Report on performance indicators, decision-support toolbox and baseline simulation results

A. Funk, P. Winkler, Th. Hein, I. Zsuffa, M. Arias Hildalgo, M. Diallo, R. Johnston, Clément Murgue, Sylvie Morardet, J. Cools, et al.

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Lead Authors:
Andrea Funk
Peter Winkler
Thomas Hein
Contributors:
István Zsuffa
Mijail Arias-Hildalgo
Mori Diallo
Robyn Johnston
Clement Murgue
Sylvie Morardet
Jan Cools
Bakary Kone
Gonzalo Villa Cox
Anne VanDam
Susan Namaalwa
Rose Kaggwa
Dries Coertjens
Samuel Fournet
Stefan Liersch

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Lead authors	Andrea Funk, WCL, Lunz, Austria Peter Winkler, WCL, Lunz, Austria, Thomas Hein, WCL, Lunz, Austria
Contributors	István Zsuffa, Mijail Arias-Hildalgo, Mori Diallo, Robyn Johnston, Clement Murgue, Sylvie Morardet, Jan Cools, Bakary Kone, Gonzalo Villa Cox, Anne VanDam, Susan Namaalwa, Rose Kaggwa, Dries Coertjens, Samuel Fournet, Stefan Liersch
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Contents

1 Introduction

The primary objective of this report is to summarize and link the evaluation criteria defined during the WETwin project, the available assessment tools and their application (baseline simulations results and updated descriptions of the status quo) within the four dimensions of sustainable wetland management (hydrology, environment/ecology, livelihood and policy; UNESCO, 2005) for all tropical case study sites. The problems identified in the DSIR analysis will be linked to the assessment done in the 6 case studies and to the indicators that can be derived from the assessment. For the problems identified in the DSIR analysis (Zsuffa & Cools, 2011), it is summarized which of the associated research questions could be covered based on the available data and knowledge; which approach, quantitative modelling, qualitative tool or expert judgement, can be used for each specific topic, and which criteria/indicators can be derived from the approach.

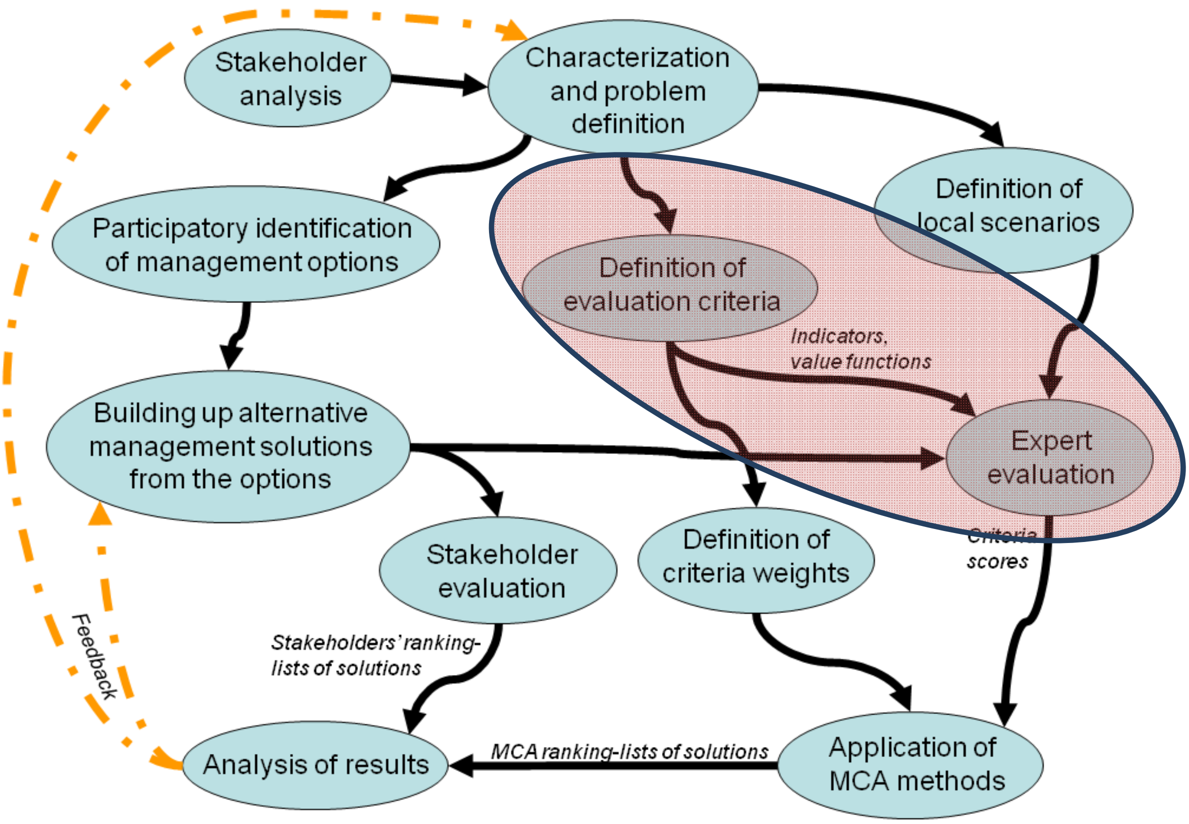


Figure 1: ***Focus of this report in the Trade-off Analysis –based Decision Support Framework of the WETwin project***

In a first step (**chapter 2**) the importance of the different wetland dimensions is summarized and compared with the research effort (quantitative model, qualitative assessment tool or expert judgement) made in the respective case study system.

In a second part (**chapter 3**) the problems and associated questions derived from the DSIR analysis are listed for each case study and a link to the model and assessment tools (chapter 5) and reports on the specific application of these tools.

The third part (**chapter 4**) contains the list of indicators that can be derived from the different modelling and assessment tools.

The fourth part (**chapter 5**) contains the list of models and assessment tools used in WETwin.

The last part (**chapter 6**) contains short assessment reports not delivered separately.

Evaluation criteria

Evaluation indicators/criteria are essential to assess the resources and health of a wetland as well as measure stakeholder satisfaction with wetland management. According to the HELP initiative of the UNESCO (HELP, 2005) there are four dimensions of sustainability, Hydrology, Environment, Livelihood and Policy, in wetland management. Based on this approach indicators are adapted and developed for WETwin for the four components:

- Hydrology including water quantity and quality aspects
- Ecology focusing on habitat assessment for ecological health
- Livelihood, with special focus on drinking water supply and sanitation
- Policy based on the institutional capacity

Indicators are developed for the evaluation of management solutions which are combinations of specific management options (Johnston et al. 2012, D7.2/8.1, WETwin report). Indicators can either be qualitative, and can be assessed rapidly without modelling work or quantitative based on detailed modelling and monitoring activities and detailed expert knowledge.

Hydrology/water quantity:

Hydrological indicators are important to describe physical and biological functions as well as livelihood in wetland systems. They can be used to characterize natural flow regimes, which are needed to maintain ecological conditions, and to predict the impact of hydrologic change associated with altered watershed condition (Navarro et al. 2007, Merrey et al. 2005). Included are measures of seasonality, magnitudes, frequency and duration of high and low flows. These indicators are also essential to predict availability of water for human benefits like drinking water supply and irrigation schemes or vulnerability to risks like damage due to flood events or drought (Merrey et al. 2005).

Ecology:

Ecological indicators can be defined as measurable characteristics of the structure, composition, or function of ecological systems and can be used to describe the present status of a system or predict changes in the environment (Niemi and McDonald, 2004). Habitat assessment is based on the linkage between species and the physical (hydrology and geomorphology), chemical (water quality) and biotic conditions (especially vegetation) of their habitat (Maddock, 1999, Thomson et al., 2001). It is used for several purposes in river management including monitoring of river health in general, designing and evaluating management programmes (Harper et al., 1992, Kempe et al., 1999), and is used as surrogate for biodiversity since it can be used to make predictions without cost intensive direct investigation of species (Harper et al. 1992, Thomson et al., 2001).

Livelihood/Benefits:

In general the concept of livelihoods reflects the greater aim of global poverty reduction. Livelihood indicators should reflect income and consumption levels, or levels of health, literacy and education (Bahndarin et al. 2007). A special focus is on water quality aspects with regard to drinking water supply and sanitation (Millennium indicators).

Policy:

Policy indicators aim to measure the capacity and effectiveness of institutions to manage the wetland and its resources (Ostrovskaya et al. 2010, 2011, institutional capacity).

Costs:

Additionally cost for implementation and maintenance of specific measures are an important factor for evaluation of management options/solutions (Interwies and Cools 2010, Wetwin report).

2 Overview and evaluation

The objective of this chapter is to evaluate the relevance in relation to the assessment “intensity” of the different wetland components (hydrology, environment/ecology, livelihood and policy) in the 7 case study systems. Therefore, in a first table (Table 1) the importance of each component in terms of percentage of area or proportion of population that is affected, is listed. In the second table (Table 2) the effort made for assessment ranging from a complex quantitative modelling approach to expert judgement, is summarized. Relevant information is taken from DSIR analysis, model reports, fact sheets and indicator description.

Tab 1: Short description and evaluation of importance of the different components in the 7 case study wetlands.

	Inner Niger Delta	**Nabajuzzi**	**Namatala**	**GaMampa**	**Abras de Mantequila**	**Gemenc**	**Lobau**
Hydrology	Climate change and water abstraction	Climate change and water abstraction	Climate change	Climate change and drainage	Dam construction and water transfer project	Riverbed incision, floodplain aggradation, climate change	Floodplain connection, Floodplain aggradation
Water quality	Reduced water quality close to settlements	Reduced quality in Wetland and downstream	Reduced quality in Wetland and downstream	No	No	No	No
Ecology	High biodiversity-RAMSAR site	High biodiversity-RAMSAR site	Dominated by agriculture	Dominated by agriculture	RAMSAR site Dominated by agriculture	RAMSAR site Dominated by forestry	High biodiversity-RAMSAR site
Health	Vector-born and water-born disease	Water-born disease	Water-born disease	No	Water-born disease	No	No
Agriculture	Rice	Subsistence farming	Rice	Maize, sugar cane,..	Maize and rice	No	In small areas, of minor importance
Fish	Fisheries	Fisheries	Fisheries	Fisheries	Fisheries	Fisheries	Angling

Tab 1:continued

	Inner Niger Delta	Nabajuzzi	Namatala	GaMampa	Abras de Mantequila	Gemenc	Lobau
Drinking water	Partly from wetland	From wetland	Riparian communities	No	From wetland	No	City of Vienna
grazing	Whole delta	Wetland edges	Wetland edges	In dry season	No	No	No
Harvesting	Flood forest	Parts of the wetland	Parts of the wetland	In dry season	No	Wood production all over the wetland	No
Ecotourism or recreation	Tourism in parts of the Delta	Tourism in parts of the wetland	No	Local people and tourists	Future interest	Tourism and recreation in parts of the wetland	Tourism and recreation in large parts of the wetland
Navigation	Wet and dry season	No	No	No	Wet season	All year accept winter	adjacent, in the main channel

High important in large parts or the whole wetland system or for large part of the Population or from a legal basis
Low important in small areas of the wetland or for small part of the population
No not relevant in the system

Tab 2: Short description and evaluation of the intensity of the assessment of the different wetland components in the 7 case studies

	Inner Niger Delta	Nabajuzzi	Namatala	GaMampa	Abras de Mantequila	Gemenc	Lobau
Hydrology	Flood levels and flood duration	Water volume in wetland pool	No	River discharge and groundwater levels	River discharge	Water levels and flood duration	Connectivity, water levels, groundwater levels,…
Water quality	Spatial distribution of E. coli concentration	Potential nutrient concentration in wetland	Potential nutrient concentration in wetland	No	Nutrient concentration in river	No	No
Ecology	habitat availability - vegetation, bird, fish	Water availability WETHealth tool	Area with natural vegetation Risk of degradation due to pollution	Water availability, area with natural vegetation WETHealth tool	Area with natural vegetation Potential impact on biodiversity	habitat availability - vegetation Impacts on biodiversity	habitat availability, diversity – selected elements of fauna and flora
Health	Trends in disease rates, Spatial distribution of E. coli concentration, Expert judgement	Potential health risk due to sewage inflow	Potential health risk due to sewage inflow	No	Water quality of the river	No	No
Agriculture	Area suitable for rice growing	Potential for agricultural production	Available area, Potential for rice production	Farming system model	Potential for agricultural production	No	Area for farming
Fish	habitat availability - fish	Potential for fish production	Potential for fish production	Total provisioning services	No	habitat availability- fish, lateral connectivity	Water bodies for angling

Tab 2:continued

	Inner Niger Delta	Nabajuzzi	Namatala	GaMampa	Abras de Mantequila	Gemenc	Lobau
Drinking water	Contamination and health risk	Water availability	No	No	Water quality of the river	No	Potential availability and quality of groundwater
grazing	Potential biomass for grazing	No	No	Potential grazing opportunities	No	No	No
Harvesting	No	Availability of goods	Availability of goods	Availability of goods	No	Areas available for wood production	No
Ecotourism or recreation	No	No	No	Alternative livelihood opportunities	Touristic potential	State and trend of tourism and recreation	State and trend of tourism and recreation
Navigation	Navigable water depth	No	No	No	Potential navigability	No	No

High quantitative model/tool
Low qualitative assessment tool or expert judgement
No not analysed

Comparing both tables it can be summarized that the wetland components of highest importance in the respective wetland systems are analysed with quantitative models or assessment approaches or at least addressed with qualitative assessment within the WETwin project. Less important factors were mostly addressed with expert judgement or in few cases not examined.

3 Problem definition

This part of the document contains a list with the problems in the case study systems defined in the DSIR analysis (Zsuffa & Cools, 2011) including the associated questions that have to be answered in the different case studies and a link to the toolbox, where all models and tools available at the partner institutions of WETwin are listed and described, and a link to the model reports and fact sheets, where the application of the different models and tools at the case study systems is described. The following table describes structure and content of the list.

DSIR link	Potential problem	Research topic	Asessment tool
Link to the DSIR chain presented in Zsuffa & Cools, (2011)	Problem defined in the DSIR chain	Question answered with the selected tool or expert judgement including link to model reports or fact sheets	Link to the toolbox: **quantitative**, **qualitative** tools or answered by expert judgement (**EXP**), **not assessed**

3.1 GaMampa

The main problems in the GaMampa wetland are increased cropping and grazing, burning, and drainage, caused by poor wetland management, population growth and poverty. The poor state of the irrigation schemes in the system is a direct driving force for use of the wetland resulting in uncontrolled expansion of private cropping activities in the community owned wetland area. A loss of natural wetland habitats, destruction of sources of livelihood or low agricultural yields may be the consequences.

3.1.1 Hydrology

DSIR link	Potential problem	Research topic	Asessment
I	Reduced water supply in wetland and catchment and degradation of low-flow regulatory capacity of the wetland due to increased drainage network density for cropping	Impact of drainage system on the hydrology of the wetland (Morardet 2012)	E3
I	Reduced water availability due to climate variability	Water availability in the wetland habitat (Morardet et al. 2012)	E3

3.1.2 Ecology

DSIR link	Potential problem	Research topic	Asessment tool
I	Loss of habitat and biodiversity due to increased cropping, drainage and grazing in the wetland	Trends in cropping and crazing in the wetland (Morardet 2012)	E3
		Loss of habitat due to agriculture in the wetland (Morardet 2012)	E3; E6;
I	Degradation of natural wetland habitat due to desiccation and depletion of organic matter caused by drainage	Impact of drainage on the quality of natural wetland habitat (Morardet 2012)	E3; E6;

3.1.3 Livelihood

DSIR link	Potential problem	Research topic	Asessment tool
I	Destruction of sources of livelihood due to increased cropping and grazing in the wetland as a consequence of collapsed irrigation scheme	Impact of cropping and crazing in the wetland on dessication and loss of wetland area (Morardet 2012)	E3
I	Low agricultural yield due to poor management of irrigation scheme	Impact of improved irrigation scheme on the crop yield in the system (Morardet 2012)	E3

3.1.4 Policy

DSIR link	Potential problem	Research topic	Asessment
II	Collaps of irrigation scheme due to reduced government support to irrigation and agriculture	Impact of change in legislation and policy on wetland management and use	EXP
	Lack of control of wetland use due to uncoordinated legislation and policy		

3.2 Nabajuzzi

Nabajjuzi wetland is a Ramsar site and in largely natural state. The main problems are reduced water quantity and water quality. Increased drinking water needs of the population expectably lead to a reduction of water availability for the wetland and its ecosystem. Climate change may lead to a further reduction of water availability. Increasing sewage input, agriculture and high iron content of the water may lead to decrease in water quality.

3.2.1 Hydrology

DSIR link	Potential problem	Research topic	Asessment tool
I	Increasing number of periods with limited water resources at Masaka and downstream due to increasing water intake by Masaka and climate variability	Impact of climate change and water intake from Masaka on water availability downstream of Masaka (Winkler 2012; Fournet 2011)	H3, H4b
		Impact of climate change and population growth on water availability for Masaka (Winkler 2012; Fournet 2011)	H3, H4b

3.2.2 Ecology

DSIR link	Potential problem	Research topic	Asessment tool
I	Damages to wetland habitats downstream of Masaka due to limited water resources	Impact of changes of the water availability on habitat availability and biodiversity (Winkler 2012; Fournet 2011)	H3, H4b, EXP
III	Loss of habitat and biodiversity due to increasing pollution	Impact of pollution on habitat quality and biodiversity (Mahieu 2010)	EXP
IV	Loss and degradation of habitat due to conversion to settlement and agricultural land, exploitation and disturbance	Impact of the loss of habitat on the biodiversity in the papyrus wetland (Mahieu 2010)	E6, EXP
		Impact of exploitation and disturbance on biodiversity of the papyrus wetland (Mahieu 2010)	E6, EXP

3.2.3 Livelihood

DSIR link	Potential problem	Research topic	Asessment tool
I	Damages of wetland based livelihoods (papyrus harvesting, fishing,..) downstream of Masaka	Impact of changes of the water availability on availability of natural goods (Winkler 2012; Fournet 2011; Mahieu 2010)	H3, H4b, EXP
II	High costs of water purification due to high iron content in the water at Masaka	Impact of erosion in the catchment on the iron content of the wetland (Mahieu 2010)	EXP
III	Increasing costs of water purification at Masaka due to increasing pollution	Impact of increasing diffuse-source and point-source pollution on the water quality of the wetland (Mahieu 2010)	EXP
III	Higher health risk for riparian communities due to increasing pollution		

IV	Thread to community-based ecotourism due to ecroachment, exploitation and disturbance of the ecosystem	Impact of ecroachment, exploitation and disturbance on the habitat quality and biodiversity in the system (Mahieu 2010)	EXP
V	Reduced crop yields in the basin due to destruction of soils by erosion	Impact of de-forestation and non-sustainable agriculture on the soil structure and crop yield	NO

3.3 Namatala

Namatala wetland is a highly modified papyrus wetland. Large parts are converted into rice fields. The main problems are the dramatic loss of natural habitat, changes in nutrient and sediment balance that may also damage natural habitat as well as livelihood opportunities besides agriculture and increased sewage inflow that may cause health risk, pollution and degradation of natural wetland.

3.3.1 Ecology

DSIR link	Potential problem	Research topic	Asessment tool
I	Loss of habitat and biodiversity due to conversion of the natural wetland to agricultural land	Trends in land-use changes and impact on habitat availability and biodiversity (chapter 6.1)	H4b, E6, EXP
II	Loss of habitat and biodiversity due to increasing pollution, sediment and nutrient loads	Impact of the loss of habitat on the biodiversity in the papyrus wetland (chapter 6.1)	EXP
		Impact of agricultural encroachment on nutrient and sediment loads (chapter 6.1)	EXP

3.3.2 Livelihood

DSIR link	Potential problem	Research topic	Asessment tool
I	Poor water quality due to soil errosion, higher sediment discharge, channelization and nutrient export and retention as a consequence of conversion of natural wetland to agricultural land	Impact of agricultural encroachment on the nutrient and sediment balance and the water quality of the wetland	EXP
I	Increase in provisioning services due to conversion of wetland vegetation into agricultural crops	Define compromis between agriculture and harvesting of natural goods (fishing papyrus harvesting) in the wetland	EXP

	Decrease in income from harvesting of natural goods (fishing papyrus harvesting) due to conversion of wetland vegetation into agricultural crops.		
II	High nutrient and pollution loads in the wetland due to limited capacity of the wastewater treatment.	Changes in the water quality of the wetland due to improved wastewater treatment practice.	EXP
	Increased sediment and nutrient loads due to unsustainable farming in the catchement	Changes in the water quality of the wetland due to improved farming practices in the catchment	NO
II	Increased health risk for riparian population due to limited capacity of the wastewater treatment	Impact of improved wastewater treatment practice on the concentration of disease bacteria ain the wetland	EXP
II	Increased agricultural yields due to increased nutrient loads in the wetland	Impact of nutrient loads on agricultural yields in the wetland	EXP

3.4 Inner Niger Delta

The problems in Inner Niger Delta are mainly related to the hydrology of the Niger impacted by water allocation upstream of the Delta. One dam, the Selingue dam is mainly used for energy production and reduces flow in wet season whereas it increases flow in wet season. The second dam, the Markala dam, which is used for irrigation, decreases flow during wet and dry season. These changes in hydrology presumably have strong impact on food production, quality of the ecosystem, human health and other ecosystem values.

