Downstream Impact of Blue Nile Basin Development

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Abstract

A considerable number of water projects are planned and/or under implementation in the Blue Nile sub-basin: The Grand Ethiopian Renaissance Dam (previously Border), Mandaya Dam, additional installed HP capacity at Roseires, Irrigation Scheme Extensions at Rahad II, Kenana II and III in addition to Irrigation projects in Dinder, Tana Beles and Anger-Didessa-Finchaa Subbasins. In this study, the Nile Basin Decision Support System is used as a tool to assess the positive and negative impacts of these projects on both national and regional levels, not only on the Blue Nile Sub-basin, but also downstream. The development projects in all other sub-basins located upstream the Blue Nile are considered as well through a series of development scenarios and relevant social, environmental and economic indicators. A multi criteria analysis is undertaken to evaluate these scenarios.
Based on the quantification of environmental, social and economic indicators and their comparative analysis, this study aims to present an optimized set of development projects within the Blue Nile basin that can stimulate the win-win regional approach, maximizing the regional benefit while minimizing the negative impacts.

Key words: Blue Nile, Nile Basin Decision Support System, Dams, Irrigation, Hydropower, Downstream Impact, Multi Criteria Analysis

1 INTRODUCTION

The Nile Basin is considered among the most complex and unique river basins due to its size associated with disparity in climate, hydrology, topography and demography throughout the basin. A considerable number of water resources development projects are being under planning and implementation on both national and transboundary levels within the Nile Basin in order to overcome the present and future challenges of rapid population growth, urbanization, industrialization, both economic and food crises, climate change which represent a threat on the region's natural resources. These projects also aim to achieve sustainable socio economic development on both national and regional levels. Although The Blue Nile (BN) sub basin comprises only 8% of the total Nile Basin catchment area, it contributes to 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. Generally, three seasons are defined in Ethiopia: The rainy season from June to September which contributes about 70% of the annual rainfall; the dry season from October to January; and the short rainy season between February and May. The Blue Nile(the Abbay) and its tributaries flow from the Ethiopian Highlands providing most of the flow into the lower Nile. The Blue Nile finds its source on the Ethiopian plateau at an elevation of approximately 2000 to 3000 masl. The plateau has varying topography, with broken and hilly areas, grassy uplands, swamp valleys and scattered trees (Sutcliffe & Parkes, 1999).

Lake Tana in the upper basin has an estimated catchment area of 12 129 km2. The lake tributaries include the Gilgel Abbay, the Gumara, the Ribb and the Megech which are perennial streams that are highly seasonal. The Blue Nile flows from the lake through a series of cataracts and the Tis Issat falls where there is a hydropower plant with an installed capacity of 73 MW.

The main river is joined by many tributaries including the Jemma, the Muder, the Guder and the Finchaa rivers. Significant contributions are made by the Didessa and Dabus tributaries, which drain the south-western, humid part of Ethiopia. The Beles tributary joins the main river from the northeast just before the site of the Great Ethiopian Renaissance Dam (GERD) on the Ethiopia- Sudan border -

previously Border with different dimensions. The Mean Annual Runoff (MAR) at this site is estimated to be 48 billion m3/a. Downstream of El Diem, the Roseires and Sennar dams on the Blue Nile provide water for the large irrigation schemes further downstream to the confluence with the White Nile at Khartoum. The Gezira irrigation scheme and Managil extension scheme are amongst the largest in the world, covering a combined area of approximately 8000 km2. Downstream of Sennar Dam, the Rahad and Dinder tributaries join the Blue Nile before the confluence with the White Nile near Khartoum. From here, the main Nile flows about 1500 km to Lake Nasser (Aswan Dam) with the only major inflow from the Atbara River some 300 km downstream from Khartoum.

The basin is under consideration for various hydropower and irrigation projects as shown in Figure 1 and Tables 1&2. The Nile Basin Decision Support System (NB DSS) is a comprehensive analytical framework that integrates Information management system, Water Resources Modeling system, Analytic tools (optimization, benefit-cost analysis, multi-criteria analysis...) and it is intended to serve as water resources-based DSS for use in the context of an international river basin in a user friendly graphical user interface (GUI). Consequently, the NB DSS is used in this study to assess the downstream impact of the development of the BN sub basin from different perspectives taking into account the cumulative impact resulting from the development of the Equatorial Lakes and Baro Akobo Basin as well.

