SYNTHESIS REPORT

Eastern Nile Joint Multipurpose Programme: Blue Nile

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Climate Systems Analysis Group (CSAG), University of Cape Town

Data Compilation and Pilot Application of the Nile Basin Decision Support System (NB-DSS): Work Package 2: Stage 2

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TERMINOLOGY

Development Intervention	A specific infrastructure implementation for regulating the water resources of a basin (e.g. dams, canals, irrigation systems, etc).
Management Option	A specific plan for the allocation and/or operation of the water resources of a basin aimed at prioritizing hydropower production, minimizing environmental impacts, etc.
Indicator	A socio-economic, environmental or hydrological characteristic that can be quantified across different model scenarios, for the purpose of choosing between alternative development and/or management scenarios.
Scenario	A contemplated state of a basin induced either through targeted human intervention (e.g. combinations of development and management interventions) or through externalities (e.g. climate change, economic policies etc.).
Decision Support System	A tool which supports decision making and the integrated management of a river basin based on the integration of the results of various analyses and the evaluation of scenarios and their implications.
Multi Criteria Analysis	A structured approach towards solving decisions and planning problems involving multiple criteria.
Cost Benefit Analysis	A systematic process for calculating and comparing benefits and costs of a project to determine if it is a sound investment and/or to evaluate how it compares with alternate projects.
Integrated Water Resource Management	A participatory planning and implementation process, based on sound science, that brings stakeholders together to determine how to meet long-term needs for water while maintaining essential ecological services and economic benefits.

LIST OF ACRONYMS

BCR	Benefit Cost Ratio
CBA	Cost Benefit Analysis
ENJMP	Eastern Nile Joint Multipurpose Programme
GIS	Geographic Information System
MCA	Multi Criteria Analysis
NB-DSS	Nile Basin Decision Support System
NBI	Nile Basin Initiative
WP	Work Package
WRPMP	Water Resource Planning and Management Project

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1. BACKGROUND

The trans-boundary nature of the Eastern Nile offers a unique opportunity for cooperative development and management, which can have major forward linkages into regional relations and trade in the sub-region and provide transformational socio-economic benefits. Cooperation will also enable the joint management of risk related to floods, droughts and climate change impacts. The Eastern Nile Joint Multipurpose Program (ENJMP) is a long-term program that includes a coordinated set of investments to ensure the sustainable development and management of the shared Eastern Nile waters. Potential water resource related developments in the Blue Nile River constitute a key element of the ENJMP. Within the Blue Nile (Abbay) catchment, there is still considerable potential for development of water resource infrastructure for hydropower generation, flow regulation to support downstream irrigation abstractions and for flood control. If operated within a transboundary water management framework, these developments could provide benefits for all of the local riparian countries. However, there are also concerns for Sudan and Egypt as to how their current water availability will be impacted by significant upstream water resource developments in the Blue Nile catchment.

Although the Blue Nile comprises only 8% of the total Nile Basin catchment area, on average, the Blue Nile contributes almost 60% of the Main Nile River flow at Aswan Dam in Egypt. Mean annual rainfall in the Blue Nile Basin varies between less than 400 mm in Sudan close to the confluence with the White Nile to more than 2000 mm in the Ethiopian highlands. The Blue Nile Basin hydrology is characterised by seasonal and annual variability, very steep catchment and channel gradients and rapidly eroding watersheds, which result in very high sediment loads. This is exacerbated by poor agricultural practices, overgrazing and deforestation. There are currently three major hydropower schemes in the Blue Nile catchment in Ethiopia viz. Beles, Tis Abbay and Fincha. In Sudan, there are two major dams in the Blue Nile River supplying water for irrigation and hydropower viz. Roseires and Sennar dams. The major consumptive water user in the Blue Nile catchment is linked to irrigation along the lower Blue Nile River in Sudan. On the Main Nile River downstream of the Blue Nile confluence, more Sudanese irrigation schemes are located upstream and downstream of Merowe Dam. Merowe Dam is located close to the 4^{th} cataract near the city of Merowe and its main purpose is for hydroelectricity. The High Aswan Dam on the Main Nile River just downstream of the Sudan/Egypt border is operated primarily to regulate downstream releases for irrigation demand, with flood control and hydropower generation being secondary benefits.

