IMPACT OF UPPER NILE PROJECTS ON THE HYDRAULIC PERFORMANCE OF THE WHITE NILE AND JEBEL AULIA DAM OPERATION

A.S. ZAGHLOUL[1], M. ELSAYED[2], A. EL ZAWAHRY[3]

[1]Associate Prof., Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University, Giza, Egypt, E-mail: ashraf_zaghloul@yahoo.com
[2] Chairman, High Dam authority, MWRI, Egypt, E-mail: Magdysayed61@yahoo.com
[3]Professor, Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University, Giza, Egypt, E-mail:alaa.zawahry@gmail.com

ABSTRACT

To increase the Nile flow and to secure water requirements for the Egyptian population, one of the options is to implement Upper Nile Projects. Studies showed that these projects might secure about 9 BCM per year for Egypt after implementation (estimated at Aswan). There are three mega projects in the upper Nile reach to increase the yield of River Nile through saving the lost water in the swampy area in sudd region in South Sudan. The yieldof these projects will flow into the White Nile which is already suffering from overflow in some reaches due to its limited flow capacity. Also increasing the discharges and levels in the White Nile may have a negative effect on Jebel Aulia Dam and cause hazardous overtopping.

The objective is to assess the White Nile hydraulic capacity to accommodate the additionally expected discharges from the upper Nile projects and simulate the locations of expected floods. Also, the gate operation of Jebel Auliadam is studied, and the necessary modifications of its operation rules to accommodate the new White Nile increased flow arerecommended.

HEC-RAS Program is used to estimate the water levels in the cross sections at different points along the White Nile.Water budget or water balance method is used for estimating water losses in the study area. Frequency analysis and water budgetwere done using Mat lab program.River flow simulation is presented for eight scenarios of Upper Nile project implementation. Points along the study reach which need bank rising are presented and the minimum gate opening at Jebel Aulia dam are calculated and recommended. Results can be applied to floodplain management and flood protection in the study area and used in the operation of Jebel Aulia dam.

Keywords: White Nile, Capacity, Upper Nile Projects

Received 25May 2017.Accepted 18 November 2017
Presented in IWTC 20

1 THE STUDY REACH

As shown in “Fig.1”, The study reach extends 767 km, it starts from Malakal station in the south at km800 on the White Nile, measured from Khartoum, and extends to Jebel Aulia Dam in the north atkm 44, (NWS, 2000). The average bed slope for the study reach is about 1.7 cm/ km. HEC-RAS Software is dependent on geometric, hydraulic, and hydrologic data. Geometric data consists of cross-sectional geometry along the study reach and available in the literature, (NWS, 2000) and(Samah 1974). Data of 50 cross-sections done by the Egyptian engineering missions in Sudan (Mission,1961 & Mission1970) are used in the analysis. Sections are surveyed from the top of the left bank to the top of the right bank. Monthly data of discharges measured at Malakal station from 1907 to 1997 is used(MWRI, 2000). Gauge stations in the White Nile are located in Getein, Wad El-Zaki, El-Shawal, Rabak, Gebalien, Renk, Melut, and Makakal. Discharge Stations are located in Malakal, Melut, and

Mogern (D.S. Jebel Aulia dam). Jebel Aulia Dam was constructed in 1937 on the White Nile (about 40 km south of Khartoum).

