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**SYNTHESIS REPORT
Integrated Nile Basin**

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

SYNTHESIS REPORT: Integrated Nile Basin

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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
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

1.1 THE NILE BASIN

At approximately 6700 km, the Nile River is the longest river in the world. It extends from Lake Victoria in the south to Lake Nasser (Aswan Dam) in the north with a total catchment area of approximately 3 million km² before flowing into the Mediterranean Sea. The river traverses the countries of Tanzania, Uganda, Rwanda, Burundi, DRC, Kenya, Ethiopia, South Sudan, Sudan and Egypt.

The main subcatchments of the Nile Basin are summarised below:

- The Equatorial Lakes comprising Lake Victoria, the Upper Victoria Nile, Lake Kyoga, the Lower Victoria Nile, Lake Albert, Lake Edward and Lake George;
- The Bahr el Jebel Basin – the main feature of this basin is the Sudd swamps and wetlands;
- The Bahr el Ghazal Basin;
- The Sobat Basin comprising the Baro and Pibor tributaries;
- The White Nile which extends from the foothills of the lake plateau in the south to the confluence with the Blue Nile, and from the foothills of the Ethiopian Plateau in the east to the Nile-Congo divide in the west;
- The Ethiopian (or Abyssinian) Plateau comprising the Blue Nile and the Atbara Rivers;
- The Main Nile from Khartoum to Aswan and from Aswan to the Mediterranean Sea.

The climate of the Nile Basin is extremely variable owing to its geographic extent. The seasonal pattern of rainfall shows bimodal rainfall in the Equatorial Lakes area; a transitional zone between Lake Albert and Mongalla to a single rainfall season in the Bahr el Jebel basin; and a shorter rainfall season in the eastern and northern tributaries and lower parts of the basin. Compared to the size of the basin, the total runoff from the Nile is relatively small, with average annual runoff at about 30 mm. However, the distribution of runoff is not uniform and significant flow volumes are generated from relatively small and isolated tributaries, in the Equatorial lakes region and in the Ethiopian highlands.

Existing major water resource infrastructure in the Nile Basin includes the Owen Falls Dam at Lake Victoria, the Jebel Aulia Dam on the White Nile upstream of the Blue Nile confluence, the Roseires and Sennar Dams in the Blue Nile, the Khashm el Girba and TK5 dams in the Tekeze-Atbara basin, the Merowe Dam in Sudan and the High Aswan Dam in Egypt.

The major consumptive water use in the Nile Basin is irrigation. The irrigation supply from Aswan Dam to users downstream in Egypt is estimated to be some 55 billion m³/a. Major irrigation schemes are also located in the Blue Nile sub-basin, where the average annual supply for irrigation in the Gezira and Managil Schemes is about 6 billion m³/a. Additional smaller irrigation areas comprise the irrigation areas upstream and downstream of Sennar Dam as well as upstream of Jebel Aulia Dam, downstream of the Blue Nile confluence to users at Tamaniat, Hassanab and Dongola and in the Tekeze-Atbara sub-basin.

The Equatorial Lakes region is dominated by Lake Victoria, which is operated according to an agreement which was concluded between Uganda and Egypt when Owen Falls Dam was constructed to ensure that there is sufficient flow in the White and Main Nile for irrigation. Existing hydropower schemes downstream of Lake Victoria are operated as run-of-river schemes and do not violate this agreement. The Jebel Aulia Dam upstream of Khartoum is operated primarily for flood control due to flood concerns at Khartoum. The Roseires and Sennar dams on the Blue Nile are operated primarily to reduce sedimentation and to provide water for irrigation in Sudan. Similarly, Khashm el Girba Dam in the Tekeze is also operated to reduce sedimentation and to provide water for irrigation. Merowe Dam's main purpose is for hydroelectricity. Aswan Dam is operated for hydropower generation, flood control and for supplying water for irrigation downstream to the Nile Delta.

Figure 1-1 shows the extent of the Nile Basin.

IBRD 30785



Figure 1-1 : The Nile River Basin

1.2 THE INTEGRATED NILE BASIN PILOT CASE

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 to the Integrated Nile Basin, i.e. the whole of the Nile Basin and addresses the evaluation of basin-wide impacts associated with development and/or management options.

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 shows the start page of the NB-DSS.

