Dry Season Water Requirements in the Blue Nile basin (Sudan) after Roseires Dam Heightening

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Abstract

The flow pattern of the Blue Nile is characterized by its marked seasonality as it builds up from a minimum in March to a maximum in late August or early September as a result of the intensive rainfall in the Ethiopian catchment (June - October). During October the flood falls off sharply, followed with a smooth recession to the minimum. Above 80% of its average annual yield (46.6 billion m^3 at Eddeim, 1965-2008) comes in only four months (July - October). The recession flows (November - June) are limited, so the water stored from the previous flood season in Roseires and Sennar reservoirs is essential to the irrigated agriculture served from the system during the dry season. This research has evaluated the impact of Roseires dam heightening on the use of the Blue Nile waters. The analysis has basically focused on the irrigation water as major consumer (95% of the total water use). The recession period represents on average 21% and 17% of the wet season (July - October) and the total annual flows respectively. During such a risky period, the demand exceeds the river's natural flows regardless of the competition between irrigation requirements and power generation. The analysis has shown that raising Roseires dam to EL. 490 m a.m.s.l. can fully overcome the dry season deficit and satisfy the water needs of further developments (1 million feddans).

Key words: Blue Nile, Roseires dam heightening, recession flow, irrigation water requirements

1. INTRODUCTION

Irrigated agriculture has always been Sudan's largest economic investment and the Blue Nile is the most important source of irrigated agriculture as it serves almost 70% of the irrigated area in the country (more than 1.3 million ha). The river system also represents one of the main sources of hydropower. Therefore, the appropriate utilization of its water resources is fundamentally the key factor for the country's welfare, progress and socio–economic stability. The 1959 agreement sets Egypt's share of Nile waters at 55.5 billion m^3 per year and allocates to the Sudan 18.5 billion m^3 per year. Allowing for transmission losses, this is assumed as 20.35 billion m^3 at Sennar in central Sudan.

On the other hand, pressure on the Blue Nile resources is likely to increase dramatically in the coming years as a result of high population growth rates in states within the river basin, and increasing development projects related to water needs in Ethiopia (USBR, 1964; BCEOM, 1998). It is worth to mention that current water use of Ethiopia in the Blue Nile Basin is less than 2%. It is estimated that water requirement to develop fully the potential in the Blue Nile part of Ethiopia is about 5 billion m^3 representing 10% of the river's yield. Sudan is also planning to increase the area irrigated in the Blue Nile basin.

Additional new projects and extension of existing schemes are anticipated to add an additional 888950 ha by 2025. The use of the water for further development in the Sudan may lead to an additional water withdrawal of 9.5 billion m^3 from the Blue Nile Basin. Therefore, an accurate understanding of the existing water resources of the Blue Nile in Sudan, its availability, reliability and improved allocation requires additional precision, and more efforts in the assessment of such a valuable good for the purpose of rational planning, management and economical development of the country.

The current research generally aims to investigate the future allocation of the Blue Nile waters among different water uses, taking into account the changes of the flow regime (supply and demand) as a result of the increased and diverse water needs within the river system. The analysis has basically considered the impact of Roseires dam heightening on the future water allocation.

2. OBJECTIVE

The main objective of this research is to set up a proper approach for utilization of the Blue Nile waters to satisfy the growing demands taking into account the changes in the regime of the river after Roseires dam heightening. A proposed scenario, which simulates the future flow regime, will mainly consider the irrigation sector; the major user of the Blue Nile waters. The specific objective is to attain the proper water resources allocations within the river system for all corresponding demands (abstractions, reservoir evaporation, transmission losses etc…) in the dry period (November-June).

3. PRESENT AND FUTURE USE OF THE BLUE NILE WATER RESOURCES

The estimate for the total area currently irrigated from the Blue Nile in Sudan is 1.3 million ha. According to the World Bank (2000) irrigated agriculture consumes about 90% of the total abstraction from the Blue Nile. The remaining 10% goes for domestic, industry and other diverse uses. Table (1) briefly gives the net cultivable potential areas and annual irrigation water requirements of the main irrigation schemes in the area. Figure (1) shows the location of the largest irrigated schemes along the Blue Nile.

Table 1: Principal existing irrigation schemes on the Blue Nile

Scheme	**Design NCA** (1000 Feddans*)	**Irrigation** (billion m^3/year)	**Crops**
Upstream of Sennar			
Gezira/Managil Project	*2081*	*7.57*	*Cotton & mixed crops*
Abu Na'ama Kenaf	*30*	*0.10*	*Mixed crops*
Rahad Project Phase I	*300*	*1.19*	*Mixed crops*
Es Suki Pump Scheme	*87*	*0.29*	*Mixed crops*
North West Sennar Sugar	*50*	*0.25*	*Mixed crops*
Pump Schemes	*355*	*1.03*	*Mixed crops*
Downstream of Sennar			
Guneid Sugar and Extension	*84*	*0.39*	*Sugar*
Pump Schemes	*127*	*0.61*	*Mixed crops*
Total	**3114**	**11.43**	