Under the aegis of its Water Resources Planning and Management Project (WRPMP), the NBI is in the process of establishing a Nile Basin Decision Support System (NB-DSS) to support water resources planning and investment decisions in the Nile Basin, especially those with trans-boundary or basin level ramifications. To help ensure that the NB-DSS becomes a reliable and sustainable software system and to demonstrate and showcase its capabilities within the context of transboundary integrated water resource planning and management, various pilot applications of the NB-DSS were conducted across the Nile Basin. These essentially involved the configuration, calibration and validation of relevant water balance, hydrological and/or hydrodynamic models, after which the models were imported into the NB-DSS for advanced scenario evaluation based on environmental, social and economic indicators.

This report provides a synthesis of the pilot application of the NB-DSS in the ENJMP study area, the focus of which was the Blue Nile subcatchment. The Main Nile River, after the confluence of the Blue Nile at Khartoum down to Lake Nasser, was included in the analysis for this pilot application case.

The location of the Blue Nile catchment is shown in Figure 1-1.

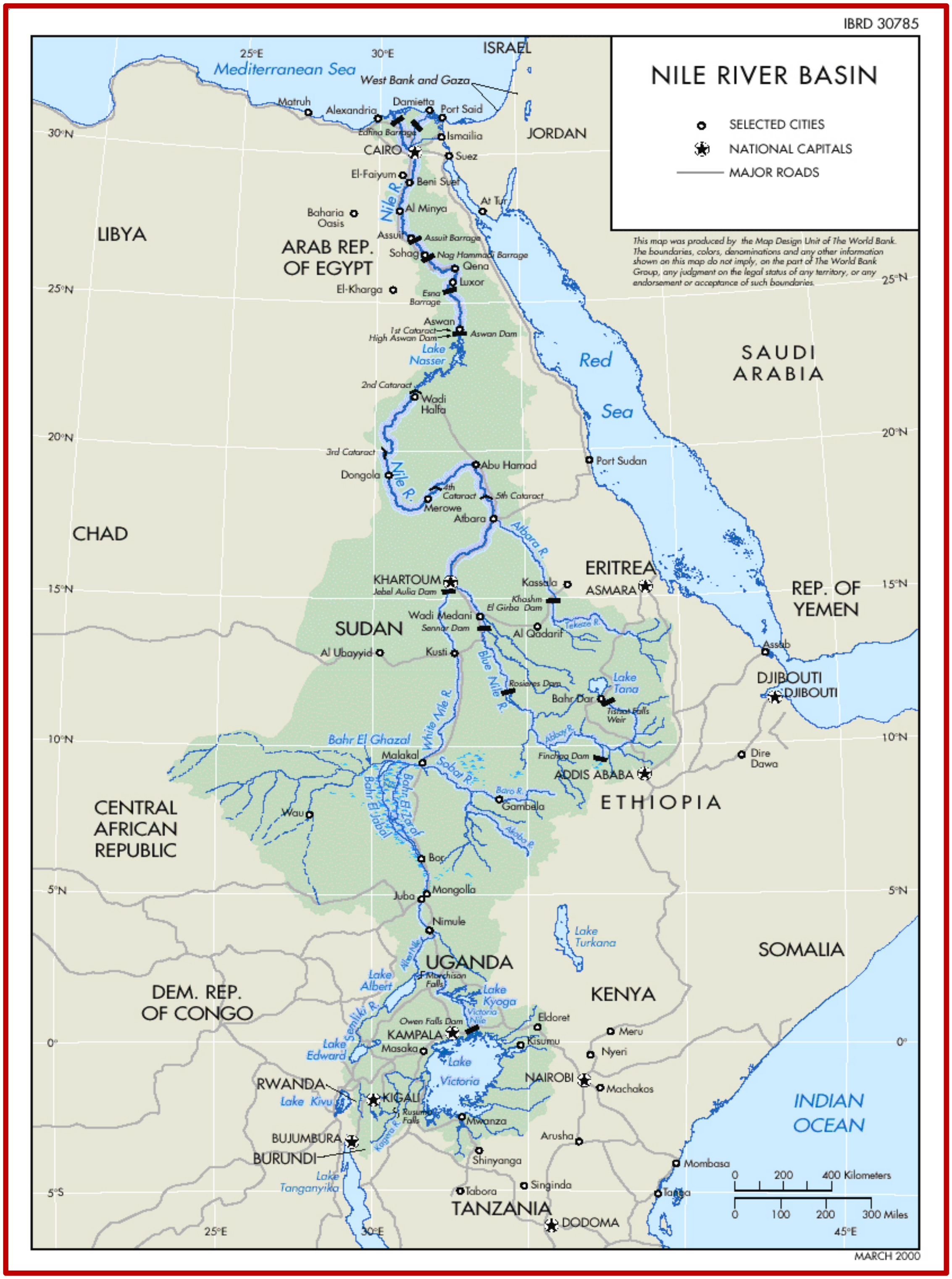

Figure 1-1 : Blue Nile Catchment

2. THE NILE BASIN DECISION SUPPORT SYSTEM

The conceptual design and development of the NB-DSS were informed by a comprehensive needs assessment of the present situation within the Nile Basin by the Nile Basin Initiative WRPMP. This involved extensive stakeholder consultations across all of the riparian countries. Issues and concerns related to water availability, hydrology and water use patterns as well as social, environmental and economic issues that were raised during these consultations, were prioritised in order to identify eight priority areas of concern viz. water resources development, optimal utilization of water resources, coping with floods, coping with droughts, energy development (hydropower), rain fed and irrigated agriculture, watershed and sediment management and navigation. Water quality and climate change were identified as cross-cutting issues. The above areas of concern guided the identification of key functionalities and model components to be included in the core of the NB-DSS in its initial phase of development.

The overarching purpose of the NB-DSS is to support water resources planning and investment decisions in the Nile Basin, especially those with trans-boundary or basin level ramifications. It aims to provide a framework for sharing knowledge and understanding river system behaviour as well as for designing and evaluating alternative development scenarios, investment projects and management strategies. Its main goal is to support informed, scientifically based, rational cooperative decision making to improve the overall benefit from harnessing the Nile River, and to develop economically efficient, equitable, environmentally compatible and sustainable strategies for sharing the benefits. The NB-DSS will *serve as a shared knowledge base, provide analytical capacity, and support stakeholder interaction for cooperative planning and management decision making in the Nile River Basin.* The NB-DSS comprises an information management system, a regional river basin modelling system, and a suite of analytical tools to support multi-objective analyses.

