	9.96	38.78	577.9
DSLF - Volumes (MCM)	42.4	254.2	106.05	234.31	463.36	11.25	43.36	475.96
Class 1 - Annual Frequency	4.63	1.37	0	1.68	1.32	2.05	0.84	0
Class 2 - Annual Frequency	4.11	5	0	3.37	5.47	2.84	7.42	1.58
Class 3 - Annual Frequency	2	5.32	2.42	3.53	2.11	2.63	4.11	3.63
Class 4 - Annual Frequency	1.53	3.16	5.47	3.21	0	1.05	2.16	2.84
1:2	P	P	P	P	A	P	P	P
1:5	P	P	P	P	A	P	P	P
1:10	P	P	P	P	A	P	P	P
1:20	P	P	P	P	A	P	P	P

A16.3 Effects on irrigated agriculture

Under this scenario, the irrigation area is decreased to 49% of current area in the Lakes zone, and about 60 -70% in the Northern Highlands and Mesic Lowlands, but remains relatively unchanged in the Eastern Highlands. Overall irrigation area decreases to about 69% of present (Addendum Figure 148).



Addendum Figure 148 Area under irrigation under Optimise Present Day with Agriculture and Storage scenario compared with the Present Day

A16.4 Effects on HEP production

HEP output is effectively unchanged at an estimated 101% of current output, resulting in an output of 610 424 MWh.

A16.5 Effects on environmental condition

A16.5.1 Summary of biophysical condition in the river

The influence of the residual flows on the condition of the rivers is described in two ways:

- as percentage change relative to present day for key indicators representing each of geomorphology, water quality, riparian vegetation, macroinvertebrates and fish;
- in terms of change in overall river condition as denoted by the integrity score

Note: The Present Day levels of the indicators have not been quantified, thus the reported change is relative to an unknown quantity.

A16.5.1.1 Geomorphology

The geomorphological improvements associated with this scenario are concentrated in the Kirua region and Lower Pangani, i.e., downstream of NyM, although there are some slight improvements in the upper catchment (increased riffles and rapids and a reduction in fine sediments; Addendum Table 150). The changes are similar to those for the Optimise Present Day scenario and can be summarised as follows:

- slight increase in rocky areas, and thus fish habitat in the Kikuletwa, Ruvu, Mkomazi and Luengera Rivers;
- slight reduction in fine sediments, and concomitant increase in coarse sediments in the Kikuletwa, Ruvu, Mkomazi and Luengera Rivers;
- significant increase in riffles, rapids and pools in the river at Kirua;
- significant increase in inundation of Kirua Swamp;
- significant increase in pools and reduced fine sediments in the Lower Pangani.

Addendum Table 150 Estimated percentage change from Present Day for geomorphological features under the Optimise Present Day with Agriculture and Storage scenario

Site No.	Name	Riffles and rapids		Pools		Fine sediments		Coarse sediments		Bank erosion		Floodplain inundation	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	1	25	0	0	1	25	0	0	0	0
2	Lower Kikuletwa	1	25	1	25	-40	-20	26	68	0	0	0	0
3	Upper Ruvu	0	0	0	0	1	25	0	0	0	0	0	0
4	Lower Ruvu	1	25	1	25	0	0	0	0	0	0	0	0
6	Pangani at Kirua	68	250	68	250	1	25	0	0	0	0	251	500
7	Lower Mkomazi	1	25	0	0	-20	0	0	0	0	0	0	0
8	Lower Luengera	1	25	0	0	-20	0	0	0	0	0	0	0
9	Lower Pangani	0	0	68	250	-60	-40	0	0	0	0	0	0

A16.5.1.2 Water Quality

The water quality changes associated with this scenario are presented in Addendum Table 151. The changes can be summarised as follows:

- negligible to slight decrease in conductivity and phosphorus in the Kikuletwa and Ruvu Rivers;
- negligible to slight increase in nitrogen levels in the Kikuletwa and Ruvu Rivers, and a negligible increase in turbidity in the upper Kikuletwa.