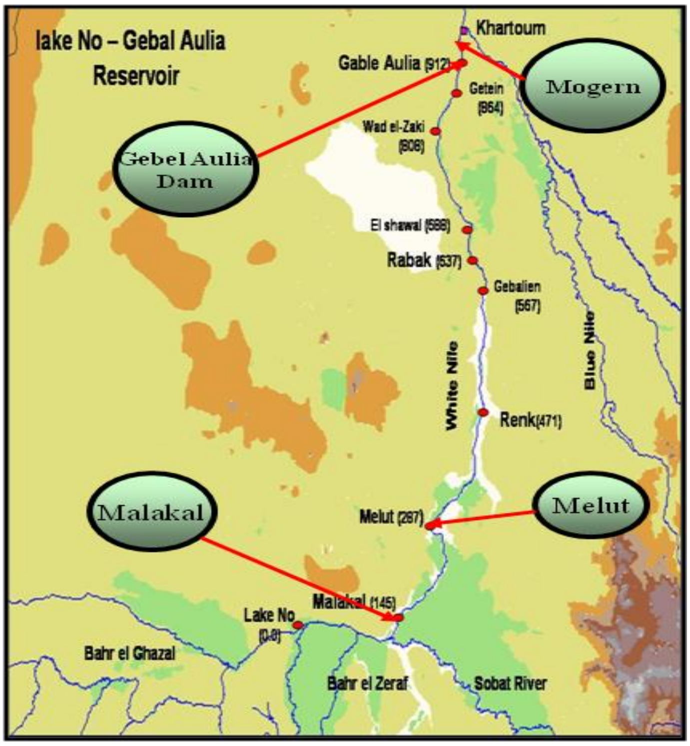

Figure 1. Location map of the study reach of the White Nile under consideration

Jebel Aulia Dam was built in 1937 on the White Nile, about 44 km south of Khartoum to provide a maximum of 3.6 BCM storage water. Due to the gentle slope of the White Nile, the upstream lake of Jebel Aulia dam extends about 628 km upstream the dam in case of maximum storage level (377.40). The backwater curve of the dam ends just upstream Melut station. The dam has a sixty sluice vents, of which the ten western vents were not fitted with gates, being blocked with heavy R.C diaphragms. Three training walls were constructed downstream of the sluice-dam, dividing the fifty sluice gates into three groups, ten, twenty and twenty respectively. Each gate is 4.5 m high and 3 m wide. The lowest downstream level is 370.75 meters. Downstream of the dam, the river is about 600 m in width; its greatest depth is 15 feet, the average discharge ranges from 500 m3/s in April to about 1,300 m3/s in November, (Mission, 1970 & MWRI, 1936).

2 UPPER NILE PROJECTS

There are three mega projects in the upper Nile reach to increase the yield of River Nile by saving the lost water in the swampy area in sudd region in SouthSudan.“Fig. 2”is a location map of these projects (NWS2009). Table 1 shows the expected water benefit from each Project (PJTC,1961& Afifi, 1995 and Elzawahry and Bekhit, 2016)

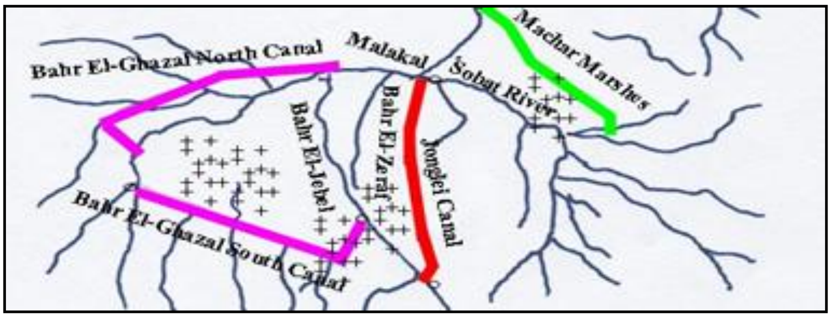

Figure 2. Location of the Upper Nile Projects

Table 1. Expected water benefit from upper Nile projects (PJTC, 1961 & Afifi, 1995)

No.	Project	Water Benefit from Upper Nile Projects (Million.m^3/ day)
1	Jonglei Canal (Phase I& II)	43
2	Machar Marshes	25
3	Bahr El-Ghazal Canals	21
	Total	**89**

3 DATA AND DESIGN DISCHARGES

Malakal discharge station was established in 1907 on the right bank of the White Nile. It is far about 146 km from Lake No and about 2652 km from Aswan. The discharge at the station is usually measured threetimes per week while the staff gauge is read every day. The maximum discharge which was measured at Malakal station is 211.7 M. m^3/day, while the minimum discharge is 27.6 M. m^3 /day for the period (1907-1997), (El-Sayed, 2013 & Elzawahry and Bekhit, 2016). Malakal design discharge which will be applied in Hec-Ras Model is calculated as the summation of Malakal normal monthly discharge and the expected flow rates of Upper Nile Projects.

3.1 Malakal Station Design Discharge.

Frequency analysis of flow data at Malakal is done using Matlab program. Extreme values of normal monthly discharges are estimated based on the available data from 1907 to 1997 for return periods (10, 25, 50, and 100) years. Extreme values for max daily discharges at Malakal are calculated as the average obtained byMatLab, applying four methods (log Pearson III- log normal- normal- Pearson III). For example, the resulting design discharge for 100 years return period is $Q_{malakal}$ =(164.7895+166.1694+192.6401+191.7669)/4=178.8 M.m^3/ day which is equivalent to 2069 m3/ sec.

Thus, Malakal design discharge which will be applied in Hec-Ras Model is equal to the summation of Malakal normal monthly discharge and the expected flow rates of Upper Nile Projects. Therefore, Max design discharge = Q Normal + Q Upper Nile Projects = 178.8+ 89 = 267.8 M.m^3/ day, =3100 m^3/ sec.The discharge which will be used in HEC RAS model is Malakal design discharge at the first upstream section (RS=100) and will decreaseaccording to the distance between sections by the rate of losses until US Jebel Aulia Dam section (RS=51).