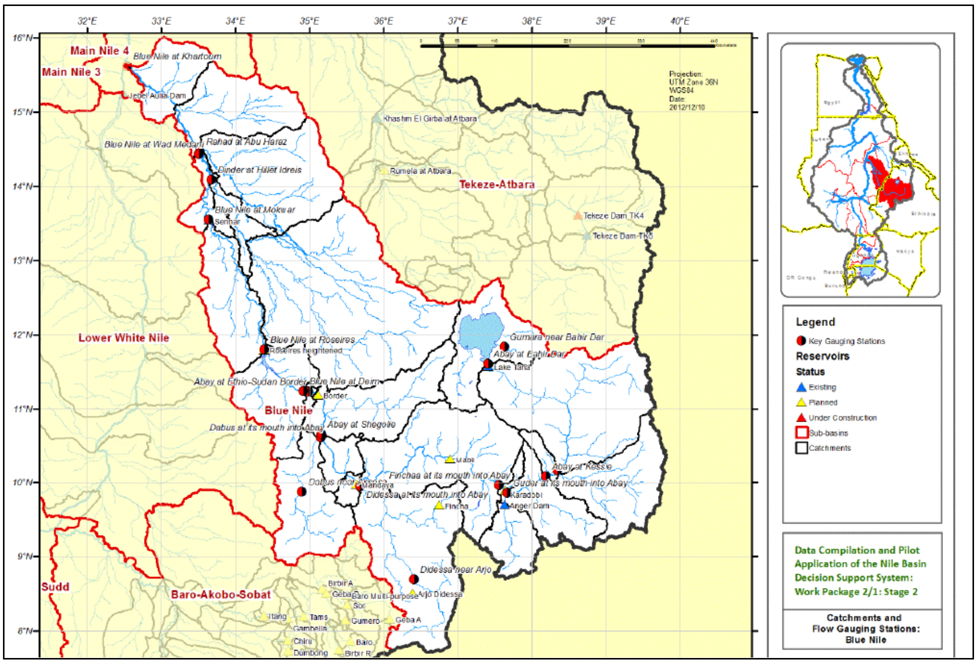

Figure 1: Blue Nile Sub basin (study area) Existing and Proposed Projects

2 PROBLEM STATEMENT

The Nile River loses 95% of its water within its trajectory from source to mouth: out of the 1661 BCM of rains falling on the Basin, only 84 BCM reach Aswan upstream High Aswan Dam (HAD). The difference is lost in swamps and through evaporation and seepage. In the last decades, many water resources and hydropower development projects are being studied in order to benefit from the River for the welfare of its people. National water development plans and donors' funded projects lead to a series of prefeasibility and feasibility studies targeting the construction of a set of multipurpose and hydropower dams in addition to a number of irrigation schemes all through the Nile Basin . These projects need to be studied in an integrated manner in order to assess their impacts locally and regionally. This study focuses on the Blue Nile Sub basin (BN) since it is considered as the most promising region in the Eastern Nile Sub-basin and a number of water resources development projects are being planned/under implementation for this purpose: The Grand Ethiopian Renaissance Dam, Mandaya Dam, additional installed HP capacity at Roseires, Irrigation Scheme Extensions at Rahad II, Kenana II and III in addition to Irrigation projects in Dinder, Tana Beles and Anger-Didessa-Finchaa Subbasins. . Although different development scenarios have been studied within the preparation and case studies undertaken in the scenario analysis reports developed by the Nile Basin Initiative (NBI), this development has not been studied on the total Nile basin level in order to assess the impact of the development of each sub basin alone and in a progressively cumulative manner on the downstream.

3 OBJECTIVE

The main objective of this study is to assess the impact of BN projects on both national and regional levels in order to reach an optimal solution for an integrated development of the sub basin while minimizing the negative impact on the basin level downstream using the NB-DSS tool. This involves:

- Defining scenarios and a set of economic, environmental and social evaluation criteria (indicators) using the NB-DSS tool.
- Using the MCA tool and associated functionalities embedded in the NB-DSS to evaluate scenarios based on the quantification of economic, environmental and social indicators.

It is important to note that this work will be considered as a part of a wider research work aiming to study the cumulative impact of the development of each sub basin (Equatorial lakes, Baro Akobo Sobat (BAS) ,Bahr el Ghazal, White Nile, Atbara and Main Nile) using the same above mentioned approach .

4 METHODOLOGY

A Mike Basin model is used to simulate the Nile Basin: the present state of water resources development in the Equatorial Lakes, White Nile, Eastern Nile and Main Nile up to Aswan (Baseline) and the planned projects in the BN, Baro Akobo Sobat (BAS) and the Equatorial Lakes.

The model simulations' results are assessed under different scenarios: baseline, BN projects (hydropower only), BN projects (irrigation only), BN projects (irrigation +hydropower), Equatorial Lakes' projects+ BAS + BN projects (irrigation + hydropower).

Relevant social, environmental and economic indicators on both local and downstream levels are measured and a multi criteria analysis is undertaken to evaluate these scenarios. Figure 2 presents a scheme of both irrigation and hydropower proposed projects in the BN.

5 The NB DSS

The design and development of the NB-DSS were informed by a comprehensive needs assessment of the present situation within the Nile Basin by the NBI Water Resources Planning and Management Project through stakeholder consultations across all of the riparian countries. Water availability, hydrology and water use patterns as well as social, environmental and economic issues that were raised during the consultations were prioritized as follows:

- Water Resources Development
- Optimal Water resources utilization
- Coping with floods and droughts
- Energy development (hydropower)
- Rain fed and irrigated agriculture
- Watershed and sediment management
- Navigation
- Climate change impacts and water quality issues are defined as cross-cutting issues.

The basic purpose of the NB-DSS is to provide a framework for sharing knowledge, understanding river system behavior, 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.

MIKE Basin model representing the baseline scenario for the entire Nile Basin is being configured at appropriate temporal and spatial resolutions. The primary data sources for the Baseline Model were the Nile Encyclopedia (MWRI, Egypt), Ethiopian and Sudanese Master Plans and inflow records into Lake Victoria supplied by the riparian countries.

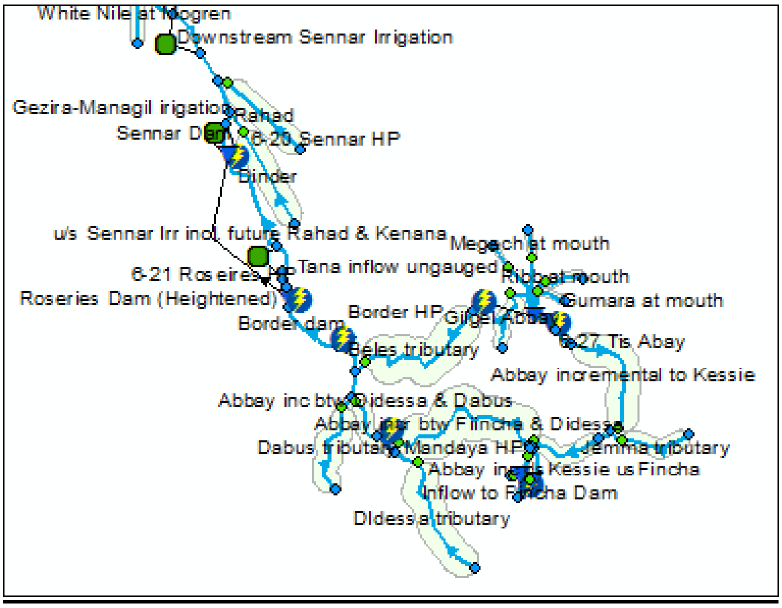

Figure 2: Irrigation and Hydropower proposed projects in the BN

5.1 Scenario Definition

The approach adopted for scenario implementation involved the modification of the BN baseline model within the entire Nile Basin for representation of the various development and management options (Irrigation, Hydropower, Irrigation +Hydropower). A baseline and four other scenarios for the development of BN and its impact on downstream were identified. A simulation period of 1951 to 1990 was used for all scenarios. This short simulation period is due to the lack of complete data in all sites within a larger and later period. The scenarios are based on the full future development interventions in the BN within the context of the entire basin . Table 1 shows the different scenarios used in the study.