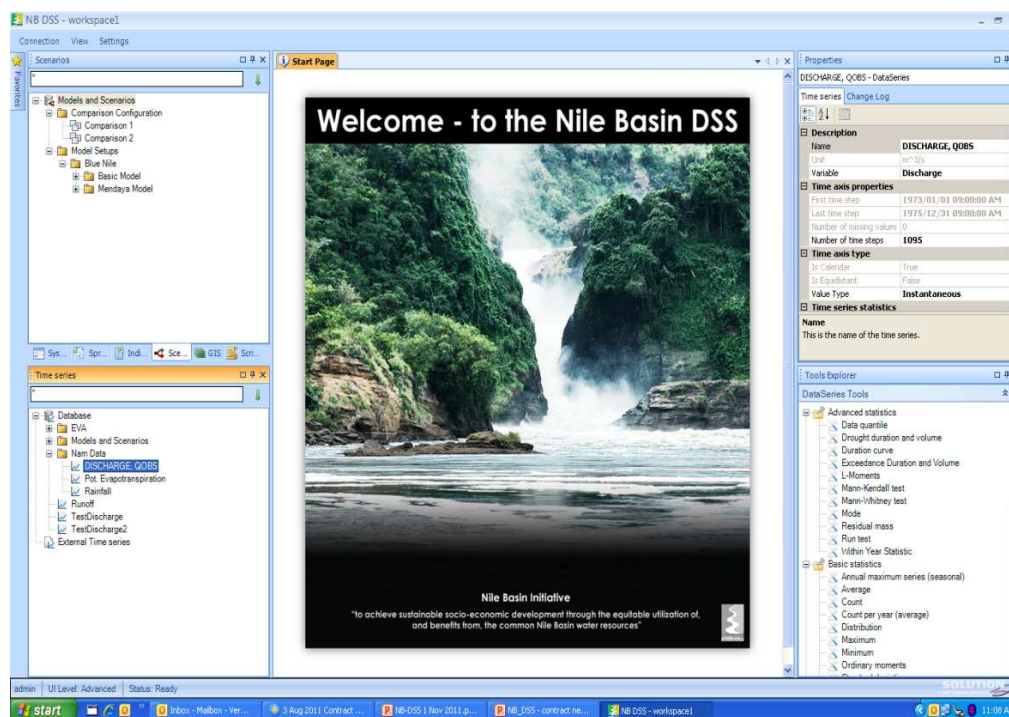


Figure 2-1 : Start Page of the Nile Basin Decision Support System

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 Nile Basin 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 Basin, 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 stakeholders, a baseline and five other scenarios for the Integrated Nile Basin pilot case were identified. In essence, the scenarios concerned a full future development intervention in the Nile Basin (Scenario 1), coupled with specific management options (Scenarios 2 to 4) as summarised in Table 4-1. These management options entail the construction of Jonglei Canal and/or the regulation of Lake Albert outflows in conjunction with specific operating rules. Scenarios 5a and 5b compare the potential impacts of significant expansion in irrigation development in different parts of the Nile Basin.

Table 4-1 : Integrated Nile Basin Scenarios

Scenario	Development Intervention	Management Options
SC0	Baseline	Current
SC1	Full basin development based on interventions considered in regional pilot cases – irrigation / HPP	None
SC2	As for SC1 – construct Jonglei Canal at full capacity (43 million m ³ /day).	Divert water into Jonglei Canal during Jun - Nov only.
SC3	As for SC1 - regulate Lake Albert outflow and construct Jonglei Canal at full capacity (43 million m ³ /day)	Store excess water in Lake Albert, which is released when water level in Lake Nasser drops to critical level.
SC4	As for SC1 - regulate Lake Albert outflow and construct Jonglei Canal at full capacity (43 million m ³ /day)	Optimise: Maintain high flood flows into Sudd; Revise Roseires Dam operating rule; Increase BAS outflow by adopting revised operating rule for Tams Dam.
SC5a	As for SC1 - Hypothetical future development scenario assuming significant growth in irrigation development (+ 7 550 km ²) along lower Blue Nile in Sudan	None
SC5b	As for SC1 - Hypothetical future development scenario assuming significant growth in irrigation development (+ 7 550 km ²) in Nile Equatorial Lakes region	Evaluate potential benefits of a more humid climate on water use. Assess the 'buffering' effect of Sudd on increased water use upstream.

The approach that was adopted for scenario implementation involved the modification of the Integrated Nile Basin 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 were generated for inclusion in the subsequent scenario analyses and Multi Criteria Analysis (MCA). A simulation period of 1951 to 1990 was used for all scenarios.