Addendum Table 151 Estimated percentage change from Present Day for water quality under the Optimise Present Day with Agriculture and Storage scenario

Site No.	Name	Turbidity/TSS		Conductivity/TDS		Phosphorus		Nitrogen	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	1	25	-20	0	-20	0	1	25
2	Lower Kikuletwa	0	0	0	0	0	0	0	0
3	Upper Ruvu	0	0	0	0	0	0	0	0
4	Lower Ruvu	0	0	-20	0	-20	0	1	25
6	Pangani at Kirua	0	0	0	0	0	0	0	0
7	Lower Mkomazi	0	0	0	0	0	0	0	0
8	Lower Luengera	0	0	0	0	0	0	0	0
9	Lower Pangani	0	0	0	0	0	0	0	0

A16.5.1.3 Vegetation

The changes in riparian vegetation associated with this scenario (Addendum Table 152) can be summarised as follows:

- noticeable increase in wet bank vegetation in the vicinity of Kirua;
- negligible changes at Lower Kikuletwa and Lower Pangani Rivers.

Addendum Table 152 Estimated percentage change from Present Day for vegetation under the Optimise Present Day with Agriculture and Storage scenario

Site No.	Name	Dry Bank Trees		Dry Bank Herbs & Shrubs		Dry Bank Grasses		Wetbank Trees		Wetbank Herbs		Wetbank grasses and reeds	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	0	0	0	0	0	0	0	0	0	0	0	0
2	Lower Kikuletwa	1	25	0	0	0	0	0	0	1	25	0	0
3	Upper Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
4	Lower Ruvu	0	0	0	0	0	0	0	0	0	0	0	0
6	Pangani at Kirua	0	0	0	0	0	0	68	250	68	250	68	250
7	Lower Mkomazi	0	0	0	0	0	0	0	0	0	0	0	0
8	Lower Luengera	0	0	0	0	0	0	0	0	0	0	0	0
9	Lower Pangani	0	0	0	0	0	0	-20	0	-20	0	-20	0

A16.5.1.4 Macroinvertebrates

The changes in macroinvertebrates associated with this scenario (Addendum Table 153) can be summarised as follows:

- negligible to slight decreases in tolerant and/or pest species at various points in the basin;
- negligible to slight increases insensitive species at Upper Kikuletwa and Kirua.

Addendum Table 153 Estimated percentage change from Present Day for macroinvertebrates under the Optimise Present Day with Agriculture and Storage scenario

Site No.	Name	Sensitive species		Tolerant species (e.g., Dysticidae, Chironominae and Culicidae)		Pest Simuliidae	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	1	25	0	0	0	0
2	Lower Kikuletwa	0	0	-40	-20	-20	0
3	Upper Ruvu	-20	0	0	0	0	0
4	Lower Ruvu	0	0	0	0	0	0
6	Pangani at Kirua	1	25	-20	0	0	0
7	Lower Mkomazi	0	0	0	0	0	0
8	Lower Luengera	0	0	-20	0	0	0
9	Lower Pangani	0	0	0	0	0	0

A16.5.1.5 Fish

The changes in fish associated with this (Addendum Table 154) can be summarised as follows:

- increase in *Clarias* and *Labeo* in the Kikuletwa, in the Pangani at Kirua and the Lower Pangani, particularly at Kirua.

Addendum Table 154 Estimated percentage change from Present Day for fish under the Optimise Present Day with Agriculture and Storage scenario

Site No.	Name	*Clarias* group		*Tilapia* group		*Labeo* group	
		Lower	Upper	Lower	Upper	Lower	Upper
1	Upper Kikuletwa	1	25	0	0	0	0
2	Lower Kikuletwa	26	68	0	0	68	250
3	Upper Ruvu	0	0	0	0	-20	0
4	Lower Ruvu	0	0	0	0	1	25
6	Pangani at Kirua	500	800	251	500	0	0
7	Lower Mkomazi	0	0	0	0	0	0
8	Lower Luengera	0	0	0	0	0	0
9	Lower Pangani	26	68	68	250	0	0

A16.5.1.6 Overall condition

The changes in overall river condition associated with this scenario are provided in Addendum Table 155. There is a slight to moderate improvement in overall condition at most sites, and a considerable improvement at Kirua. There is a mild shift toward higher condition classes.