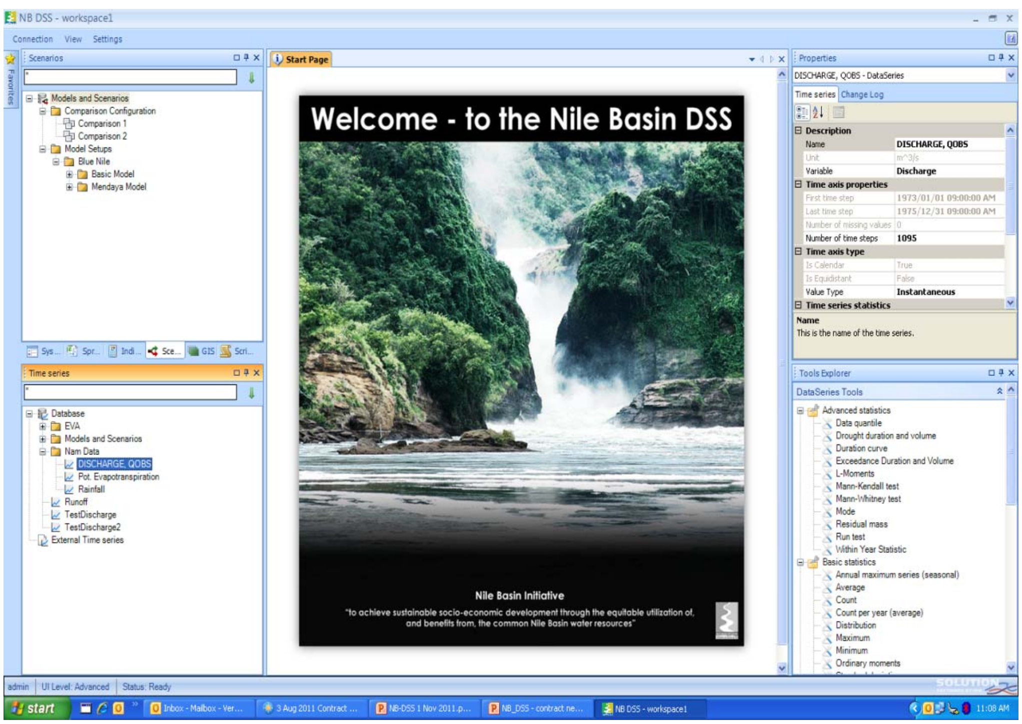

Figure 2-1 : Start Page of the Nile Basin Decision Support System

3. STAKEHOLDER INVOLVEMENT

One of the primary objectives of the NB-DSS is "…*to serve as a shared knowledge base, provide analytical capacity, and support stakeholder interaction, for cooperative planning and management decision making for the Nile River Basin… As such the Nile Basin DSS is expected to be an agreed upon tool that will be accepted and used by all riparians in the management of the shared Nile water resources*". In light of this objective, a key component of the pilot application of the NB-DSS to the ENJMP study area concerned the involvement of stakeholders through a participatory process to ensure that the pilot applications address stakeholder expectations and concerns. The prioritisation of water management issues in the Blue Nile, the identification of various potential development interventions and management options to address these issues, the definition of scenarios and the identification of environmental, social and economic indicators (evaluation criteria), were undertaken with inputs from various stakeholders.

As part of the pilot application, various workshops took place. The specific objectives of the workshops varied, but in general, the workshops were aimed at providing stakeholders from the Nile riparian countries with a platform to raise relevant water resource management concerns and issues. Furthermore, the workshops ensured buy-in from riparian stakeholders in the NB-DSS as a potential tool for transboundary integrated water resource planning and management.

Participants at the workshops included members of the Regional DSS Network, the WRPM Project Steering Committee, members of the DSS Core Team, representatives from NBI programs/projects, NBI WRPM staff and NB-DSS technical advisors as well as counterpart staff from relevant ministries and government departments in the Nile riparian states.

4. SCENARIOS

Scenarios are used to compare various "what if" cases and provide a structured method of consensus building and decision making about possible future water resource development and management options, opportunities and risks, and how these might interact. Within the context of this pilot application, a scenario was defined as *"a contemplated state of the Nile Basin induced either through targeted human intervention (e.g. combinations of development and management interventions) or through externalities (e.g. climate change, economic policies etc.)".*

In consultation with the stakeholders, a baseline and four other scenarios for the ENJMP pilot case were selected for evaluation. (The baseline scenario included the heightening of Roseires Dam.) The scenarios were based on two future development interventions on the Blue Nile River in Ethiopia, i.e. the construction of Border Dam **(Scenario 1)** and the construction of both Border and Mandaya dams **(Scenario 2)**. **Scenario 3** was similar to Scenario 2, except that the operating rules of some of the key dams in the Blue Nile system were amended in order to increase hydropower generation, while simultaneously ensuring that all irrigation demands are met. As part of Scenario 3, the sediment flushing operating rule at Roseires Dam was also abandoned, i.e. the dam is no longer drawn down at the start of each wet season. **Scenario 3a** constituted a climate change scenario. As part of Scenario 3a, climate change induced rainfall-runoff impacts were imposed on the Scenario 3 model with rainfall, temperature and evaporation as the main drivers. Irrigation input climate data along the Blue Nile River was also replaced with climate change altered sequences for the relevant climate stations, while losses and gains to reservoirs and lakes in the Blue Nile basin (precipitation and evaporation) were adjusted based on climate change information. In order to investigate the economic impacts of flood damage, **Scenarios 4 and 4a** represented flood damage scenarios along the lower reach of the Blue Nile River (Roseires Dam to Khartoum).