Table1: Different scenarios used in the study

Scenarios	Description
S0	Baseline: Current situation
S1	Blue Nile planned projects(Irrigation+Hydropower): GERD (Hydropower) Mandaya (Hydropower) Roseires hightenig (Irrigation+Hydropower) Rahad II Irr Scheme Great Kenana Irr Scheme Dinder Irr Schemes Tana Beles Irr Schemes Anger-Didessa-Finchaa Subbasins Irr Schemes
S2	Integrated Blue Nile + BAS + Equatorial Lakes projects : Scenario 1+ (Baro-1 and Baro-2 Dams + Geba-A and Geba-R dams +Genji Scheme + Birbir A and Birbir R Dams + TAMS Dam (Hydropower))+ Itang + Kano (Irr Scheme) , Gilo-2+ Dumbong (Dam and Irr Scheme), Bugesera Irrigation in the Kagera, Rusumo Falls run-of-river scheme+ Kakono Dam(hydropower and irrigation), Karuma + Ayago + Magwagwa + Sondu Miriu Dam + Nandi Forest (Dam and Hydropower)
S3	Blue Nile Hydropower projects
S4	Blue Nile Irrigation projects

The following tables (Tables 2 and 3) represent some detailed information regarding the proposed hydropower dams and irrigation projects within the BN sub basin used in the study. Hydropower projects' data as well as estimated areas and crop water requirements for future irrigation schemes were based on the following sources of information:

- ENTRO. 2007. Eastern Nile Power Trade Program Study. Prepared by EDF and Scott Wilson.
- The series of reports named "Data Compilation and Pilot Application of the Nile Basin Decision Support System (NB-DSS): Work Package 2: Stage 2: Scenario Analysis Reports" for: Integrated Nile Basin and Eastern Nile Joint Multipurpose Programme: Blue Nile. (NBI, 2012) represent the source of compiled information and model configuration for the BN, BAS sub basins, the Equatorial Lakes Plateau and their planned projects, and the entire basin baseline configuration.
- Eastern Nile Irrigation and Drainage Studies Cooperative Regional Assessment Analysis report (NBI-ENSAP, May 2009).
- International Panel of Experts (IPoE) on GERD Project Final Report, May 31st 2013.

Table 2: BN Planned HP Dams

	GERD	Mandaya	Roseires Heightening
Dam Crest Level (masl)	**645**	**803**	**490**
Dead Storage (masl)	**590**	**741**	**467**
Bottom Level (masl)	**500**	**610**	**465**
Flood Control Level (masl)	**640**	**801.24**	**490**
Installed Capacity (MW)	**6000**	**2000**	**415**
Target Power (MW)	**6000**	**2000**	**280**

Table 3: BN Planned Irrigation Dams

Planned Irrigation Schemes	Net Area (Ha)	Annual water requirement (MCM)
Rahad II	**210,000**	**2,000.0**
Great Kenana	**420,000**	**3,990.0**
Upper Dinder	**8,500**	**72.0**
Lower Dinder	**49,600**	**555.5**
Tana Beles	**252,640**	**2,316.0**
Anger-Didessa-Finchaa Subbasins.	**343 780**	**2 449,2**

5.2 Key Study Assumptions:

This study assesses the impact of BN proposed projects (irrigation and hydropower) on both national and regional levels under the following assumptions:

- The BN Reservoir(s) are filled up. Therefore the results address the post filling period.
- GERD and Mandaya reservoirs proposed in the study are used only for hydro power production.
- Blue Nile flows entering the system are not less than the minimum historic record at the same time.

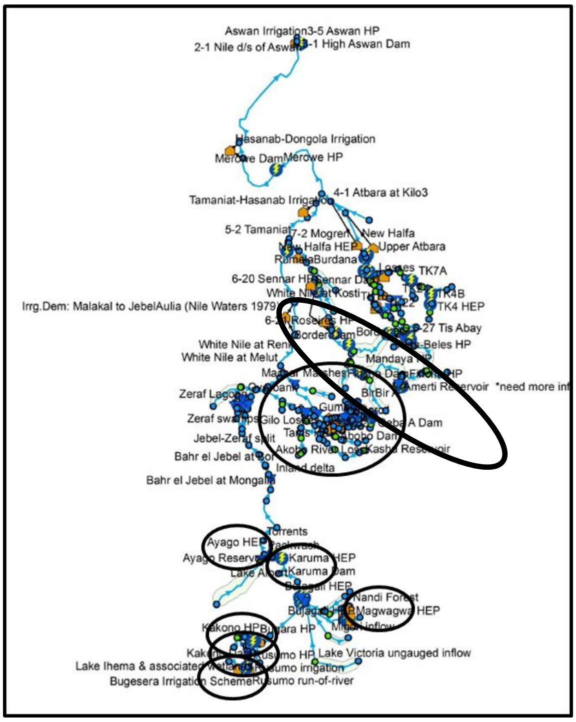

Figure 3: Irrigation and Hydropower Proposed Projects in the BN- BAS and Equatorial Lakes (Scenario2)

5.3 Indicators' Selection and Results

Indicators quantify and simplify information in a manner that facilitates understanding of environmental, social and economic implications related to water resource interventions. Only Five basic environmental indicators **were** selected from a list of thirteen indicators installed in the NB DSS to describe possible changes that could be linked to the proposed development interventions as shown in Table 4.They were grouped into two categories viz. Footprint Areas and downstream.

Table 4: Environmental Indicators Definitions and Measurement Units

Indicator			
Category	**ID**	**Name**	**Definitions & (Units)**
Footprint Areas	**EN3**	**Fisheries production**	**Dam/ Lake / Wetland: Median surface area (tons/a)**
	EN4_1	**Floodplain Area Inundated (Recession Agriculture)**	**Median flow during wettest month (% change compared to baseline)**
Downstream Areas	**EN5**	**Ecological Stress**	**Dry season low flow: Median flow during lowest consecutive 3 months in dry season Wet season low flow: Median flow during lowest consecutive 3 months in wet season Within year flow variability: Median value of annual flow amplitude (Index)**
	EN6	**Biological Production**	**Wet season duration based on median monthly flows(% change compared to baseline)**
	EN10	**Seasonal Shift**	**(no weeks)delay in onset of wet season**

Four different social indicators out of fifteen under the following three social categories were selected: water availability, community health and safety and food security and livelihoods (Table 5).