* 1 Feddan = 0.42 ha

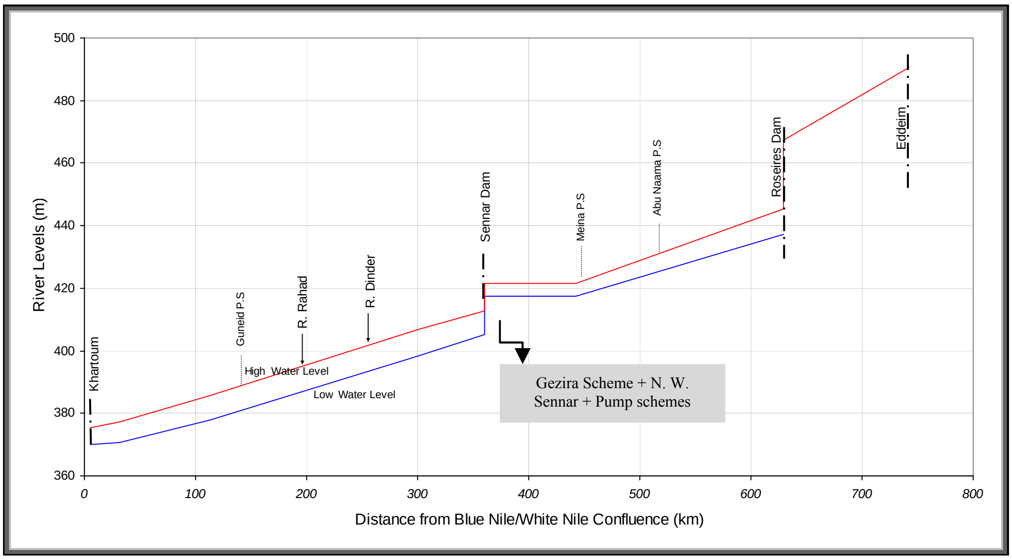

Figure 1: The locations of irrigated schemes along the Blue Nile

The future utilization of the Blue Nile waters can be seen in the highlight of different factors that affect the prospected use. These issues can be short listed as follows:

- The heightening of Roseires dam;
- The proposed development projects in Ethiopia; and
- The probable impacts of climate change.

At present, Sudan is planning to increase the irrigated area in the Blue Nile Basin. Additional new projects and extension of existing schemes are anticipated to add an additional 888950 ha by 2025, Table (2). Unless irrigation efficiencies are significantly better than those currently achieved in the Gezira and other schemes, this will require approximately 9 billion m^3 more water than is abstracted at present, which is about 18.5% of the annual flow of the Blue Nile.

Table 2: Planned irrigation development in the Sudanese Blue Nile

Project name	**Catchment**	**Command area ha**	**Description**	**Possible completion date**
Rahad	Rahad	19740+	Extension of existing scheme	2025
Es Suki		6300+	Extension	2025
Public Pumps		39900+	Extension	2025
Private Pumps		4200+	Extension	2025
N. W. Sennar		4200+	Extension	2025
Abu Na'ama		2100+	Extension	2025
Al Silait, Waha		50410+	Extension	2025
Kenana II and III		420100		2025
Rahad II	Rahad	210000		2025
South Dinder	Dinder	132000		2025
Total		**888950**		

\+ additional areas (i.e. to be added to existing schemes)

Source: Awulachew et al, 2008

4. ROSEIRES DAM HEIGHTENING (RDH)

The objective of the RDH Project is to increase the size of the reservoir and thus the storage capacity. This will enable existing agricultural activities to continue and increase the production through expansion of current schemes. It will similarly offer future opportunities for irrigation schemes and further agricultural development. Since the reservoir also includes a hydropower generating facility, the additional volume of water and increased head will allow for the optimized operation of the existing units and the future installation of additional units, possibly in the irrigation canal outlet works, thus increasing the energy output considerably. It will also allow for improved management of water resources in a manner that better meets the demands of downstream consumers while ensuring a continuous supply of water for irrigation of the project area. Table (3) previews the characteristics of Roseires dam before and after heightening.

Table 3: Comparison between the basic features of Roseires dam before and after heightening

Feature	As Completed in 1966 to EL 480	After Completion of Heightening to EL 490
Reservoir:		
Volume(without siltation)	3.00 billion m^3	7.40 billion m^3
Area	290 km^2	627 km^2
Maximum Water Level (FSL)	EL 481.00	EL 490.00
Overtopping Level (Concrete Dam)	EL482.20	EL 492.20
Overtopping Level (Embankment)	EL482.50	EL 492.50
Minimum Drawdown Level	EL435.50	
Tailwater:		
Maximum Tailwater Level	EL 456.00 (PMF)	
Nominal Wet Season Tailwater Level	EL 448.00	
Minimum Tailwater Level	EL 440.00	

4.1. System Operating Rules

The operating rules have been developed with the intent of providing a balance between the requirement to fill the storage and the requirement to minimize the buildup of sediment in the reservoir. Coyne Et Bellier et. al. (1977) provided a recommendation on the rules to be adopted once the impoundment level is raised to EL490. The proposed rules are as follows:

Proposed operating rules after dam heightening:

- Reservoir to be emptied completely (EL460.0) at the end of the dry period
- Reservoir to be raised to EL 467.0 by June 30
- Level of EL 467.0 to be held until filling begins
- Filling of the reservoir typically begins on 1st September provided inflows have dropped below 450 million m^3/day
- The filling of the reservoir may be delayed until as late as 15th September if flows do not drop below 450 million m^3/day
- Maximum impoundment level is EL 490.0

4.2. Water Availability during Low Flow Season

Figure (2) shows the maximum, minimum and mean recession flow hydrographs for the period (1965-2008) at Eddeim station besides the recession flow patterns of years 1998 and 1984 as representatives for high and low river flow years. The analysis covers the dry season from November (Ni, Nii, Niii) to June (Ji, Jii, Jiii) of the following year on 10-day time step.

Generally, the dry season as defined in this study from November to June has an average total flow equal to 21% in comparison with the wet season flow. Eddeim flow data are arranged into three categories: low, mean and wet river flows according to the bluck of the wet season flow. The ranges, within which the three categories are arranged, can be good indicators for the quantification and in other words for the expected amount of the dry season flow, Table (4). The wet season averages of the three categories are determined as 29.67, 39.26 and 51.19 billion m^3 respectively and the corresponding dry flows are 6.60, 7.56 and 11.04 billion m^3. It is to be stated clearly that from December to April the water requirements from the system exceed the natural river supply before Roseires dam heightening.