Table 4-1 summarises the scenarios which were investigated for the ENJMP (Blue Nile) pilot case.

Table 4-1 : Eastern Nile Joint Multipurpose Programme (Blue Nile) Scenarios

Scenario	Development Intervention	Management Option	Climate Change
SC0	Baseline	Current	None
SC1	Border Dam	Maximize hydropower generation at Border Dam	None
SC2	Border Dam Mandaya Dam	Maximize hydropower generation at Border and Mandaya dams	None
SC3	Border Dam Mandaya Dam	Maximise hydropower generation at all dams along Blue Nile River; Maintain irrigation supply	None
SC3a			Blue Nile SRES A2 – CNRM CM3
SC4	Border Dam	No flood control operation	N.A.
SC4a		Operate Border Dam for flood mitigation downstream	N.A.

The approach that was adopted for scenario implementation of Scenarios 1 to 3 involved the modification of the EN-JMP MIKE Basin baseline model, as appropriate, for representation of the various water management interventions being considered in each scenario. The baseline and scenario models were registered in the **NB-DSS Scenario Manager.** Under each model in the Scenario Manager, scenarios were defined which represented specific development interventions and/or management options to be simulated with that particular model. For each scenario, model objects (nodes) and associated output time series were also specified as necessary. These represented the model nodes (locations) where outputs will be generated for inclusion in the subsequent Multi Criteria Analysis (MCA). A simulation period of 1951 to 1990 was used for all scenarios. Scenarios 4 and 4a entailed simulations with a MIKE 11 hydrodynamic model.

5. EVALUATION CRITERIA

The definition of evaluation criteria is a key component associated with the evaluation of water management scenarios. These criteria assess how interventions affect the direction of change in environmental, social and economic performance, and measure the magnitude of that change. Within the NB-DSS, the scenario evaluation approach that was followed firstly entailed the definition and quantification of environmental social and economic indicators, after which the indicator values were used to construct meaningful evaluation criteria.

An indicator's defining characteristic is that it quantifies and simplifies information in a manner that facilitates an understanding of the implications related to water resource interventions. In essence, the selection of indicators was based on links (responses) to water-related DSS outputs, its ability to distinguishing between alternative development scenarios, its relevance to key issues, its compatibility with the resolution and limitations of the DSS, the availability of reliable data, simplicity and its ability to be quantified across different model scenarios.

Table 5-1 lists the indicators that were defined for the ENJMP pilot application. These include:

- Social indicators which can be grouped under four categories viz. Water availability, Community health and safety, Food security and livelihoods and Displacement.

- Environmental indicators which represent three categories viz. Footprint areas, Downstream areas and Water quality.
- Economic indicators derived from location specific DSS outputs as well as detailed cost-benefit analyses.

Table 5-1 : Indicators used for scenario evaluation in the ENJMP Pilot Case

SOCIAL INDICATORS	ENVIRONMENTAL INDICATORS	ECONOMIC INDICATORS
Water availability	Impact on environmentally sensitive areas	Impact on navigation
Malaria risk	Carbon emissions	Energy production
Pest diseases	Fisheries production	Evaporation loss in dams/wetlands
Water pollution	Floodplain inundation	Flood damage
Flood risk	Extent of wetlands	Food production
Drowning risk	Ecological stress	Benefit/cost ratio (BCR)
Extent of commercial irrigation	Biological production	
Impact on recession agriculture	Abundance of pest blackflies	
Fish production	Bank stability	
Loss in productive land	Recovery distance	
Loss of access to natural resources	Seasonal shift	
Physical displacement	Phytoplankton growth potential	
Economic displacement	Aquatic macrophytes growth potential	