3.2 Water Losses from Malakal Station toJebel Aulia Dam

El-Sayed (2013) considered the actual data of water losses in the different parts of the reach (NWS 2000) for estimating the water losses in the study reach.Water losses and water abstraction for irrigation purpose in the reach between Malakal and Jebel Aulia Dam is assumed to accrue uniformly along the Nile reach and subtracted from Malakal design discharge to estimate the design flow rates for all thecross-sections.

In this study, the losses considered are 3.15 BCM/year for the losses and 1.500 BCM/year for water abstraction for irrigation purpose. This makes a maximum total of 4.65 BCM/ year, equivalent to 0.1902 m^3/ sec /km. In the absence of daily losses data, the ratio between the extreme value of Malakal discharge based on max daily discharge and the extreme value Malakal discharge based on monthly discharge are used in estimating the extreme value of daily losses. El-Sayed (2013) generated these factors for the different return periods as 1.7, 1.17, 1.13, and 1.09 for the return periods 10, 25, 50, and 100 years respectively

4 MODEL CALIBRATION

The HEC-RAS model is calibrated against the Manning's roughness coefficient (n-value) using the flow hydrograph passed through Malakal station at the section RS= 100 during the year (2000-2001).Calibration began with an estimate of n equal (0.018-0.03) for the main channel and (0.022-0.04) for the floodplains as recommended by (Eizel, 2010). Taking the boundary condition is the stage hydrograph upstream Jebel Aulia Dam and flow hydrograph at Malakal station RS= 100, (2000-2001) and running unsteady flow. Trial and error iterations are done until matching with the measuredstage hydrograph for Rabek station section RS= 70 (km 492 from Malakal). "Table 2" shows the different n–values used.

Table 2. The different valuesofRoughness Coefficient n

(n-value)	n1	n2	n3	n4
Main Channel	0.03	0.025	0.02	0.018
Floodplain	0.04	0.03	0.025	0.022

A comparison between the measures and simulated hydrographs, for different n values, at Rabek station section RS=70 are plotted in "Fig. 3". It shows that the hydrograph of n2 well matches the observed one. Figures 4 and 5 Show the water surface levels at Malakal (River Station) RS= 100 and upstream Jebel Aulia Dam (RS =51) for the flow hydrograph of Malakal 2000-2001.

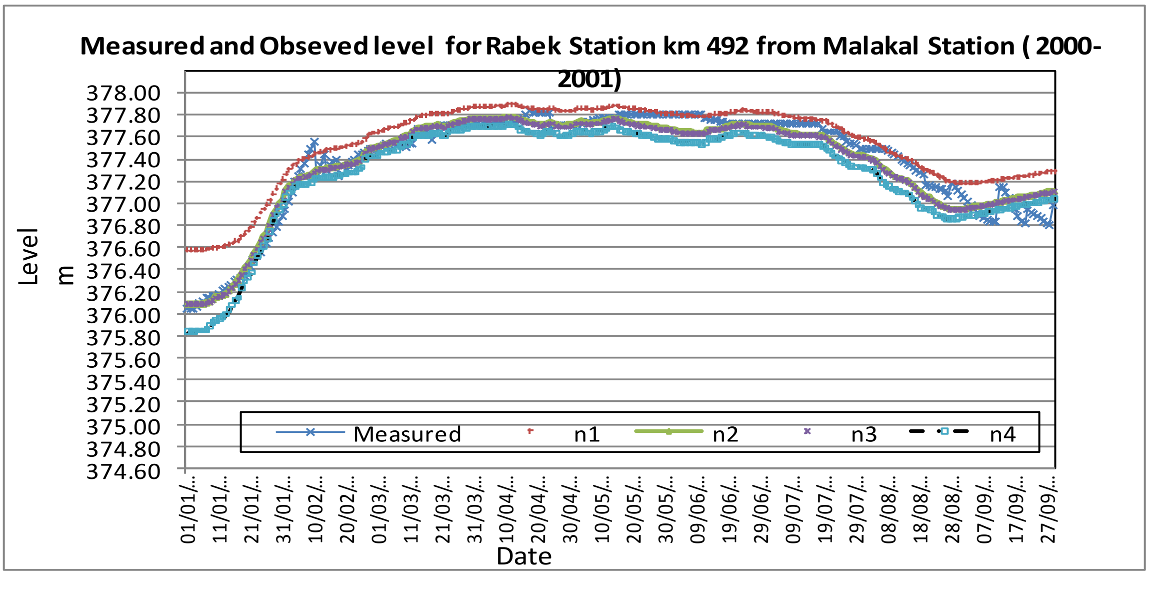

Figure 3. Simulated and measured stage hydrographs for Rabek station at RS=70 for different n values