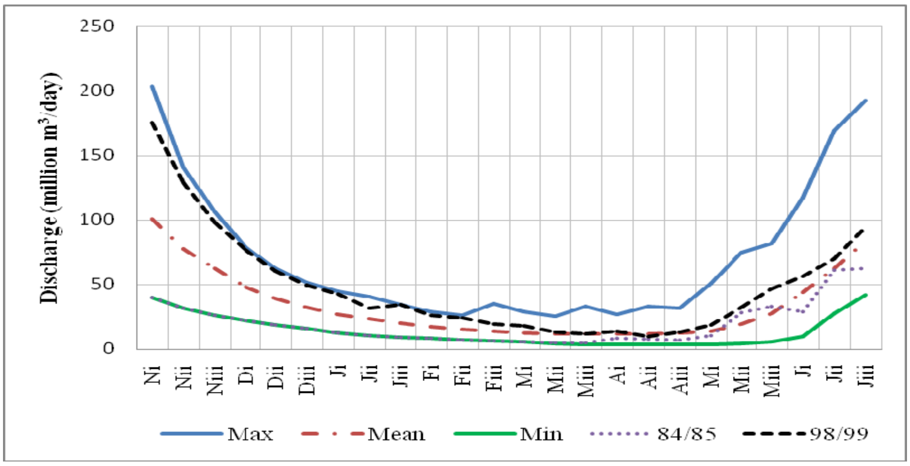

Figure 42: Flow hydrographs of the recession period at Eddeim station

Table 4: Estimation of the dry season flow with relevance to the preceding flood flow

Classified years	Wet season flow billion m^3	Dry season flow billion m^3	Average flow billion m^3
Low river flow	24.90 – 34.09	4.71 – 9.80	6.60
Mean river flow	34.09 – 45.08	5.51 – 11.79	7.56
Wet river flow	45.08 – 57.88	8.57 – 14.14	11.04

4.3. Analyzing the River System after Roseires Heightening

The heightened dam would increase the storage capacity from 3 to 7.4 billion m^3 (without siltation). That means around 4 billion m^3 more stored water can be available for usage within the river system.

The most important question that should be answered is how this additional amount of stored water will be utilized. According to the author, four optional posibilities or theoretical answers can arise as follows:

- Hydropower generation
- To satisfy the shortage during the recession season
- For the proposed irrigated projects and extensions in the reach Roseires-Khartoum
- To be used for irrigation downstream Khartoum i.e. in the Main Nile

Although many tasks are to be explained in details, the proposed scenario is analyzed in the highlight of the following assumptions:

- Water balance concept is adopted to predict the flows in the major measuring stations along the Blue Nile
- The key site for inflows data is Eddeim measuring station
- Emptying program of Roseires reservoir is adopted from (Gibb, 1987), Figure (3) presents the water stages as adopted in the analysis
- Analysis is conducted on 10-day basis
- The Blue Nile is divided into three sub-reaches as follows: the reach from Eddeim to Roseires, the reach from Roseires to Sennar, and the reach from Sennar to Khartoum.

The general equation governing flows routing at the downstream gauging sites can be written as:

$$Q_{D/S} = Q_{U/S} + R - A_b - E_L - \Delta S \qquad m^3/\text{time unit} \qquad (1)$$

Where

$Q_{D/S}$ = Discharge of downstream gauging site

$Q_{U/S}$ = Discharge of upstream gauging site

R = Runoff from catchment between upstream and downstream sites (not considered in this analysis)

A_b = Abstraction by irrigation schemes within the river reach
E_L = Evaporation etc…
ΔS = Change of storage content of reservoirs

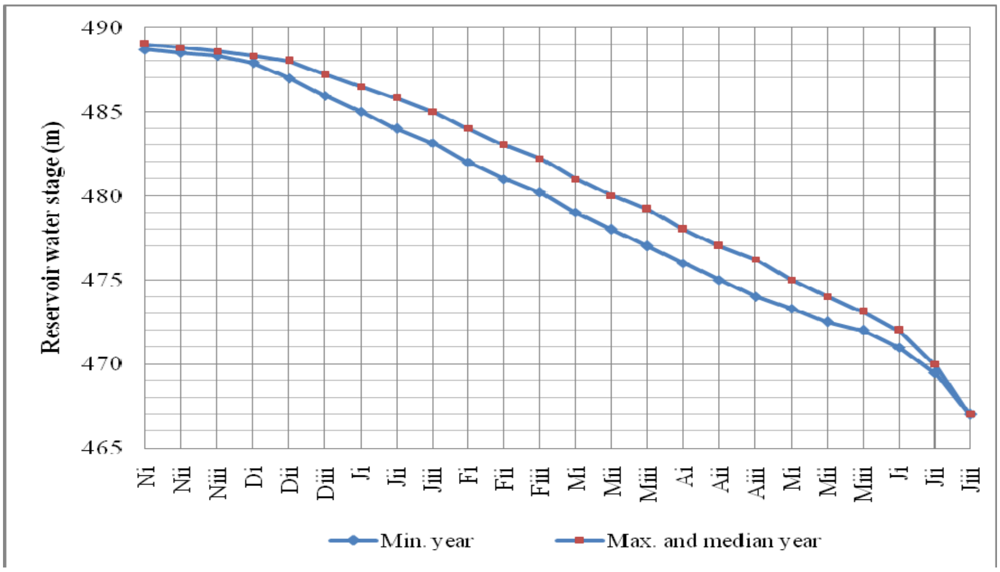

Figure 3: Emptying rules adopted for the heightened dam

In this scenario, all of the recession flow hydrographs of Eddeim are dealt with as one band and only three representative flow hydrographs are analyzed under the condition of raising Roseires dam by 10 m i.e. to R.L. 490. One of the three hydrographs represents the highest recorded flows (optimistic case) in the dry season (1965 - 2008), another one for the normal flow records and the last one for the lowest dry season flows at the gauging site (risky case).