Table 5: Social Indicators Definitions and Measurement Units

Indicator		
Category	**ID**	**Definitions & (Units)**
Water Availability	**SO1**	**Dry season low flow: Median flow during lowest consecutive 3 months in dry season (% Change from Baseline)**
Community Health and Safety	**SO3**	**Prevalence of diseases resulting from pest species (index)**
	SO4	**Time of decay (h) to acceptable coliform concentrations**
Food security and Livelihoods	**SO92**	**Change in Fish Productivity along river reach (% Change from Baseline)**

Three out of ten economic indicators were derived. These typically included navigation and hydropower production as presented in Table 6.

Table 6: Economic Indicators Definitions and Measurement Units

Indicator			
Category	**ID**	**Name**	**Units**
Navigation	**EC1**	**Navigability – Vessels**	**Change from Baseline in days/year**
Energy	**EC21**	**Average Energy generated at specific HP node**	**GWh/a**
	EC22	**Total Average Energy generated – system wide**	**GWh/a**

The reason behind the selection of these specific indicators for this case study in each sector (environmental, social and economic) is their clearness, simplicity, measurability and their possible comparability which can clearly reflect the expected impact of different interventions on the water resources availability and livelihood of the stakeholders within the footprint area as well as in the downstream.

5.4 Environmental Indicators Results

As shown in Table 7 the fishery production indicator (EN3) is calculated in both foot print area in addition to the downstream Dams following the considered scenario. The summation of all is configured as an evaluation criteria “Total Fish production”. Percentage change in the flood plain inundated area (indicator on recession agriculture- EN41) is also calculated in the lower BN, lower main Nile, main Nile downstream Khartoum and lower Atbara being the key areas where change due to cumulative interventions could be measured. Ecological stress index (EN5) was calculated in the lower Main Nile, Atbara outflow and BN outflow in order to reflect the ecological stress taking place in response to different proposed scenarios. Percentage change in the biological production (EN6) represented by the wet season duration (based on median monthly flows) is calculated in the lower main Nile in order to assess the cumulative impact of different possible interventions. The seasonal shift represented with the number of weeks delay in onset of wet season (EN10) is calculated in in the lower Main Nile, Atbara outflow and BN outflow since they represent key areas of change in the flow regime after different implementation of the different activities. Four other direct indicators are also considered due to their high importance in reflecting the magnitude and direction of impact: the mean annual inflow to Aswan (i.e. downstream impact of BN, BAS and EL development) and the mean annual outflows from both BN and White Nile at their confluence. Their summation represents the mean annual outflow of the Main Nile at Khartoum.

Table7: Environmental Indicators Results

	S1 Blue Irr –HP	S2 Blue HP	S3 Blue Irr	S4 Blue- BAS-EL (Irr-HP)	S0 Baseline
EN3 Aswan Dam	16209.1	16846.5	16114.2	16424.7	16747.2
EN3 Roseires	2628.1	2640.4	1651.9	2628.1	2245.1
EN3 Sennar	292.5	292.5	128.6	292.5	261.9
EN4_1 Lower Blue Nile	-10.1	-7.3	15.8	-18.4	0
EN4_1 Lower Main Nile	0.1	0.1	0.1	-2.7	0
EN4_1 Lower Atbara	-4.5	-4.5	-4.5	-4.5	0
EN5 Atbara outflow	-5.0	-5.0	-5.0	-5.0	-5.0
EN5 Blue Nile outflow	-3.0	-2.0	-3.0	-3.0	-2.0
EN6 Lower Main Nile	-34.8	2.1	6.4	-26.8	0
EN10 Blue Nile outflow	7.7	8.0	7.6	7.7	0
EN10 Lower Main Nile	7.7	0.6	7.4	7.6	0

Environmental indicators reveal percentage change in fish production in Roseires, Sennar and Aswan dams respectively by (17, 11 , -3)% under S1 , (17, 11, 1) under S2, (-26, -50, -4)under S3 and (17, 11, -2) under S4. The increase is in both Roseires and Sennar in S1, S2 and S4 is due to the upstream hydroelectric projects and the absence of huge irrigation schemes upstream the dams while in Aswan, the Nile flow is used for irrigation in its trajectory in important irrigation schemes on both the BN and main Nile basins. The case is more acute in S3 where the implementation of only the irrigation projects in the Blue Nile impact considerably the fish production in the absence of hydropower projects.

Recession agriculture practiced on flood plains will be reduced in lower BN ranging from 7 to 18.5% compared to baseline under scenario1, 2 and 4 due to the construction of HP dams upstream leading to flow regulation and increased by about 16% under scenario3 due to water released for irrigation. No significant change will take place in the lower Main Nile in this regard except for scenario 4 during which the inundated areas will decrease by about 3%.

The developments associated with all Scenarios except S3 will increase the ecological stress along the lower BN with a negative index of -3 while baseline as well as S2 displays a negative index of -2. The Atbara sub basin, being totally independent, will not be impacted by any water development intervention upstream. The wet season duration along the lower Main Nile will decrease from 27 to 35 % compared to baseline under scenarios 1 and 4 while it proves a slight increase from 2 to 6% under S2 and 3. A shift in the start of the wet season should be experienced along both Blue and Main Nile inflow by 7 to 8 weeks for all scenarios except for lower main Nile under scenario 2 (3 days). The results of this indicator need further investigation.

5.5 Social Indicators Results:

Table 8 represents the Social Indicators Results under different scenarios.