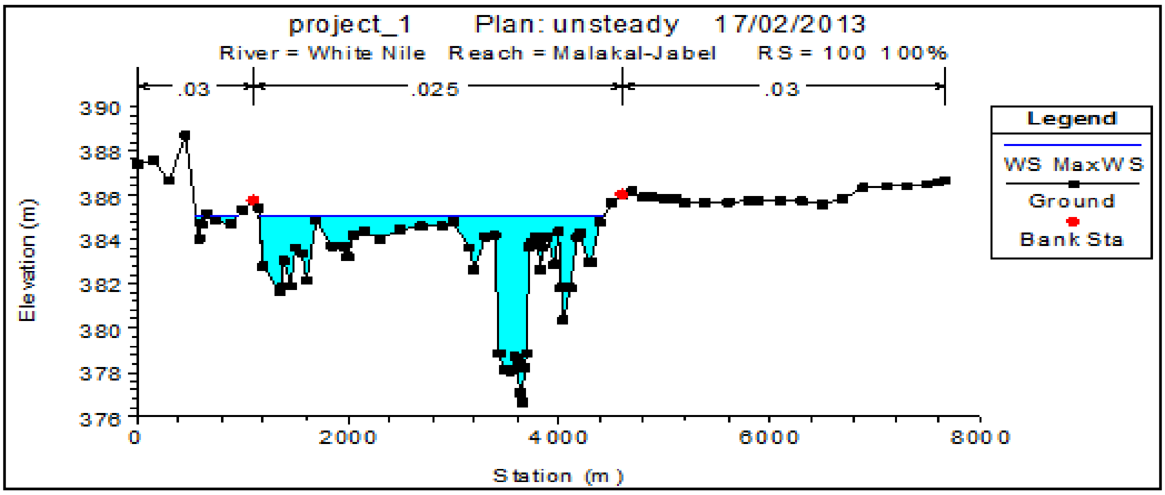

Figure 4. Cross section (RS=100) of White Nile at Malakal

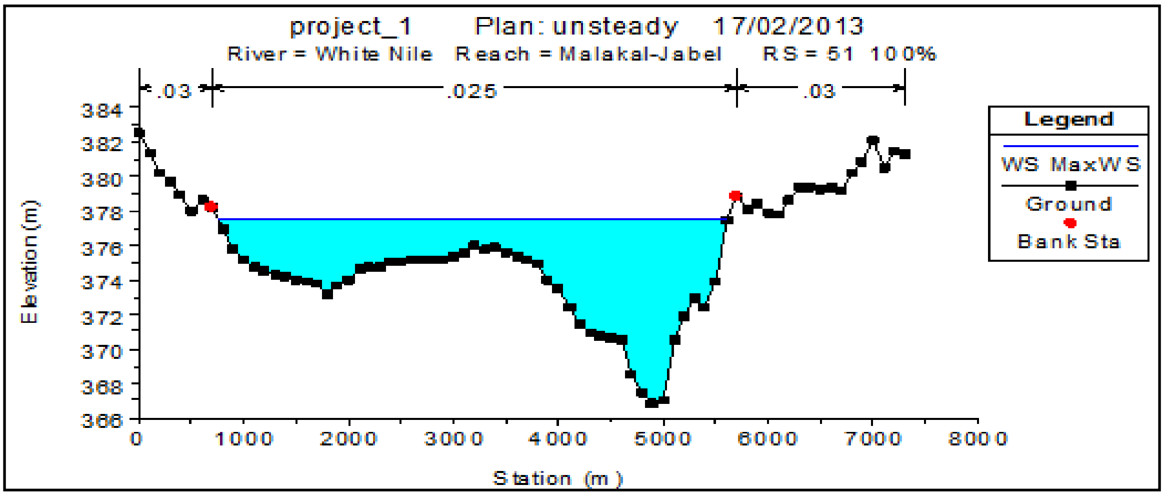

Figure 5. Cross section (RS=51) of the White Nile upstream Jebel Aulia Dam km (767) from Malakal

5 MODEL VALIDATION

For assessment of the model's ability to accurately reproduce known results, the developed Hec-Ras model was run at the high flow rate. The computed water surface profile is compared to the measured profile. Actual data of the White Nile flow hydrograph for Malakal Station (2007-2008) at upstream with a boundary condition stage and flow hydrograph upstream of Jebel Aulia Dam are used. The calibrated n-value 0.025 for the main channel and 0.03 for the flood plains are used. The stage hydrograph is calculated for Renk station RS=80, located at km 326from Malakal."Fig. 6" shows that the simulated stage hydrograph wellmatches the observed one.