This scenario is carried out into two parallel parts; the first one has analyzed the Blue Nile system under the condition of Roseires dam heightening to El. 490 m and the current irrigation developments while the other part of analysis has considered proposed irrigation developments accompanying the heightening of the dam.

Tables (5, 6, and 7) present the predicted flows at Roseires d/s, Sennar d/s and Khartoum using maximum, mean and minimum 10-day flow records at Eddeim as inputs for the analysis under the conditions of heightening Roseires dam and the existing irrigation development.

Parallel analysis is also carried out taking into consideration probable future developments estimated at around one million feddans irrigated by gravity from upstream of Roseires dam (Dinder, Roseires and Rahad II projects). These areas are located on the east bank of the Blue Nile and shared between four states the Gezira, Gedarif, Blue Nile and Sennar. Tables (8, 9, and 10) present the routed flows at Roseires d/s, Sennar d/s and Khartoum. In the two analyzed cases, it is very essential to check the magnitude of the minimum flows at Khatoum station. The main purpose is to ensure that they are at least sufficient enough to satisfy the environmental needs (at least 11 million m^3/day, SMEC, 2007).

Table 5: Detailed calculations using maximum records at Eddeim as inputs (existing irrigation development condition; all figures in million m^3/day)

Decade	Max. records at Eddeim	Reservoir evapo-ration	Change of storage ÄS	Roseires routed	Gezira & Managil	All pumps	Reach evapo-ration	Sennar routed	Guneid schemes	Pump schemes	South Khartoum schemes	Evapo-ration	Khartoum routed
Ni	203.70	2.78		200.93	32.20	11.53	1.39	155.80	1.73	1.13	0.77	1.59	150.58
Nii	140.23	2.74	-11.48	148.97	32.20	11.53	1.39	103.84	1.73	1.13	0.77	1.59	98.62
Niii	105.88	2.71	-11.48	114.65	32.20	11.53	1.39	69.53	1.73	1.13	0.77	1.59	64.31
Di	78.74	2.78	-17.22	93.19	28.35	8.29	1.34	55.21	1.68	1.00	0.77	1.42	50.34
Dii	62.38	2.72	-17.22	76.88	28.35	8.29	1.34	38.89	1.68	1.00	0.77	1.42	34.02
Diii	51.15	2.71	-43.12	91.56	28.35	8.29	1.34	53.58	1.68	1.00	0.77	1.42	48.70
Ji	44.31	2.76	-36.08	77.64	23.90	7.10	1.38	45.26	1.68	1.00	0.77	1.41	40.40
Jii	40.15	2.56	-34.76	72.36	23.90	7.10	1.38	39.98	1.68	1.00	0.77	1.41	35.12
Jiii	34.45	2.42	-37.84	69.87	23.90	7.10	1.38	37.50	1.68	1.00	0.77	1.41	32.64
Fi	29.08	2.54	-44.00	70.54	19.18	5.93	1.61	43.83	1.61	1.14	0.89	1.68	38.51
Fii	25.81	2.33	-40.60	64.08	19.18	5.93	1.61	37.36	1.61	1.14	0.89	1.68	32.04
Fiii	35.12	2.17	-29.76	62.72	19.18	5.93	1.61	36.00	1.61	1.14	0.89	1.68	30.68
Mi	28.67	2.15	-41.14	67.67	9.71	4.58	1.82	51.55	1.06	1.06	0.71	1.90	46.81
Mii	25.14	1.94	-30.50	53.70	9.71	4.58	1.82	37.59	1.06	1.06	0.71	1.90	32.85
Miii	32.61	1.83	-22.32	53.10	9.71	4.58	1.82	36.99	1.06	1.06	0.71	1.90	32.25
Ai	26.69	1.75	-31.38	56.31	5.00	4.53	1.92	44.86	1.07	0.97	0.77	2.03	40.04
Aii	33.01	1.62	-23.80	55.18	5.00	4.53	1.92	43.73	1.07	0.97	0.77	2.03	38.91
Aiii	31.78	1.53	-17.68	47.92	5.00	4.53	1.92	36.47	1.07	0.97	0.77	2.03	31.64
Mi	50.43	1.33	-25.02	74.12	2.90	4.42	1.89	64.91	1.06	1.00	0.74	2.16	59.95
Mii	74.72	1.24	-19.20	92.68	2.90	4.42	1.89	83.47	1.06	1.00	0.74	2.16	78.51
Miii	81.76	1.16	-16.02	96.62	2.90	4.42	1.89	87.41	1.06	1.00	0.74	2.16	82.45
Ji	117.32	0.86	-18.38	134.84	20.57	4.67	1.66	107.95	1.30	1.03	0.77	2.12	102.73
Jii	169.00	0.73	-29.40	197.67	20.57	4.67	1.66	170.78	1.30	1.03	0.77	2.12	165.56
Jiii	192.30	0.55	-35.40	227.15	20.57	4.67	1.66	200.26	1.30	1.03	0.77	2.12	195.04

Table 6: Detailed calculations using mean records at Eddeim as inputs (existing irrigation development condition; all figures in million m^3/day)