Table 8: Social Indicators Results

	Blue Irr – HP	Blue HP	Blue Irr	Blue BAS-EL Irr-HP	Baseline
SC1 Lower Blue Nile	-12.0	43.0	-40.5	-12.0	0
SC1 Lower Main Nile	45.4	59.4	-11.6	59.9	0
SC3 Lower Atbara	0.0	0.0	0.0	0.0	0.0
SC3 Lower BLue Nile	0.0	-1.0	0.0	0.0	0.0
SC3 Lower Main Nile	-1.0	-1.0	0.0	-1.0	0.0
SC4 ds Khartoum	40.2	40.2	40.3	40.2	40.2
SC9_2 Lower Blue Nile	-40.2	-40.8	-46.2	-40.2	0
SC9_2 Lower Main Nile	-34.8	2.1	6.4	-26.8	0
SC9_2 Main Nile ds Khartoum	-36.9	-38.4	-45.6	-36.4	0
Mean Annual Inflow to Aswan	2215.9	2401.3	2213.4	2241.7	2465.7
Mean Annual Outflow from Blue Nile at confluence with White	1114.9	1300.8	1112.3	1114.9	1357.4
Mean Annual Outflow from White Nile at Mogren to confluence with Blue	927.9	927.9	927.9	953.7	935.9
Mean Annual Outflow Main Nile after confluence Blue and White	2042.8	2228.7	2040.2	2068.5	2293.3

The percentage change of dry season low flow (Median flow during lowest consecutive 3 months in dry season) known as “water availability” is reduced by (12,40.5,12) % downstream the BN under S1, S3 and S4 respectively due to the water abstractions used for irrigation differently than S3 where dry season low flow increases by 43% due to increased flow regulation. On the other hand, dry season low flow increases in the lower Main Nile in S1, S2 and S4by (45.4, 59.4, 59.9) % respectively due to flow regulation caused by HP production in the first two scenarios and to saved evaporation losses in the BAS which compensates the losses caused by the integrated development in the upstream while it decreases by about 12% in S2 due to BN irrigation abstractions.

A decrease in fish productivity varying between 26 and 46 % is registered under all scenarios along the BN and in the Main Nile except for S1 and S3 where a very slight increase is registered. The mean annual inflow to Aswan decreases by (10, 3, 10, 9) % under S1, S2, S3 and S4 respectively which makes the HP scenario the best after the baseline with regard to water security. The BN mean outflow decreases by (18, 4, 18, 18) % under S1, S2, S3 and S4 respectively. The independence of the BN system is the reason behind that the percentage change from baseline remains the same under S1 and S4.

5.6 Economic Indicators Results

Economic Indicators’ Results are shown in Table 9.

Table 9: Economic Indicators Results

	Blue Irr – HP	Blue HP	Blue Irr	Blue BAS-EL Irr-HP	Baseline
EC1 Main Nile ds Aswan	-22.0	15.0	-34.0	-21.0	0
EC1 Main Nile ds Khartoum	25.0	72.0	-58.0	45.0	0
EC21 Aswan	4360.1	4925.7	4426.3	4438.1	4908.9
EC21 Roseires	1496.7	1499.3	1283.4	1496.7	1435.0
EC22 System	69699.4	69699.4	69025.9	69025.9	69699.4

Economic benefits are closely related to additional hydropower generation, improved navigation and increased food production. The economic indicators reveal a considerable decrease in navigability in the lower Main Nile ranging from 21 to 34 days per year except in S2 where an increase of 15 days per year takes place. On the other hand, an increase in navigability will take place in the Main Nile downstream Khartoum ranging from 25 to 72 days per year in S1, S2 and S4 while a decrease of 58 days will take place under S3 due to water abstraction for irrigation.

Average energy generated at Aswan decreases under S1, S2, S3, and S4 by (11, 0, 10, 10) % respectively. As per Roseires, the average energy generated increases by 4% except for S3 in which it decreases by about 11%.

5.7 Multi Criteria Analysis

In general, Multi Criteria Analysis (MCA) is used in order to assess how interventions affect the direction of change in environmental, social and economic performance, and to measure the magnitude of that change. MCA is concerned with structuring and solving decision and planning problems involving multiple solutions and criteria that don't have a unique optimal solution. It is a support tool where preferences are used to differentiate among solutions for decision makers who face such problems. Many MCA techniques exist. The NB DSS implements the MCA Decision Matrix which compares criteria for various solutions (aka scenarios), weighted by preferences in a matrix form. It allows comparison of multiple decision matrices that were created by different stakeholders. Figure 4 is a scheme which explains the MCA process and its application in the NBDSS.

5.8 Evaluation Criteria

The evaluation criteria were defined for a comparison of scenarios 1, 2, 3 and 4 along with their calculated values. The criteria were categorized into three groups representing the MCA sessions: Environmental, Social and Economic. Table 10 summarizes the evaluation criteria that were defined for a comparison of the four scenarios along with their calculated values.

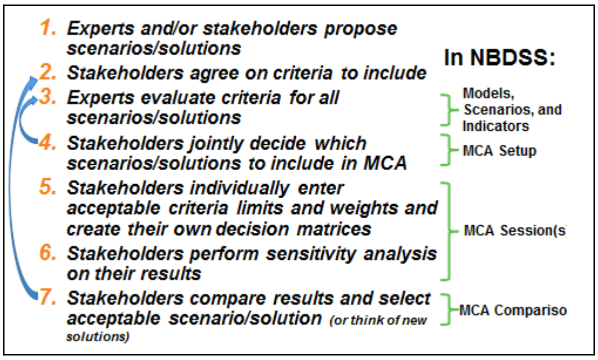

Figure 4: Scheme Explaining the MCA process and its application in the NB DSS

Table 10: Evaluation Criteria

	Group	Unit	Blue Irr -HP	Blue HP	Blue Irr	Blue BAS-EL Irr	Baseline
Total Fish Production	ENV	ton/a	299477	300127	292444	282221	300,560
Area Inundated Lower Main Nile	ENV	% change compared to baseline	0	0	0	-3	0
Area Inundated Lower Blue Nile	ENV	% change compared to baseline	-10	-7	16	-18	0

Table 10: Evaluation Criteria (Cont.)

	Group	Unit	Blue Irr -HP	Blue HP	Blue Irr	Blue BAS-EL Irr	Baseline
Area Inundated Lower Atbara	ENV	% change compared to baseline	-5	-5	-5	-5	0
Atbara Outflow Ecological stress	ENV	Index	-5	-5	-5	-5	-5
Blue Nile outflow Ecological stress	ENV	Index	-3	-2	-3	-3	-2
Lower Main Nile Biological Production(we t season duration)	ENV	% change compared to baseline	-35	2	6	-27	0
Blue Nile Outflow Seasonal Shift	ENV	Weeks	8	8	8	8	8
Lower Main Nile Seasonal Shift	ENV	Weeks	8	1	7	8	8
Warter Availability in Lower Blue Nile	SOC	% change compared to baseline	-12	43	-41	-12	0
Water Availability Lower Main Nile	SOC	% change compared to baseline	45	59	-12	60	0
Prevalence of diseases	SOC	Index	-5	-7	0	-6	-3
Urban Pollution DS Khartoum	SOC	Hours	40	40	40	40	40
Fish Productivity AlongRiver Reach Blue Nile	SOC	% Change compared to baseline	-40	-41	-46	-40	0
Fish Productivity AlongRiver Reach Main Nile	SOC	% Change compared to baseline	-35	2	6	-27	0
Fish Productivity Along River Reach Lower Atbara	SOC	% Change compared to baseline	-1	-1	-1	-1	0
Mean Annual Inflow to Aswan	SOC	m3/sec	2216	2401	2213	2242	2,466

Table 10: Evaluation Criteria (Cont.)