Addendum Table 155 Overall condition at each river site for the Optimise Present Day with Agriculture and Storage scenario

Site No.	Name	Present Day River Health Category	Change from Present Day ecological integrity	River Health Category for the scenario
1	Upper Kikuletwa	B/C	0.056	C
2	Lower Kikuletwa	D	0.088	D
3	Upper Ruvu	C/D	-0.023	C/D
4	Lower Ruvu	D	0.016	D
6	Pangani at Kirua	C	0.235	B
7	Lower Mkomazi	C/D	0.006	C/D
8	Lower Luengera	C	0.017	C
9	Lower Pangani	C	0.097	C

A16.5.2 Summary of biophysical condition in NyM

A16.5.2.1 Water level change

The FA Tool assesses likely change in two parameters associated with NyM Dam – fish catch and reed area. These parameters are affected by water area (volume) of the lake and the variation in area, which are derived from the Pangani Basin hydrological model. Variation in these parameters and their respective drivers under the Optimise Present Day with Agriculture and Storage scenario are presented in Addendum Table 156 and discussed in the respective sections below.

Addendum Table 156 Mean lake area (ha) and relative variation in water level (as measured by the standard deviation of mean monthly water level) in NyM under the Optimise Present Day with Agriculture and Storage scenario relative to PD, and predicted change in reed area (ha) and fish catches (tonnes) under this scenario

	Present Day	This Scenario	% Change
Mean lake area (ha)	103.8	69.9	-33%
Std dev of lake area (m)	1.24	2.1	69%
Max lake area (ha)	137.1	130.8	-5%
Mean lake level (m)	15.9	12.2	-23%
Std dev of lake level (m)	1.2	2.1	75%
Reed area (ha)	33.3	61	83%
Fish catch (tonnes)	3538.8	2676	-24%

A16.5.2.2 Reeds

Reeds occur around the perimeter of NyM, and their extent is determined by lake area and the inter-annual variability in this parameter. According to the literature, reeds are only able to survive in damp or wet soil but are unable to tolerate conditions where water depth exceed 1 m for more than three months in any one year and tend to die back due to desiccation if their roots are inundated for less than 30 days in a period of three years. Thus, the extent of the reed area surround NyM is dependent on both the annual average lake area, the extent to which this varies both within and between years and the maximum area inundated under any particular scenario. Reeds are likely to proliferate under a scenario where average lake area decreases provided variability and the maximum area inundated remains high, but will shrink under a scenario where lake area expands and/or variability and maximum area inundated declines.

Under this scenario, lake area shrinks by 33%, variability increases by 69%, and maximum area decreases by 5% (Addendum Table 156). The net result of this is that total reed area is expected to increase by 83%.

A16.5.2.3 Fish

Fish catches from NyM are affected by the absolute area (or volume) of the lake and the variability in water level. Lake area determines total habitat area available to the fish in the lake, while variations in water level (and hence area) affect the nutrient input (and hence food availability) to the fish in the lake. Under a scenario where the variation in lake level (and area) increases relative to the present day we expect fish populations to expand in responses to increased food availability, provided sufficient habitat area is available to accommodate this expansion. Conversely, where variability in lake level declines and/or average volume declines or remains constant fish abundance is likely to decline or remain constant.

Under this scenario, variability in lake level increases by 75% but average area declines by 5% (Addendum Table 156). Fish catches as a result, are expected to decline by 24%.

A16.5.3 Summary of biophysical condition in Kirua Swamp

Predictions of changes in fish abundance are based on the estimated current annual catch of 133 tonnes and vegetation changes are taken to be directly proportional to the change in swamp area. Both are expressed as changes relative to present day.

Under this scenario, fish abundances are predicted to increase to 232% of present day (440 tonnes) and floodplain vegetation to increase to 244% of its present day extent.

A16.5.4 Summary of biophysical condition in the Estuary

A16.5.4.1 Hydrology

Freshwater flows reaching the estuary are effectively the same as those recorded at Pangani River Site 9 but are characterised in a different way in the model inputs and outputs.

Under this scenario freshwater flows reaching the estuary are similar to Present Day with slight decreases in all seasons except the Long Rains (Addendum Table 157). Volumes of agricultural return flows are reduced in all seasons except the long rains, where these remain as for Present Day. Number of months where flow exceeds 250 Mm^3 is up by 25%.