Decade	Mean records at Eddeim	Reservoir evapo-ration	Change of storage ÄS	Roseires routed	Gezira & Managil	All pumps	Reach evapo-ration	Sennar routed	Guneid schemes	Pump schemes	South Khartoum schemes	Evapo-ration	Khartoum routed
Ni	100.69	2.78		97.91	32.20	11.53	1.39	52.78	1.73	1.13	0.77	1.59	47.56
Nii	77.09	2.74	-11.48	85.83	32.20	11.53	1.39	40.70	1.73	1.13	0.77	1.59	35.48
Niii	62.03	2.71	-11.48	70.80	32.20	11.53	1.39	25.67	1.73	1.13	0.77	1.59	20.45
Di	48.25	2.78	-17.22	62.69	28.35	8.29	1.34	24.71	1.68	1.00	0.77	1.42	19.84
Dii	39.32	2.72	-17.22	53.81	28.35	8.29	1.34	15.83	1.68	1.00	0.77	1.42	10.96
Diii	32.05	2.71	-43.12	72.46	28.35	8.29	1.34	34.48	1.68	1.00	0.77	1.42	29.61
Ji	26.79	2.76	-36.08	60.11	23.90	7.10	1.38	27.73	1.68	1.00	0.77	1.41	22.87
Jii	22.98	2.56	-34.76	55.19	23.90	7.10	1.38	22.81	1.68	1.00	0.77	1.41	17.95
Jiii	19.85	2.42	-37.84	55.26	23.90	7.10	1.38	22.89	1.68	1.00	0.77	1.41	18.03
Fi	16.97	2.54	-44.00	58.43	19.18	5.93	1.61	31.72	1.61	1.14	0.89	1.68	26.39
Fii	15.00	2.33	-40.60	53.27	19.18	5.93	1.61	26.56	1.61	1.14	0.89	1.68	21.23
Fiii	13.65	2.17	-29.76	41.25	19.18	5.93	1.61	14.53	1.61	1.14	0.89	1.68	9.21
Mi	12.28	2.15	-41.14	51.27	9.71	4.58	1.82	35.16	1.06	1.06	0.71	1.90	30.41
Mii	11.68	1.94	-30.50	40.24	9.71	4.58	1.82	24.13	1.06	1.06	0.71	1.90	19.39
Miii	11.97	1.83	-22.32	32.46	9.71	4.58	1.82	16.35	1.06	1.06	0.71	1.90	11.61
Ai	11.70	1.75	-31.38	41.33	5.00	4.53	1.92	29.88	1.07	0.97	0.77	2.03	25.05
Aii	11.45	1.62	-23.80	33.63	5.00	4.53	1.92	22.18	1.07	0.97	0.77	2.03	17.35
Aiii	12.19	1.53	-17.68	28.34	5.00	4.53	1.92	16.89	1.07	0.97	0.77	2.03	12.06
Mi	13.67	1.33	-25.02	37.36	2.90	4.42	1.89	28.14	1.06	1.00	0.74	2.16	23.18
Mii	19.48	1.24	-19.20	37.44	2.90	4.42	1.89	28.23	1.06	1.00	0.74	2.16	23.27
Miii	27.31	1.16	-16.02	42.17	2.90	4.42	1.89	32.96	1.06	1.00	0.74	2.16	27.99
Ji	44.14	0.86	-18.38	61.66	20.57	4.67	1.66	34.76	1.30	1.03	0.77	2.12	29.55
Jii	62.22	0.73	-29.40	90.89	20.57	4.67	1.66	64.00	1.30	1.03	0.77	2.12	58.78
Jiii	83.81	0.55	-35.40	118.65	20.57	4.67	1.66	91.76	1.30	1.03	0.77	2.12	86.54

Table 7: Detailed calculations using minimum records at Eddeim as inputs (existing irrigation development condition; all figures in million m^3/day)

Decade	Min. records at Eddeim	Reservoir evapo-ration	Change of storage ÄS	Roseires routed	Gezira & Managil	All pumps	Reach evapo-ration	Sennar routed	Guneid schemes	Pump schemes	South Khartoum schemes	Evapo-ration	Khartoum routed
Ni	39.69	2.73		36.97	32.20	11.53	1.39	-8.16	1.73	1.13	0.77	1.59	-13.38
Nii	31.80	2.70	-11.48	40.59	32.20	11.53	1.39	-4.54	1.73	1.13	0.77	1.59	-9.76
Niii	26.17	2.66	-11.48	34.99	32.20	11.53	1.39	-10.13	1.73	1.13	0.77	1.59	-15.35
Di	21.93	2.72	-17.22	36.43	28.35	8.29	1.34	-1.55	1.68	1.00	0.77	1.42	-6.42
Dii	18.18	2.70	-53.90	69.37	28.35	8.29	1.34	31.39	1.68	1.00	0.77	1.42	26.52
Diii	15.68	2.40	-50.60	63.89	28.35	8.29	1.34	25.90	1.68	1.00	0.77	1.42	21.03
Ji	12.50	2.42	-47.30	57.38	23.90	7.10	1.38	25.00	1.68	1.00	0.77	1.41	20.14
Jii	10.25	2.24	-44.00	52.01	23.90	7.10	1.38	19.63	1.68	1.00	0.77	1.41	14.77
Jiii	8.70	2.09	-34.51	41.12	23.90	7.10	1.38	8.74	1.68	1.00	0.77	1.41	3.88
Fi	8.20	2.13	-43.29	49.37	19.18	5.93	1.61	22.65	1.61	1.14	0.89	1.68	17.33
Fii	6.84	1.92	-33.70	38.61	19.18	5.93	1.61	11.90	1.61	1.14	0.89	1.68	6.58
Fiii	6.05	1.78	-24.40	28.68	19.18	5.93	1.61	1.96	1.61	1.14	0.89	1.68	-3.36
Mi	5.21	1.80	-34.00	37.41	9.71	4.58	1.82	21.30	1.06	1.06	0.71	1.90	16.55
Mii	4.46	1.66	-25.80	28.60	9.71	4.58	1.82	12.49	1.06	1.06	0.71	1.90	7.75
Miii	3.43	1.53	-23.80	25.70	9.71	4.58	1.82	9.59	1.06	1.06	0.71	1.90	4.84
Ai	3.43	1.51	-22.10	24.02	5.00	4.53	1.92	12.56	1.07	0.97	0.77	2.03	7.74
Aii	3.72	1.41	-20.60	22.91	5.00	4.53	1.92	11.46	1.07	0.97	0.77	2.03	6.64
Aiii	3.56	1.31	-19.20	21.45	5.00	4.53	1.92	10.00	1.07	0.97	0.77	2.03	5.17
Mi	3.53	1.18	-12.46	14.81	2.90	4.42	1.89	5.60	1.06	1.00	0.74	2.16	0.64
Mii	4.07	1.11	-13.64	16.60	2.90	4.42	1.89	7.39	1.06	1.00	0.74	2.16	2.43
Miii	5.56	1.07	-8.30	12.79	2.90	4.42	1.89	3.58	1.06	1.00	0.74	2.16	-1.38
Ji	9.62	0.79	-15.30	24.13	20.57	4.67	1.66	-2.77	1.30	1.03	0.77	2.12	-7.99
Jii	27.20	0.70	-20.55	47.06	20.57	4.67	1.66	20.16	1.30	1.03	0.77	2.12	14.94
Jiii	41.55	0.55	-28.95	69.95	20.57	4.67	1.66	43.06	1.30	1.03	0.77	2.12	37.84