Once relevant environmental, social and economic indicators were defined, the indicators were quantified. In the NB-DSS**,** the quantification of indicators is achieved through the development of scripts in the **Script Manager**. In essence, scripts represent response functions which describe the relationship or linkage between water resource driven processes (i.e. model outputs) and impacts on indicators by means of algorithms or matrices. Typically these response functions are based on empirical relationships derived from observed data, on physically based conceptual models which describe indicator responses in relation to physical parameters or on statistical indices or relevant values extracted from output time series. Within the context of the NB-DSS, the response functions are intended to describe the environmental, social and economic consequences of changed flow regimes and other developmental impacts due to water management interventions. For example, the Ecological Stress environmental indicator measures the degree of change compared to baseline, of key flow components e.g. dry season low flow, wet season low flow, within year flow variability and the rate of change in seasonal flow and combine these into an index value which expresses the degree of anticipated ecological stress associated with any particular water management intervention along any defined river reach.

In the **NB-DSS Indicator Manager**, relevant indicators are defined at key locations and, following a “simulation run” in the **NB-DSS Scenario Manager**, indicator values are generated and available for viewing. Evaluation criteria, which form the basis of scenario evaluation, are then defined as a single or combined set of indicators.

6. SCENARIO EVALUATION RESULTS

The Scenario Evaluation for the ENJMP Pilot Case entailed three separate evaluations:

- The evaluation of cumulative development impacts
- The evaluation of climate change impacts
- The evaluation of flood damage along the lower Blue Nile River

Cumulative impacts: Scenario 1 vs Scenario 2 vs Scenario 3

In order to assess the cumulative impacts related to future development in the Blue Nile River, the **Analysis Manager** in the NB-DSS was used to evaluate three scenarios: Scenario 1 (Border Dam); Scenarios 2 (Border Dam and Mandaya Dam); Scenario 3 (Border Dam and Mandaya Dam - with revised operating rules). Nineteen evaluation criteria categorised into three interest groups viz. Environmental, Social and Economic were defined for the MCA. Table 6-1 lists the evaluation criteria along with their calculated values.

Table 6-1 : Evaluation criteria

Criteria	Group	Unit	SC1	SC2	SC3
Env Sens Area	ENV	km2	0	0	0
Carbon emissions	ENV	million ton	2.26	8.39	8.39
Eco Stress	ENV	Index	-3	-4	-5
Bank Stability	ENV	Index	-4	-4	-4
Wet season shift	ENV	no weeks	8.4	8.4	7.7
Phytoplankton	ENV	retention time (days)	135	193	210
Macrophytes growth potential	ENV	Index	-2.0	-1.5	-1.5
Biological production	ENV	% change	16	23	40
Water availability	SOC	% change	2	61	55
Pest Disease	SOC	Index	-3	-5	-5
Urban pollution	SOC	time of decay (h)	-102	-110	-107
Recession Agric	SOC	% change	-36	-40	-61
Fish production - dams	SOC	ton/a	4097	6615	7705
Loss productive land	SOC	km2	2131	2145	2145
Physical displacement	SOC/ECON	no households	502	2613	2613
Navigation	ECON	change days/a	51	73	100
Avg Energy System	ECON	GWh/a	28111	43105	44638
Evap loss system	ECON	million m3/a	14806	21253	21713
BCR	ECON	Index	6.59	10.45	11.19

By allocating different weights associated with each of the three interest groups to the above criteria and by employing sensitivity and trade-off analyses, a decision matrix was developed and the scenarios were scored.

Figure 6-1 graphically displays the results of the scenario evaluation and shows that in general, all scenarios scored high from an economic perspective, while Scenario 1 has the highest environmental and social scores. The high economic scores are mainly due to the additional energy which will be produced by Border and Mandaya dams, while the construction of these dams will also lead to improved navigation and fish production. Furthermore, the increased regulation afforded by the construction and operation of these dams will add more navigable days to the lower Blue Nile River. Coupled with this, it was found that the construction of these dams will have no significant negative impact on irrigation water requirements and existing hydropower installations along the Blue Nile and Main Nile rivers downstream. In fact, the mean annual inflow into Aswan Dam will reduce by less than 2% in all of the development scenarios.