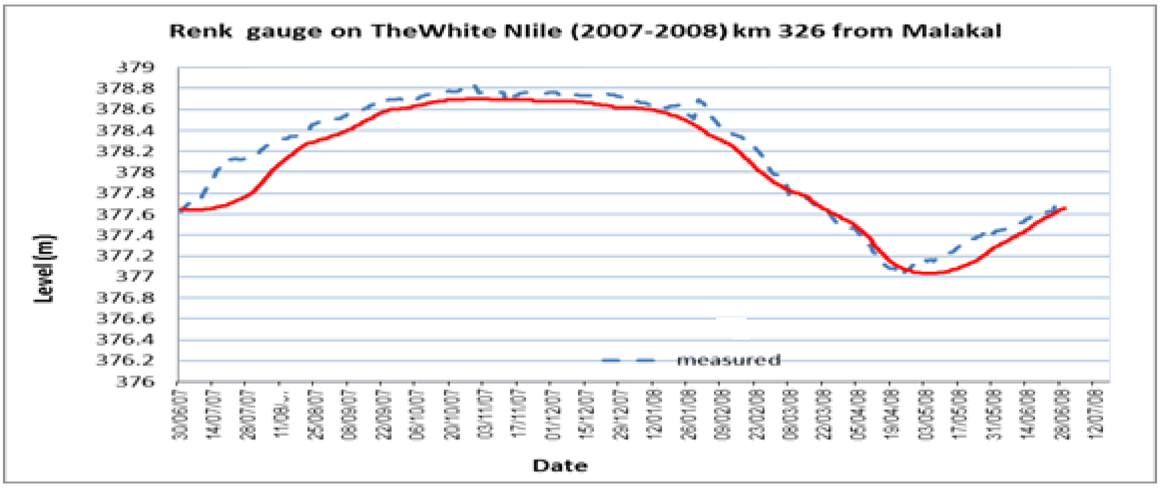

Figure 6.The stage hydrographs at Renk Station RS=80, located at km 326 from Malakal Station

6 RESULTS OF MODEL APPLICATION AND DISCUSSIONS

The developed Hec-Ras model is used for simulating the water surface profiles for the channel reach under consideration for different flow scenarios understeady-state conditions. The simulation results are further used for estimating the locations of expected overflow regions which need protection works and raising the banks. Also, the resulting simulation water levels upstream of the dam are further used to find the minimum gate openings of the dam to avoid overtopping.

6.1 Simulation of Current Situation for White Nile (Malakal- Jebel Aulia Dam).

The current flow condition is simulated for the study reach to know the current problems. The design discharge in this case study will be only the extreme values for daily discharge at Malakal station and the corresponding losses and abstraction without any upper Nile projects contribution, fordifferent return period (10,25,50,100 years).Thus: Q_{design}at Malakal are taken 2069, 1944, 1805 and 1642 m^3/sec respectively, and the boundary conditions of the Hec-Ras model is the water level upstream the Dam's gate (377.40).The water profile “Fig. 7”and floodplain for different cross sections in the study reach along 767 km from Malakal to Jebel Aulia Dam areobtained. Also “Fig. 8” shows cross section NO: 95 at 113.75 km from Malakal and the occurring overflow and the different water level for different return periods. “Table 3” shows the different overflow lengths in Left and right banks for Base Line conditions for Q100 years. From the table, it can be concluded that the White Nile already have overflow problems in about 154.9 km of its length.

Table 3.The different overflow lengths for the current flow conditions (Base Line)

Sec No:	95	94	93	78	77	70	64	58	57	56	**Total**
km From Malakal	103.04	122.55	142.08	372.7	392.59	492.24	578.49	680.14	693.14	704.14	
Left Bank m	0	19523	19210	0	9800	7900	0	13000	11000	19100	**99500**
Right Bank	19508	0	0	19890	0	0	16000	0	0	0	**55400**

Sec No:	95	94	93	78	77	70	64	58	57	56	Total
km From Malakal	103.04	122.55	142.08	372.7	392.59	492.24	578.49	680.14	693.14	704.14	
m											