Table 8: Detailed calculations using maximum records at Eddeim as inputs (future irrigation development condition; all figures in million m^3/day)

Decade	Max. records at Eddeim	Reservoir evapo-ration	Change of storage ÄS	Add. water need	Roseires routed	Gezira & Managil	All pumps	Reach evapo-ration	Sennar routed	Guneid schemes	Pump schemes	South Khartoum schemes	Evapo-ration	Khartoum routed
Ni	203.70	2.78		7.03	193.89	32.20	11.53	1.39	148.77	1.73	1.13	0.77	1.59	143.55
Nii	140.23	2.74	-11.48	7.03	141.93	32.20	11.53	1.39	96.81	1.73	1.13	0.77	1.59	91.59
Niii	105.88	2.71	-11.48	7.03	107.62	32.20	11.53	1.39	62.49	1.73	1.13	0.77	1.59	57.27
Di	78.74	2.78	-17.22	4.32	88.86	28.35	8.29	1.34	50.88	1.68	1.00	0.77	1.42	46.01
Dii	62.38	2.72	-17.22	4.32	72.55	28.35	8.29	1.34	34.57	1.68	1.00	0.77	1.42	29.70
Diii	51.15	2.71	-43.12	4.32	87.23	28.35	8.29	1.34	49.25	1.68	1.00	0.77	1.42	44.38
Ji	44.31	2.76	-36.08	3.65	73.99	23.90	7.10	1.38	41.61	1.68	1.00	0.77	1.41	36.75
Jii	40.15	2.56	-34.76	3.65	68.71	23.90	7.10	1.38	36.33	1.68	1.00	0.77	1.41	31.47
Jiii	34.45	2.42	-37.84	3.65	66.23	23.90	7.10	1.38	33.85	1.68	1.00	0.77	1.41	28.99
Fi	29.08	2.54	-44.00	2.46	68.08	19.18	5.93	1.61	41.37	1.61	1.14	0.89	1.68	36.04
Fii	25.81	2.33	-40.60	2.46	61.61	19.18	5.93	1.61	34.90	1.61	1.14	0.89	1.68	29.58
Fiii	35.12	2.17	-29.76	2.46	60.25	19.18	5.93	1.61	33.54	1.61	1.14	0.89	1.68	28.22
Mi	28.67	2.15	-41.14	2.65	65.02	9.71	4.58	1.82	48.91	1.06	1.06	0.71	1.90	44.17
Mii	25.14	1.94	-30.50	2.65	51.06	9.71	4.58	1.82	34.94	1.06	1.06	0.71	1.90	30.20
Miii	32.61	1.83	-22.32	2.65	50.46	9.71	4.58	1.82	34.35	1.06	1.06	0.71	1.90	29.60
Ai	26.69	1.75	-31.38	3.40	52.91	5.00	4.53	1.92	41.46	1.07	0.97	0.77	2.03	36.64
Aii	33.01	1.62	-23.80	3.40	51.78	5.00	4.53	1.92	40.33	1.07	0.97	0.77	2.03	35.51
Aiii	31.78	1.53	-17.68	3.40	44.52	5.00	4.53	1.92	33.07	1.07	0.97	0.77	2.03	28.24
Mi	50.43	1.33	-25.02	3.16	70.96	2.90	4.42	1.89	61.75	1.06	1.00	0.74	2.16	56.79
Mii	74.72	1.24	-19.20	3.16	89.52	2.90	4.42	1.89	80.31	1.06	1.00	0.74	2.16	75.35
Miii	81.76	1.16	-16.02	3.16	93.46	2.90	4.42	1.89	84.25	1.06	1.00	0.74	2.16	79.28
Ji	117.32	0.86	-18.38	22.00	112.84	20.57	4.67	1.66	85.95	1.30	1.03	0.77	2.12	80.73
Jii	169.00	0.73	-29.40	22.00	175.67	20.57	4.67	1.66	148.78	1.30	1.03	0.77	2.12	143.56
Jiii	192.30	0.55	-35.40	22.00	205.15	20.57	4.67	1.66	178.26	1.30	1.03	0.77	2.12	173.04