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 Integrated Nile Basin 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 cost-benefit and macro-economic analyses.

Table 5-1 : Indicators used for scenario evaluation in the Integrated 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	Food production
Extent of commercial irrigation	Extent of wetlands	Benefit/cost ratio (BCR)
Impact on recession agriculture	Ecological stress	Internal Rate of Return (IRR)
Fish production	Biological production	Gross Domestic Product (GDP)
Loss in productive land	Abundance of pest blackflies	Employment opportunities
Loss of access to natural resources	Bank stability	Household Income
Physical displacement	Recovery distance	
Economic displacement	Seasonal shift	
	Phytoplankton growth potential	
	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 Integrated Nile Basin Pilot Case addressed three separate cases:

- An assessment of the potential impacts associated with a full basin development scenario.
- The evaluation of three possible future development scenarios in the Nile Basin:
 - Full Nile Basin development
 - Full Nile Basin development with Jonglei Canal
 - Full Nile Basin development with Jonglei Canal and regulation of Lake Albert outflow. In essence, this entailed that Aswan Dam is operated at lower levels and that water is stored in Lake Albert for drought periods.
- The evaluation of irrigation expansion in the Lower Blue Nile catchment vs. irrigation expansion in the Lake Victoria Basin.

Full Development Nile Basin Scenario (Scenario 1)

This scenario presents a possible future development scenario in the Nile Basin and is based on the assumption that all countries will unilaterally go ahead with the implementation of national schemes which have been identified for possible implementation. Various future hydropower and irrigation schemes across the basin were considered in this scenario. Impacts and benefits related to this scenario were assessed by interpreting indicator values as calculated in the **Scenario Manager**.

Based on the results of the NB-DSS, the following conclusions can be drawn:

- Water availability, which is a reflection of dry season low flow, will improve along the White Nile, lower Blue Nile, lower BAS and Main Nile River upstream of Aswan Dam due to the increased flow regulation as a result of upstream dams, which will lead to elevated dry season flows. Along the Lower Atbara River, however, water availability will reduce significantly, which can be attributed to the increased consumptive use of water in the Tekeze-Atbara Basin under the full development scenario. Downstream of Aswan Dam, water availability is expected to decrease by 11%. Downstream of Lake Victoria, water availability will be slightly reduced.
- Fish production in certain river reaches will be severely impacted, specifically along the lower Blue Nile, the White Nile, the lower Atbara and the Main Nile River downstream of Aswan Dam.
- The most severe impact in terms of fisheries production in wetlands is linked to the Machar Marshes, where the existing annual fish production of about 8 900 ton/a, will be reduced by 17%. Fish production in the Sudd will be reduced by about 3%. Fish production in Lake Victoria, Lake Albert, Jebel Aulia Dam and Aswan Dam remain almost unaffected. However, in Merowe dam, fish production is expected to increase by 11% under Scenario 1.

- The impact on recession agriculture due to the attenuation of flood peaks by upstream dams will be most severe along the lower Atbara and Blue Nile rivers as well as along the Main Nile River downstream of Atbara and Aswan Dam.
- The urban water pollution risk in the Main Nile River downstream of Khartoum as expressed by the time of decay to an acceptable coliform count, will increase under Scenario 1.
- The dams and irrigation schemes which will be constructed under Scenario 1 will result in a total displacement of about 101 000 households across the Nile Basin.
- Environmentally sensitive areas will be inundated by some of the dams, while some of the planned irrigation schemes will also require clearing of environmentally sensitive areas.
- Important Bird Areas (Birdlife International) have also been identified in some of the dam and irrigation footprint areas.
- All of the proposed dams will, to some extent, result in carbon emissions.
- The areal extent of the Machar Marshes will reduce by 20% under Scenario 1, while the Sudd area will reduce by only 4%.
- The ecological stress index along the lower Baro, Atbara and Blue Nile rivers will increase significantly. The Nile River downstream of Lake Victoria as well as the Albert Nile will not be severely impacted.
- The duration of the wet season along certain river reaches, specifically along the lower Blue Nile, White Nile, lower Atbara and Main Nile downstream of Aswan Dam, will be significantly reduced.
- A significant shift in the start of the wet season will be experienced along the lower Baro, Blue Nile and Atbara rivers upstream of their confluence with the Main Nile River. The cumulative effect of this, is a shift of almost 17 weeks in the start of the wet season in the Main Nile River downstream of the Atbara confluence.
- Average annual flows along the lower Atbara and Blue Nile rivers will be significantly reduced, as will the inflow into Aswan Dam (-11%). Outflow from the BAS system will increase by 14% due to less water being "lost" in the Machar marshes due to upstream regulation.
- It is anticipated that Scenario 1 will increase the GDP of the Nile Basin by 6 700 million USD, will result in 75 000 direct employment opportunities and about 260 000 total employment opportunities and has a BCR of 1.17.