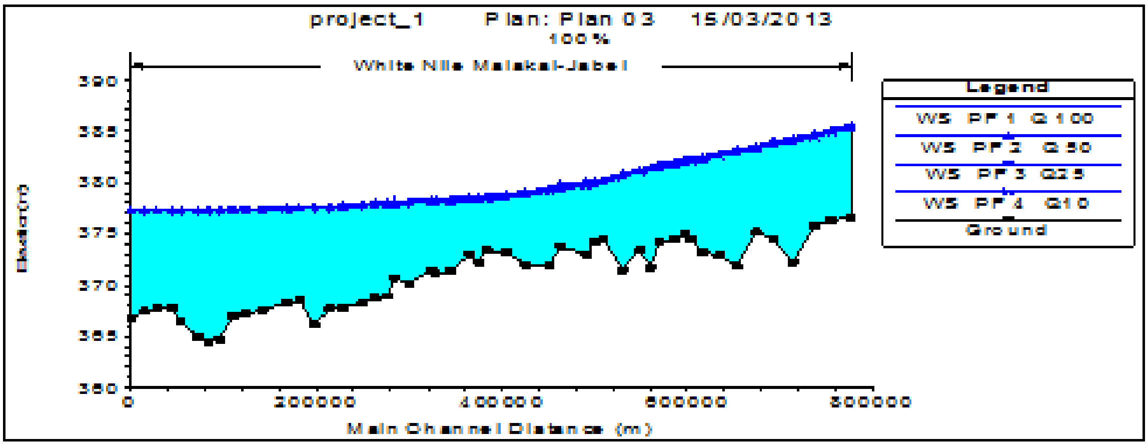

Figure 7.Longitudinal Water surface profile along the White Nile between Malakal and Jebel Aulia Dam (Base Line Situation)

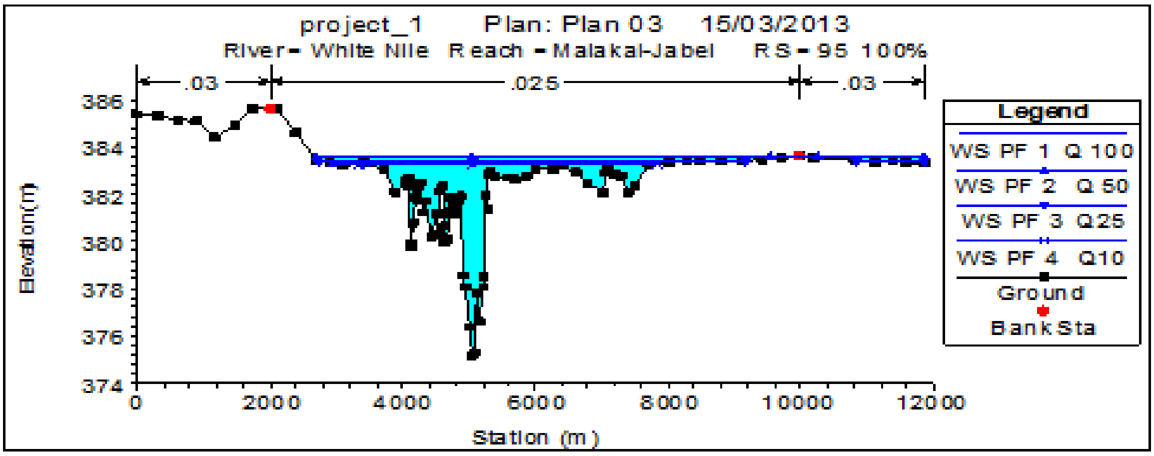

Figure 8.Cross section at RS= 95, located 103.44 km from Malakal (Base Line Situation)

6.2 Flow Simulation for Different Implementation Scenarios

Table 4 shows the different scenarios of implementation of the Upper Nile projects mentioned in “Table 1” and the Baseline Situation. The downstream boundary condition is the water levels upstream the dam's gate (377.40). For each scenario, Hec-Ras was run to simulate the flow along the river reach that considered. Only results of scenario (1) will be presented as it represents the worst flow conditions.

Table 4.Flow in the different scenarios and the Baseline Situation used for simulation

Scenarios NO:	Details of projects	Q 100 years m^3/sec (Malakal)
1	Q Malakal+ Q Ghazal +Q Machar +Q Jonglie	3100
2	Q Malakal+ Q Jongli	2567
3	Q Malakal+ Q Machar	2358
4	Q Malakal+ Q Ghazal	2312
5	Q Malakal+ Q Jongli+Q Machar	2856
6	Q Malakal+ Q Jongli+Q Ghazal	2810
7	Q Malakal+ Q Ghazal+Q Machar	2601
8	Q MalakalBase Line Situation (current conditions)	2069