3.4.1 Hydrology

DSIR link	Potential problem	Research topic	Asessment tool
Ia	Decrease of flood water levels and flooded areas due to water intake by Office du Niger and climate change	Impact of climate change and water intake from Office du Niger on flow regime of the Niger (Liersch et al. 2012)	H4b, H9a
Ib	Decrease of floodwater levels during wet season and increase during dry season due to upstream reservoirs	Impact of the upstream reservoirs on flow regime of the Niger (Liersch et al. 2012)	H4b, H9a
Ic	Reduced lateral connectivity due to increased sediment transport and sedimentation rates.	Impact of deforestation and agriculture in the catchment on the sediment transport.	NO, lack of data

3.4.2 Ecology

DSIR link	Potential problem	Research topic	Asessment tool
Ia, Ib	Reduction of key habitat (bourgoutiere, flooded forest,…) as feeding and nesting ground for birds and feeding and spawning habitat for fish	Impact of changes of the flow regime of the Niger on the habitat availability for bird and fish (Zsuffa et al. 2012)	H9a
Ic	Reduced access of fish to spawning habitats due to loss of lateral connectivity	Impact of sedimentation in lateral channels on spawning success of fish	NO, lack of data
IIb	Destruction of habitats due to increasing loads of nutrients and chemicals in the surface waters (over-saturation of the system)	Impact of concentrations of nutrient and chemicals on habitats in the Delta	NO, no impact expected because of low concentrations

3.4.3 Livelihood

DSIR link	Potential problem	Research topic	Asessment tool
Ia, Ib, Ic	Decreased fish stock due to habitat destruction and to overfishing	Impact of habitat destruction and overfishing on fish stock and catch	EXP
Ia, Ib	Decrease in floating rice area due to decreased water levels	Impact of changes of the flow regime of the Niger on total rice production in the Delta (Liersch et al. 2011)	H4b, H9a
Ia, Ib	Decreased livestock due to overgrazing and reduction of areas of bourgou fields	Impact of changes of the flow regime of the Niger and overgrazing on availability of bourgou and the live stock in the Delta (Liersch et al. 2012)	H4b, H9a
Ic	Reduced fish stock due to reduced access of fish to spawning habitats as aconsequence of loss of lateral connectivity	Impact of sedimentation in lateral channels on spawning success of fish and fish stock	NO, lack of data
IIa	Higher risk for water born disease due to changed hydrological regime (lower flush-through of contaminants)	Impact of changes of the flow regime of the Niger on concentrations of disease bacteria in surface waters (Zsuffa et al. 2012)	H4b, H9a
IIa		Impact of changes of the flow regime of the Niger on disease rates of water born disease (chapter 6.3)	statistic analysis
IIa	Higher risk for water born disease due to lack of sanitation ond supply of clean drinking water	Impact of changes of sanitary situation and drinking water supply on disease risk (Cools et al. 2012, chapter 6.3)	EXP

IIb	Obstruction of navigability and dsiturbance of fishing activity as aconsequence of proliferation of invasive weeds due to increasing loads of nutrients in the surface waters	Impact of concentrations of nutrient and chemicals loads on growth of invasive weeds in the Delta	NO, lack of data
III	Proliferation of disease vectors (Mosquitos, snails) due to creation of rice fields and stagnant water bodies.	Impact of creation of rice fields and stagnant water bodies on risk for waterborn disease (chapter 6.3)	statistic analysis
Ia, Ib	Worsened navigation conditions due to decrease ofwater levels in dry season	Impact of changes of the flow regime of the Niger on navigability (Liersch et al. 2012)	H4b, H9a

3.4.4 Policy

DSIR link	Potential problem	Research topic	Asessment tool
IV	Lack of implementation of the Action plan of the national wetlands policy and Ramsar convention	Impact of local laws, limited financial resources or institutional capacity on the implementation of national management plan and RAMSAR convention	EXP

3.5 Abras de Mantequilla

In the Abras de Mantequilla wetland the main problem is the aggressive agricultural activity causing increased nutrient and pollutant load and loss of natural wetland habitat. Additionally sewage input from human settlements is increasing what may cause a further risk of pollution and eutrophication. From upstream the wetland is potentially threatened by some planned large-scale infrastructure projects, mainly reservoirs and water diversions). This could lead to lower water levels, cause problems for navigation due to the proliferation of water hyacinths and ultimately loss of wetland area and biodiversity

3.5.1 Hydrology

DSIR link	Potential problem	Research topic	Asessment
II	Reduction of inflows to the wetland due to construction of multipurpose dam and water transfer projects upstream of AdM	Impact of dam construction and water transfer project on water availability (chapter 6.2, Villa-Cox et al. 2011)	H5, H7a, H7b, H8
	Decreased surface water levels, water level fluctuations and groundwater levels due to reduced inflows into the wetland	Impact of changes in inflow on water levels and water level fluctuations in the wetland (chapter 6.2)	H5, H7a, H7b, H8

3.5.2 Ecology

DSIR link	Potential problem	Research topic	Asessment tool
I	Loss of habitat and biodiversity due to agricultural encroachment and fish farming in the wetland	Impact of land-use change on biodiversity (Villa-Cox et al. 2011)	E6, EXP
		Impact of water quality on habitat quality and biodiversity (appearance of exotic species) (Villa-Cox et al. 2011, Alvarez-Mieles et al. 2012)	EXP
II	Increased risk of eutrophication due to reduction of inflows to the wetland.	Impact of c hydrology on nutrient retention of the surface water (Villa-Cox et al. 2011, Minaya et al. 2012)	H5, H7a, H7b, H8
II	Loss of biodiversity due to reduced inflows as a consequence of upstream dam and water transfer projects	Impact of changes in hydrology on habitat and biodiversity (appearnce of exotic species) (Villa-Cox et al. 2011)	EXP

3.5.3 Livelihood

DSIR link	Potential problem	Research topic	Asessment tool
I	Danger of water born diseases due to increased inflow of agrochemicals and domestic wastes	Impact of pollution, nutrient input and land-use change on risk of water born diseases	NO
I	Risk of navigation blockage due to proliferation of water hyacinths as a consequence of eutrophication	Risk of eutrophication due to increased inflow of agrochemicals and domestic wastes and impact on growth of water hyacinth (Villa-Cox et al. 2011)	EXP
II	Risk of blockage of navigation due to improved habitat conditions for water hyacinths as a consequence of reduced inflows	Risk of eutrophication due to reduced inflows and impact on growth of water hyacinth (Villa-Cox et al. 2011)	EXP
II	Reduced access to water for drinking and irrigation due to reduction of inflows into the wetland	Impact of changes in hydrology on water availability in the wetland (Villa-Cox et al. 2011)	EXP
II	Damage to food production (agriculture, fisheries) due to reduced inflows in the wetland	Impact of changes in hydrology on agricultural production and fisheries. (Villa-Cox et al. 2011)	EXP

3.6 Gemenc

Although Gemenc still hosts typical rich and diverse alluvial ecosystems and provide several ecosystem services, its state has been degraded a lot during the past 100-150 years. This degradation has been caused mainly by river regulation. Regulation resulted in the incision of the river bed and in the aggradation of the floodplain surface, which ultimately led to the desiccation of the wetland. Since these external drivers are still active, the process of degradation will continue in the future as well.

The Gemenc is also exposed to the negative consequences of the conflict between the two main land users, the National Park and the Forestry Company. The former is interested in nature conservation while the latter in wood production.

3.6.1 Hydrology

DSIR link	Potential problem	Research topic	Asessment tool
I	Decreasing water levels in the river and on the floodplain	Impact of riverbed incision, floodplain aggradation and climate change on the water regime of the Gemenc (Pataki et al. 2012)	C1, H15, H10

3.6.2 Ecology

DSIR link	Potential problem	Research topic	Asessment tool
I	Reduction of key habitats: shrinking water bodies, decreasing wet areas	Impact of riverbed incision, floodplain aggradation and climate change on habitat availability (Pataki et al. 2012)	C1, H15, H10, E1, G2
I	Reduced access of fish to spawning habitats due to loss of lateral connectivity	Impact of riverbed incision, floodplain aggradation and climate change on lateral connectivity (Pataki et al. 2012)	C1, H15, H10

3.6.3 Policy

DSIR link	Potential problem	Research topic	Asessment tool
III	Inadequate management of the Gemenc due to the conflict between the National Park and the forestry company	Analysis of institutional capacity in wetland management (Ostrovskaya et al., 2011)	EXP

3.7 Lobau

The “Lobau” is an urban floodplain of the Danube River in Vienna. The former dynamic system was disconnected from the main channel by the construction of a flood protection dam in 1875. In its present status it is a system of groundwater-fed and back-flooded floodplain lakes where terrestrialisation and sedimentation processes prevail. The artificially created habitat types host a high biodiversity, including many protected species which led to the designation as a site of European and International importance (NATURA 2000, UNESCO Men and Biosphere Reserve, RAMSAR). An important fact for the system is that without any management activity most aquatic and semi-aquatic habitats will disappear within the next decades (e.g. Funk et al. 2009).

3.7.1 Hydrology

DSIR link	Potential problem	Research topic	Asessment tool
I	Reduced surface water connectivity between river & floodplain + ongoing aggradation due to flood protection dam & channelized river bed	Impact of the flood protection dam on the water regime of the Lobau (Hein et al. 2008)	H1, H13

3.7.2 Ecology

DSIR link	Potential problem	Research topic	Asessment tool
I	Decreased habitat variability and disappearance of sensitive species due to reduced surface water connectivity and aggradation	Impact of reduced surface connectivity and aggradation on the habitat availability and abundance of sensitive species (Funk et al. 2012, Baart et al. 2010)	E1, G1
I	Dissapearance of sensitive species due to disturbance as a consequence of increasing number of visitors (recreation)	Impact of disturbance due to visitors on the habitat availability for sensitive species (Hein et al. 2008)	G1, EXP
I	Degraded water quality in the floodplain water bodies due to high nutrient loads entering the floodplain in case of floods	Impact of change in connectivity on the accumulation of nutrient rich sediments (Bondar-Kunze et al., 2009)	Statistic analysis

4 Site-specific performance indicators

This part of the document contains a list of performance indicators measuring ecosystem services (some of them directly linked to livelihood issues), ecological integrity, costs and the potential for adoption of the investigated management solutions. The basic concept of this list is that **qualitative** and **quantitative** indicators are used to complement each other: Where possible, quantitative modelled indicators are used. To overcome the modelling gaps (indicators which cannot be modelled within the available human and technical resources), qualitative indicators are included. The latter can also be used alone in order to perform an assessment with less computational and time efforts.
There are two kinds of references within the table: The red numbers in the first column correspond to the DSIR components (see deliverable D3.2). This makes it able to relate the indicators to the problems identified in the DSIR analysis. Thereby, most references are referring to the “Impacts” within the DSIR analysis. In some cases, however, there are references to the drivers or states. In such cases the numbers are preceded by D or S, respectively. The second type of references is in column three: Here, the reference is to the modelling tools used to determine the actual value of the indicator (summarised in the toolbox document, part of deliverable D7.1). This shows which kind of investigations have to be carried out to determine the actual value of the indicator under consideration. In case of expert judgement, this is indicated by “Exp”. All other referencing codes can be found in the toolbox document.

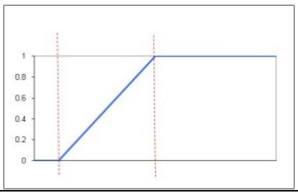
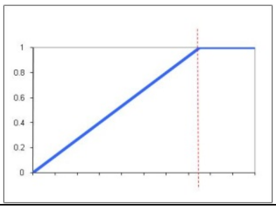
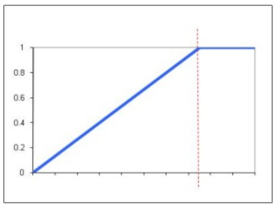
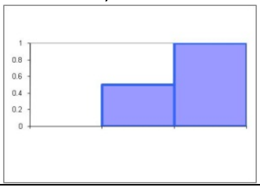
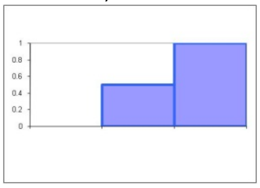
It can be seen that there is an emphasis on (i) expert judgement methods and (ii) hydrology-based indicators. The reason is that WetWin aims at obtaining practical relevant results also in cases of data shortage. Therefore expert judgement methods and hydrology-based assessment is optimal for this approach. Moreover, hydrology is clearly one of the most important factors for livelihood and ecology in wetlands.
The structure of the table is as follows:

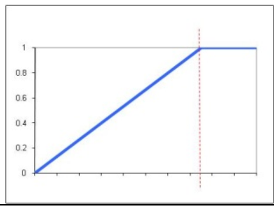
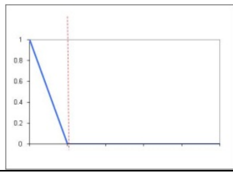
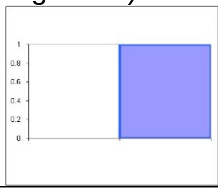
- The first column “Indicators for” contains the concrete object that is measured by the indicators: Thereby, the emphasis is on non-scientific, well-understandable properties which can be easily discussed by experts, stakeholders and scientists.
- The second column “Indicators” contains rapid assessment indicators and quantitative measures, which require detailed modelling and monitoring activities or expert judgement.
- The third column “Evaluation method” contains the kind of investigations which are necessary to determine the actual value of the indicator under consideration.
- The fourth column “Type of value function” contains the type of value function used for this indicator. Thereby, “maximise” means that the maximal value of the indicator is optimal, “minimise” means that the minimal value of the indicator is optimal and “optimum” means that an intermediate value of the indicator gives the highest score.

4.1 GaMampa

4.1.1 Livelihood

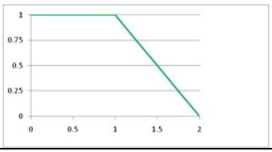
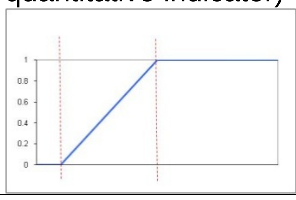
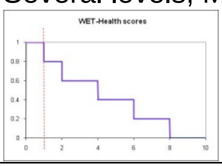
For details and methodology see Morardet (2012)

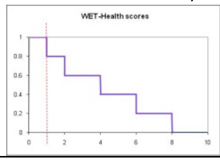
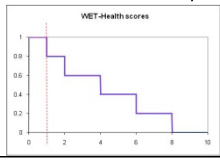
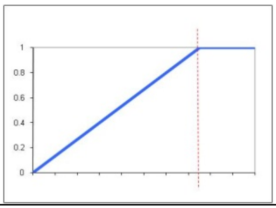
Indicators for:	Indicators:	Evaluation method	Type of value function
D16 Irrigation scheme use, equitable access to water ("irrigation water is sufficient to satisfy crop needs")	Percentage of irrigation scheme area irrigable in dry season	En4 Farming system model, and IS technical assessment	Maximise, minimum and maximum thresholds 
I2 Building and craft materials	Percentage of households engaged in reeds and sedges collection	E3 WETSYS & En4 farming system model	Maximise, maximum threshold 
D10, D17 Food production ("community can feed itself from local resources")	Percentage of maize needs covered by local production (wetland + irrigation)	E3 WETSYS & En4 farming system model	Maximise, minimum and maximum threshold 
D11 all provisioning services	Percentage of cash basic needs covered by cash income from natural resources	E3 WETSYS & En4 farming system model	Optimum at mean level
D17 Grazing	Grazing opportunities in the wetland	Exp	3 levels, maximise 
D11 Income from alternative livelihood activities	Opportunities for local off-farm jobs	Exp	3 levels, Maximise 

D10, D17 Equitable access to cropping land ("cropping land is available for those who need it for subsistence")	Percentage of households with a plot either in wetland or irrigation scheme	E3 WETSYS & En4 farming system model	Maximise, maximum threshold 
	Percentage of wetland farmers having a plot in the irrigation scheme	E3 WETSYS & En4 farming system model	Minimise, minimum threshold 
	Type of land access	Exp	2 levels (unregulated, regulated) 

4.1.2 Ecology

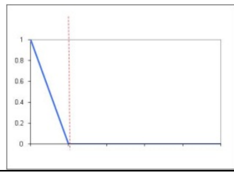
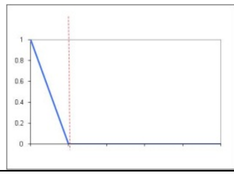
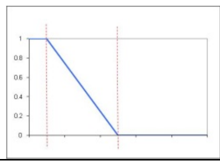
For details and methodology see Morardet (2012)

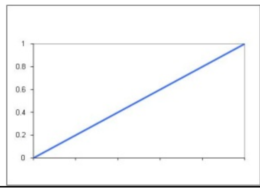
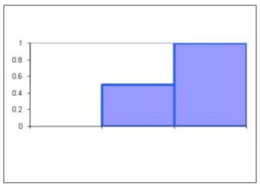
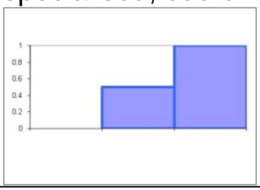
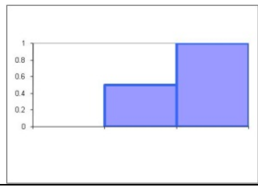
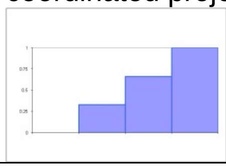
Indicators for:	**Indicators:**	**Evaluation method**	**Type of value function**
I3, I4, S3 Water quantity for the ecosystem	average depth of groundwater level during the dry season [m]	E3 WETSYS model	Maximise, maximum threshold 
	River outflow as a percentage of natural flow in dry season	E3 WETSYS model	Maximise, minimum and maximum thresholds (for quantitative indicator) 
	Hydrological health score (Ecosystem)	E6 WETHealth tool	Several levels, Minimise 

D19 Geomorphological state	Geomorphological health score (Ecosystem)	E6 WETHealth tool	Several levels, Minimise 
S2, I1 Vegetation health	Vegetation health score (Ecosystem)	E6 WETHealth tool	Several levels, Minimise 
	Percentage of initial wetland area under natural vegetation	E3 WETSYS model	Maximise, maximum threshold 

4.1.3 Societal institutional

For details on institutional capacity and cost see WETwin reports Ostrovskaya et al. (2011) and Interwies and Cools (2011) respectively.

Indicators for:	**Indicators:**	**Evaluation method**	**Type of value function**
D14 Capital (or investment costs)	Investment costs as a percentage of municipal capital budget	economic assessment	Minimise, minimum threshold 
Costs for operation and maintenance of infrastructure	Operation and maintenance costs as percentage of household income	economic assessment	Minimise, Minimum thresholds 
Contribution of local users to capital costs	Share of capital costs supported by local users	economic assessment	Minimise, Minimum and maximum thresholds 

Contribution of local users to O&M costs	Share of operation and maintenance costs supported by local users	economic assessment	Maximise 
D6, D7, D3, D9, D14, D15 Implementation challenges, institutional capacity and community ownership	Awareness raising & training programs	Exp	3 levels: none, once off, continuous 
	Local committees and participation	Exp	3 levels : none, specialised, coordinating 
	Clarity of rules & responsibilities for natural resources management	Exp	3 levels: none, existent, coordinated & enforced 
	Coordination of government programs	Exp	4 levels: None, Separated plans from each government department, Active communication among government departments, community & government coordinated project 

4.2 Nabajuzzi

4.2.1 Livelihood

For model on water quantity see Winkler et al. (2012) and Fournet (2011).

For general information on the wetland see Fournet (2011) and on the qualitative assessment see Mahieu (2010).

Indicators for:	**Indicators:**	**Evaluation method**	**Type of value function**
4, S2 Water quality (drinking water from the wetland)	Connection to the sewage treatment [% of households]	Exp Develop options to upgrade the public sewage infrastructure	Maximise
	Level of sewage treatment	Exp Expert judgement: scores for level of treatment	3 levels: rehabilitate existing treatment, expand stabilization ponds, both
	Individual waste water treatment at houses and farms (latrines, soakpits) [% of households]	Exp Develop options to promote the individual sewage treatment	Maximise
	Quantity of agrochemicals used [kg/year]	Exp Develop alternative agricultural practices	Minimise
	Papyrus harvesting in Nakaiba arm [% of papyrus/year]	Exp Develop harvesting scenarios	Optimum between 10 and 20%
	Nutrient concentrations in Nakaiba arm	Exp Nutrient contamination	Optimum
	Measured water quality parameters (e.g. BOD, COD, E.coli, nutrients)	Ongoing monitoring by NWSC	only for status quo; no evaluation of mgmt options possible
2, 3, 5, S1Water quantity	Water quantity available per day for drinking and sanitation in dry season [m³/day]	H3, H4b Hydrological modelling	Optimum, dependent on population
Quality of water network	Improve the drinking water network [% of households connected]	Exp Develop options for improving the water network	Maximise
	Average distance to the next drinking water source (time spare due to better water supply)	Exp Expert judgement; develop options for improving the water network	Minimise
1, 2, 6 Alternative livelihoods (additional income)	Papyrus harvesting in the wetland [% of papyrus/year]	Exp Develop harvesting scenarios	Optimum between 10 and 20%

4.2.2 Ecology

For model on water quantity see Winkler et al. (2012) and Fournet (2011).

For general information on the wetland see Fournet (2011) and on qualitative assessment see Mahieu (2010).

Indicators for:	**Indicators:**	**Evaluation method**	**Type of value function**
1 Integrity of the papyrus ecosystem (including rare bird species depending on papyrus)	Permanently flooded area in the wetland close to Masaka (“pool 1”) [m²]	H3, H4b Hydrological modelling	Optimum
	Hydrological health score (Ecosystem)	E6 WETHealth tool	Several levels, Minimise
	Vegetation health score (Ecosystem)	E6 WETHealth tool	Several levels, Minimise
1, 4, 5 Wetland pollution (e.g. motorcycle washing, tank washing, waste dumping)	No of polluting activities per day	Exp Expert judgement	Minimise
1, 6 Sustainable land-use	% of the agricultural land under sustainable land-use	Exp Develop alternative land-use practices (e.g. erosion prevention)	Maximise
	Use of agrochemicals (fertilisers, pesticides) [amounts per year]	Exp Develop alternative land-use practices	Minimise
1, 7 Erosion control	Percentage of area prone to erosion (e.g. clear-cut forest, river bank cultivation, cultivation on steep slopes)	Exp develop erosion control measures	Minimise
	Geomorphological health score (Ecosystem)	E6 WETHealth tool	Several levels, Minimise

4.2.3 Societal/ institutional

For details on institutional capacity and cost see WETwin reports Ostrovskaya et al. (2011) and Interwies and Cools (2011) respectively.