	Group	Unit	Blue Irr -HP	Blue HP	Blue Irr	Blue BAS-EL Irr	Baseline
Mean Annual Outflow from Blue Nile at confluence with White	**SOC**	**m3/sec**	**1115**	**1301**	**1112**	**1115**	**1,357**
Mean Annual Outflow from White Nile at Mogren to confluence with Blue	**SOC**	**m3/sec**	**928**	**928**	**928**	**954**	**936**
Mean Annual Outflow Main Nile after confluence Blue and White	**SOC**	**m3/sec**	**2043**	**2229**	**2040**	**2069**	**2,293**
Navigability DS Aswan	**ECO**	**days/year**	**-22**	**15**	**-34**	**-21**	**0**
Navigability DS Khartoum	**ECO**	**days/year**	**25**	**72**	**-58**	**45**	**0**
Average Energy Generated at Aswan	**ECO**	**GWh/a**	**4360**	**4926**	**4426**	**4438**	**4,909**
Average Energy Generated at Roseires	**ECO**	**GWh/a**	**1497**	**1499**	**1283**	**1497**	**1,435**
Average Energy Generated System	**ECO**	**GWh/a**	**69699**	**69699**	**69026**	**69026**	**69,699**

5.9 Weights

Five different groups of stakeholders where defined as MCA sessions, each having different priorities defined by weighted criteria: in the BN (environment, social and economic) criteria were weighted for each MCA session, in addition to two down streamers in both Khartoum and Aswan with different weighted criteria.

At the local level (BN), three categories of beneficiaries were identified and the weights were ranked according to the interests of each category. For the economic group, the power production followed by the navigability then the fish production (first on the local level then the regional one) was given the highest weights since they are the most economically viable activities. While in the BN environmental group, the environmental aspects were given the priority and the highest weights: area inundated and ecological stress and seasonal shift at the local level (BN level). The same goes to the social group were the water availability, the prevalence of diseases, the urban pollution are given the priority. As for the two downstream groups, Aswan and Khartoum, weights are given following the priorities and the interests of each country from the river.

5.10 Scenario Evaluation Results

The following matrices represents the ranks and scores resulting from different MCA sessions based on the weighted criteria previously selected for each session and under each scenario. The summary of the results shows that BAS HP scenario has the highest rank in all MCA sessions in both BAS and downstream. The baseline scenario is ranked second, BAS irrigation third, BAS Irr-HP fourth and BAS-EL last under all MCA sessions. Table 11 and Figure 5 represent the ranks and scores resulting from different MCA sessions.

Table 11: Ranks Resulting from Different MCA Sessions

	Blue ECO	Blue SOC	Blue ENV	Blue Main Nile Khartoum	Blue Main Nile Aswan
Blue Irr -HP	4	4	4	4	4
Blue HP	1	2	2	1	1
Blue Irr	3	3	3	3	3
Blue BAS-EL Irr-HP	5	5	5	5	5
Baseline	2	1	1	2	2
	Blue ECO	**Blue Soc**	**Blue Env**	**Blue Main Nile Khartoum**	**Blue Main Nile Aswan**
Blue Irr -HP	0.53	0.48	0.53	0.18	0.15
Blue HP	1.01	0.99	0.98	0.86	0.93
Blue Irr	0.62	0.76	0.74	0.53	0.47
Blue BAS-EL Irr-HP	-11.95	-10.21	-9.24	-5.36	-3.78
Baseline	0.97	0.99	1.06	0.82	0.84

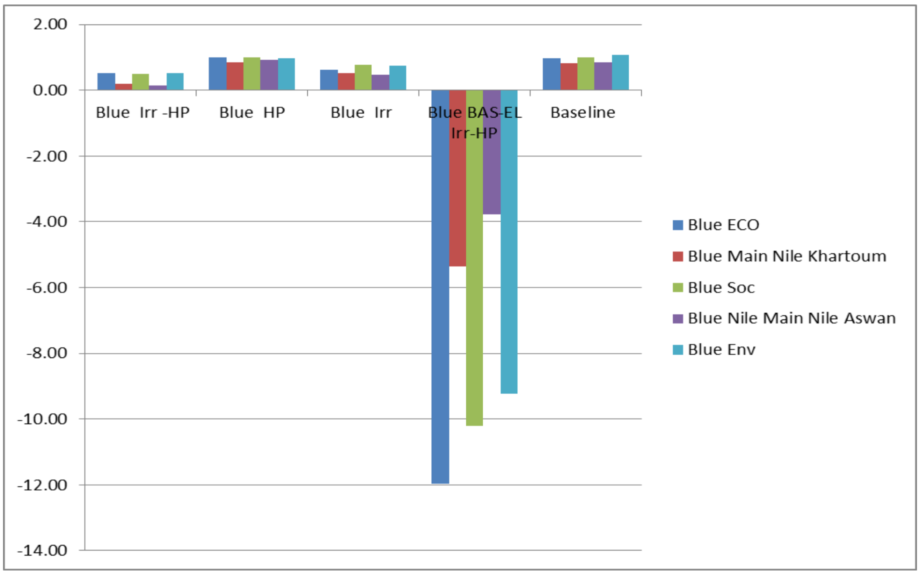

Figure 5: Scores resulting from different MCA sessions

6 Literature Review on GERD's Filling and Water Infrastructure Development in the BN and their Downstream Impact:

Although the NBDSS results indicate that the BN development on hydropower is the first alternative for downstream, yet it is important to note that this exercise is undertaken under the above mentioned conditions / assumptions and without taking into account the probability of a succession of severe drought periods. Moreover, being the biggest reservoir under construction on the BN, the GERD reservoir filling and operation are expected to have a significant impact on downstream. Accordingly, many researchers have already started to elaborate on these two issues and came up to the following findings:

6.1 GERD's Filling and its Downstream Impact:

- (Mulat et al, 2014 b) used Mike Basin river basin simulation model which indicated that the planned 6years filling period was sufficient to fill the reservoir with little impact on the current irrigation water demands from HAD in Egypt without additional management investment. There will be about 12% and 7% of reduction of annual energy output from High Aswan Dam during the filling and after filling stage of GERD respectively.