As expected, Scenario 1 is the most favourable from an environmental and social perspective. The lower environmental and social scores of Scenario 2 and Scenario 3 can mainly be ascribed to the loss in productive land, significant physical displacement of people and risk of pest diseases associated with the construction of Mandaya Dam, while the dam will also have a serious impact on recession agriculture along the Blue Nile River downstream.

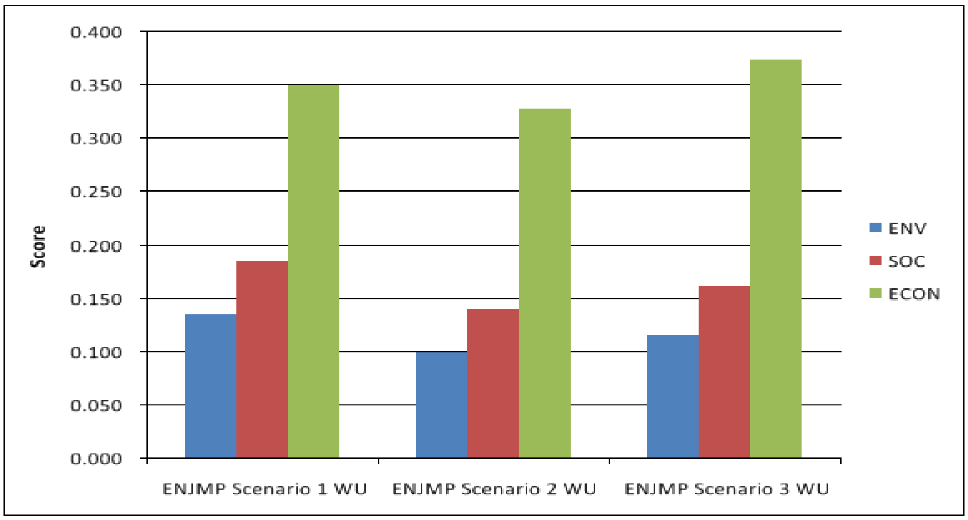

Figure 6-1 :Cumulative impact scenario scores

Evaluation of climate change impacts on future development scenario: Scenario 3 vs Scenario 3a

This evaluation considered the responses of key indicators to climate change impacts in the Blue Nile basin under a future development scenario, i.e. after construction of both Border and Mandaya dams.

The main findings of the scenario evaluation were:

- The mean annual volume of water that is discharged by the Blue Nile River into the Main Nile will reduce by 9.5% due to climate change.
- Open water evaporation loss in the Blue Nile basin will increase by about 0.8 billion m^3/a
- A 7% reduction in combined hydropower energy output at the four main dams along the Blue Nile River (Mandaya, Border, Roseires and Sennar) is expected
- A slight reduction in fish production (-2% to -3%) in Border and Mandaya dams is expected

- A significant decrease (up to -65%), in dry season low flows along the lower Blue Nile River will occur. This could have negative consequences on water availability for riparian communities, ecological processes, water quality and navigation.

Evaluation of Blue Nile Flood Damage: Scenario 4 vs. Scenario 4a

Based on MIKE 11 simulations in combination with land use data and depth-damage functions, the potential reduction in flood damage costs along the lower Blue Nile River upstream of Khartoum due to the implementation of a flood control operating rule at Border Dam (Scenario 4a) was investigated. Table 6-2 summarises the flood damage costs as calculated in the NB-DSS. From the table it is evident that, for the reach of the Blue Nile River which has been considered, the largest economic impact of floods is associated with structural damage which is estimated at about 749 Million USD. This is reduced to about 673 million USD under Scenario 4a, once flood control measures have been implemented at Border Dam. Damage costs linked to roads and agriculture along the study reach are insignificant.