Indicators for:	Indicators:	Evaluation method	Type of value function
Direct costs	Investment costs for infrastructure measures	Exp Expert judgement: estimation of costs at once	Minimise
	Costs to maintain the infrastructure (costs for operation and management)	Exp Expert judgement: estimation of costs/year	Minimise
Potential for adoption	Risk of technical failure	Exp Qualitative assessment of the risk to have technical failures	Minimise
	Acceptance of measures	Exp Stakeholder involvement; expert judgement	Maximise
	Level of awareness raising programs	Exp Qualitative assessment of the necessity of awareness raising programs, in order to have an efficient implementation of the option.	Minimise
	Financial sustainability	Exp Evaluate how much the option is dependent on external funds and how well these funds are managed.	Maximise
	Availability of financial resources	Exp Evaluate the necessity of financial resources for the option's implementation	Maximise

	Institutional capacity	Exp Evaluation of the institutional capacity to apply management options: availability of means (technical, knowledge) and human resources.	Maximise

4.3 Namatala

4.3.1 Livelihood

For general information see Namaalwa et al. (2012), chapter 6.1 and Guruh Satria (2010)

Indicators for:	**Indicators:**	**Evaluation method**	**Type of value function**
1, D5 Potential rice production in wetland (tonnes/year)	Total rice production in the wetland (tonnes/year)	G1, Exp Develop land-use change and harvesting options	Maximise
1, S1 Potential fish production in wetland (tonnes/year)	Total fish production in the papyrus wetland (tonnes/year)	G1, Exp Develop land-use change and harvesting options;	Maximise
1, S1 Potential production of papyrus for harvesting	Total amount of papyrus being harvested	G1, Exp Develop land-use change and harvesting options;	Maximise
disease risk	disease risk due to contact with contaminated water (coliforms and toxic substances)	Exp, potential contamination with disease bacteria, develop wastewater treatment options	Minimise, 3 levels

4.3.2 Ecology

For general information see Namalwa et al. (2012), chapter 6.1 and Guruh Satria (2010)

Indicators for:	**Indicators:**	**Evaluation method**	**Type of value function**
2 Integrity of the remaining papyrus wetland	Area covered by papyrus wetland	G1, Exp Develop land-use change options	Maximise

3 Water quality	Total suspended solids at the downstream point	Exp Develop land-use change and harvesting scenarios	Minimise
	Total nitrogen at the downstream point	Exp Potential impact of management options	Minimise
	Total phosphorus at the downstream point	Exp Potential impact of management options	Minimise
	Total area of buffer strips in Upper Namatala Wetland	Exp Potential impact of management options	Maximise
	Nutrient removal by rice [tons of rice/year]	Exp Potential impact of management options	Optimum
	Nutrient removal by papyrus lower wetland [kg/year]	Exp Potential impact of management options	Optimum

4.3.3 Societal/ institutional

For details on institutional capacity and cost see WETwin reports Ostrovskaya et al. (2011) and Interwies and Cools (2011) respectively.

Indicators for:	**Indicators:**	**Evaluation method**	**Type of value function**
Direct costs	Investment in rehabilitation of water treatment facility	Exp based on estimated costs	Minimise
	Cost of training of communities	Exp based on estimated costs and population	Minimise
	Cost of awareness campaign	Exp based on estimated costs and population	Minimise
Potential for adoption	Risk of technical failure	Exp Qualitative assessment of the risk to have technical failures	Minimise, 3 levels
	Risk of non-acceptance by community	Exp Stakeholder involvement; expert judgement	Maximise, 3 levels

	Lack of institutional capacity	Exp Evaluation of the institutional capacity to apply management options: availability of means (technical, knowledge) and human resources.	Minimise, 3 levels

4.4 Inner Niger Delta

4.4.1 Livelihood

Local scale: Indicators developed for the assessment for the regions of Mopti and Macina for details and methodology on qualitative assessment see (Cools et al. 2012).

Indicators for:	Indicators:	Evaluation method	Type of value function
15, 10, 3 Health hazard	Schistosomiasis hazard	Exp, Logbooks from health centers and Expert judgement	Minimise, 5 levels
	Malaria hazard	Exp, Logbooks from health centers and Expert judgement	Minimise, 5 levels
	Diarrheic disease hazard (Diarrhea and Cholera)	Exp, Logbooks from health centers and Expert judgement	Minimise, 5 levels
	Malnutrition hazard	Exp Qualitative assessment	Minimise, 5 levels
10 Water quality	Groundwater	Exp Qualitative assessment	Maximise, 5 levels
	Water quality of urban wetland	Exp Qualitative assessment	Maximise, 5 levels
	Urban water quality – streets and housholds	Exp Qualitative assessment	Maximise, 5 levels
	Stagnant water	Exp Qualitative assessment	Maximise, 5 levels

Delta scale: Indicators developed for the assessment for the whole Inner Niger Delta

for details and methodology on quantitative assessment see Liersch et al. (2012)

Indicators for:	**Indicators:**	**Evaluation method**	**Type of value function**
3 Agricultural food production in the IND (e.g. rice)	Potential area for rice production [m²]	H4b Hydrological modelling	Maximise
3 Potential livestock in the IND	Potential area for Bourgou production	H4b Hydrological modelling	Maximise
Flow regulation	Maximal flooded area	H4b Hydrological modelling	Maximise
	Usable flooded area	H4b Hydrological modelling	Maximise
5 Navigability	Minimum flow downstream of Markala	H4b Hydrological modelling	Optimum
Hydropower production	Total electricity production by hydropower dams	H4b Hydrological modelling + Expert judgement	Maximise

4.4.2 Ecology

Local scale: Indicators developed for the assessment for the regions of Mopti and Macina

for methodology on qualitative assessment see (Cools et al. 2012).

Indicators for:	**Indicators:**	**Evaluation method**	**Type of value function**
1, 2 Biodiversity of fish	Habitat availability and reduction of human pressures for fish	Exp, potential impact of management options on conservation of fish	Maximise, 5 levels
1, 2 Biodiversity of birds	Habitat availability and reduction of human pressures for birds	Exp, potential impact of management options on conservation of birds	Maximise, 5 levels

Delta scale: Indicators developed for the assessment for the whole Inner Niger Delta

for details and methodology see Zsuffa et al. (2012)

Indicators for:	Indicators:	Evaluation method	Type of value function
1, 2 Habitat for fish	Habitat availability for fish during hydrological year	H9a, G1 Hydrological modelling, habitat modelling	Maximise
1, 2 Habitat for birds	Habitat availability for birds during hydrological year	H9a, G1 Hydrological modelling, habitat modelling	Maximise

4.4.3 Societal/institutional

For details on institutional capacity and cost see Ostrovskaya et al. (2010) Interwies and Cools (2011) respectively.

Indicators for:	Indicators:	Evaluation method	Type of value function
Affordability	Affordability for local people (incl. access to micro-credit)	Exp Qualitative assessment	Maximise, 5 levels
	Affordability for local authority	Exp Qualitative assessment	Maximise, 5 levels
	Income generation	Exp Qualitative assessment	Maximise, 5 levels
Organizational capacity	Capacity to implement	Exp Qualitative assessment	Maximise, 5 levels
	Capacity for maintenance	Exp Qualitative assessment	Maximise, 5 levels
	Capacity to operate	Exp Qualitative assessment	Maximise, 5 levels
Cooperation	Government Coordination	Exp Qualitative assessment	Maximise, 5 levels
	Level of participation	Exp Qualitative assessment	Maximise, 5 levels
	Education and awareness raising of people	Exp Qualitative assessment	Maximise, 5 levels
Robustness	to flow variability	Exp Qualitative assessment	Maximise, 5 levels
	to population growth	Exp Qualitative assessment	Maximise, 5 levels

4.5 Abras de Mantequilla

4.5.1 Livelihood

For details and methodology see Villa-Cox et al. (2011) and Arias-Hildalgo et al. (2012)

Indicators for:	Indicators:	Evaluation method	Type of value function
D4, 5 Food production and income	Inversion costs/seeding per Ha of crop	Exp Qualitative assessment	5 levels: Maximise
	Maintenance costs per Ha of crop	Exp Qualitative assessment	5 levels: Maximise
	Local food security	Exp Qualitative assessment	5 levels: Maximise
	Productivity per Ha of Crop	Exp Qualitative assessment	5 levels: Maximise
	Sediment and nutrient input for soil use	Exp Qualitative assessment	5 levels: Maximise
	Income level of the local population	Exp Qualitative assessment	5 levels: Maximise
	Economical Associability potential of local actors	Exp Qualitative assessment	5 levels: Maximise
	Turistic potential of AdM	Exp Qualitative assessment	5 levels: Maximise
	Education level/environmental conscience	Exp Qualitative assessment	5 levels: Maximise
3 Navigation	Navigability of the water body	Exp Qualitative assessment	5 levels: Maximise

4.5.2 Ecology

For details and methodology see chapter 6.2 and Villa-Cox et al. (2011) and Arias-Hidalgo (2012).

Indicators for:	Indicators:	Evaluation method	Type of value function
1, S1 Habitat integrity	Vegetation health score (Ecosystem)	E6 WETHealth tool	Minimise
	Level of Biodiversity	Exp Qualitative assessment	5 levels: Maximise
S2, 3, 4Water availability	Discharge of rivers [m³/sec]	H5, H7a, H7b, H8 Hydrological modelling	Maximise
2 Water quality	Level of Eutrophication	Exp Qualitative assessment	5 levels: Maximise

	Water quality index	H5, H7a, H7b, H8 Hydrological modelling, Nutrient modelling	Maximise with lower threshold

4.5.3 Societal/institutional

For details on institutional capacity and cost see Villa-Cox et al. 2011 and WETwin reports Ostrovskaya et al. (2010) and Interwies and Cools (2011).

Indicators for:	**Indicators:**	**Evaluation method**	**Type of value function**
Potential for adoption	Local actors capacity of adopting the measure	Exp Qualitative assessment	5 levels: Maximise
	Local management structure capacity to adopt the proposal	Exp Qualitative assessment	5 levels: Maximise
	Regional/national management structure capacity to negotiate support and coordinate actions	Exp Qualitative assessment	5 levels: Maximise
	Local budget	Exp Qualitative assessment	5 levels: Maximise

4.6 Gemenc

4.6.1 Ecology

For details and methodology see Pataki et al. (2012) and Winkler et al. (2009).

Indicators for:	**Indicators:**	**Evaluation method**	**Type of value function**
S1 Reduced lateral connectivity	Mean duration of river water levels above the connectivity threshold (actual or planned) during the growing season	C1, H15 Generation of daily water level time series for the Danube at Gemenc with the help of basin-scale hydro-meteorological modelling. Statistical analysis of water levels.	Maximise

S1 Decreasing water levels on the floodplain	Mean inundation durations on the floodplain during the growing season at different elevations (Auxiliary indicators for calculating the potential areas of ecotopes)	C1, H15, H10 Generation of water level time series on the floodplain with the help of hydraulic modelling. (Modelled river water levels and precipitation/evaporation data are used as boundary conditions.) Statistical analysis.	
S1, I1 Shrinking aquatic, semi-aquatic and wet habitats on the floodplain	Potential areas of ecotopes	C1, H15, H10, E1, G2 Elevation ranges of the different ecotopes are determined on the basis of their known preferences towards inundation durations. These ranges are mapped over the DTM of the floodplain	Optimize according to the desired areal distribution of ecotopes on the floodplain

4.6.2 Societal/ institutional

For details on institutional capacity see WETwin report Ostrovskaya et al. (2011).

Indicators for:	Indicators:	Evaluation method	Type of value function
D11, D12, S3 Management and implementation challenges, restoration and adaptation capacity	Institutional capacity	Exp Qualitative assessment of institutional capacity according to the Ramsar guidance documents	3 levels: Maximise

4.7 Lobau

4.7.1 Livelihood

Analysis of livelihood for the Lobau case study was not part of the WETwin project, but was analysed in the twinned project OPTIMA Lobau (see Hein et al. 2008).

4.7.2 Ecology

For details and methodology see Hein et al. (2008), Baart et al. (2010) and Funk et al. (2012).

Indicators for:	Indicators:	Evaluation method	Type of value function
D8, S1, I1 Availability of aquatic habitats	Area covered with water at low and mean water levels, shoreline length at low water level and proportion of connected water bodies at low water level	H1, H13, G1 2D groundwater and 2D surface water model	Maximise
S1, I1 Quality of terrestrial floodplain habitat	Flooded area at high water level of the Danube in different zones, Groundwater level and distance to surface.	H1, H13, G1 2D groundwater and 2D surface water model	Maximise
S1, I1,2,3 Integrity of terrestrial vegetation	Potential area of dynamic vegetation zones, Potential diversity and natural state of the terrestrial vegetation	H1, H13, G1, EXP 2D groundwater and 2D surface water model, expert judgement on impact on diversity and deviation from natural state	Maximize
S1, I1,2,3 Integrity of aquatic vegetation	Biomass of macrophytes and hydrophytes, area of helophytes, overall diversity, area for *Ranunculus fluitans* and for protected species	H1, H13, G1, 2D groundwater and 2D surface water model, statistic model approach	Maximize
S1, I1,2,3 Primary production	Proportion of shallow areas, areas of connected water bodies at mean water level, area with mean chlorophyll-a content, chlorophyll-a content in isolated water bodies, phytoplankton biomass	H1, H13, G1, 2D groundwater and 2D surface water model, statistic model for phytoplankton biomass and content of chlorophyll-a	Maximize, Optimize
S1, I1,2,3 Integrity of aquatic fauna	Weighted usable area for protected reptile, fish, amphibia and invertebrate species	H1, H13, G1, 2D groundwater and 2D surface water model, statistic habitat model for selected species (probability of occurrence)	Maximize

5 Toolbox

5.1 Introduction

This part of the document contains a list of modelling and assessment tools relevant for the WETwin study sites allowing quantification of wetland functions, such as drinking water supply, nutrient retention, flow control or habitat and land use functions, and the impact of management solutions and vulnerability scenarios on those. Tools are grouped in six modules namely climatic, hydrological, nutrient dynamic, ecological and economical module, additionally GIS tools and decision support tools are presented. For each module alternative quantitative and qualitative models with different levels of sophistication are available to ensure that for each study site the most appropriate modelling approach can be chosen, based on the outcome that is desired, the availability of data or the capacity of the respective institution. Listed tools are available (the software and knowledge for the use) at the indicated participating institutions of the WETwin team. Free software tools as well as commercial software are included. The list contains only tools, which are being used within the WETwin project or which the members of the WETwin consortium have experience in application. The table below describes structure and content of the toolbox table.

Model/tool	**short description** (capabilities of the model, possible output)	**data needs**	**available at**
Link to the list of indicators Name of the tool Description: (f) free software (c) commercial software [C] complex model/tool [S] simple model/tool in terms of data needs	Short description of the tool, including capabilities and output. Link to a related homepage/document where detailed information on the tool are available.	Overview of the data requirements of the tool	WETwin institution where the software is used and detailed information is available. It is not necessarily this institution that has developed the tool.

5.2 Available tools

5.2.1 Climate

Model/tool	**short description** (capabilities of the model, possible output)	**data needs**	**available at**
C1 Regional,dynamical downscaling model CCLM (f) [C]	The CCLM model is the non-hydrostatic operational weather prediction model applied and further developed by the national weather services joined in the Consortium for Small scale Modelling (COSMO). The first version of the COSMO-CLM (named CLM) was developed by colleagues from GKSS, PIK and BTU Cottbus on the basis of the Local Model (LM) version 3.1 (now COSMO model), originally developed by the German Weather Service. In 2005 the CLM became the regional Community-Model for the german climate research. The model has been applied on time scales up to centuries and spatial resolutions between 10 and 50 km in different regions of the world. In 2007/08 the CLM and the LM developments have been unified and a model version for regional climate modelling COSMO-CLM and operational weather forecast the COSMO, has been made available. The idea of a uniform model version for weather and climate became a guiding theme of the further model development. http://www.pik-potsdam.de/research/climate-impacts-and-vulnerabilities/models/cclm	GCM inputs (ECHAM5 for instance) in a specific format.	PIK

5.2.2 Hydrology

Model/tool	**short description** (capabilities of the model, possible output)	**data needs**	**available at**
H1 TUFLOW -2D (c) [C]	Complex hydrodynamics software: Calculates water levels and velocities on a 2-D grid. Most useful for stationary states. Dynamic calculations are limited due to the large computational effort. http://www.tuflow.com/	(i) Detailed DEM of the system; (ii) measured water levels and discharges for calibration; (iii) inflow to and outflow from the system for each state to be investigated	WCL
H2 InfoWorks RS Free Edition (f) (C)	1-D hydrodynamics software: Calculates water levels and discharges at subsequent nodes in 1 dimension. 2-D representation of the results is possible. Especially useful for dynamic calculations. The free edition is limited to 250 nodes. http://www.mwhsoft.com/products/infoworks_rs/	(i) Information on the morphology of the system (e.g. DEM); (ii) measured water levels and discharges for calibration; (iii) inflow to and outflow from the system (time series for dynamic calculations)	SORESMA
H3 Simple analytical 1-pool model (f) [C]	A simple dynamic hydrological model describing inflow to and outflow from a single basin based on differential equations. Can easily be applied in Excel. An extended version is being developed, taking into account the water storage by the papyrus mat. This is being programmed in Fortran (Winkler et al. 2012).	(i) Information on the morphology of the basin (e.g. DEM); (ii) measured water levels and discharges for calibration; (iii) inflow to and outflow from the system (time series for dynamic calculations)	WCL
H4a SWAT (f)[C]	Physically based semi-distribute hydrological modelling software: using HRU criteria (topography, land uses and soil types) it computes discharge routing, climate change scenarios, land use variations. http://swatmodel.tamu.edu/	i) DEM map; ii) Land use map; iii) Soil map/ soil database; iv) Stream network map; v) climate data; vi) Rainfall data; vii) Temperature data; viii) Weather generator data; ix) Other climate data; x) Reservoir operation information; xi) Agricultural management data; xii) River discharge data at hydrological stations; xiii) Water quality data; xiv) Crop parameters; xv) Crop yield data; xvi) Water quality at hydrometric stations (if water quality is required); xvi) Point sources; xvii) Inlet; xviii) Calibration and validation data.	IWMI, PIK

H4b SWIM/SWAT (f) [C]	SWIM (Soil and Water Integrated Model) and SWAT (Soil and Water Assessment Tool) are process-based eco-hydrological models. The continuous dynamic models include mathematical descriptions of physical, biogeochemical and hydrochemical processes, and combine significant elements of both a physical and conceptual semi-empirical nature. They were developed to assess the impacts of land use, land management, and climate change on water balance, water quality, and vegetation in meso- to macro- scale catchments. **SWIM**: http://www.pik-potsdam.de/research/research-domains/climate-impacts-and-vulnerabilities/models/swim/swim-description?set_language=en **SWAT**: http://swatmodel.tamu.edu/	Spatial (DEM, land use, soils), temporal (mandatory: rainfall, temperature, radiation; optional: air humidity, wind speed); other (management practices, such as dates for planting, fertilizer and pesticide applications in kg/ha, harvest)	PIK
H5 WEAP (c) [C]	Water allocation and planning tool, used to explore competing water uses under different scenarios. Calculates water demand, supply, runoff, infiltration, crop requirements, flows, and storage, and pollution generation, treatment, discharge and instream water quality under varying hydrologic and policy scenarios. http://www.weap21.org/	Time series of hydrological data (flows); rainfall and ET; data to characterise water sources; withdrawals, transmission, reservoirs, and wastewater treatment facilities, and water demands for user-defined sectors – e.g. agriculture, industry, mines, irrigation domestic supply, etc.	IWMI, ESPOL, SORESMA
H6 OASIS (f)[C]	OASIS (Options Analysis in Irrigation Systems) is a planning model for medium to large-scale canal irrigation systems (typically several thousand hectares). It specifically takes account of surface-groundwater interactions to assess the impacts on water use, depletion and productivity of a broad range of interventions in irrigated agriculture. http://www.iwmi.cgiar.org/Tools_And_Resources/Models_and_Software/OASIS/index.aspx	Information on physical settings (land-use, canals,…) and management (irrigation scheduling, conjunctive water use, water allocation,…)	IWMI

H7a HEC-RAS (f)[S]	Complex hydrodynamics modelling software: calculates water levels and discharges in a non-staggered way. Transient and steady-state analyses. Water quality and pollutants 1D dynamics computations. http://www.hec.usace.army.mil/software/hec-ras/	i): Cross sections; ii) upstream-downstream boundary conditions (Q/Wlevels); iii) Roughness values (or Manning); iv) hydraulic structures; v) Q/WL for calibration-validation	WCL, ESPOL
H7b HEC-GEO-RAS (f)[S]	HEC-GEO-RAS works under ARCMAP environment to provide HEC-RAS with a preprocessed model http://www.hec.usace.army.mil/software/hec-ras/	High resolution DTM of the bed in ArcView raster format; land cover layer in ArcView shape format showing the different roughness zones of the bed; discharge and water level data.	ESPOL, VITUKI
H7c HEC-HMS (f)[S]	HEC-HMS is a rainfall-runoff, physically-based semi-distributed model which uses hidro-meteorological parameters as input to compute runoff at the outlet of a catchment using different methods such as NCRS TR-55, Unit hydrograph, etc. www.hec.usace.army.mil/software/hec-hms/Im	i): DEM; ii) TS in meteorological parameters (precipitation, temperature, etc).; iii) landuse maps; iv) soil maps; v) TS in Discharges for calibration	ESPOL
H7d HEC-GEO-HMS (f)[S]	HEC-GEO-HMS works under ARCMAP environment to provide HEC-HMS with a preprocessed model. Hydrological delineation is previously performed using ArcHydro www.hec.usace.army.mil/software/hec-geohms/Im	i): High resolution DEM; ii) landuse maps; iii) soil maps	ESPOL
H9a River2D (f)[C]: 2-D hydrodynamic model	2-D hydraulic model. http://www.river2d.ualberta.ca/	DEM, cross sections of reach, bathymetry, upstream hydrograph (discharge or runoff) and downstream water stages	SORESMA