- (King, A. M. et al, 2013) evaluated five discrete filling rates for the GERD: three policies considering fractions of total monthly stream flow entering the reservoir, impounding 5%, 10%, or 25%, and two "threshold" policies allowing the GERD to retain 1) any quantity greater than the historical average stream flow (> 1*HASF), or 2) any quantity greater than 90% of the historical average stream flow (> 0.90*HASF). Under the 5% filling policy the reservoir never reaches Full Supply Level (FSL) by 2060 while other filling policies, under stationary climate conditions, offer more viable outcomes. As per GERD reservoir releases, a 5% filling rate would not be feasible for Ethiopia, requiring over 50 years to fill the reservoir; nor would it be likely that Egypt and Sudan accept a 25% filling rate, essentially reducing the stream flow they are accustomed to by over 10,000 Mm3 per annum with the other three filling policies falling in the middle. Regarding HP generation, for the operation period spanning 2014 – 2031, or the reservoir filling stage, and based on the model results, it can be affirmed with 90% confidence that the 17-year cumulative power production will fall between 250 GW and 305 GW with a median value of 280 in the 25% filling policy which seems highly improbable from a multi-national policy standpoint, but performs the best. The most intriguing filling policy is the >0.9*Average Monthly stream flow where the 17-year cumulative power production will fall between 229 GW and 300 GW, with a median value of 270 GW. The study stressed on the necessity of clear basin-wide water resources management and planning to balance these complicated tradeoffs.

- (Wheeler et al, 2013) used River Ware Model to simulate the water system in the Eastern Nile Basin to assess the impact and benefits of different development scenarios in the basin and especially on downstream users. River Ware model is further used to assess alternative reservoir filling options of GERD in order to minimize the impact on existing infrastructures. The assessments determined that with a three-year filling period, the reservoir level would not drop below 168 m. The lowest level with a five-year filling period would be 170 m with water levels recovering to 178 m after filling in Scenario 1A (HAD 178) and 160 with water levels recovering to 165 Scenario 1B (HAD 165) . This assessment also showed that power generation at the Merowe Dam in Sudan would not be affected if the GERD were to be filled over a five-year period. The analysis of the different scenarios was carried out to show that infrastructure development in the basin needs joint decisions. Figure 6 represents the different scenarios used in the study and the model's results.

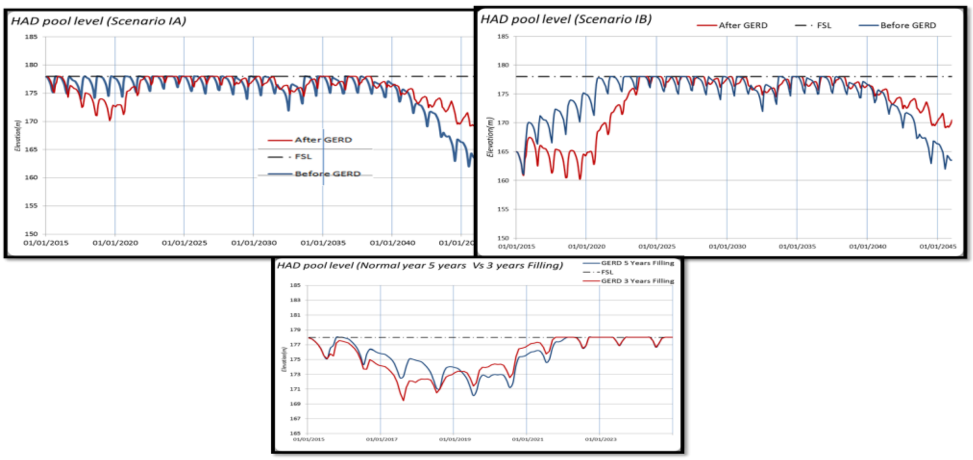

Figure 6: Different scenarios used in the study and the model's results

Source: Wheeler et al, (2013)

6.2 Water Infrastructure Development in the BN and its Downstream Impact:

- (Jeuland & Whittington, 2013) simulated real options of various infrastructure investments utilizing water resources of the Blue Nile in Ethiopia. The study assessed the economic value of different infrastructure alternatives taking into account climate change, hydrological, systems (rainfall patterns and water flows), in addition to water withdrawal rates The research results showed the disadvantages of 'one large dam' alternative are more than that of 'three smaller dams' one; the economic value of the first alternative is more vulnerable to expected reductions of water flows and increases of water withdrawals, beside its negative impacts on downstream countries in these cases; Resettlement costs of the second one would be less expensive.
- (Hassan & Kantoush, 2013) developed a hydrological model of the Eastern Nile Basin, including its tributaries, and validated it. Then, Kantoush, 2013, studied the downstream impacts of constructing the Renaissance Dam followed by the other three dams (Beko Abo, Karadobi and Mandaya) that are determined in the Ethiopia's plans. The assessment concluded the following:
    - In case of constructing the four dams, the average water flow at the High Aswan Dam would be reduced to maximum 47.9% during years of droughts whether in filling reservoirs or operation phases;
    - Reduction of water flows would negatively affect the power generation capacity of the High Aswan Dam, arable lands around the Nile, and salination of the Delta's land and ground water; Massive weights of water and sediments in the dams' reservoirs might cause earthquakes that would threaten the dam's structures;
    - Catastrophic impacts would occur in downstream countries in case of the structural failure of the Renaissance Dam due to floods of water stored in the reservoir at the borders with Sudan;
    - Water quality of the Blue Nile would be negatively affected due to the expected overuse of fertilizers in Sudan after blocking sediments behind the dams.
- (W.N.M van der Krogt & H.J.M. Ogink, 2013) used the Eastern Nile Water Simulation Model (ENWSM) powered by RIBASIM and developed by Deltares in cooperation with ENTRO. The simulations show that one or a cascade of reservoirs has a very significant effect on the Blue Nile monthly flow regime by flattening out the monthly flow variation almost completely. This effect is very beneficial for irrigation water supply along the river in Sudan, eliminating current shortages and making local storage requirements almost superfluous. Under these cascade scenarios the inflow to Lake Nasser will reduce by 9 to 11% relative to its current value due to higher water use in Sudan. However the open water evaporation from Lake Nasser will reduce, the overall open water evaporation under the cascade scenario increases a few percentages due to an increased total reservoir surface area and a higher open water evaporation at the existing reservoirs as the average reservoir level is higher (no change in reservoir operation). If the GERD is implemented, the total energy production will increase by about 75% increasing further to 170-190% of the current output under cascade scenarios. The power production at Aswan will reduce by 13-15% of the current output, and with 28% if Sudan doubles its irrigation intensity. The power production of Sudan will increase by 14-18% under the various cascade scenarios due to an average higher water level in the existing reservoirs. The lower average water level in Lake Nasser relative to the base case means higher energy consumption for the Toshka irrigation water supply pumps. The consumed energy for the supply of the full Toshka irrigation canal capacity (333 m3/s) will increase by 26% if the GERD is implemented and 46% if Sudan doubles its irrigation intensity. Under the climate change scenario case the inflow to Lake Nasser reduce further by another 4% and the energy production by some 6% relative to the Base case.