Table 9: Detailed calculations using mean records at Eddeim as inputs (future irrigation development condition; all figures in million m^3/day)

Decade	Mean records at Eddeim	Reservoir evapo-ration	Change of storage ÄS	Add. water need	Roseires routed	Gezira & Managil	All pumps	Reach evapo-ration	Sennar routed	Guneid schemes	Pump schemes	South Khartoum schemes	Evapo-ration	Khartoum routed
Ni	100.69	2.78		7.03	90.87	32.20	11.53	1.39	45.75	1.73	1.13	0.77	1.59	40.53
Nii	77.09	2.74	-11.48	7.03	78.79	32.20	11.53	1.39	33.67	1.73	1.13	0.77	1.59	28.45
Niii	62.03	2.71	-11.48	7.03	63.76	32.20	11.53	1.39	18.64	1.73	1.13	0.77	1.59	13.42
Di	48.25	2.78	-17.22	4.32	58.37	28.35	8.29	1.34	20.39	1.68	1.00	0.77	1.42	15.52
Dii	39.32	2.72	-17.22	4.32	49.49	28.35	8.29	1.34	11.51	1.68	1.00	0.77	1.42	6.64
Diii	32.05	2.71	-43.12	4.32	68.14	28.35	8.29	1.34	30.16	1.68	1.00	0.77	1.42	25.29
Ji	26.79	2.76	-36.08	3.65	56.47	23.90	7.10	1.38	24.09	1.68	1.00	0.77	1.41	19.23
Jii	22.98	2.56	-34.76	3.65	51.54	23.90	7.10	1.38	19.16	1.68	1.00	0.77	1.41	14.30
Jiii	19.85	2.42	-37.84	3.65	51.62	23.90	7.10	1.38	19.24	1.68	1.00	0.77	1.41	14.38
Fi	16.97	2.54	-44.00	2.46	55.97	19.18	5.93	1.61	29.25	1.61	1.14	0.89	1.68	23.93
Fii	15.00	2.33	-40.60	2.46	50.81	19.18	5.93	1.61	24.09	1.61	1.14	0.89	1.68	18.77
Fiii	13.65	2.17	-29.76	2.46	38.78	19.18	5.93	1.61	12.07	1.61	1.14	0.89	1.68	6.75
Mi	12.28	2.15	-41.14	2.65	48.62	9.71	4.58	1.82	32.51	1.06	1.06	0.71	1.90	27.77
Mii	11.68	1.94	-30.50	2.65	37.60	9.71	4.58	1.82	21.48	1.06	1.06	0.71	1.90	16.74
Miii	11.97	1.83	-22.32	2.65	29.82	9.71	4.58	1.82	13.70	1.06	1.06	0.71	1.90	8.96
Ai	11.70	1.75	-31.38	3.40	37.93	5.00	4.53	1.92	26.48	1.07	0.97	0.77	2.03	21.65
Aii	11.45	1.62	-23.80	3.40	30.23	5.00	4.53	1.92	18.78	1.07	0.97	0.77	2.03	13.95
Aiii	12.19	1.53	-17.68	3.40	24.94	5.00	4.53	1.92	13.49	1.07	0.97	0.77	2.03	8.66
Mi	13.67	1.33	-25.02	3.16	34.20	2.90	4.42	1.89	24.98	1.06	1.00	0.74	2.16	20.02
Mii	19.48	1.24	-19.20	3.16	34.28	2.90	4.42	1.89	25.07	1.06	1.00	0.74	2.16	20.11
Miii	27.31	1.16	-16.02	3.16	39.01	2.90	4.42	1.89	29.79	1.06	1.00	0.74	2.16	24.83
Ji	44.14	0.86	-18.38	22.00	39.66	20.57	4.67	1.66	12.76	1.30	1.03	0.77	2.12	7.55
Jii	62.22	0.73	-29.40	22.00	68.89	20.57	4.67	1.66	42.00	1.30	1.03	0.77	2.12	36.78
Jiii	83.81	0.55	-35.40	22.00	96.65	20.57	4.67	1.66	69.76	1.30	1.03	0.77	2.12	64.54

Table 10: Detailed calculations using minimum records at Eddeim as inputs (future irrigation development condition; all figures in million m^3/day)