H9b River2D (f)[C] with the River2D-Geo (f)[S] pre-processor	River2D is a 2-D depth-averaged hydrodynamic model. Geometric input for River2D can be generated with the help of the River2D-Geo program. Input to River2D-Geo are ASCII-exported DTM and land cover layers. http://www.river2d.ualberta.ca/	High resolution DTM of the bed in ArcView raster format; land cover layer in ArcView shape format showing the different roughness zones of the bed; discharge and water level data.	VITUKI
H10 FOK (f)[C]	Quasi-two-dimensional cell-based hydrodynamic model for simulating the water regime of river floodplains.	Morphological data: elevation-area data of floodplain cells, cross sections of floodplain channels. Hydro-meteorological boundary data: water level time series from the river; monthly precipitation-excess data	VITUKI
H11 OPIDIN (f)	OPIDIN is a tool for predicting flooding the Inner Niger Delta of the Niger River. The tool aims to provide to the water users of the delta (farmers, fisher, herders) missing information on the future behaviour of the flood.	a) flood level, b) river discharge, c) rainfall is the catchment area, d) satellite maps and maps of their territories made by communities	WI
H12 Selingue dam manage-ment tool (f)	For managing the reservoir of Selingue dam NBA has put in place a tool under Excel. The management of the lake water resources is forecasted at two levels: a) Strategic management once a year which is defined at the onset of the irrigation season. It allowing defining management laws to be adopted for the future hydrological cycle and b) management option each week with two goals: which minima flow (to satisfy the downstream needs) and maxima water resources to be taken (to maximise electricity production) taking into account natural contribution of natural tributaries and the main river.	rainfall, river discharge, height of the flood, level of filling the lake	WI
H13 HPP-GMS, 2D groundwater model by TU Vienna (c) [C]	Complex groundwater flow model. http://www.msb.co.at/projekte/projekte_hpp.htm	Extensive geological and hydrological information about the system; measurements for calibration (e.g. by piezometer)	WCL

H14 MODFLOW (f) [C]	3-D finite difference groundwater flow model http://water.usgs.gov/nrp/gwsoftware/modflo w.html	Extensive geological and hydrogeological information; climate data;	IWMI
H15 VITUKI-HHFS (c) [C]	Hydrological forecasting and simulation system developed for the Danube. The basis of the system is a semi-distributed hydrological model, which consists of snow, rainfall-runoff and channel routing modules.	Monitored discharge and water level data from the gauges of the River Danube	VITUKI

5.2.3 Ecology and nutrient dynamic

Model/tool	**short description** (capabilities of the model, possible output)	data needs	available at
E1 Eco-hydro-morphological indicators (conceptual model) (f) (C)	This is a conceptual model, where basic hydrological and ecological properties of a wetland are described by hydro-morphological parameters such as water areas, water depths, shore line lengths and the variations of these quantities with different characteristic water-levels. Such parameters can be (statistically, habitat models) linked to ecological properties such as species presence or abundance and diversity and overall ecological health. The basic principle behind is, that hydrological diversity leads to ecological diversity and health.	FOR PREDICTIONS, MANAGEMENT OPTIONS OR SCENARIOS: (i) morphological information (DEM) and (ii) hydrological information (e.g. 1-D simulation results); FOR ASSESSING THE PRESENT STATE: (i) aerial photos, land-use maps and (ii) measurements of water depths	WCL VITUKI
E2 CASIMIR (f) [S]	A simple habitat model software, originally developed for rivers. May also be applied to wetlands. Estimates the abundance of certain species on the basis of their habitat demands. http://www.casimir-software.de/index.html	(i) habitat demands of the species to be investigated (e.g. the ideal flow velocity for a key fish species); (ii) spatial representation of the relevant system properties (e.g. flow velocities)	WCL

E3 WETSYS: STELLA-based integrated ecological economic model (f)[C]	WETSYS (Stella based) is a dynamic system model representing the functioning of the GaMampa wetlands and the community using it. It includes six sectors: hydrology (groundwater and soil water dynamics), crop production, crop economics, natural resources, land use and community well-being. It is used to assess impacts of various wetland management options under different external drivers scenarios. It works at monthly time step with socio-economic decision occurring annually (Morardet et al. 2012).	meteorological data (rainfall, ETP), hydrological data (inflows in groundwater, river inflows and outflows, efficient rainfall coefficient) soil data (field capacity, wilting point, depth) crop data (planting and harvest dates, Kc, Ky, root depth, max yield) economic data (crop prices, prices of wetland natural products, off farm wage, social transfers, food need per person, non food expenditure per household, poverty line) demographic data (population, natural growth rate, emigration rate, percentage of children and old people, percentage of off farm workers, household size) land use data (area of irrigated land, cultivated and natural wetland, area of various crops, average wetland plot area) wetland dimensions (area, length, width) irrigation system (efficiency, area, operating time) ecological data (biomass growth rate, carrying capacity, maximum harvest per household)	Cemagref/IWMI
E4 DELWAQ (c)[c]	Water Quality modelling based on Delft3D-hydrodynamic component through a communication file; calculates water quality processes, nutrient dynamics and mass balances in a 2D and 3D rectangular or curvilinear grid. Tool to support cost-effective model applications http://www.deltaressystems.com/hydro/product/621497/delft3d-suite/1130952	**Hydrodynamic component**: i): Bathymetry; ii) upstream-downstream boundary and initial conditions (Q/W levels); iii) spatially varying processes parameters; **Water quality component**: iv) Model substances; v) processes; vi) Initial and boundary conditions; and vii) nutrient loads/fluxes	ESPOL

E5 Papyrus growth and nutrient uptake model (f) [S]	STELLA-based analytical non-spatial model for papyrus growth and uptake of nutrients from the water. Thereby, decay of papyrus material and storage in the papyrus mat and sediment is considered. There is also the option to consider papyrus harvesting (van Dam et al. 2007)	Papyrus biomass, nutrient concentrations in water, living papyrus, papyrus mat and sediment (time-series for calibration)	UNESCO-IHE
E6 WetHealth tools (f)[S]	WET-Health combines an impacts-based and indicator-based approach that enables qualitative assessment of the negative impacts of human activities, such as damming, excavation of drains, cultivation, erosion and road construction on structure and function of wetland health in a semi-quantitative manner. Hydrological, geomorphological and vegetation health is assessed in separate modules. The extent of impacts as the proportion that is affected (percentage) and the intensity of impacts as the degree of alteration that results from a given activity as well as the evaluation of common indicators are used for the calculation of an impact score. http://www.wetland.org.za/TechnicalInfo.html	Hydrogeomorphic characterisation of the wetland. Desktop and On-site evaluation of magnitude of impact of damming, channel straightening, artificial wetland infilling, land-use, canalization and stream modification, impeding features, altered surface roughness, direct water losses, deposition, infilling or excavation, erosion or deposition, on-site activities and general structure and composition of the wetland vegetation.	Tool developed under a program of the Water Research Commission in South Africa SORESMA, IWMI
E7 HABITAT (f)[S]	Tool to support the development of water management plans e.g. for the Water Framework Directive, the Birds Directive and the Habitat Directive by systematically: analysing feasibility of ecological objectives testing effects of current and projected land use; analysing effects of measures and autonomous developments; analysing cost-effectiveness of measurements and set priorities. http://public.deltares.nl/display/HBTHOME/Home	Environmental conditions: i) hydrodynamics, ii) morphology, iii) water quality, iv) human intervention, v) Response curves: Information on optimal conditions for species or groups of species.	ESPOL

5.2.4 Economy, Ecosystem Services

Model/tool	**short description** (capabilities of the model, possible output)	data needs	available at
see Ecology: E3 WETSYS: STELLA-based integrated ecological economic model (f)[C]	WETSYS (Stella based) is a dynamic system model representing the functioning of the GaMampa wetlands and the community using it. It includes six sectors: hydrology (groundwater and soil water dynamics), crop production, crop economics, natural resources, land use and community well-being. It is used to assess impacts of various wetland management options under different external drivers scenarios. It works at monthly time step with socio-economic decision occurring annually (Morardet et al. 2012)	meteorological data (rainfall, ETP), hydrological data (inflows in groundwater, river inflows and outflows, efficient rainfall coefficient) soil data (field capacity, wilting point, depth) crop data (planting and harvest dates, Kc, Ky, root depth, max yield) economic data (crop prices, prices of wetland natural products, off farm wage, social transfers, food need per person, non food expenditure per household, poverty line) demographic data (population, natural growth rate, emigration rate, percentage of children and old people, percentage of off farm workers, household size) land use data (area of irrigated land, cultivated and natural wetland, area of various crops, average wetland plot area) wetland dimensions (area, length, width) irrigation system (efficiency, area, operating time) ecological data (biomass growth rate, carrying capacity, maximum harvest per household)	Cemagref/IWMI
En1 WATERSIM [S]	Integrated hydrologic - economic model designed to explore linkages between water, food security, and environment at the global, national and basin scales. Consists of two integrated modules: the 'food demand and supply' module (run at annual time step); and the 'water supply and demand' module (monthly or seasonal). Scenario based assessment of impacts. http://www.iwmi.cgiar.org/Tools_And_Resources/Models_and_Software/WATSIM/index.aspx	The model estimates food demand as a function of population, income and food prices. Crop production depends on economic variables such as crop prices, inputs and subsidies on one hand and climate, crop technology, production mode (rain fed versus irrigated) and water availability. Water supply for each basin is expressed as a function of climate, hydrology and infrastructure.	IWMI

En2 MAgPIE (large scale agro-economy, PIK development) (f)[S]	"Management model of Agricultural Production and its Impact on the Environment" (MAgPIE) is a global bio-economic model with a special focus on spatially explicit land and water constraints as well as technological change in agricultural production. http://www.pik-potsdam.de/research/sustainable-solutions/groups/landuse-group/magpie-mathematical-description	Economic inputs: demand, cost structures; Bio-physical inputs: crop yields, land & water constraints.	PIK
En3 AgroBasinMod (f)[S]	Land-use change and agricultural frontline expansion simulation for the Guayas River Basin: By modelling and projecting the impact of climate change and population growth scenarios on crop yields and crop demand, the software models land-use pattern and agricultural frontline expansion scenarios by means of a dynamic simulation of a basin scale crop market partial equilibrium model.	i) Landuse data & map; ii) Soil type data & map; iii) Agropecuary census data (SICA-INEC 2000-2001); iv) ECV 2006 data (INEC); v) Climate time series data (air temperature and precipitation); vi) Population projection time series (INEC)	ESPOL
En4 farming system model (f)[C]	The farming system model is a linear programming model of farm-household types. It is used to assess the differentiated impacts of changes in agricultural use and practices in the wetland and in the irrigation schemes on the various types of households. The models are developed using the GAMS platform but can also be solved with other optimization software.	(i) typology of households using the wetland, describing their capital endowments (human, natural, physical, financial capitals); (ii)description of the main livelihood activities (especially and natural resources harvesting activities) for each type; (iii) areas under crop and livestock production	Cemagref/IWMI

En5 WetEco-Services (f)[S]	WET-EcoServices is used to assess the goods and services that individual wetlands provide, thereby aiding informed planning and decision-making. The tool provides guidelines for scoring the importance of a wetland in delivering each of 15 different ecosystem services (including flood attenuation, nutrient and toxicants removal, water supply for human use, harvestable natural resources, cultivated foods, sediment trapping and provision of livestock grazing). Information on the effectiveness of the wetland for supplying a particular benefit and the opportunity afforded by the wetland supplying the ecosystem service is combined into an overall rating. http://www.wetland.org.za/TechnicalInfo.html	Hydrogeomorphic characterisation of the wetland. Existing knowledge or field assessment on the characteristics of the wetland (e.g. size, slope, surface structure, sinuosity, vegetation, flow pattern, flood attenuation potential and sediment trapping), the catchment (e.g. rainfall intensity, slope or geology) and human impacts (e.g. land-use, nutrient input, water abstraction)	Tool developed under a program of the Water Research Commission in South Africa SORESMA, IWMI

5.2.5 Decision support system

Model/tool	**short description** (capabilities of the model, possible output)	data needs	available at
D1 mDSS (f)[S/C]	Multi Criteria Decision Support System developed by the MULINO project. It ranks a finite number of alternative management solutions on the basis their criteria scores and also on the basis of stakeholder preferences. http://www.netsymod.eu/mdss/	Model- or expert-based indicators calculated for the alternative solutions; value function that translated indicator values into criteria scores; sets of criteria weights expressing the preferences of the different stakeholders	VITUKI, ESPOL
D2 LUPAS	Land use planning and analysis system - decision support system for strategic land use planning in context of multiple objectives, land use conflicts, trade-offs and uncertainty. Based on interactive multiple goal linear programming techniques. Methodology which can be developed in a range of linear programming environments (not a software package) (Laborte et al 2002).	Data requirements depend on application - data on biophysical and socio-economic resources; development targets and constraints	IWMI
D3 GIRE DecidAid	DECIDAID is decision making tool for optimizing planning and modalities for sustainable management of the water resources of the Niger Basin .It is based on the combination of statistical analysis of the behaviour of the river and economic and hydrological impacts of existing and future dams	a) river discharge at different hydrological stations, b) population of the basin, c) electricity production from dams, d) fish production, e) livestock production, f) irrigated rice production and g) biodiversity	WI
D4 Mike Basin [S]	Mike Basin is a software for DSS developed by DHI and functioning under GIS interface. This tool allows planners, water resources managers to have a global view at basin scale, users and uses and availability, http://www.crwr.utexas.edu/gis/gishyd98/dhi/mikebas/Mbasmain.htm	pollution sources (municipal, industry and non-point), recipient waters, existing water quality conditions, water supply and waste water treatment facilities, and technical options for improvements; DEM, rainfall, river discharge of different hydrological stations and data pertinent to water rights (water supply or irrigation)	WI

D5 DSTool (f)[S]	A tool that helps to build up a structured database of potential management options formulated for a wetland. It helps to assess the compatibility of the options, and visualizes these compatibilities in the form of a Planning Graph. DSTool also helps to identify alternative management solutions on the basis of the Planning Graph,	Management options identified with the help of the stakeholders.	VITUKI
D6 GARP (f) [S]	Qualitative reasoning software: schematic representation of the components and interactions in a system. Is able to investigate possible future developments of a system on a qualitative basis (no simulation but listing of qualitative possibilities), http://hcs.science.uva.nl/QRM/index.html	(i) relevant system components; (ii) relevant interactions between these components	WCL
D7 PODIUM (f) [S]	The IWMI Global Policy Dialogue Model (PODIUM) is a interactive policy planning and scenario analysis tool which explores the trade-offs and future demands on water resources on a national scale, to explore the complex interactions of water scarcity, food security, and environment needs, see http://podium.iwmi.org/podium/	Trends derived from FAO statistics (already included), user definable scenarios of population growth, changing diets and improvements in agricultural productivity and/or water efficiency.	IWMI

5.2.6 GIS (Geographical Information System)

Model/tool	**short description** (capabilities of the model, possible output)	**data needs**	**available at**
G1 Arc GIS (c) [C]	Standard GIS software, http://www.esri.com/	All kinds of spatially distributed information - depends on the problem to be investigated.	WCL, VITUKI, SORESMA, PIK, ESPOL
G2 ArcView (c) [C]	Standard GIS software, much less user-friendly than ArcGis, http://www.esri.com/	All kinds of spatially distributed information - depends on the problem to be investigated.	WCL, VITUKI
G3 GRASS 6.4 (f) [C]	GRASS: Geographic Resources Analysis Support System is a free Geographic Information System (GIS) software used for geospatial data management and analysis, image processing, graphics/maps production, spatial modelling, and visualization. GRASS is an official project of the Open Source Geospatial Foundation. http://grass.itc.it/ GRASS is available for Windows, Mac OSX, and Linux operating systems. http://grass.fbk.eu/	All kinds of spatially distributed information - depends on the problem to be investigated.	PIK
G4 MapWindow (f) [S]	The MapWindow application is a free, extensible, geographic information system (GIS). http://www.mapwindow.org/ MapWindow is available for Windows operating systems only. http://www.mapwindow.org/	All kinds of spatially distributed information - depends on the problem to be investigated.	PIK

6 Reports

6.1 Land-use trends in Namatala wetland and implication for livelihoods and ecology

Andrea Funk

For the Namatala wetland land-use maps are available for 1990 and 2005 (provided by the National Forestry Authority of Uganda). Based on satellite images and a ground survey the map could be updated for the actual status (2010). In its current status approx. 85% of the total wetland area of the Namatala wetland is converted into commercial farmland (Figure 6.1.1). Between 1990 and 2010 more than 50% of natural wetland area has been converted into farmland (Figure 6.1.2). If the current trend would continue the remaining wetland area would be replaced by farmland during the next 20 years. The main crop is rice. With current technology the use of fertilizers and pesticides is low but there is an increased tendency for intensified agricultural practice.

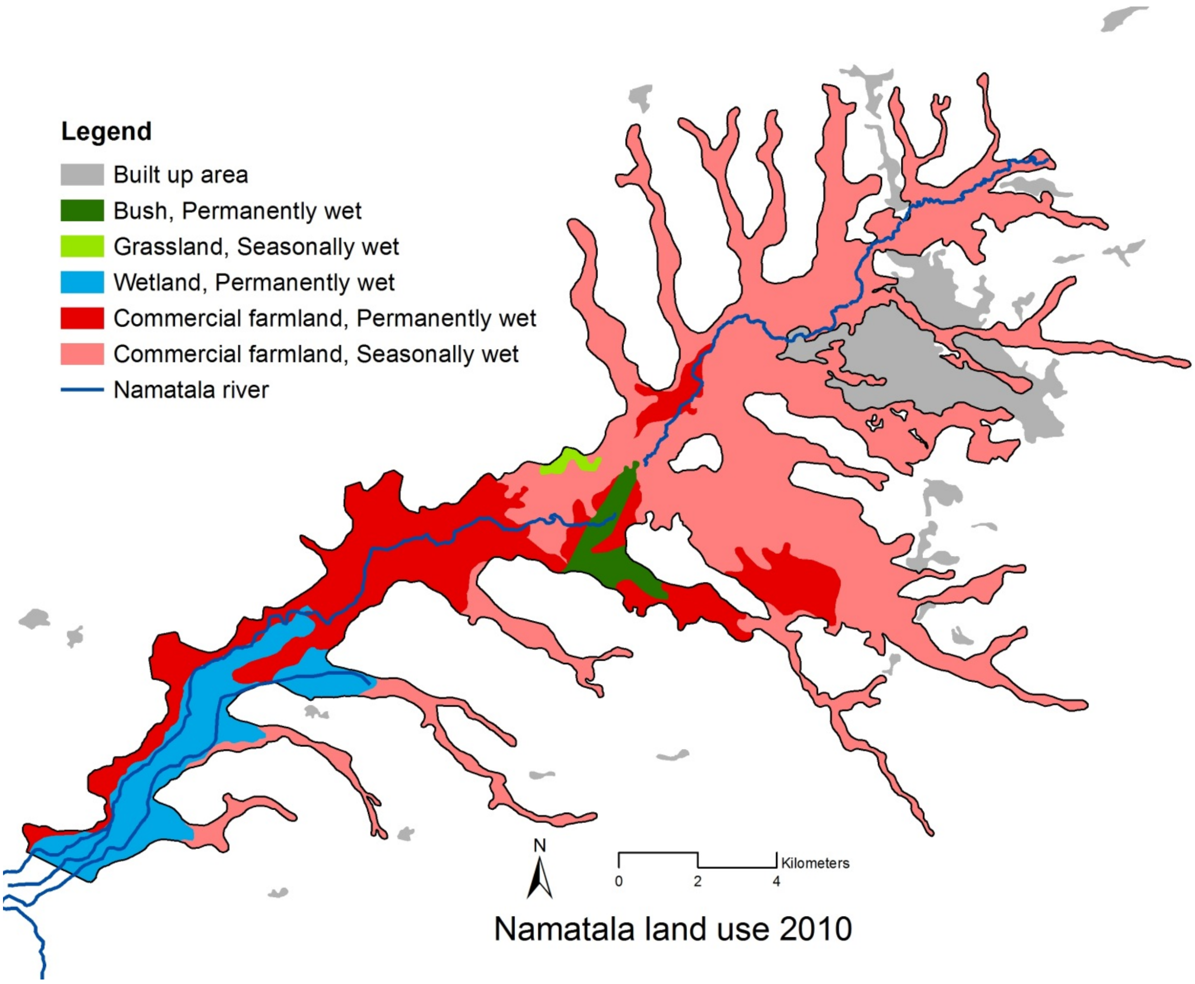


Figure 6.1.1: Land-use in the Namatala wetland 2010.