7 CONCLUSION

- The study shows that HP development in the BN is the best alternative economically on the BN sub basin level, and on downstream while the baseline is the best option for both social and environmental stakeholders in the BN. The baseline (current situation) and HP scenarios alternate the first and second ranks with very slight difference in scoring while the irrigation development of the BN is ranked third, followed by the integrated (Irrigation and hydropower development) and finally the accumulated hydropower and irrigation development in both BN , BAS and EL combined which confirms the cumulative impact on downstream.

- Environmental Impact:
  - Total fish production will be reduced under all scenarios. The reduction ranges from 0 to 6 %.
  - The inundated areas in the lower BN will be reduced ranging from 7 to 18.5% compared to baseline under scenario1, 2 and 4 due to the construction of HP dams upstream leading to flow regulation and increased by about 16% under scenario3 due to water released for irrigation. No significant change will take place in the lower Main Nile.
  - The developments associated with all Scenarios will increase the ecological stress along the lower BN with a negative index between -2 and -3 while the Atbara sub basin, being totally independent, will not be impacted by any water development intervention upstream keeping an ecological stress index of -5 under all scenarios.
  - The wet season duration along the lower Main Nile will decrease from 27 to 35 % compared to baseline under S1 and S4 while it proves a slight increase from 2 to 6% under S2 and S3.
  - A shift in the start of the wet season should be experienced along both Blue and Main Nile inflow by 7 to 8 weeks for all scenarios except for lower main Nile under scenario 2 (3 days). The results of this indicator need further investigation.
- Social Impact:
  - The percentage change of dry season low flow is reduced by (12, 40.5,12) % downstream the BN under S1, S3 and S4 respectively due to the water abstractions used for irrigation differently than S3 where dry season low flow increases by 43% due to increased flow regulation. On the other hand, dry season low flow increases in the lower Main Nile in S1, S2 and S4by (45.4, 59.4, 59.9) % respectively due to flow regulation caused by HP production in the first two scenarios and to saved evaporation losses in the BAS which compensates the losses caused by the integrated development in the upstream while it decreases by about 12% in S2 due to BN irrigation abstractions.
  - A decrease in fish productivity varying between 26 and 46 % is registered under all scenarios along the BN and in the Main Nile except for S1 and S3 where a very slight increase is registered.
  - The mean annual inflow to Aswan decreases by (10, 3, 10, 9) % under S1, S2, S3 and S4 respectively which makes the HP scenario the best after the baseline with regard to water security although it marks a decrease . The BN mean outflow decreases by (18, 4, 18, 18) % under S1, S2, S3 and S4 respectively. The independence of the BN system is the reason behind that the percentage change from baseline remains the same under S1 and S4.
- Economic Impact:
  - The economic indicators reveal a considerable decrease in navigability in the lower Main Nile ranging from 21 to 34 days per year except in S2 where an increase of 15 days per year takes place. On the other hand, an increase in navigability will take place in the Main Nile downstream Khartoum ranging from 25 to 72 days per year in S1, S2 and S4 while a decrease of 58 days will take place under S3 due to water abstraction for irrigation. It is well noted that the results of the estimated number of days resulting from the exercise are exaggerated and need to be checked by other methods.
  - Average energy generated at Aswan decreases under S1, S3, and S4 by (11, 10, 10) % respectively. As per Roseires, the average energy generated increases by 4% except for S3 in which it decreases by about 11%.
- From previous, it can be concluded that BN sub basin has significant potential for hydropower and irrigation but the development of this potential has to be studied very cautiously in order to avoid negative impact on downstream. It is also well noted that EL, BAS, Atbara and the Blue Nile sub basins are totally independent. Nevertheless, following the Nile flow from source to mouth, each sub basin impacts its downstream in a cumulative manner which means that the most downstream point is the most sensitive to all upstream developments. Therefore, a very well-coordinated regional development of available water resources is indispensable for the welfare of both upstream and downstream stakeholders.

- The NB DSS is a good and promising tool to study all water resources development projects at both local and regional levels but it might need to be reviewed in some certain parts since some results are not realistic.

8 RECOMMENDATIONS

- Due to the huge dimensions of the GERD, the impact of the reservoir filling in different proposed timeframes need to be studied thoroughly in addition to the study of the probability of consecutive dry seasons and their downstream impact both during filling and operation. Different alternatives of dam dimensions to substitute GERD should also be proposed and studied.
- More detailed information and longer time series can help in a better simulation of the Nile Basin. In this regard and on a wider scope, a solid updated and living database of water levels, discharges and water quality indices for the entire Basin is a crucial need.
- This work needs to be applied for the rest of the sub basins in order to study the impact of the development of each sub basin alone and the cumulative effect of development on the sub basin itself and downstream.
- A more updated version of the NBDSS may lead to more accurate results. But this version was used since it is the latest available in Egypt.
- In this case study, due to short time and for simplicity, optimization exercise was not applied. It is recommended that Future case studies include the application of optimization.

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