Addendum Table 157 Change in freshwater flows reaching the estuary under the Optimise Present Day with Agriculture and Storage scenario relative to Present Day

		Short rains	Dry 1	Long rains	Dry 2	All months
Average monthly flows	Current day (Mm^3)	91.3	72.7	186.9	80.7	102.1
	Optimise Present Day with Agriculture and Storage (Mm^3)	81.1	62.0	225.7	69.8	102.9
	% Change	-11.1	-14.6	20.7	-13.5	0.8
Agricultural monthly return flows	Current day (Mm^3)	42.9	40.2	15.9	43.8	37.5
	Optimise Present Day with Agriculture and Storage (Mm^3)	17.5	21.9	20.3	18.1	24.3
	% Change	-25.4	-20.0	0.5	-28.4	-13.1
No. months flow >250 Mm^3	Current day	8.0				
	Optimise Present Day with Agriculture and Storage (Mm^3)	10.0				
	% Change	25.0				

Addendum Table 158 Health scores for the estuary as a whole and the component parameters under the Optimise Present Day with Agriculture and Storage scenario relative to Present Day

	Present day	This scenario	% change from PD (+/-)
Geomorphology	40%	42%	2%
Water Quality	53%	53%	0%
Micro-algae	40%	40%	0%
Vegetation	60%	61%	1%
Invertebrates	60%	60%	0%
Fish	50%	50%	0%
Birds	40%	41%	1%
Overall health score	57%	58%	1%

A16.5.4.2 Geomorphology

The size of the tidal prism (amount of water moving in and out of the estuary mouth) at the Pangani estuary is extremely large due to the Present Day status of the mouth, which is both wide and deep. Thus, only the extreme high monthly freshwater flows (i.e. those >250 Mm^3) are likely to significantly affect geomorphological conditions in the estuary such as channel width and depth, and intertidal area, albeit on a relative small scale due to the large size of the tidal prism.

These high flows have changed little from the present day under this scenario (up by 25%, Addendum Table 157) and given that they contribute less to the current mouth status than the tidal flow, the resulting change in geomorphological conditions in the estuary can be expected to be small (up by 2%, Addendum Table 158).

A16.5.4.3 Water Quality

Water quality in the estuary is affected by mean monthly runoff as well as the contribution from agricultural return flows entering the system. Reduced flow volumes have a reduced capacity to dilute industrial, agricultural and domestic effluents entering the river channel at various points in the catchment, while agricultural return flows generally carry a high nutrient load and are likely to contribute to eutrophication of the estuary.

Under this scenario, mean monthly flows are higher and contributions by agricultural return flows have changed little and no change in water quality is anticipated. Slight changes in flow during the different seasons tend to cancel one another out.

A16.5.4.4 Microalgae

The Pangani estuary in its current state is considered to be highly eutrophic (i.e. has high nutrient level) with the result that phytoplankton concentrations in the system are extremely high. However, given that no net change is anticipated in water quality from Present day, microalgae score remain as for present day% under this scenario.

A16.5.4.5 Vegetation

Vegetation in the estuary, which includes submerged and emergent vegetation in the estuary channel and semi-terrestrial vegetation along the banks, is influenced primarily by water clarity and salinity. These parameters in turn are influenced primarily by mean monthly freshwater flows reaching the estuary and the contribution by agricultural return flows. As mean monthly flows under the Present Day scenario are lower than natural and include a contribution from agricultural return flows, there has been a concomitant reduction in water clarity and an increase in salinity levels in the estuary. These flow-related effects have translated to a reduction in the health score for the estuarine vegetation but the contribution from this source is relatively minor in comparison to the effects of the historic reduction in sediment supply to the system (caused by dam construction) and other anthropogenic influences (i.e. clearing of vegetation for human settlements and crop production).

Changes in flow and water quality are small under this scenario, thus change in vegetation is also expected to be small (1% improvement) (Addendum Table 158).

A16.5.4.6 Macroinvertebrates

Macroinvertebrate communities in the Pangani estuary (zooplankton, intertidal and subtidal invertebrates) have been heavily impacted by changes in the geomorphological characteristics of the estuary (loss of intertidal sand and mud banks, increase in channel width and depth, increase in the size of the tidal prism) and by reductions in water quality (reduced water clarity and oxygen levels, increased nutrients) between the natural and Present Day situations. Changes in flow, water quality, and microalgae are small under this scenario, thus change in invertebrates is expected to be negligible (no change, Addendum Table 158).