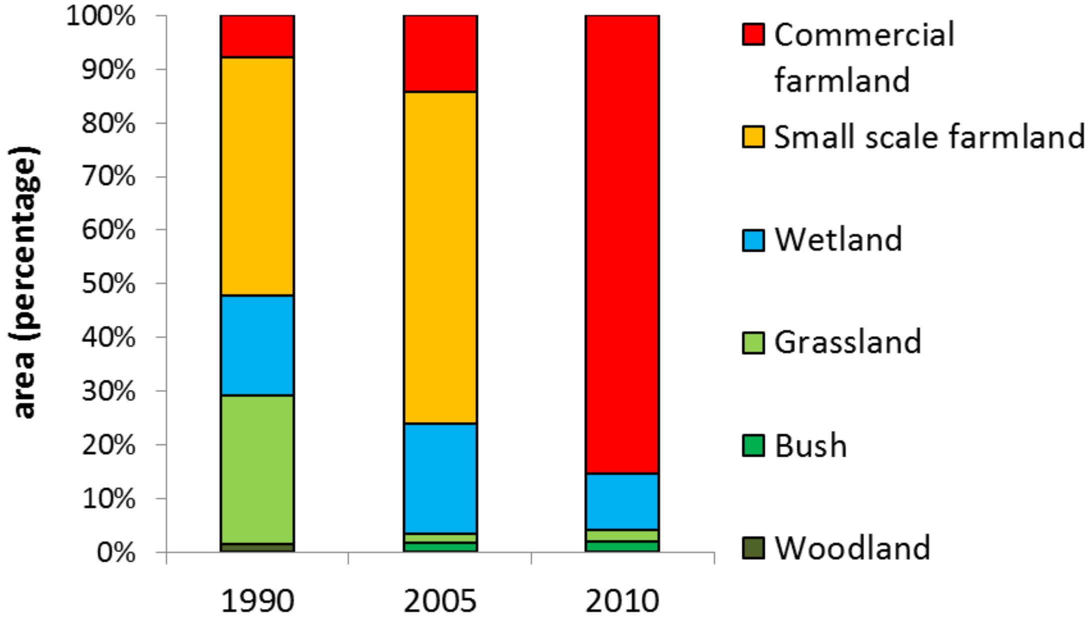


Figure 6.1.2: Land-use change in the Namatala wetland between 1990 and 2010.

Farmers have high disease risk due to contact with contaminated water (coliforms and toxic substances). This is mainly relevant in the agricultural plots close to sewage inflows and inflows of industrial waste in the proximity of built up areas (see Fig. 6.1.1).
Fishing and papyrus harvesting are important livelihood factors in the remaining natural wetland in the lower part of the system. Fish production is highly dependent on the spawning success of fish. The most important spawning habitat is the natural wetland (Goudswaard 2002, Aloo 2003). Papyrus harvesting is directly dependant on the availability of papyrus stands in the wetland.

Approx. 10% of the wetland area is papyrus wetland in the current status. Papyrus wetlands are key habitats for highly threatened (papyrus-) endemic bird species like the Papyrus Gonolek (*Laniarius mufumbiri*) and the Papyrus Yellow Warbler (*Chloropeta gracilirostris*) (Maclean 2003, 2006) and important spawning habitat for indigenous fish e.g. Mudfish (*Clarias mossambicus*) and Lungfish (*Protopterus aethiopicus*) (Goudswaard 2002, Aloo 2003). A further reduction of papyrus stands will thus lead to a reduction of biodiversity in the system. Additionally, Pollution and intensive harvesting (burning, herbivores,...) leads to degradation of papyrus wetlands, papyrus endemic bird species are absent from highly disturbed areas (Maclean 2003) whereas moderate use has no negative effect on habitat quality (Maclean 2006). Fish species might be negatively affected by pollution due to reduced oxygen availability under the Papyrus mats.

6.2 Report on modelling activities (Hydrology/hydrodynamics/water allocation), Abras de Mantequilla

Mijail Arias-Hidalgo

6.2.1 Introduction and modeling framework

According to the DSIR chains defined in the project proposal (Zsuffa 2008) as well as in work package 3 (Debels P., Zsuffa et al. 2011), the goal of modelling activities is to assist in the simulation of diverse processes that take place in and around the wetland. A second objective is to provide information to decision makers when policies and guidelines must be developed (WP 8 & 9). DSIR indicators for the Ecuadorian case study, from the hydrological point of view, can be summarized in two categories: water quantity and water quality.

Daule River as well as Vinces and Chojampe Rivers (Figure 1) flow southwards. Most of the system is still natural with the exception of two major hydraulic works: Daule-Peripa reservoir (6 Km3 of capacity) (Arriaga 1989) which is used for irrigation, flood control in Daule River and deviates 18 m3/s outside Guayas Basin towards La Esperanza Dam, especially during dry season (May to December) The second one is Chongon project in which 44 m3/s go to Santa Elena Peninsula, mainly for irrigation purposes.

Vinces and Nuevo River are quite important for Abras de Mantequilla ecosystem. This is because of an interconnection between Vinces and Nuevo River which allows water from the former to reach southern Abras and viceversa, depending on the season. At the beginning of rainy season (mid-December, January) water flows from Nuevo River to the wetland inundating an area of almost 10 Km2 in Chojampe subbasin. Conversely, when dry season approaches (May) the wetland drains onto Nuevo River until equilibrium is reached thus water stages remain almost constant due to a natural embankment.

In order to perform an analysis of indicators and evaluate the management solutions envisaged by the project, some modelling activities were developed as shown inFigure 2. They started with a rainfall-runoff model in Vinces and Chojampe subbasins, where HEC-HMS (Sharffenberg W.A. and Fleming M.J. 2010) was the selected tool. This first model made use of the available meteorological data and perform a rainfall runoff simulation to compute the discharges at a subcatchment's outlet.

With such an output, a hydrodynamic model was built along Vinces & Nuevo Rivers that included the interactions between the latter and Abras de Mantequilla system, using HECRAS (USACE 2010). The hydrodynamic model is necessary because as mentioned before, there is a time dependant water flux between Vinces River and Abras de Mantequilla wetland through Nuevo River. The Rainfall-runoff and hydrodynamic simulations provided the input for a final water allocation model using WEAP (Stockholm_Environment_Institute 2009).

An assessment on water quality parameters was undertaken also in WEAP to compute the water quality index in the wetland area. The main target of the WEAP model was to undertake a final comparison between the proposed management solutions on the wetland. Simultaneously, the evaluation of the impact of climate changes on the system was performed using meteorological projected time series by PIK (Potsdam Climate Institute, Germany). These time series (especially the rainfall ones) were the inputs for two HEC-HMS models in Vinces and Chojampe rivers and then finally again incorporated into the WEAP system

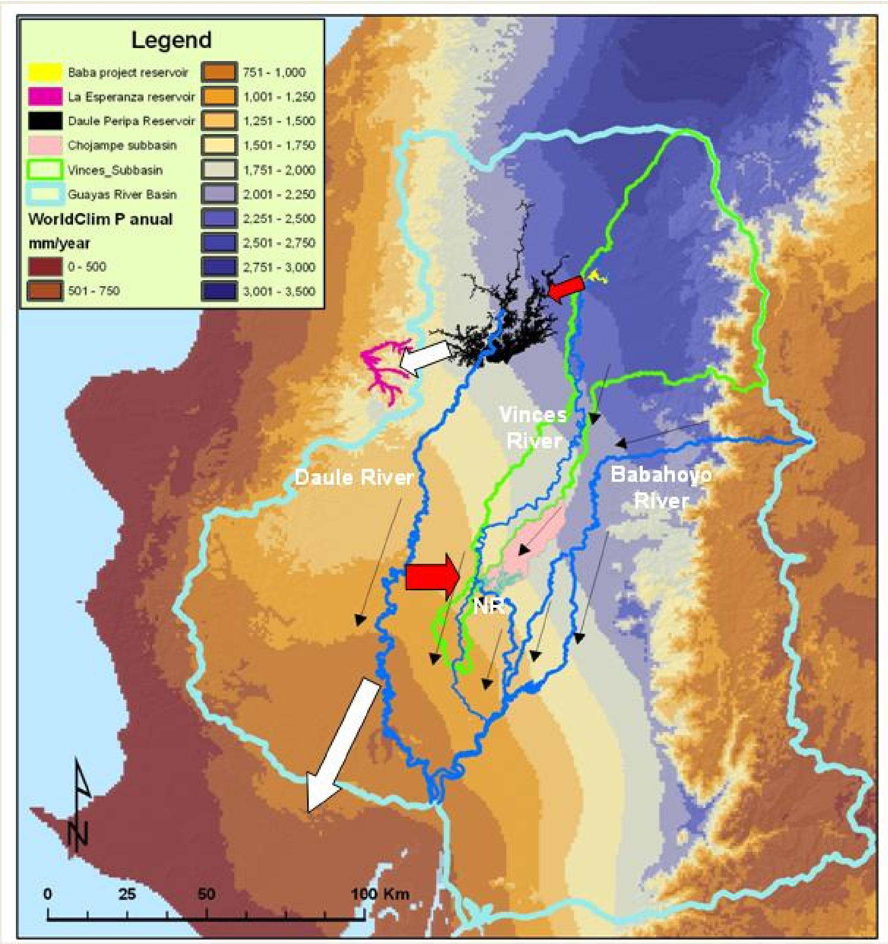


Figure 1: General flow scheme around Chojampe Subbasin (Abras de Mantequilla wetland in cyan spot inside Chojampe subbasin, Nuevo River (NR), south of the wetland). White arrows show current water transfer projects (Upstream: Daule Peripa to La Esperanza. Downstream: Chongon project, Daule River to Santa Elena peninsula). Red arrows mark future infrastructure works: Baba Dam (upstream zone to Daule Peripa) and Dauvin transfer project (Daule to Vinces and Nuevo River).

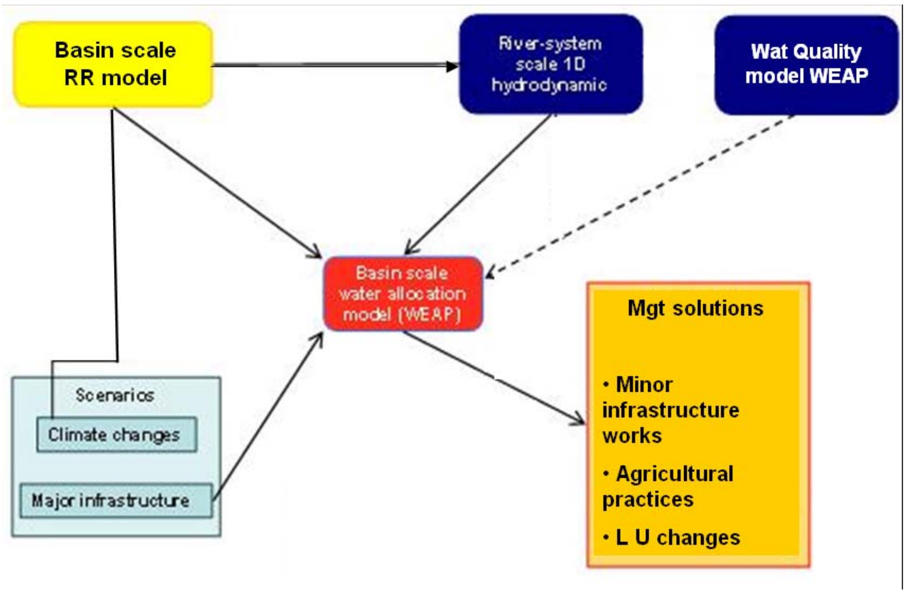


Figure 2: Modeling framework for Abras de Mantequilla case study.

6.2.2 Hydrological model

In order to feed with lateral inflows to the further hydrodynamic model and WEAP model, a rainfall runoff simulation is required. Since Lulu and San Pablo Rivers are important to determine their inflows to Vinces River (Figure 3), a simulation considering all these was carried out. Vinces' basin has been divided in 8 subbasins (6 are shown in Figure 3). Vinces Hcda. Casa Vinces and Vinces en Vinces subbasins are far downstream and are overlapping the hydrodynamic study hence they were not considered for hydrological investigation. Thus, the net area is 3416.53 Km^2. The selected modeling tool was HEC-HMS (Sharffenberg W.A. and Fleming M.J. 2010). The main target is, thus, to compute the hydrographs at the interception points (yellow dots in Figure 3).

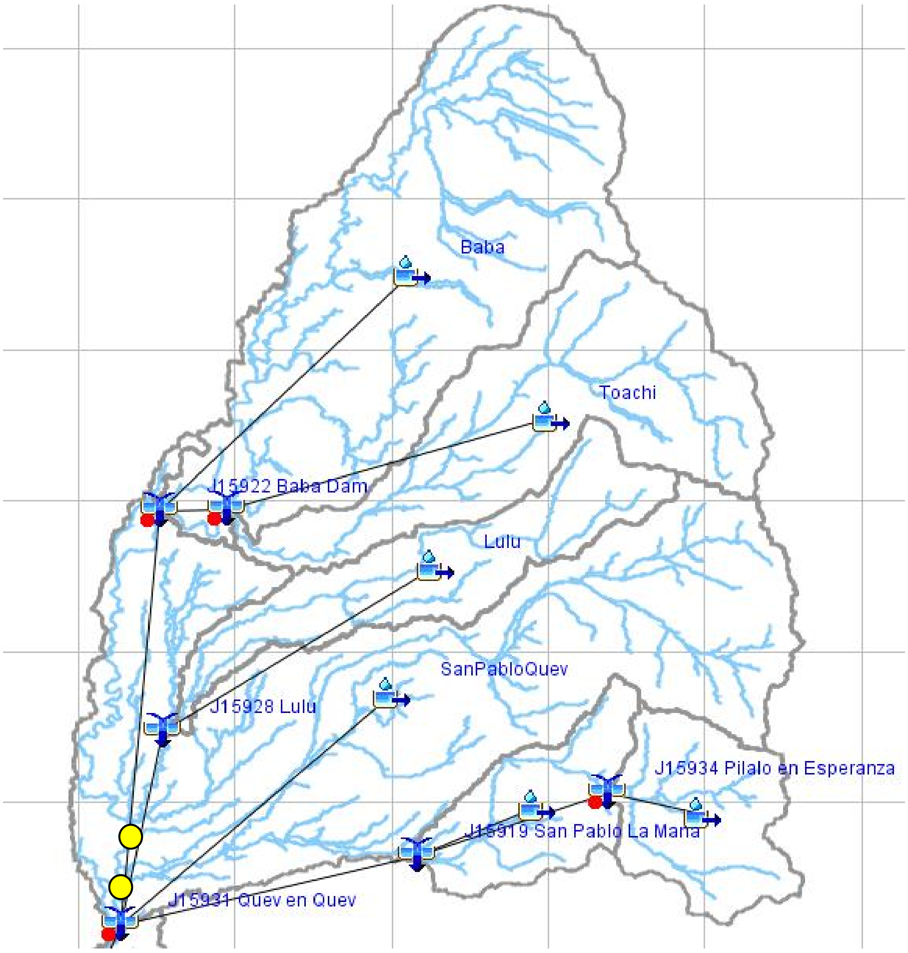


Figure 3: General schematization of a HEC-HMS model for the upper part of Vinces River catchment with its subbasins. Red dots mark the calibration points (streamflow stations) whereas the yellow ones are interception points of Vinces with Lulu and San Pablo Rivers.

The chosen method for accounting the losses from rainfall is NRCS (Natural Resource Conservation Service of USA, former known as Soil Conservation Service, SCS) curve number (USDA 1986). SCS method was aimed initially to small catchments; nevertheless, nowadays is widely used for subbasins as large as 300 Km2, since there is no clear alternative methodology for such areas (USDA 2004).

Hydrological parameters required for SCS methodology are shown on Table 1. In order to obtain those, HEC-GEO-HMS, a GIS-based tool developed by (Fleming M.J. and Doan J.H. 2009) was applied. Curve number was calculated based on the combinations of soil types and landuse maps that were available from PIGSA project database (scale 1:250000 (CEDEGE 2002)). Landuse maps were also crucial to compute the percentage of imperviousness. Initial abstraction was estimated as 20% of the maximum storage. The Lag time method was employed to compute the hydrograph transformation (USDA 2004).

Punctual rainfall was spatially propagated according to the Thyessen polygons criterion. Although it is not the most suitable method for hilly basins (especially the north-eastern corner of Vinces' catchment) it is simple and fast to implement and give a good idea on how precipitation is spatially distributed. Merging the areas of influence with the subbasins previously delineated using GEOHMS it was possible to estimate the weights for each subbasin (Figure 4 and Table 3)

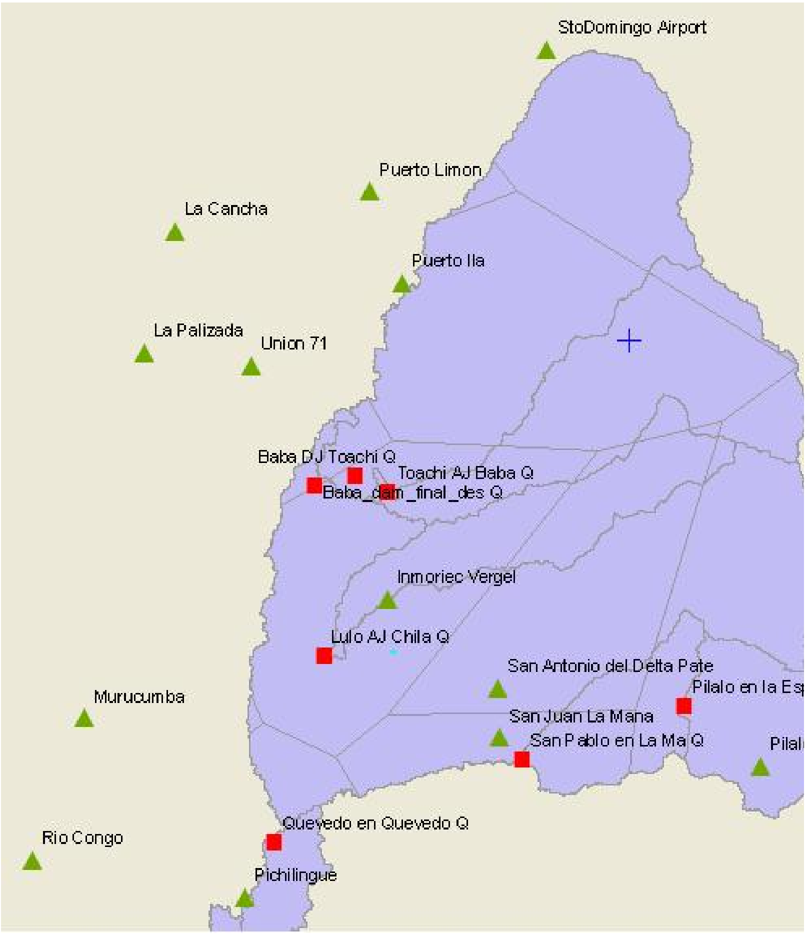


Figure 4: Thyessen polygons across Vinces' upper catchment. Rainfall stations are in green and streamflow measurement locations are in red. An example of distribution of rainfall weights is shown for SanPablo-Quevedo sub-basin

Baseflow estimation was done according to the recession method. Table 2 shows the different involved parameters. Especially recession constant (Qbi+1/Qbi, after the baseflow Qb) and ration to peak (Qb/Qp) were derived from the existent river flow time series.

Table 1: Surface water parameters for HEC-HMS

Subbasin	Area (Km^2)	Initial Abstraction (mm)	Curve Number	% Imperviousness	Lag time (min)
Baba	925.2	0.086	81.145	4.0764	301
Toachi	504.8	0.791	72.012	4.5263	222
SanPabloQuevedo	1290.3	0.395	69.992	5.8566	267
Pilalo	212.9	0.647	85.57	4.6734	78
San Pablo La Mana	190.0	0.915	69.54	3.7651	111
Lulu	293.4	0.798	71.771	5.278	210
Vinces Hcda.	240.5	1.011	70.781	8.9296	210
Vinces en Vinces	483.2	1.439	63.931	6.5618	310

Table 2: Baseflow parameters for HEC-HMS

Subbasin	Initial Discharge (m^3/s)	Recession constant	Ratio to Peak
Baba	140.7	0.84	0.60
Toachi	57.3	0.84	0.31
SanPabloQuevedo	180.0	0.85	0.67
Pilalo	11.2	0.95	0.80
San Pablo La Mana	14.2	0.82	0.56
Lulu	36.5	0.93	0.48
Vinces Hcda	421.4	0.82	0.56
Vinces en Vinces	664.7	0.98	0.88

Table 3: Gage weights for San Pablo-Quevedo subbasin, Vinces' upper catchment model

Gage Name	Weight
Inmoriec Vergel	0.31
Pichilingue	0.05
Pilalo	0.22
Puerto ila	0.00
San Antonio Delta Pate	0.30
San Juan La Mana	0.10
Union 71	0.02

Computation time control parameters were taken as follows:

Time span = Jan 2, 2006 – Dec 30, 2006

Time step = Daily (because there were only daily measurements for comparison).

After initial computations were carried out, a clear peak could be detected on April 2nd. A snapshot of Baba subbasin in Figure 5 details this as well as a global summary of peak volumes (Table 4). As an example, in Quevedo en Quevedo (SanPablo-Quevedo subbasin) 11.56 Km3 were registered in the April 2nd, 2006 peak.

In order to calibrate the model, the main parameters were: initial discharge, ratio to peak, curve number and initial abstraction. The optimization method was Univariate Gradient with a tolerance of 1% and iterating 100 times. The objective function was Peak-Weighted Root Mean Square Error which assigns larger weights to discharges above the mean and conversely for the rest (Sharffenberg W.A. and Fleming M.J. 2010).