"Fig. 9" shows the longitudinal water profile in scenario (1), along 767 km from Malakal to Jebel Aulia Dam for different return periods. "Fig. 10" shows section RS= 95 and different water surface level for a different period and different discharges and overflow as an example and typical cross section."Table 5" shows the lengths of expected overflow regions in Left and right banks in scenario (1) for 100 years return period. From "Table5" and "Fig. 10" it can be concluded that the length of overflow regions will increase to a total of 439 km. "Table 6" summarizes the results obtained for all the different scenarios and baseline situation. It is clear that the White Nile has already overflow problems in different sections. From "Table3" and Table (5), it can be noticed that most of the overflow sections are in the upper downstream portion of study reach as shown in "Fig. 11"

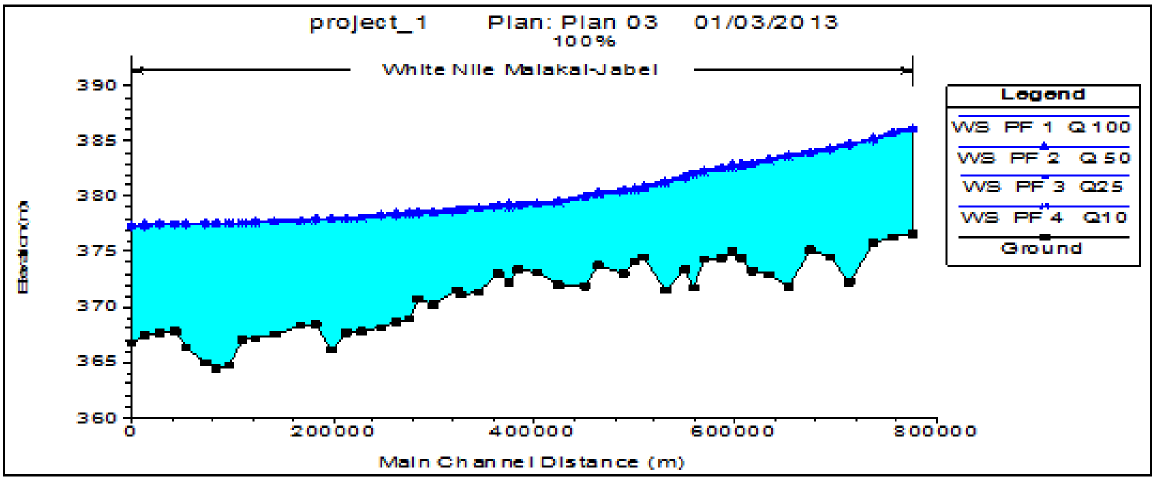

Figure 9. Longitudinal water surface profile along the White Nile between Malakal and Jebel Aulia dam for Scenario (1)

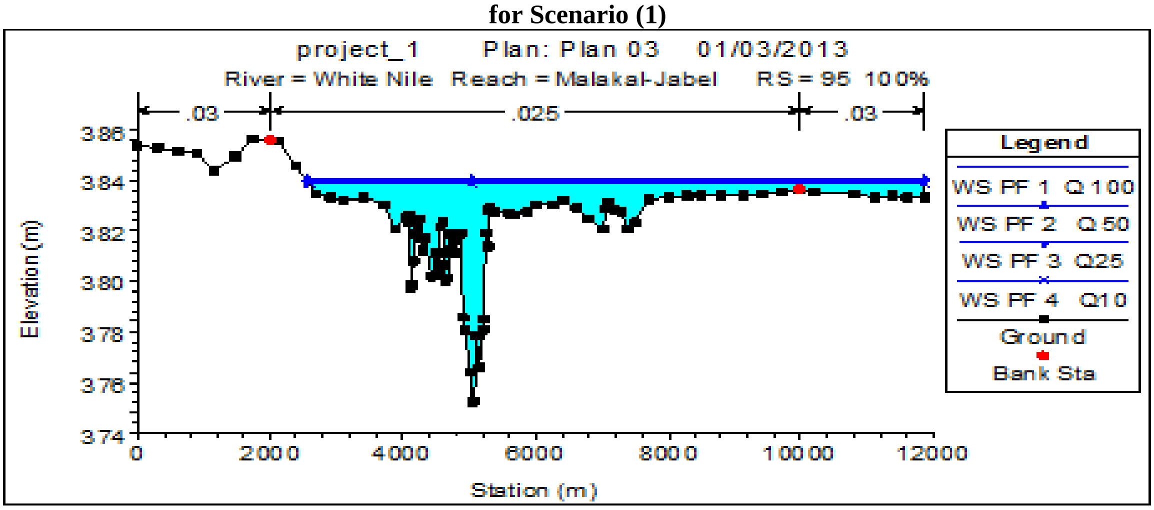

Figure 10. Cross section RS= 95, located 103.44 km from Malakal for Scenario (1)