A16.5.4.7 Fish

Fish in the Pangani estuary have been similarly impacted by changes in geomorphological characteristics and water quality as well as by the decline of their main food supply (invertebrates). Changes in flow, water quality, microalgae and invertebrates are small under this scenario, thus change in fish is expected to be negligible (no change, Addendum Table 158).

A16.5.4.8 Birds

Abundance and diversity of birds on the Pangani estuary is exceptionally low relative to similarly sized estuaries in east Africa and is believed to be largely a function of low food (invertebrate and fish) abundance in the estuary and compromised foraging habitats (virtual absence of intertidal sand and mud flats and poor water clarity). Changes in flow, water quality, microalgae, invertebrates and fish are small under this scenario, thus change in bird fauna is expected to be negligible (1% change, Addendum Table 158).

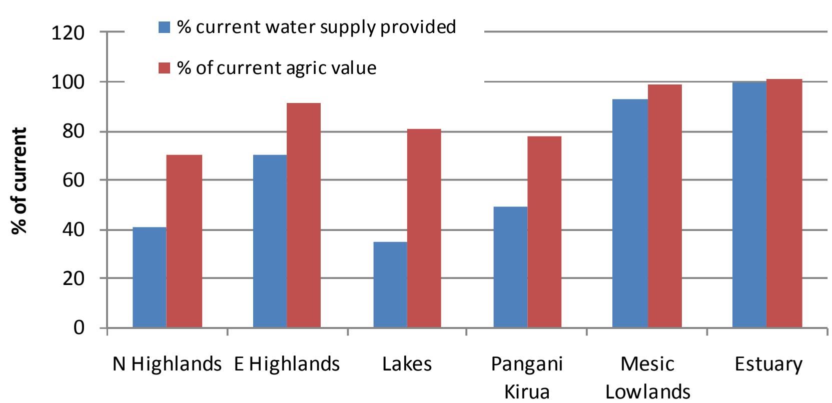
A16.5.4.9 Overall condition

Measured health parameters in the estuary show little change from the present day under this scenario with the result that change in the overall health score of the estuary is expected to be small (1% improvement).

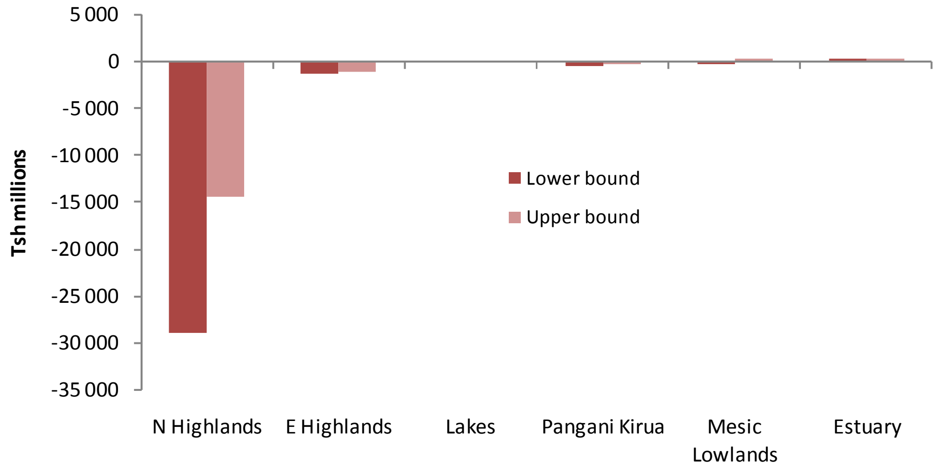
A16.6 Effects on livelihoods

A16.6.1 Income from small-scale agriculture

Addendum Figure 149 shows aggregate net income from agriculture to rural households within 5 km of rivers under the scenario as a percentage of current value. Under this scenario, income is substantially reduced in the Highland zones, Lakes and Pangani Kirua, but is maintained close to present levels in the remaining zones. Because of the large proportion of the population being in the Northern Highlands, the absolute change in value occurs mainly in this zone (Addendum Figure 150).