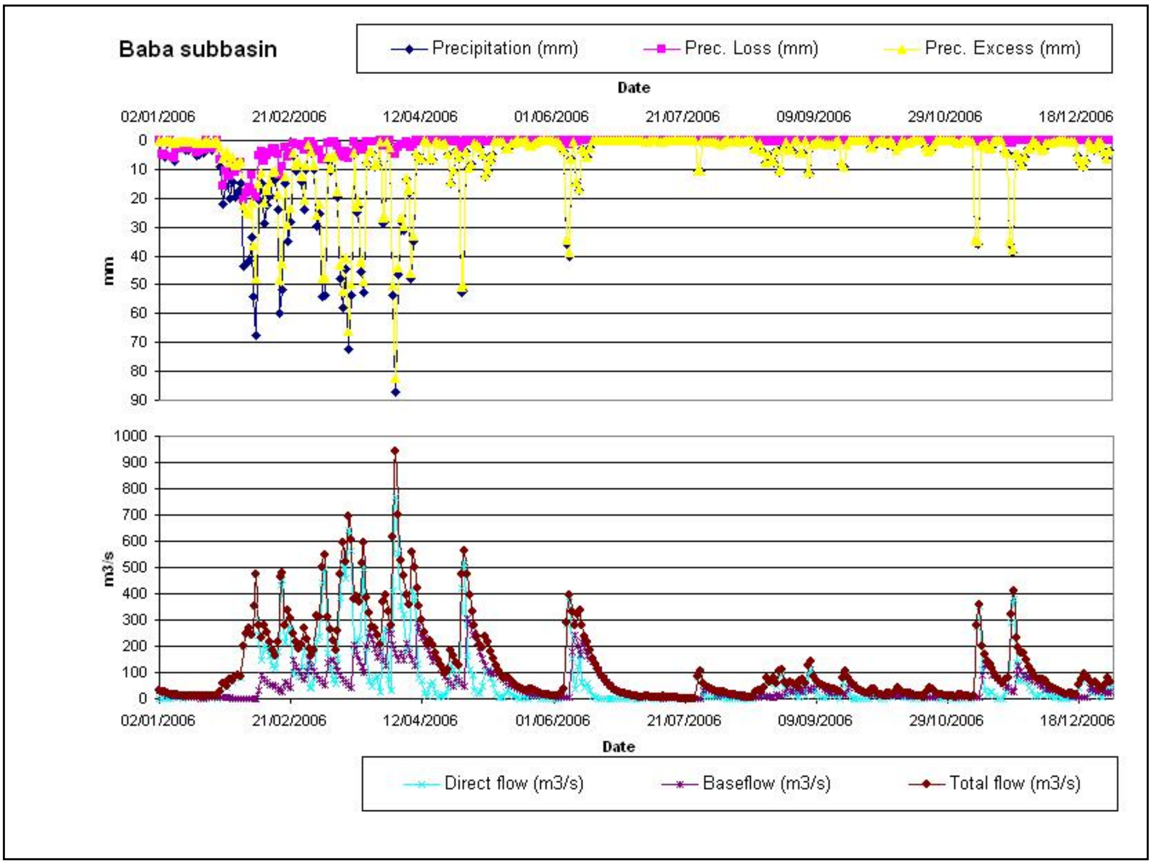


Figure 5: Baba subbasin rainfall – runoff computation (including precipitation losses and baseflow estimation)

Table 4: Global summary of computed peak volumes.

Hydrologic Element	Drainage Area (Km^2)	Peak Discharge (m^3/s)	Time of Peak	Volume (1000 m^3)
Baba	925.20	941.3	02abr2006, 12:00	3973346.1
Toachi	504.75	379.5	02abr2006, 12:00	1392602.7
J15925 Toachi AJ Baba	504.75	379.5	02abr2006, 12:00	1392602.7
J15922 Baba Dam	1429.95	1320.8	02abr2006, 12:00	5365948.8
SanPabloQuev	1290.30	835.7	02abr2006, 12:00	3951733.7
Pilalo	212.88	43.6	02abr2006, 12:00	321987.7
J15934 Pilalo en Esperanza	212.88	43.6	02abr2006, 12:00	321987.7
San Pablo La Mana	189.96	137.4	02abr2006, 12:00	577242.0
J15919 San Pablo La Mana	402.84	180.9	02abr2006, 12:00	899229.7
Lulu	293.44	234.3	02abr2006, 12:00	1339158.7
J15928 Lulu	293.44	234.3	02abr2006, 12:00	1339158.7
J15931 Quev en Quev	3416.53	2571.8	02abr2006, 12:00	11556070.8

Figure 6 shows an example of hydrograph comparison between observed and computed values, in Quevedo en Quevedo streamflow station. Evidently it is clear that although some of the observed peaks are not accurately matched by the simulation, at least the trend is very well predicted. However, due to most likely wrong or poor measurements during “dry season” (May to December), the model efficiency is very low during low flow, whereas it is acceptable in rainy season (Nash-Sutcliffe coefficient = 0.22 & 0.65, respectively (Nash J.E. and Sutcliffe J.V. 1970)). HEC-HMS computed several flow peaks in this period responding to the respective rainfall events (as in Baba subbasin, see Figure 5).

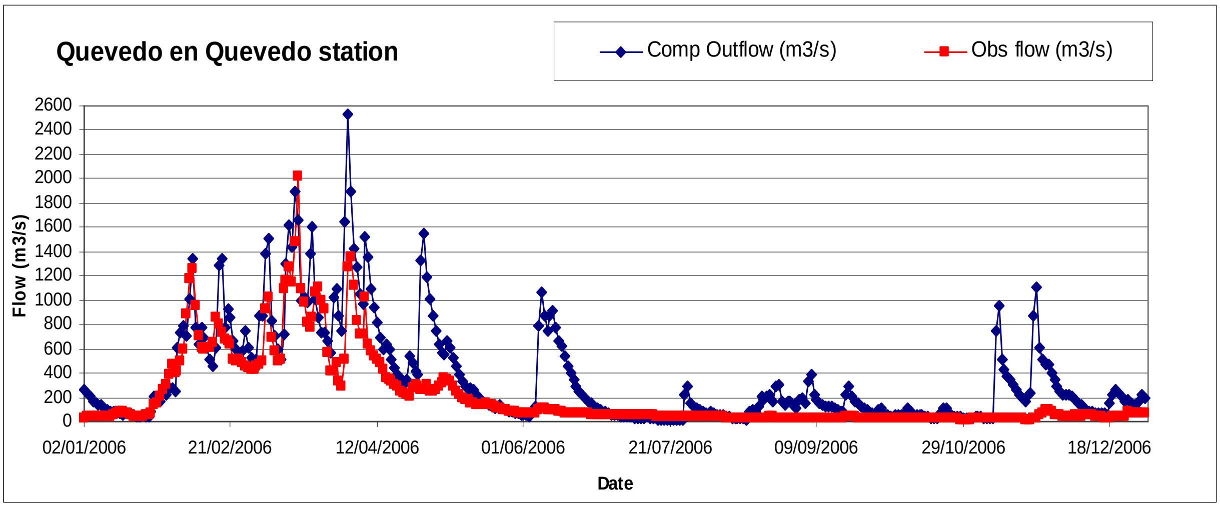


Figure 6: Comparison of hydrographs, Quevedo en Quevedo station

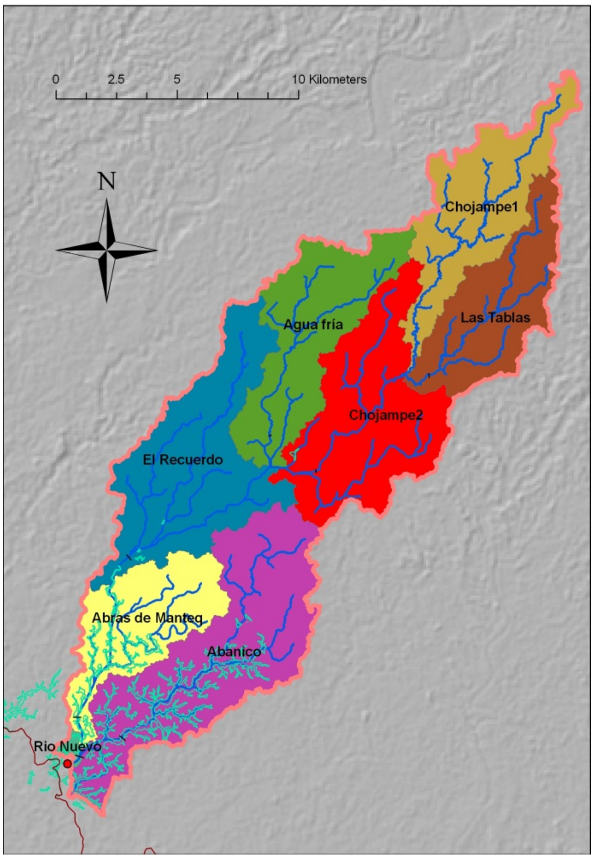


Figure 7: Schematization of HMS model in Chojampe subbasin (pink area in Figure 1). The subbasin's outlet is the red dot at the low-left corner (Rio Nuevo).

Finally, connection with the HECRAS model was envisaged using Lulu and San Pablo Rivers' outlets as shown in Figure 4 (yellow dots). These computed streamflows were part of the boundary conditions for the referred simulation.

Table 5: Micro-basins' data for HMS model in Chojampe sub-catchment.

Micro-basin	Area (Km2)	Initial Abstraction (mm)	Curve Number	Impervious ness (%)	Lag Time (min)	Recession Constant	Ratio to Peak
Las Tablas	27	1.14	46.2	5	302.4	0.71	0.36
Chojampe 1	29	0.95	48.6	6	326.4	0.50	0.36
Chojampe 2	39	0.53	56.4	8	456.0	0.50	0.36
Agua fría	31	0.56	56.4	9	323.4	0.50	0.36
El Recuerdo	41	0.53	56.4	9	357.6	0.76	0.68
Abras de Mantequilla	24	0.48	57.9	12	265.8	0.86	0.68
Abanico	49	0.48	57.9	11	230.4	0.81	0.68
Río Nuevo	1	0.53	61.4	30	67.8	0.60	0.68

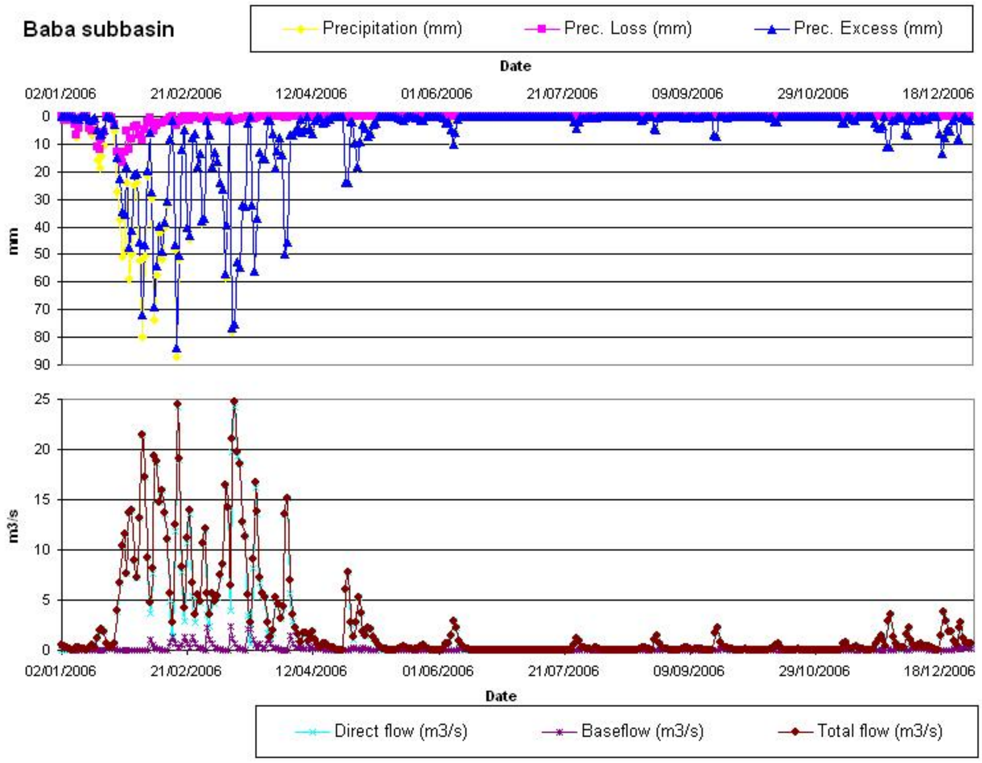


Figure 8: Rainfall hyetograph and flow hydrograph at Chojampe 1 microbasin.

For the rainfall-runoff model in Chojampe subbasin, 8 micro-basins were considered (Figure 8). Similar methodology (TR-55) was employed as in the Vinces case. The microbasins' features are shown in Table 5. The most important results were those of Chojampe 1 & Rio Nuevo microbasins, since these were the link points between HMS and WEAP model (Chojampe Headflow and Flow from the wetland to the river). For instance, Chojampe 1 hydrograph can be seen in Figure 8 where flows are in the range 5 to 25 m3/s for the rainy season and having some few localized peaks of 2 m3/s during dry periods.

6.2.3 Hydrodynamic model

In order to compute an unsteady flow analysis along Vinces River, HECRAS has been chosen as the modeling software. HECRAS uses the shallow water De-Saint Venant equations for routing flows along a river, canal, including also features such as inline or lateral structures (e.g. bridges, culverts), or storage areas.

This hydrodynamic analysis includes Vinces & Nuevo Rivers as well as Abras de Mantequilla wetland. The upstream boundary condition is a flow hydrograph, located where the Baba multipurpose project is going to be built soon (Section 174000 in Figure 9) (Efficacitas 2006). Other boundary conditions on Nuevo River and on the downstream part of Vinces River are also shown in Figure 9. The wetland was simulated as a storage area, connected to Nuevo River via a “weir” (lateral structure).

Digital Elevation Model data came from several sources: the first 70 Km from upstream were a bathymetry carried out during the project feasibility studies (Efficacitas 2006). The middle 50 Km are derived from SRTM, version 4, in a resolution of 30 by 30 meters. And the lower segment (last 60 Km) as well as the wetland area and Nuevo River zone come from a DEM processed by Ecuadorian army geographical institute (scale 1:10000).

Using HEC GEO RAS (Ackerman Cameron T. 2009) it was possible to generate cross sections from the DEM and export them together with river axis to HEC-RAS. Delta X was setup in 1000 m although later on new interpolated sections were included every 200 m.. Manning coefficients were assigned to each cross section (channel, left & right banks) according to what existent literature refers from the land uses along the river (Chow V.T. 1959). Those values range from 0.03 to 0.04 along the channels and can reach a maximum of 0.06 along the banks (presence of dense vegetation – Nuevo River). Expansion and contraction coefficients for the De Saint-Venant equations were left as default i.e. 0.3 and 0.1 respectively.

Boundary conditions as stated before were setup using flow and water level discharges available for several stations (Table 6): For Vinces River, Baba dam location (upstream) Vinces and Hcda Vinces (downstream), Nuevo DD Vinces (upstream for Nuevo River) and Nuevo Hcda Lolita (downstream). Initial conditions were assigned as well, including a 8.0 m water level in Abras de Mantequilla. The results of hydrological modeling (HMS) were included via lateral inflow hydrographs in stations 122000 and 127000 (San Pablo and Lulu Rivers, respectively).

Computation time control parameters were taken as follows:

Time span = 2006, 12 months.

Time step in measurements = Daily (the only available).

Computational time step = 3 minutes = 180 min

Time span was selected in this way in order to have enough measurements for validation. This training span includes both low and high discharges values allowing the model “to learn” from a longer range of flows. Quevedo en Quevedo station was kept for calibration. Since velocities were expected to be around 1m/s a Courant number is given as follows: Cr = 1*(180)/200m = 0.9 < 1, ensuring thus computational stability.

A longitudinal profile of Vinces River is depicted in Figure 10. Maximum water surface in magnitudes of 6 meters average were found along the river. Figure 12 shows also maximum water surface in Quevedo en Quevedo station (110000). Interesting to note is what happens in most of Nuevo River’s cross sections (see one of them in Figure 11). There is over banking in both sides of the channel. Indeed, this is an area traditionally prone to floods due to its flatness.

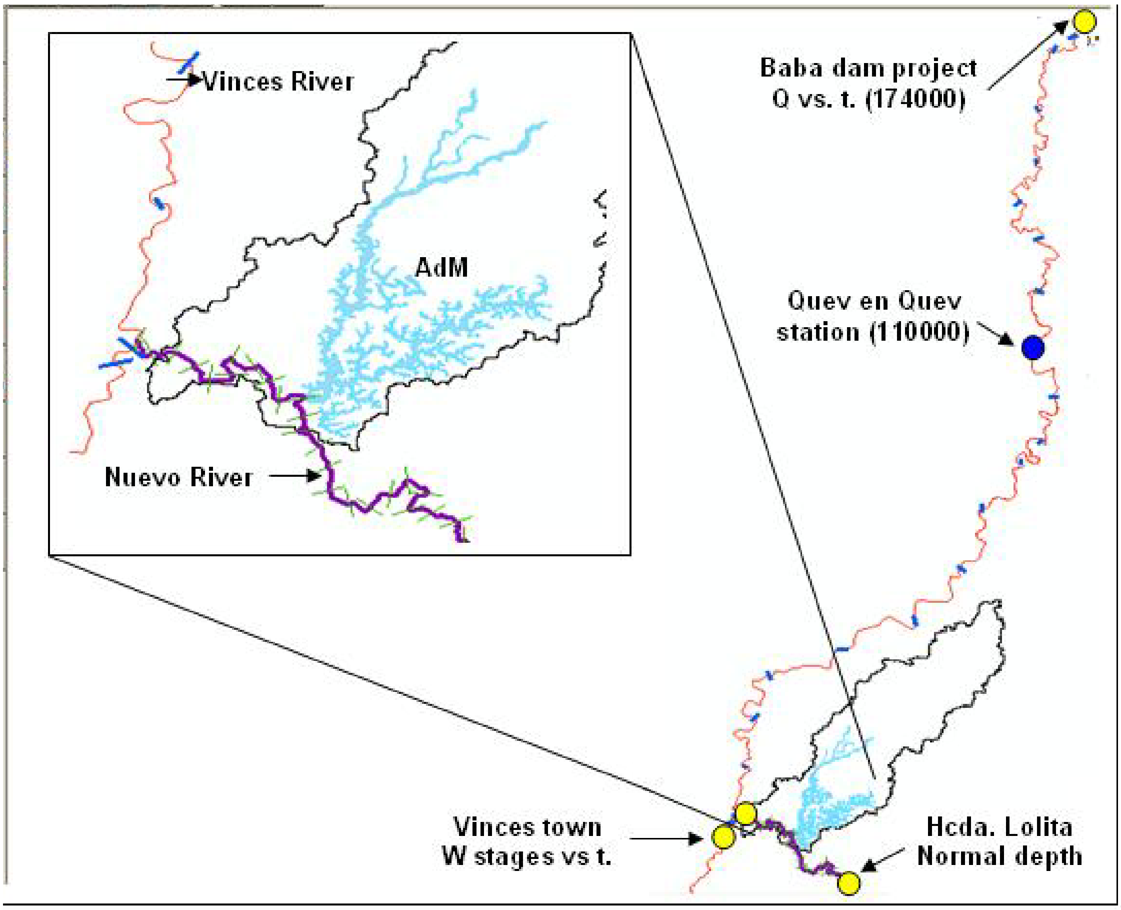


Figure 9: HECRAS model geometric schematization (wetland as storage area in zoom). Yellow dots mark the location of boundary conditions. Blue dot is the calibration point.

Table 6: Boundary conditions Vinces-Nuevo-AdM hydrodynamic simulation.

River	Reach	RS	Type	Location
Nuevo	01	1000	Normal depth	Hcda. Lolita
Vinces	01	174000	Flow hydrograph	Baba Dam
Vinces	01	127000	Lateral Inflow hydr.	Lulu River
Vinces	01	122000	Lateral Inflow hydr.	San Pablo River
Vinces Down	01	1000	Stage hydrograph	Vinces Town

Water stages in the connection of Abras de Mantequilla with Nuevo River were also computed (as seen inFigure 13). The regime is such (as observed in the field) that while rainy season takes place (January to April), water comes from Vinces to Nuevo River and thence flows towards the wetland. When dry season starts, water levels in the wetland start decreasing until an equilibrium takes place between levels in the river and the wetland (most of dry season), with some few exceptions in June and late November. This confirmed the initial hypothesis that the connection between AdM and Nuevo River is bi-directional and the direction varies seasonally.