Table 6-2 : Flood damage costs as calculated in NB-DSS (Million USD)

	Structural	Agricultural	Roads	Total Damage/Loss
Scenario 4	748.63	0.02	0.01	748.66
Scenario 4a	672.74	0.02	0.01	672.77

7. TRADE-OFFS AND OPPORTUNITIES

The construction of Border and Mandaya dams and the implementation of operating rules to maximise hydropower generation (Scenario 3) in the Blue Nile catchment will provide significant potential for increased hydropower production. Furthermore, the results of the scenario evaluation suggest that due to improved regulation afforded by the construction of Border and Mandaya dams, there will be negligible impact on existing irrigation schemes and hydropower installations along the lower Blue Nile and Main Nile rivers, while the mean annual inflow into Aswan Dam will reduce by less than 2%. The dams will also lead to improved water availability and an increase in fish production. Although there are numerous socio-economic benefits associated with the construction of Mandaya and Border dams, the construction of both these dams are linked to serious environmental and social impacts, both at the dam sites and along the downstream river reaches. These include high carbon emissions, an increased risk of pest diseases, loss in productive land, significant physical displacement associated with the construction of Mandaya Dam and impacts on recession agriculture along the Blue Nile River downstream. Scenario 1 (construction of Border Dam only) is more favourable than Scenario 3 from an environmental and social perspective. However, economically, Scenario 1 does not have the same benefits as Scenario 3 in terms of improved navigation and hydropower generation. The trade-off between Scenarios 1 and 3 therefore essentially entails a trade-off between economic benefits and social and environmental "costs".

As demonstrated by Scenarios 4 and 4a, there is significant potential for a reduction in flood damage along the lower Blue Nile River upstream of Khartoum due to the implementation of a flood control operating rule at Border Dam, which essentially entails operating the dam at a lower level to create buffer storage at the start of the wet season. This would inevitably result in a reduction in hydropower generation at Border Dam. The trade-off in this case therefore centers around the economic benefits related to a reduction in flood damage and the economic loss due to less hydropower generation at Border Dam.

8. CONCLUSIONS

Based on the findings of this pilot application, the potential environmental, social and economic impacts and/or benefits associated with development in the Blue Nile Basin under the various scenarios which were considered may be summarised as follows:

- The Blue Nile basin has significant potential for development i.t.o. hydropower.
- The improved regulation afforded by the construction of Border and Mandaya dams will enable further expansion of the existing irrigation schemes along the lower Blue Nile River.
- Although there are numerous socio-economic benefits associated with the construction of Mandaya and Border dams, these dams are also linked to serious environmental and social impacts, both at the dam sites and along the downstream river reaches, which will have to be managed and mitigated in order for the development to be sustainable.
- The construction of Mandaya and Border dams will have negligible impact on existing irrigation schemes and hydropower installations along the Blue Nile and Main Nile rivers and will also only slightly reduce inflow volumes into Aswan Dam.

Based on an assessment of climate change impacts on the Blue Nile system, after construction of Border and Mandaya dams, the mean annual volume that is discharged by the Blue Nile River into the Main Nile will reduce by 9.5% due to climate change. Further significant expected climate change related impacts include a 7% reduction in hydropower at the four main dams along the Blue Nile River, a slight reduction in fish production (-3%) and a significant decrease in dry season low flows along the lower Blue Nile River.

It is recommended that measures to address the above impacts should mainly entail the implementation of specific operating rules at major dams along the Blue Nile River, aimed at realising agreed trade-offs between environmental, social and economic costs and benefits, and at mitigating climate change impacts .

It is important to note that, in line with the overarching objective of this pilot case application, which was to showcase the NB-DSS capabilities within the context of transboundary integrated water resource planning and management, the scenario evaluations which were undertaken as part of this pilot application were based on a single set of indicators, the subjective definition of evaluation criteria and a relatively random weighting approach. However, the outcomes of the pilot applications confirmed that the NB-DSS is indeed a powerful tool which is sufficiently capable of advanced water management scenario evaluation. In future, more detailed planning appraisals and scenario evaluations in the Blue Nile catchment will inevitably require changes to the existing indicators, the addition of more indicators and more inclusive approaches towards criteria weighting.