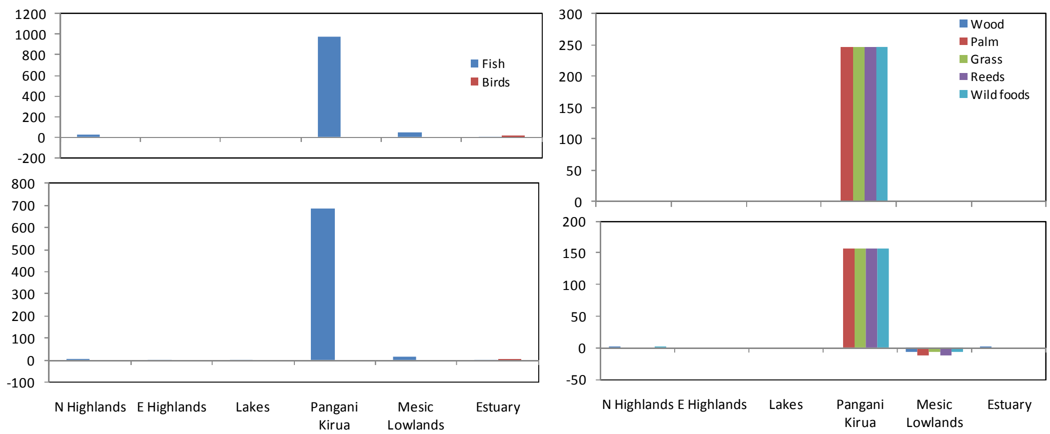
Addendum Figure 149 Area under small-scale irrigation under the Optimise Present Day with Agriculture and Storage scenario compared with the Present Day



Addendum Figure 150 Lower and upper bound estimates of the aggregate change in income from small-scale agriculture under the Optimise Present Day with Agriculture and Storage

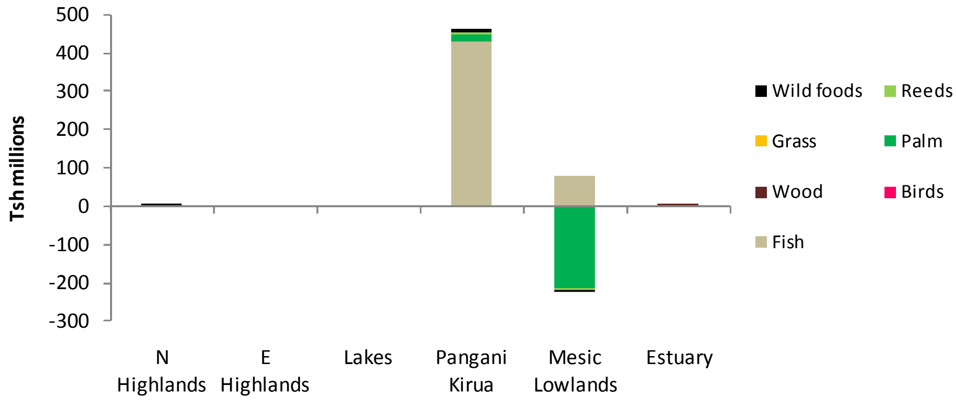
A16.6.2 Income from natural resources

There is a massive increase in the abundance of fish and a substantial in plant resources in Pangani-Kirua, but comparatively little change in resources in the other zones (Addendum Figure 151).