The potential benefits of constructing the Jonglei Canal (Scenario 2) and regulating Lake Albert outflow (Scenario 3) on the full basin development scenario (Scenario 1)

In essence, Scenarios 2 and 3 evaluated the potential increase in water availability at Aswan Dam due to constructing the Jonglei Canal (Scenario 2) and regulating Lake Albert outflow (Scenario 3). An assumption was made that additional water at Aswan Dam will be used to expand irrigation downstream of Aswan Dam in Egypt. Both scenarios were imposed on Scenario 1 (full development scenario).

The NB-DSS results showed that Scenarios 2 and 3 have the following impacts relative to Scenario 1:

- Water availability will improve along the lower Main Nile River (downstream of Aswan Dam), due to the increase in irrigation water releases from Aswan Dam.
- The construction of Jonglei Canal (Scenarios 2 and 3) will pose a drowning risk, will result in the physical displacement of about 430 households and will impose economic displacement as a physical barrier over a length of 385 km.
- Floodplain inundation and recession agriculture will improve significantly along the White Nile River under both scenarios. However, along the lower Main Nile River (downstream of Aswan), floodplain inundation will be reduced due to the fact that Aswan Dam is operated at lower levels.
- Fish production in the Sudd will reduce by about 16 000 tons/a due to a significant reduction in area compared to baseline).
- Fish production in the White Nile and Main Nile upstream of Aswan Dam will increase. However, fish production in the Lower Main Nile downstream of Aswan Dam will reduce.

- The ecological stress index along the Bahr el Jebel River reduces from -1 to -4 under Scenario 2. For Scenario 3, the ecological stress index along the Albert Nile and the Bahr el Jebel River reduces from -1 to -5 and along the Lower Main Nile River this index reduces from -2 to -4.
- Navigation generally improves along the White Nile and Main Nile rivers. However, for Scenario 3, navigation is severely affected along the Albert Nile due to the regulation of Lake Albert outflows.
- Average energy production at Merowe and Aswan dams increases by about 10% under both scenarios.
- Evaporation losses in the Sudd reduce by about 11 billion m³/a under Scenario 2. For Scenario 3, evaporation losses in the Sudd reduce by about 9 billion m³/a and by almost 1.5 billion m³/a in Aswan Dam due to the fact that Aswan Dam is operated at lower levels. However, evaporation losses in Lake Albert increase by 1 billion m³/a under Scenario 3.
- Food production downstream of Aswan Dam increases by 2.2 million tons/a (Scenario 2) and 3.2 million tons/a (Scenario 3).
- The average flow along the White Nile and Main Nile rivers increase by about 6 billion m³/a under Scenario 2 and by about 4.5 billion m³/a under Scenario 3.
- For Scenario 3, there is a significant shift in wet season of 28 weeks along the Albert Nile due to the regulation of Lake Albert outflows.
- Due to the fact that Aswan dam is operated at lower levels, the retention time in Aswan Dam is reduced from 638 days to 519 days under Scenario 3.

In order to compare Scenarios 2 and 3, the **Analysis Manager** in the NB-DSS was used. 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	scenario1	scenario2	scenario3
Env Sens Hotspots	ENV	Index	-5	-5	-5
Wetland Area Sudd	ENV	% change baseline	-4	-27	-22
Eco Stress	ENV	Index	-2.0	-2.3	-3.3
Wet Season Shift Main Nile	ENV	no weeks	16.9	16.0	15.1
Wet Season Shift Sudd Inflow	ENV	no weeks	2.9	2.9	27.4
Wet Season Duration Main Nile	ENV	% change baseline	-2.3	13.9	10.0
Retention Time Reservoirs	ENV	no days	238	219	198
Fish Production Dams & Wetlands	SOC	ton/a	118114	102151	106964
Fish Production Rivers	SOC	% change baseline	-33	-22	-21
Physical displacement	SOC	no households	101,106	101,537	101,628
Economic displacement	SOC	Index	0	-1	-1
Drowning Risk	SOC	Index	0	-1	-1
Recession Agriculture	SOC	% change baseline	-17	4	3
Pest Diseases	SOC	Index	-1.5	-1.3	-1.8
Water availability	SOC	% change baseline	5.6	8.6	15.4
Navigation Wite & Main Nile	ECON	no days baseline	32	44	40
Energy Produced - System	ECON	GWh/a	70280	71649	71533
Food production ds Malakal	ECON	million ton/a	21.3	23.6	24.5

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.