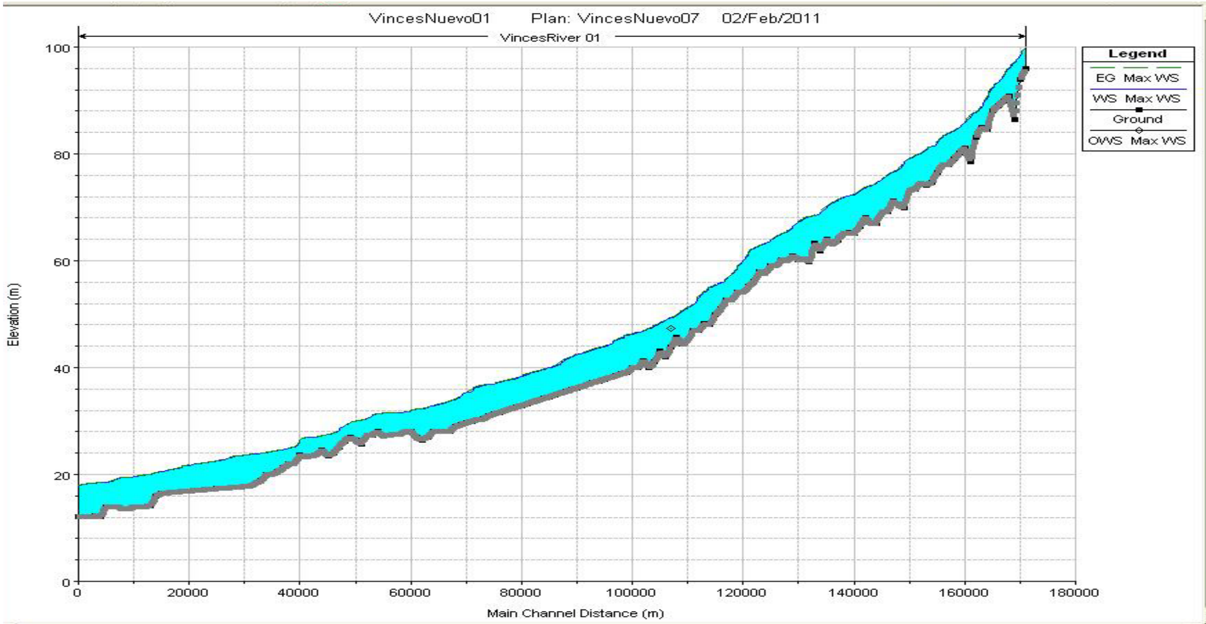


Figure 10: Longitudinal water levels profile, Vinces River, HEC-RAS

Finally, a hydrograph comparison between observed and computed flows was performed in Quevedo and Quevedo station once roughness values were adjusted (Figure 14). The general trend is well predicted by the model, although it tends to underestimate the flows during peaks (May, June and December). As in the rainfall-runoff model, this might be caused mainly due to poor quality observational data.

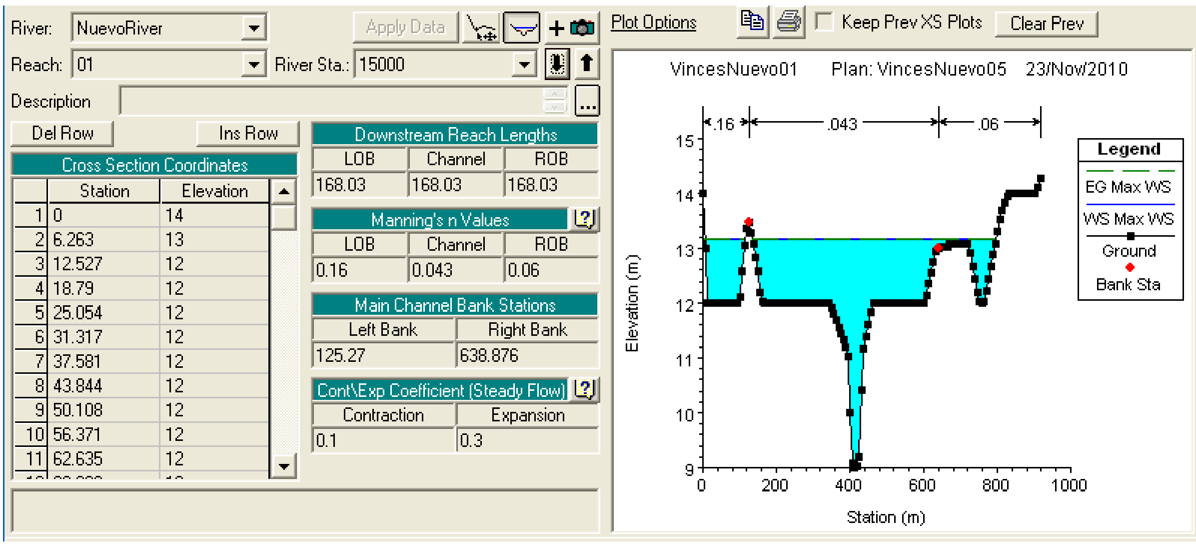


Figure 11: Overbanking in Nuevo River

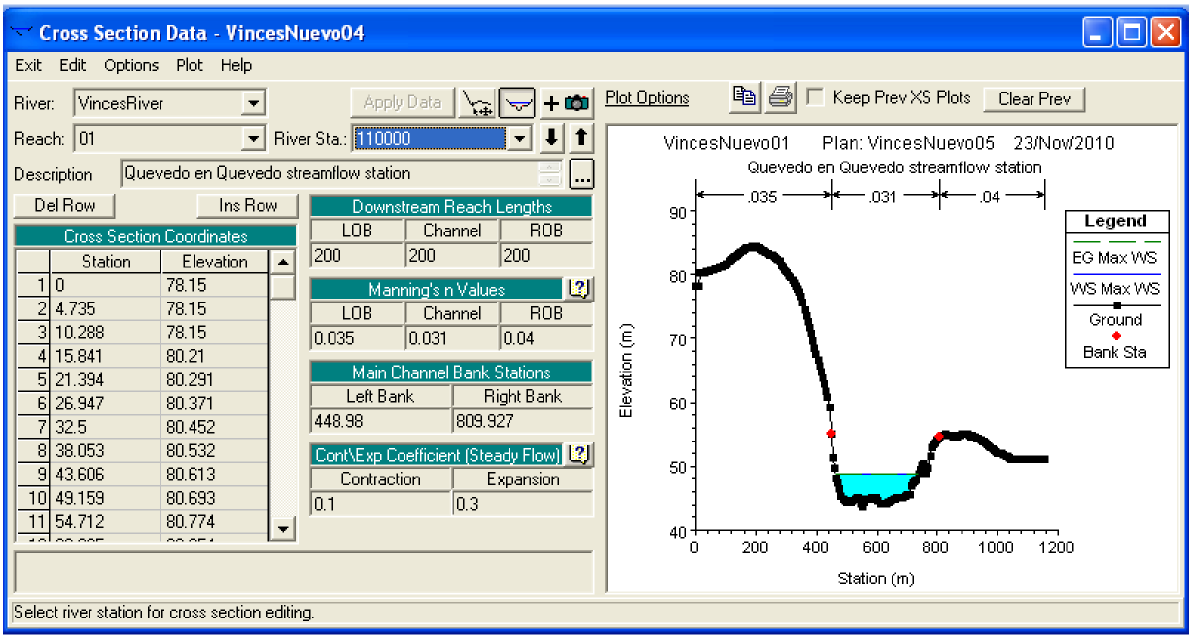


Figure 12: Cross section maximum water surface (Quevedo en Quevedo station)

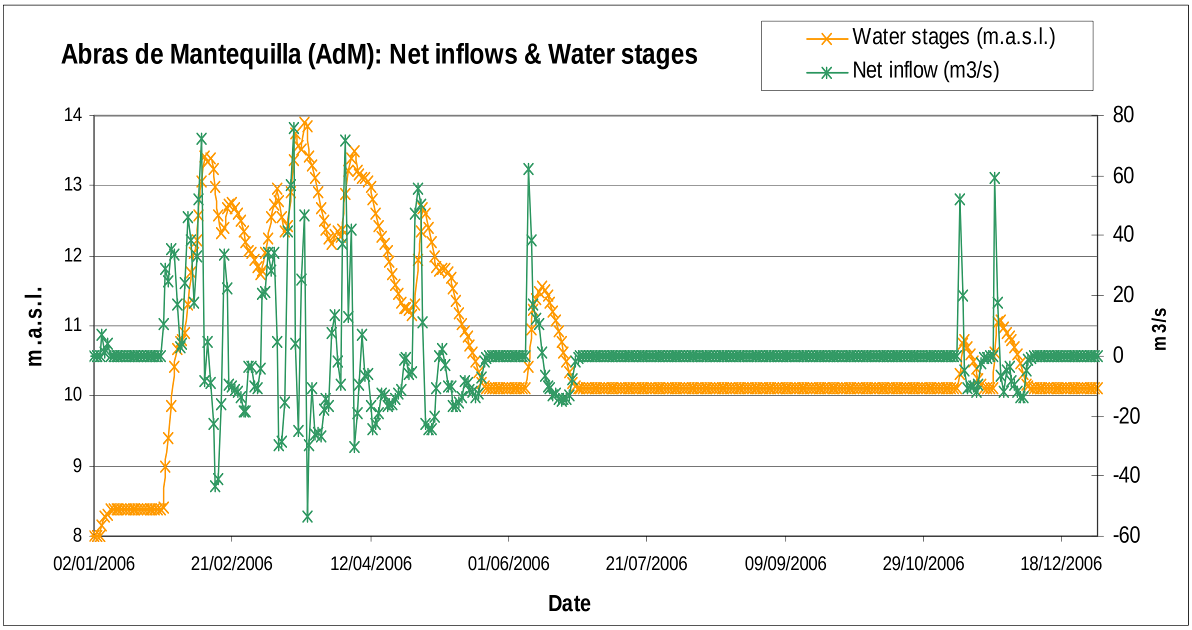


Figure 13: Water levels in Abras de Mantequilla at the connection with Nuevo River. Orange: stages; green: water flows (+) to the wetland, (-) from the wetland

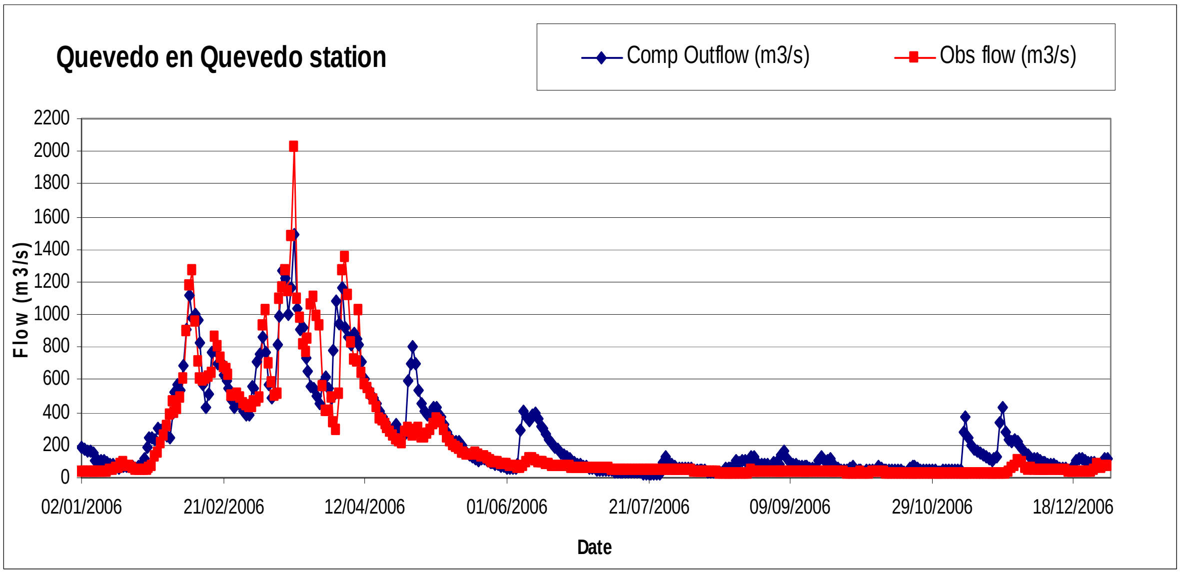


Figure 14: Flow comparison between computed and observed values (Quevedo en Quevedo station)

6.2.4 BAU Scenario in weap

With the HMS and HECRAS outputs, a water allocation model was built using WEAP (Stockholm_Environment_Institute 2009). The several scenarios for Abras de Mantequilla, how the model was built in WEAP and the data used, are widely described in the Fact-sheet of WP7 (Villa-Cox G., Arias-Hidalgo M. et al. 2011).

Business As Usual scenario (BAU), for Abras de Mantequilla consists of the current situation plus the effects that the major planned infrastructure works and climate change scenarios have on the wetland and riverine system. As seen on the fact-sheet, whereas Baba Dam causes a reduction of 30% in Vinces River's streamflow and its dependants (Nuevo River & AdM), DAUVin project does neither affect nor benefit AdM but only results in an increment of 6 m3/s in the areas downstream the project.

A result summary of BAU scenario along Chojampe River is shown in Figure 15 with locations before and after the wetland (modeled as a 'reservoir'). As expected according to local literature (Nieto J.J., Martínez R. et al. 2002) along Ecuadorian coastal region, there are increasing trends of air temperature (+0.5° C) and thus precipitation which are expected, slightly, by year 2012 (simulating the averaged decade 2021-2030) (+5%) and more remarkably, by year 2013 (in the analysis means 2031-2040) (+43%). Of course, the BAU scenario was the reference against which all the proposed management solutions were compared.

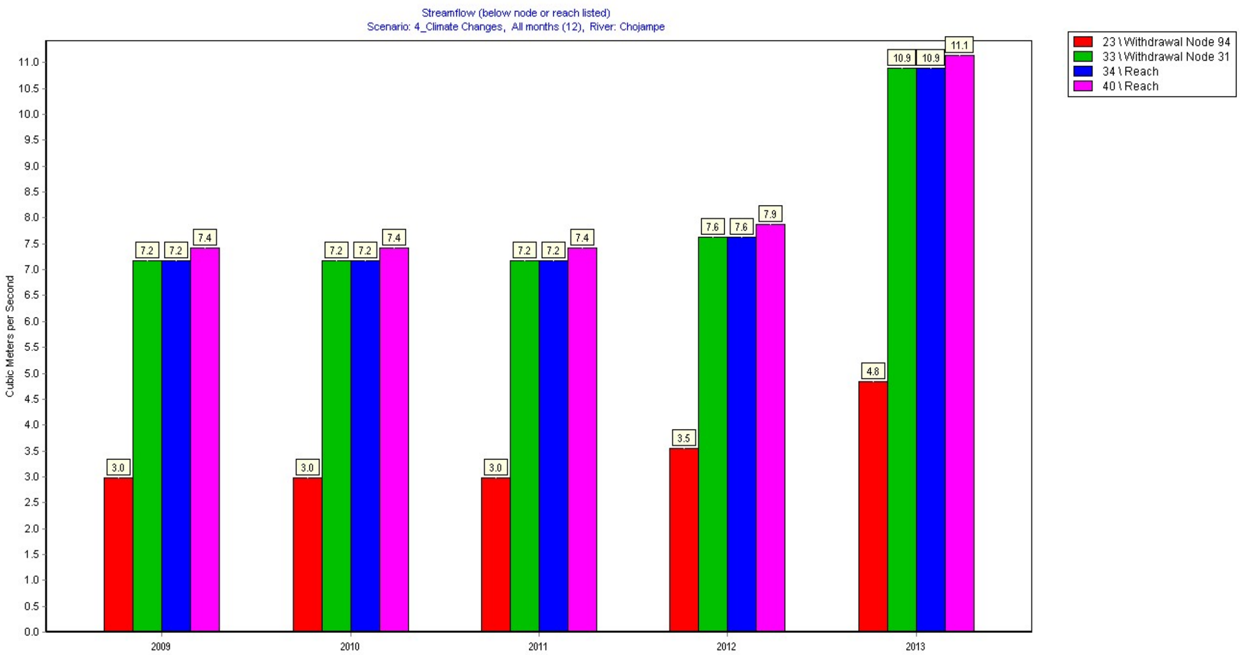


Figure 15: BAU Scenario: flows along Chojampe River, when the introduction of Baba & DauVin projects (“2009”) takes place. Year “2011” simulates the average of 2011-2020 and so forth (climatic variation). 4 locations are considered here, two before and two after the wetland.

6.2.5 Management options and solutions

As the WP7 fact-sheet pointed out previously, management options (MO) were proposed based on the different axles derived (not only the hydrological but the socio-economical and biodiversity too) from the DSIR chains (Zsuffa 2008). They are aimed to help the system to adapt itself to the different scenarios described above. The reference point was the intersection between Abras de Mantequilla and Nuevo River. MO can be summarized as follows (Villa-Cox G., Arias-Hidalgo M. et al. 2011):

Option 0: BAU – Baseline: “Do nothing”. If the current situation goes forward, impact of the introduction of major infrastructure works and climatic variation (unavoidable situations).

Option 1: Gates. Keeping water for dry season (June to December mainly). With this alternative an average of 35 Hm3/year is achievable in terms of water quantity. This may ensure navigability as well as reasonable water storage for species.

Option 2: Agricultural practices, elimination of fertilizers, plaguicides, pesticides (yellow & red label).

Option 3 & 4: Substitution of short-term crops by cocoa and fruit trees. a=moderate; b= intensive. Option 3 and 4 are similar, only differ in that #3 aims to substitute 10% per decade whereas # 4 did at a rhythm of 20% every 10 years. Both have a cumulative effect.

Option 5: Ecological corridors, substituting 5% of short-term crops by vegetation, every decade.

Management solutions (MS) combined MO in order to be simulated by WEAP:

S0: BAU.
S1: O1 + O2.
S2: O1 + O2 + O3
S3: O1 + O2 + O4
S4: O1 + O2 + O3 + O5
S5: O1 + O2 + O4 + O5

In order to evaluate water quality indicator, a water-mixing simple model was built in WEAP, using current available measurements in NO_3, pH and PO_4 as part of the BAU scenario. A Water quality Index (WQI) (ICA in Spanish) was calculated based on the different results of each parameter for each management solution (http://www.water-research.net/watrqualindex/waterqualityindex.htm).

After simulations, a comparative frame is shown in Table 7 for Reach 40 in Chojampe River, which is the connection area between the wetland and Nuevo River (Villa-Cox G., Arias-Hidalgo M. et al. 2011). Remarkable changes were observed between S1 and S0 (around 29% of increment), because of the retention of water due to the gates during the dry season. Agricultural practices enforce improvements in WQI although not as in the same magnitude as water quantity. For the other management solutions, there is an evident reduction on the enhancement in water quantity, for instance, only 2% in S4 vs. S3 (water quantity. As it was aforementioned, water diversions / retentions means greater changes in water amount compared with landuse changes (S2 & S3). This was also observed along Vinces & Nuevo River. Nevertheless, not necessarily S3 means an improvement in water quantity, since cocoa also has a significant water demand (6666 m3/Ha/year). S2 thus performs slightly better than S3 might being their difference increased when cost or other socio-economical indicators be included in the DSS.

Table 7: Results on water quantity and water quality for Abras de Mantequilla.

		Chojampe River					
		S0	S1	S2	S3	S4	S5
Water quantity	WQ (Hm3/year)	76.56	98.87	100.45	99.91	101.90	101.41
	WQ (m3/s)	29.2	37.7	38.3	38.1	38.9	38.7
ICA (Water quality index)	NO3 (mg/l)	0.215	0.203	0.182	0.163	0.145	0.128
	PO4 (mg/l)	0.206	0.159	0.142	0.127	0.113	0.100
	pH	6.9	7.0	7.3	7.4	7.4	7.7
		BAU	01+02	01+02+03	01+02+04	01+02+03+05	01+02+04+05
NO3 (mg/l)		97	97	97	97	97	97
PO4 (mg/l)		91	94	94	95	95	96
pH		85	87	93	93	93	91
	ICA	91	92	95	95	95	95

Water quality is in general very high for all situations (including BAU). According to the WQI scale, values between 90 and 100 already mean outstanding levels. Anyway, some small improvements (reductions of concentration) are seen in each of the parameters (e.g. 12% in NO3 between S4 and S3. Finally, more evident changes in water quality occur when land use changes (cocoa vs. short-term crops) are taken (S2 vs. S1), however, much lesser variations occur when more aggressive landuse changes take place (only PO4), indicating that S2 was some sort of threshold beyond which only costs might rise without further benefits. Similar situation is observed between S4 and S5 in favor of the former.

6.3 Trends in disease risk in Mopti and Macina, Inner Niger Delta, Mali.

Andrea Funk

6.3.1 Introduction

One of the main issues in the Inner Niger Delta is the risk of vector and water-borne diseases. .The vector for Malaria, the *Anopheles* mosquito, reproduces in stagnant water bodies. An important transmission pathway for disease bacteria causing water-born diseases (Diarrhoea and Cholera) is trough contaminated drinking water often directly taken from surface water. Both groups of diseases are directly related to the aquatic environment thus it can be expected that the disease risks is related to the hydrology of the system. The aim of this report is to analyse the correlation between hydrological conditions and disease rates in two different areas of the Delta, Macina and Mopti. Further it is investigated if various measures undertaken to improve health conditions have been successful.

6.3.2 Material and Methods

Hydrology

All hydrological data (water level or water discharge) used in disease assessment are provided by the Regional Direction of Hydrology in Mopti.

Mopti

The area around Mopti is dominated by natural flooding following the seasonal discharge variation of the Niger river (Zwarts et al. 2005). Monthly data on water levels and discharge for the gauging station of Mopti are available for the period between 1999 and 2009. For the same period also yearly data on the areas for rice growing (for cultivation in controlled irrigation areas and naturally flooded areas) are available.

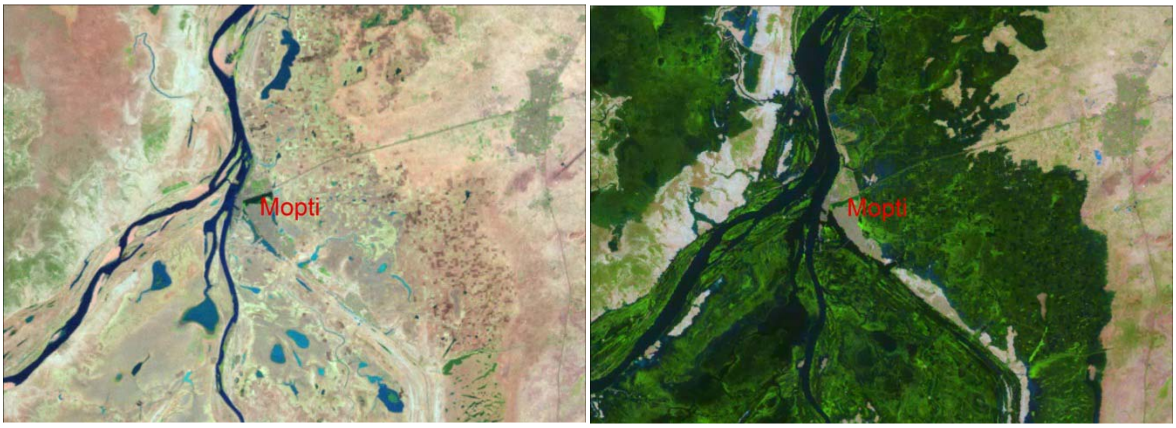


Fig. 6.3.1. Flood pattern in Mopti region during dry (left picture, 02/08/2003) and wet season (right picture, 10/16/2003). Green colour represents vegetated flooded area and blue colour open water.