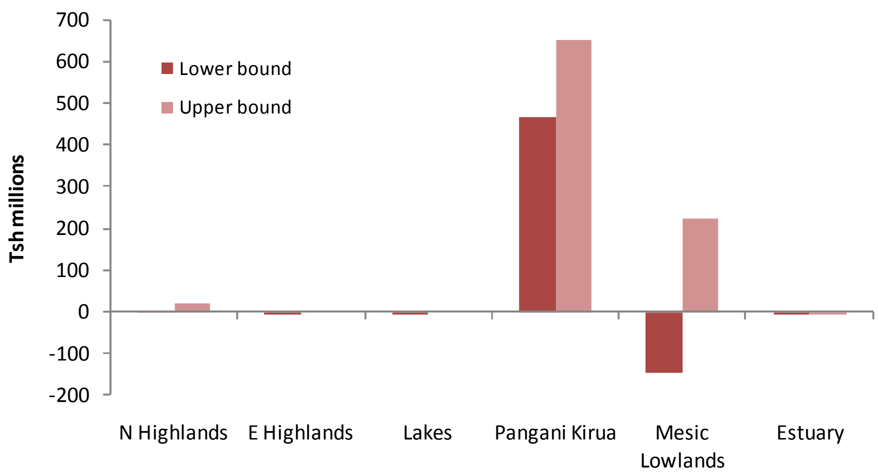
Addendum Figure 151 Lower and upper bound estimates of the percentage change from present day in the abundance of natural resources used by households, under the Optimise Present Day with Agriculture and Storage scenario

Impacts of these changes on income to households are shown in Addendum Figure 152.



Addendum Figure 152 Lower-bound estimates of the aggregate change in net income from different types of natural resources to households within 5 km of rivers, under the Optimise Present Day with Agriculture and Storage scenario

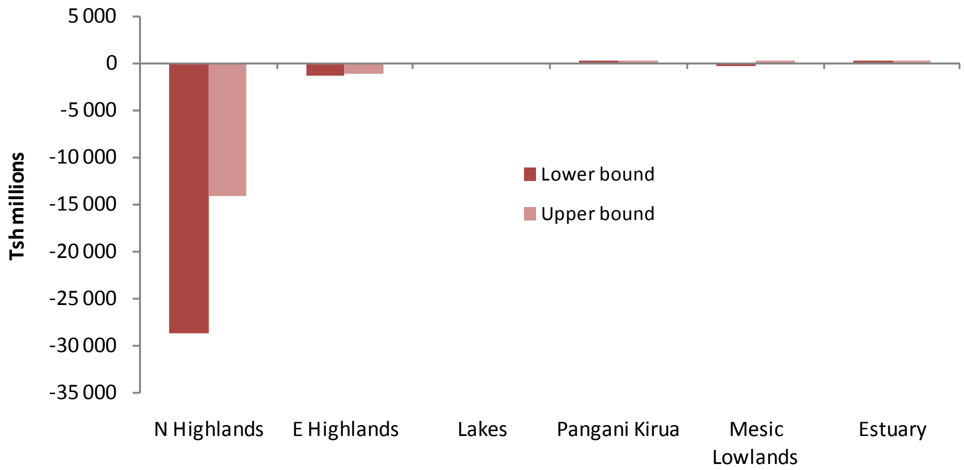
There is an increase in income from natural resources in Pangani-Kirua and possible change in the Mesic Lowlands, but no appreciable change in the other zones Addendum Figure 153.



Addendum Figure 153 Lower and upper bound estimates of the aggregate change in net income from natural resources to households within 5 km of rivers, under the Optimise Present Day with Agriculture and Storage scenario

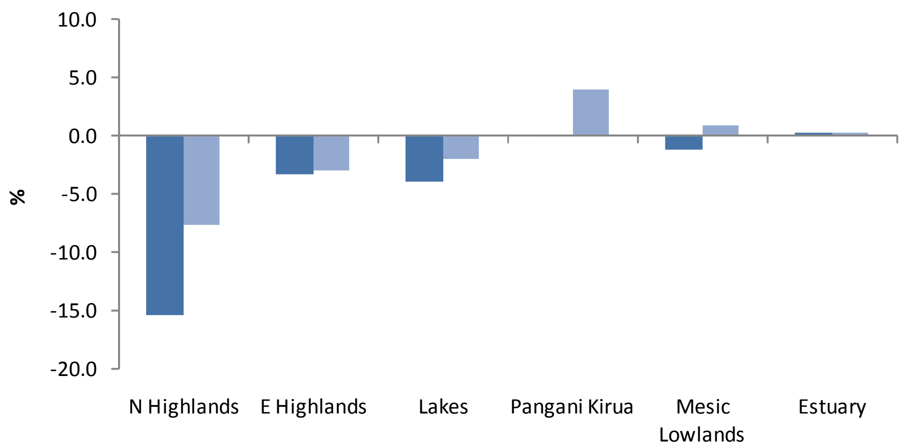
A16.6.3 Overall household income

Aggregate income is expected to decrease substantially in Northern Highlands, but effects are comparatively insignificant in other zones (Addendum Figure 154).