The summary MCA results (Figure 6-1) show that both Scenarios 2 and 3 score higher from an economic and social perspective, while Scenario 1 (full development) has the highest environmental score.

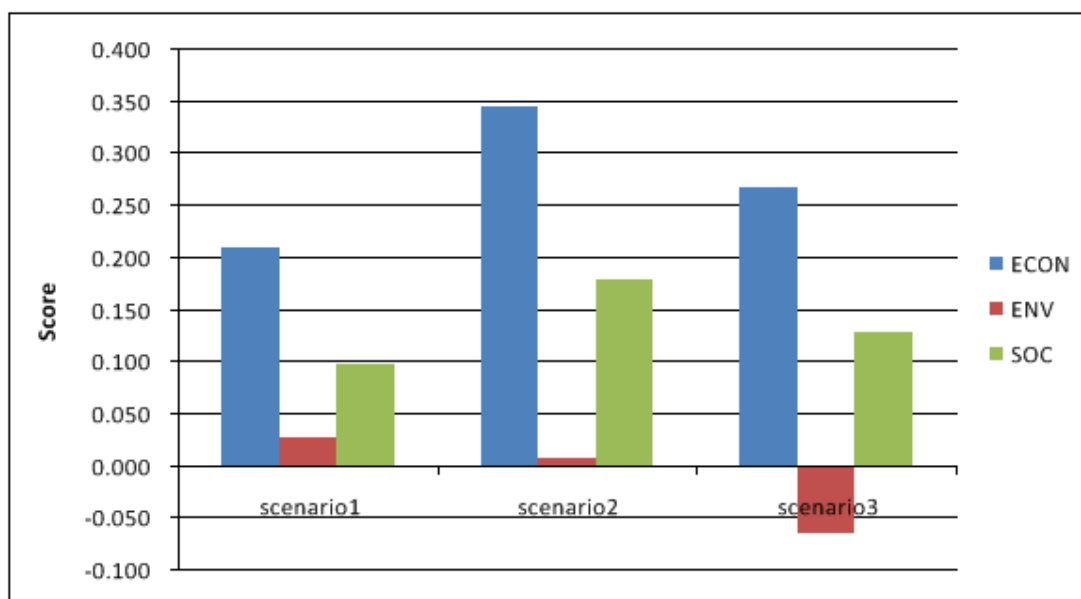


Figure 6-1 : MCA scores for Scenarios 1, 2 and 3

Irrigation expansion in Blue Nile (Scenario 5a) vs irrigation expansion in Lake Victoria Basin (Scenario 5b)

This evaluation entailed an assessment of the environmental, social and economic impacts and/or benefits associated with the following scenarios:

- Scenario 5a: Hypothetical future development scenario assuming significant growth in irrigation development (+ 7 550 km²) along lower Blue Nile in Sudan
- Scenario 5b: Hypothetical future development scenario assuming significant growth in irrigation development (+ 7 550 km²) in Nile Equatorial Lakes region.

In essence, this evaluation evaluated the potential benefits of a more humid climate in the Nile Equatorial Lakes region on water use, and assessed the 'buffering' effect of the Sudd on increased water use upstream.

The following conclusions can be drawn regarding the impacts of scenarios 5a and 5b in relation to the state of the Nile River Basin under Scenario 1:

- Due to the different climatological characteristics, the average water demand for irrigating 7500 km² is 8.5 billion m³/a along the lower Blue Nile River (Scenario 5a) and only 2.4 billion m³/a in the Nile Equatorial Lakes region (Scenario 5b).
- An increased irrigation demand of 2.4 billion m³/a in the Nile Equatorial Lakes region, results in an average flow reduction of only 0.1 billion m³/a downstream of the Sudd and 0.4 billion m³/a in the Main Nile River at Aswan Dam. However, an increased irrigation demand of 8.5 billion m³/a along the lower Blue Nile River, reduces the outflow from the Blue Nile by 7.6 billion m³/a and results in an average flow reduction of 7.5 billion in the Main Nile River at Aswan Dam
- Under Scenario 5a, hydropower generation at Merowe and Aswan Dam is reduced by almost 1600 GWh/a. Under Scenario 5b, the reduction in hydropower generation across the Nile Basin is only about 100 Gwh/a.
- Under Scenario 5a, fish production at Merowe and Aswan Dam is reduced by almost 3000 tons/a. Under Scenario 5b, the reduction in fish production across the Nile Basin is confined to the Sudd and is in the order of 5000 tons/a