Decade	Min. records at Eddeim	Reservoir evapo-ration	Change of storage ÄS	Add. water need	Roseires routed	Gezira & Managil	All pumps	Reach evapo-ration	Sennar routed	Guneid schemes	Pump schemes	South Khartoum schemes	Evapo-ration	Khartoum routed
Ni	39.69	2.73		7.03	29.93	32.20	11.53	1.39	-15.19	1.73	1.13	0.77	1.59	-20.41
Nii	31.80	2.70	-11.48	7.03	33.55	32.20	11.53	1.39	-11.57	1.73	1.13	0.77	1.59	-16.79
Niii	26.17	2.66	-11.48	7.03	27.96	32.20	11.53	1.39	-17.17	1.73	1.13	0.77	1.59	-22.39
Di	21.93	2.72	-17.22	4.32	32.11	28.35	8.29	1.34	-5.88	1.68	1.00	0.77	1.42	-10.75
Dii	18.18	2.70	-53.90	4.32	65.05	28.35	8.29	1.34	27.07	1.68	1.00	0.77	1.42	22.20
Diii	15.68	2.40	-50.60	4.32	59.56	28.35	8.29	1.34	21.58	1.68	1.00	0.77	1.42	16.71
Ji	12.50	2.42	-47.30	3.65	53.74	23.90	7.10	1.38	21.36	1.68	1.00	0.77	1.41	16.50
Jii	10.25	2.24	-44.00	3.65	48.36	23.90	7.10	1.38	15.98	1.68	1.00	0.77	1.41	11.12
Jiii	8.70	2.09	-34.51	3.65	37.47	23.90	7.10	1.38	5.10	1.68	1.00	0.77	1.41	0.24
Fi	8.20	2.13	-43.29	2.46	46.90	19.18	5.93	1.61	20.19	1.61	1.14	0.89	1.68	14.87
Fii	6.84	1.92	-33.70	2.46	36.15	19.18	5.93	1.61	9.44	1.61	1.14	0.89	1.68	4.11
Fiii	6.05	1.78	-24.40	2.46	26.21	19.18	5.93	1.61	-0.50	1.61	1.14	0.89	1.68	-5.83
Mi	5.21	1.80	-34.00	2.65	34.76	9.71	4.58	1.82	18.65	1.06	1.06	0.71	1.90	13.91
Mii	4.46	1.66	-25.80	2.65	25.96	9.71	4.58	1.82	9.84	1.06	1.06	0.71	1.90	5.10
Miii	3.43	1.53	-23.80	2.65	23.05	9.71	4.58	1.82	6.94	1.06	1.06	0.71	1.90	2.20
Ai	3.43	1.51	-22.10	3.40	20.62	5.00	4.53	1.92	9.16	1.07	0.97	0.77	2.03	4.34
Aii	3.72	1.41	-20.60	3.40	19.51	5.00	4.53	1.92	8.06	1.07	0.97	0.77	2.03	3.24
Aiii	3.56	1.31	-19.20	3.40	18.05	5.00	4.53	1.92	6.60	1.07	0.97	0.77	2.03	1.77
Mi	3.53	1.18	-12.46	3.16	11.65	2.90	4.42	1.89	2.44	1.06	1.00	0.74	2.16	-2.52
Mii	4.07	1.11	-13.64	3.16	13.44	2.90	4.42	1.89	4.23	1.06	1.00	0.74	2.16	-0.73
Miii	5.56	1.07	-8.30	3.16	9.63	2.90	4.42	1.89	0.42	1.06	1.00	0.74	2.16	-4.54
Ji	9.62	0.79	-15.30	22.00	2.13	20.57	4.67	1.66	-24.77	1.30	1.03	0.77	2.12	-29.99
Jii	27.20	0.70	-20.55	22.00	25.06	20.57	4.67	1.66	-1.84	1.30	1.03	0.77	2.12	-7.06
Jiii	41.55	0.55	-28.95	22.00	47.95	20.57	4.67	1.66	21.06	1.30	1.03	0.77	2.12	15.84

5. RESULTS AND CONCLUSIONS

- The ratio of the heightened Roseires storage to the Blue Nile flow in the critical period (Nov. – Jun.) ranges from 63 to 131% in the dry years, from 54 to 115% in the normal years, and from 45% to 74% in the wet years.
- In the two cases, the flows at Roseires d/s have increased with factors ranging from 1.15 to 2.17 in comparison with the historical flow regime for the different flow conditions at the upstream station. The same conclusion is valid for Sennar d/s as the flows have increased with factors ranging from 1.07 to 2.73.
- At Khartoum, the percentage of the routed flows to the measured ones ranges from 68% to 87%. For the risky case, the predicted flows are enlarged by about 4 to 5 times of the measured flows.
- Minimum flows at Khartoum lesser than the target environmental requirements and even negative values are reported. This can be manipulated by managing the demand estimates within certain periods.
- Dry season flows (≥ the historical annual mean (1965-2008) i.e. 8 billion m^3 at Eddeim) plus Roseires storage have proved to fulfill the water requirements from the system under the two conditions namely with and without irrigation developments.
- Total dry season flows (< 8 billion m^3) plus the storage have shown poor performance to satisfy the system's needs but the outcomes can significantly be enhanced by adopting the reservoir regulation rules as of the previous category.
- The analysis has shown that the storage is completely consumed by the system demand. The contribution of the natural river flow is estimated to be around 3 and 1.5 billion m^3 for the two conditions: with and without irrigation developments respectively.

6. RECOMMENDATIONS

- The water balance computations are recommended for such studies because:
  - i. It is relatively simple to apply,
  - ii. It can work with the relatively limited data available,
  - iii. It gives a good chance for close inspection of the data in terms of quality as well as quantity,
  - iv. It can simulate the operation of hydraulic structures.

Direct use of models developed elsewhere for other hydro-meteorological, climatic and physical conditions cannot provide accurate simulation results.

- The patterns of the Blue Nile water utilization is determined by the amount of water carried by the river, which fluctuates from year to year. The major determinant of the basin water balance remains the agricultural sector. One of the scopes of this analysis is to provide a recommendation on the appropriate manner in which to manage dry season water demand under various inspected conditions. There is actually insufficient data to provide an understanding of current demands and farming practices. Neither the future plans for development are clearly set nor irrigation systems have been enhanced. In the absence of such data, it is considered that very limited useful recommendations on alterations to demand management can be provided.
- The dry season flows (November – June) have been quantified, categorized, and correlated with the wet season flows by this study. However, it is highly important to consider the appropriate and practical methods for recession flow forecasting to enable the decision makers from the early planning of winter plantation.
- The most important issue regarding the performance of Roseires Dam is the adaptation of the appropriate regulation rules that enable the dam to be filled to its capacity.
- As the location of Eddeim station would definitely be inundated by the backwater due to Roseires dam heightening, so this vital key site should be replaced by a representative one.

- Regularly the operational programs of the recession period are prepared at the end of December after the recession is smoothed. However, early evaluation of the probable available water and close following up to the start of the recession period after the flood peaks diminish can provide stakeholders with a clarified image of all supply-demand components to set appropriate programs of high efficiency.

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