Addendum Figure 154 Lower and upper bound estimates of the aggregate change in overall net income to households within 5 km of rivers, under the Optimise Present Day with Agriculture and Storage scenario

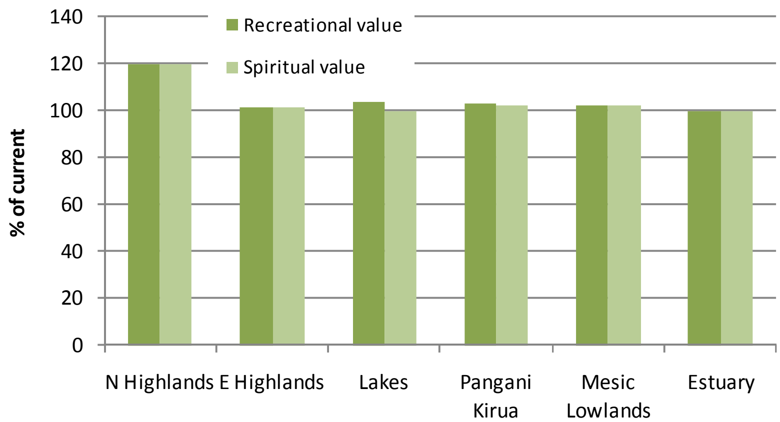
Aggregate household income decreases by up to 15% in all the upper zones and increases slightly in Pangani-Kirua (Addendum Figure 155).



Addendum Figure 155 Lower and upper bound estimates of the percentage change in aggregate overall net income to households within 5 km of rivers, under the Optimise Present Day with Agriculture and Storage scenario

A16.6.4 Intangible values

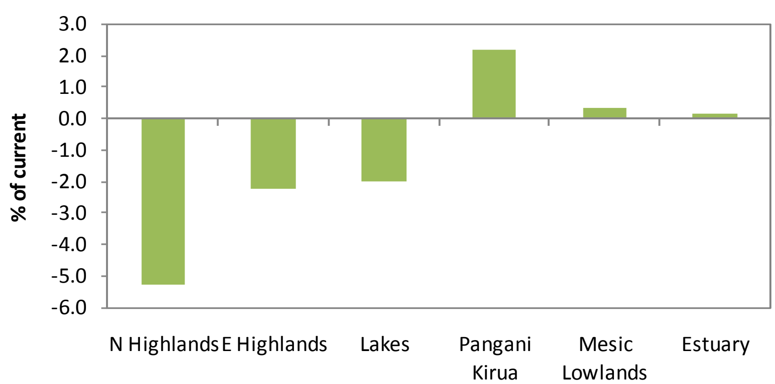
There is a 20% increase in recreational and spiritual well-being among households in the Northern Highlands and no change in the remaining zones (Addendum Figure 156).



Addendum Figure 156 **Overall recreational and spiritual well-being (derived from rivers and other sources) under the Optimise Present Day with Agriculture and Storage scenario as a percentage of current well-being**

A16.6.5 Overall well-being

Based on a weighted average of 80:20 for well-being derived from tangible and intangible benefits, respectively, the overall change in well-being is summarised for the different zones in Addendum Figure 157. There is a negative impact on well-being in all of the upper zones, but a slightly positive effect in Pangani-Kirua. The magnitude of change is small in all cases.



Addendum Figure 157 **Percentage change in overall well-being of households within 5 km of rivers under the Optimise Present Day with Agriculture and Storage scenario**

A16.7 Effects on economic value

Under this scenario, improvements in environmental quality and function lead to an increase in value in terms of ecosystem regulating services, but this is offset by the loss of value in the agricultural sector. These losses are, in turn, slightly offset by gains in the energy sector (Addendum Table 159). The outcome is a net loss in value.

Addendum Table 159 Gains and losses in the value of HEP, agriculture, natural resources and ecosystem regulating services (Tsh millions per year) under the Optimise Present Day with Agriculture and Storage scenario

HEP	Agriculture	Natural resources	Ecosystem regulating services	Total
25 315	-51 365	605	184	-25 262