- Environmental and social impacts related to floodplain inundation (recession agriculture), ecological stress, wet season duration, fish production and pest diseases along the Main Nile River downstream of Khartoum are negatively impacted under Scenario 5a. These impacts are especially severe along the lower Main Nile River downstream of Atbara as well as downstream of Aswan Dam. However, under Scenario 5b, there is a negligible impact along these river reaches.
- Under Scenario 5a, the number of navigable days along the Main Nile downstream of Aswan Dam will reduce by 80 days per annum. Under Scenario 5b, this reduction is only 4 days per annum.
- In general, water availability will not be negatively impacted by Scenarios 5a or 5b.
- The most severe impact under Scenario 5b is the anticipated decrease in the area of the Sudd Wetland (from -4% under Scenario 1 to -12% under Scenario 5b).

7. TRADE-OFFS AND OPPORTUNITIES

The economic impacts associated with the full development of the Nile Basin in terms of hydropower and irrigation, are mainly as a result of consumptive water use, changed flow regimes and increased losses due to operating rules, which result in less water being available in the river system. Average annual flows along the lower Atbara (-37%) and Blue Nile (-11%) rivers will be significantly reduced, as will the inflow into Aswan Dam (-11%). The economic benefits relate to additional hydropower generation, improved navigation and water availability along certain reaches and increased food production. This will increase the GDP of the Nile Basin by 6.7 billion USD, while 75 000 direct employment opportunities will be created. However, the fully developed basin will also result in significant social and environmental impacts related to loss in recession agriculture, less fish production, reduction in wetland areas and increased ecological stress. It is recommended that mitigation measures to address the above negative social and environmental impacts under the full development scenario entail the implementation and optimisation of basin-wide operating rules, aimed at realising agreed trade-offs between environmental, social and economic costs and benefits.

The construction of Jonglei Canal and the regulation of Lake Albert outflows will result in additional water being available along the White Nile and Main Nile rivers, with significant socio-economic benefits linked to increased hydropower generation along the Main Nile and increased food production downstream of Aswan Dam. However, it is also foreseen that the construction of Jonglei Canal as well as the regulation of Lake Albert outflows will have huge social and environmental impacts due to the reduction of the Sudd Wetland area and the highly unnatural flow regimes along the main stem of the Nile River. The trade-offs related to the construction of Jonglei Canal and the regulation of Lake Albert outflow therefore mainly relate to an agreeable compromise between environmental, social and economic stakeholders.

As demonstrated in the NB-DSS, irrigation expansion upstream of Lake Victoria as an alternative to further irrigation expansion in the lower Main Nile and/or Blue Nile catchments, holds significant potential in terms of water efficiency, and also has negligible impacts along the White Nile and Main Nile rivers. The most significant negative impacts associated with irrigation expansion in the Lake Victoria Basin, relate to the anticipated decrease in the area of the Sudd Wetland.

8. CONCLUSIONS

Based on the findings of this pilot application, the following conclusions may be drawn:

- Although the unilateral full development of the Nile Basin will lead to economic benefits, it will have significant social and environmental impacts.
- The construction of Jonglei Canal and the regulation of Lake Albert outflows will result in additional water being available along the White Nile and Main Nile rivers. This will improve fish production, recession agriculture, navigation and water availability along these rivers, which offsets the potential negative social and environmental impacts due to the reduction of the Sudd Wetland area and the highly unnatural flow regimes along the main stem of the Nile River. Economic benefits include increased hydropower generation along the Main Nile and increased food production downstream of Aswan Dam.
- From a water efficiency, environmental and social perspective, there is significant potential associated with increased irrigation expansion upstream of Lake Victoria as an alternative to irrigation expansion in the lower Main Nile and/or Blue Nile sub-basins.

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 arbitrary 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 Nile Basin will inevitably require changes to the existing indicators, the addition of more indicators and more inclusive approaches towards criteria weighting and normalisation, which will be done in stakeholder sessions.