Macina

The area around Macina is dominated by artificial irrigation fields for rice growing, natural flooding is of low relevance in the area. Water availability decreases during dry season but is high enough to ensure productivity over the whole year (Zwarts &Leclert, 2010).

Yearly data on the total irrigation area in the Macina region are available for the period between 1999 and 2009.

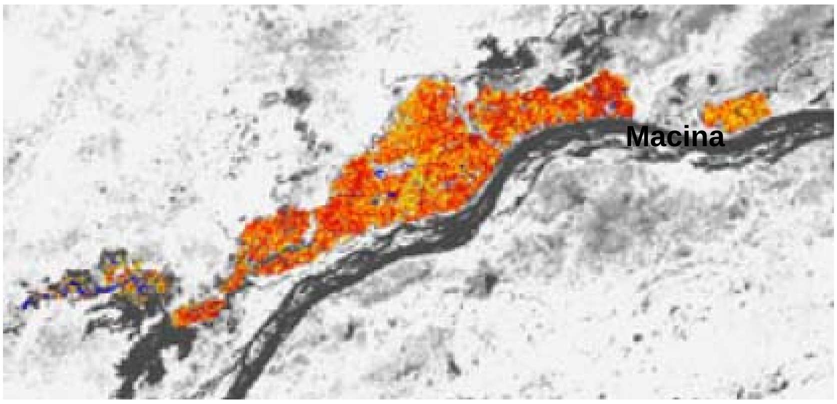


Fig.6.3.2: Irrigated rice fields (coloured) and inundated areas (grey) in the region of Macina (modified after Zwarts & Leclert, 2010)

Water supply, sanitation and health improvement

In Mopti as well as Macina region, sanitation conditions and drinking water supply have been improved in the period (1999-2010) where health data are available. Many latrines have been constructed in that period as well as new wells have been constructed. For both cases no relevant quantitative data are available to specify the changes in sanitary conditions.

Additionally in both areas there are many activities related to awareness raising programme from NGOs and many other institutions dealing with sanitation and health treatment (e.g. bed net treatment in Mopti; Rose-Wood, 2010) in the relevant period.

In contrast to the rural area of Macina in Mopti city also a water purification system has been set up in 2002 and started functioning in 2004 and between approx. 100 and 500 people were connected to a tab water system between 1999 and 2010.

Population

Population counts are conducted every 10 years in Macina and Mopti region. Data are available for 2000 and 2010. Yearly population were calculated with a constant yearly growth rate of 5 and 7% for Mopti and Macina respectively. The source of the data is the Statistical Division of the Reference Health Centers who provided it with the authorization of Regional Direction of Health (RDH).

Health treatment

In Mopti area 6 health centers are available for approx. 134,000 people, two of them started operating in 2004/05. In Macina area 5 health centers are available for approx. 87,000 people, two of them started operation in 2000 and one in 2005. People can freely choose which Health center they use, the selection of Health center is dependent on the distance to travel but also on the type and strength of disease since different Health centers have different specialisation regarding treatment of different diseases.

Health data

For both regions continuous health data, number of cases and number of fatalities, per health center are available in a trimestral period (three month interval) between 1999 and 2010 for three of the most important diseases in the regions the two vector-borne diseases, Malaria and Bilharziose and the water-borne diseases Diarrhea. Population values were used to calculate relative disease rates based on disease cases. The source of the data is the Statistical Division of the Reference Health Centers who provided it with the authorization of Regional Direction of Health (RDH).

6.3.3 Results

Malaria
Seasonal pattern

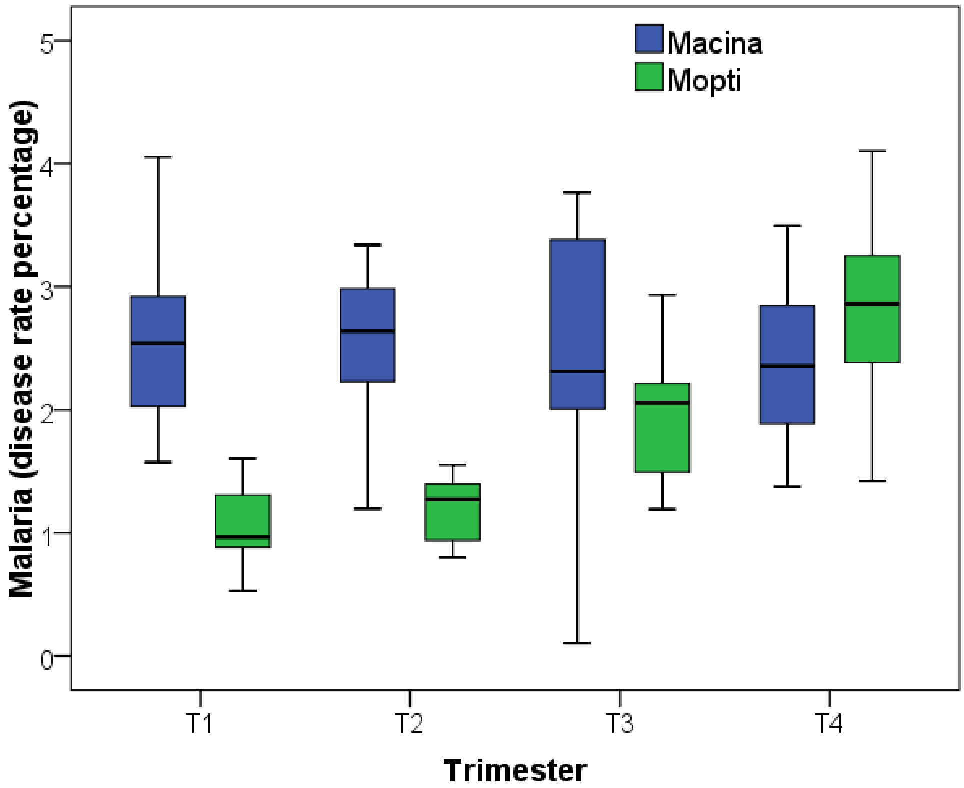


Fig.6.3.3: Seasonal variation of Malaria disease rate (median and confidence limits) for Mopti and Macina region.

In the Mopti region there is a significant seasonal variation of Malaria disease rate (Kruskal-Wallis test, $p<0.001$). Rates are low in the first two trimesters (dry period) and high during wet season (trimester 3 and 4). Flooded areas provide habitat for mosquitos and infection risk is consequently higher in wet season than during dry season when areas with standing water habitats are scarce.

In contrast Malaria rate in the Macina region is constantly high over the whole year (Kruskal-Wallis test, $p=0.95$). Permanently irrigated fields and irrigation channels seem to generate constant good habitat conditions for mosquitos and thus infection risk is constantly high over the whole year.

Hydrology

Mopti

Disease rate in Mopti region increases significantly with water level over all data (Fig.6.3.4) and if only wet season data (trimester 3 and 4) are included ($R^2=0.35$, $p<0.01$). Unexplained variation might be explained with changes in health treatment between years or may be impacted by other measures in the area like awareness raising programmes.

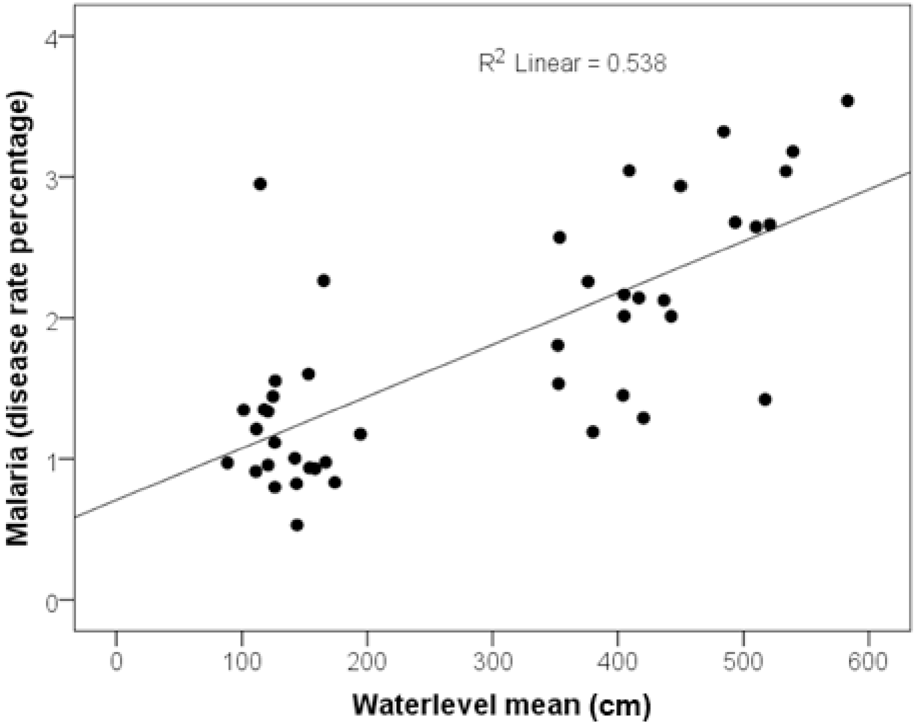


Fig 6.3.4: Malaria rates in dependency of waterlevel (gauge of Mopti).

Macina

Disease rate in Macina region increases significantly ($p<0.001$) with area of the irrigation zone over all data (Fig.6.3.5) and if trimesters are treated separately the increase is significant for trimester 1, 3 and 4 ($p>0.05$). As in Mopti region unexplained variation might be explained with changes in health treatment between years or may be impacted by other measures in the area like awareness raising programmes.

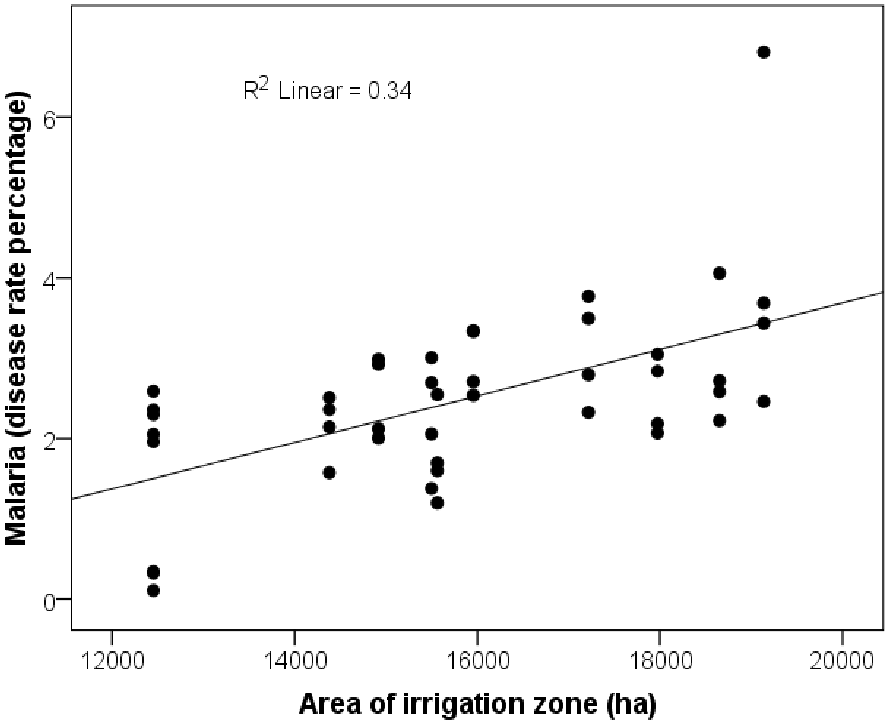


Fig. 6.3.5: Malaria rates in Macina region in dependency of irrigated area.

Malaria

Time trend

As visible in Figure 6.3.5 in the first half of the period where disease data are available, there is a clear continuous decrease in disease rates visible in both regions, Mopti and Macina. Most likely this improvement of health conditions is related to the diverse measures aimed to improve sanitary conditions and increased availability of clean drinking water.

Since there is no detailed information available on the specific measures in that period and changes could not be quantified only data from the second half of the period (starting with 2006) could be taken to analyse for an impact of hydrological conditions.

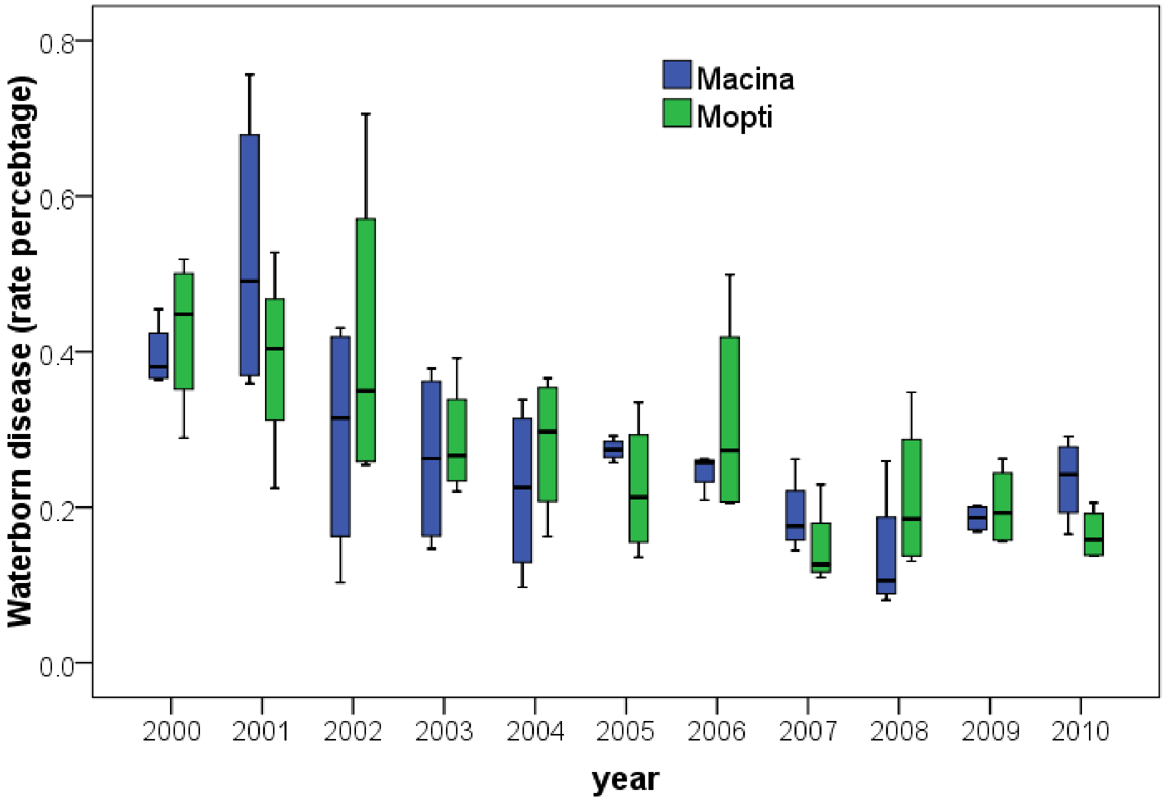


Fig. 6.3.6: Time trend in disease rates of waterborn diseases (Median and confidence limits).

Seasonal pattern

As for Malaria, there is a significant seasonal trend in waterborn disease rate for the Mopti region (Fig. 6.3.7; Kruskal-Wallis test, $p<0.05$). Disease rate is low in the dry season and high in the wet season. Most likely this trend can be explained with the fact that during flood period most of the wells are flooded and only river water is available for drinking. Additionally local people prefer to take their drinking water from the river instead of using ground water from the wells.

For Macina region there is no significant difference between the four seasonal periods (Kruskal-Wallis test, $p=0.68$) there is only a weak trend visible that disease rates are higher in the beginning of the wet season.

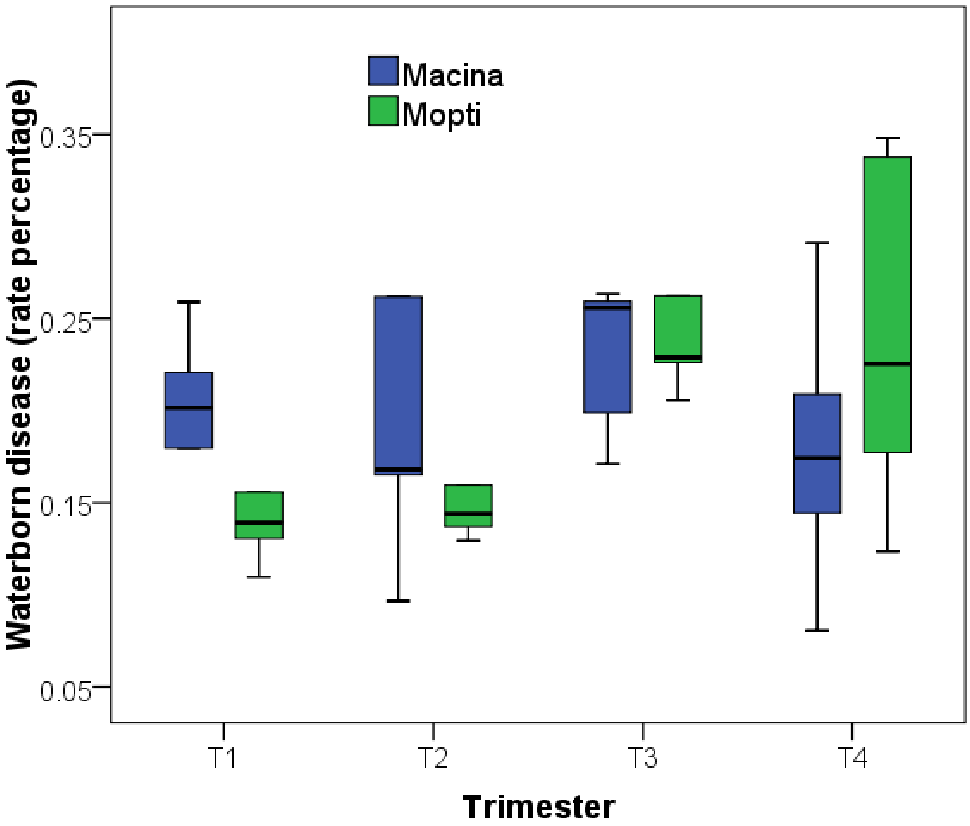


Fig. 6.3.7: Seasonal variation of waterborn disease rate (median and confidence limits) for Mopti and Macina region.

Hydrology

Mopti

As expected from the seasonal trend, there is a significant positive correlation between the mean water level (gauge Mopti) and the disease rate if data for dry and wet season area included in the analysis ($R=0.55$, $p<0.05$).

Another hypothesis that has to be tested is that higher discharge of the river increases quality of the river water and thus decreases health risk. Due to higher water levels, discharge and velocity sewage water is transported away from settlements and diluted, and the risk is lower for people to drink contaminated water. The significant negative regression (Fig. 6.3.8; $p<0.05$) between disease rate in wet season and maximum flood level strongly supports that hypothesis.

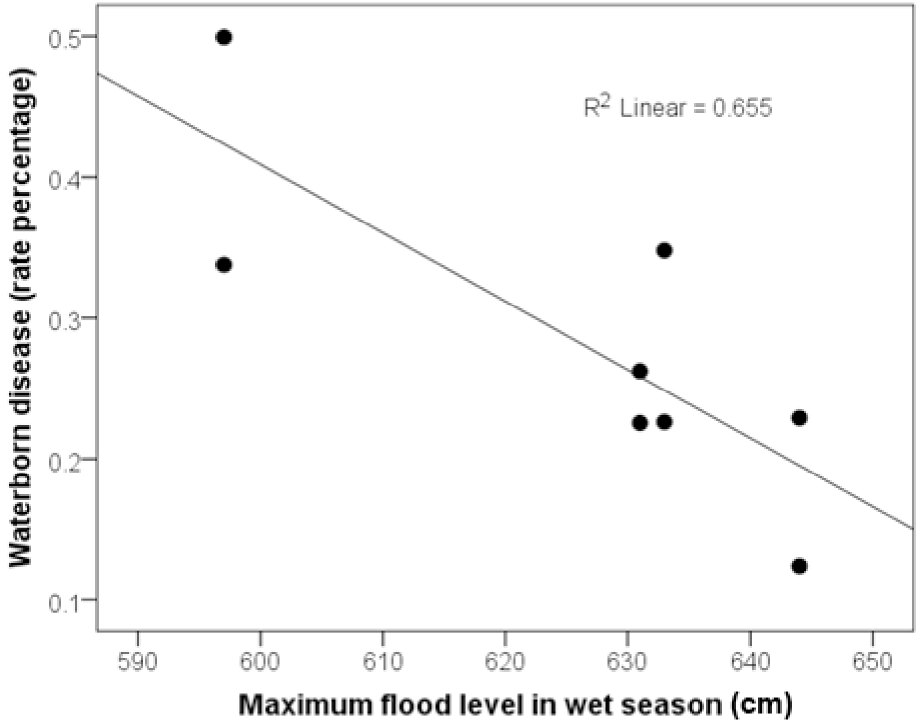


Fig. 6.3.8: Rate of waterborn disease during wet season (trimester 3 and 4) in relation to maximum flood level (gauge Mopti) in the wet season.

Macina

For Macina area no comparable significant trends of waterborn disease rate with water levels, discharge or irrigated area could be found with the reduced dataset.

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