Table 5. The different overflow lengths in Left and right banks for Scenario (1)

NO	km From Malakal	River Station	Left Bank m	Right Bank m
1	0	100	0	20750
2	20.750	99	18889	0
3	63.519	97	0	19845
4	83.364	96	19680	0
5	103.044	95	0	19508
6	122.552	94	19523	0
7	142.075	93	19210	0
8	191.485	89	0	15660
9	287.325	82	26995	0
10	372.698	78	0	19890
11	392.588	77	9800	0
12	411.888	75	20858	0
13	432.746	74	15990	0
14	448.736	73	0	5550
15	477.536	71	14700	0
16	492.236	70	7900	0
17	578.486	64	16000	16000
18	634.186	61	18950	0
19	653.136	60	13000	0
20	680.136	58	13000	0
21	693.136	57	11000	1100
22	704.136	56	19100	0
23	734.136	54	15000	0
25	749.136	53	15000	0
26	764.136	52	13100	13000
	Total Length		**308000**	**131000**

6.3 Safety of Jebel -Aulia Dam Against Overtopping

To determine the minimum gate opening to avoid dam overtopping, the well known gate discharge equation is used as;

$$Q = c_d * A * \sqrt{2 * g * (y - y_{tail})} \quad (1)$$

Where Number of Gates =50 Gate, Q is the gates discharge, A is the area of the gate, yis the upstream water depth = (dam crest level- upstream bed level) = 379-368=11 m, $y_{tail}$is the normal downstream water depth, and Cd is calibrated coefficient for dam gate = 0.66

Manning equation is used to calculate the normal y_{tail}. The roughness coefficient is taken 0.04 downstream of the dam where the flow is shallow, and cross-section bed width is taken 2000 m. The resulting $y_{tail}$is 4.5 m. Considering the crest level 379 and the discharge at the dam, the critical minimum gate opening, required to prevent overtopping is calculated using Equation 1.

Outputs of the Hec-Ras model obtained for the 8 scenarios mentioned in "Table 4" provided the water level and discharged upstream the dam gates. Corresponding maximum water levels and depths are calculated downstream of dam gates. These levels are used in equation (1) to obtain the minimum gate opening to pass the discharge of each scenario."Table 7" shows the Minimum Gate Opening at maximum and minimum downstream water levels of Jebel Aulia Dam for the different 7scenariosand for the current condition for Q100 years. It shows that the 50 gates of Jebel Aulia Dam are enough to pass the maximum discharges after implementing the upper Nile projects subject to the condition of opening the control gates more than the minimum shown values. Back-water curve extends upstream of the dam as simulated in "Fig. 11".

Table 6.The different overflow lengths for All Scenarios and Base Line Situation for Q100 years.

Scenarios NO:	Details of projects	Q 100 years m^3/sec Malakal	Left Bank km	Right Bank km	Total Length km
1	Q Malakal+QGhaza+QMachar+QJongli	3100	308.0	131.0	439.0
2	Q Malakal+QJongli	2567	233.0	61.0	294.0
3	Q Malakal+QMachar	2358	198.0	61.0	259.0
4	Q Malakal+Q Ghazal	2312	182.0	61.0	243.0
5	Q Malakal+QJongli+Q Machar	2856	284.0	97.0	381.0
6	Q Malakal+QJongli+Q Ghazal	2810	284.0	82.0	366.0
7	Q Malakal+QGhaza+Q Machar	2601	260.0	82.0	342.0
8	Base Line Situation (current condition)	2069	99.5	55.4	154.9

Table 7. The Minimum Gate Opening for the two cases of max and min downstream water level

Scenarios NO:	Details of Projects	Q Malakal 100 years m^3/sec	Min Gate Opening (m) H .L.D S	Min Gate Opening (m) L .L.D S
1	Q Malakal+QGhaza+QMachar+QJongli	3100	4.09	2.44
2	Q Malakal+QJongli	2567	3.47	2.05
3	Q Malakal+QMachar	2358	3.11	1.87
4	Q Malakal+Q Ghazal	2312	3.06	1.83
5	Q Malakal+QJongli+Q Machar	2856	3.82	2.27

Scenarios NO:	Details of Projects	Q Malakal 100 years m^3/sec	Min Gate Opening (m) H .L.D S	Min Gate Opening (m) L .L.D S
6	Q Malakal+QJongli+Q Ghazal	2810	3.78	2.20
7	Q Malakal+QGhaza+Q Machar	2601	3.65	2.07
8	Base Line Situation	2069	2.76	1.70

H.L.D.S high water level at downstream.
L.L.D.S low water level at downstream.

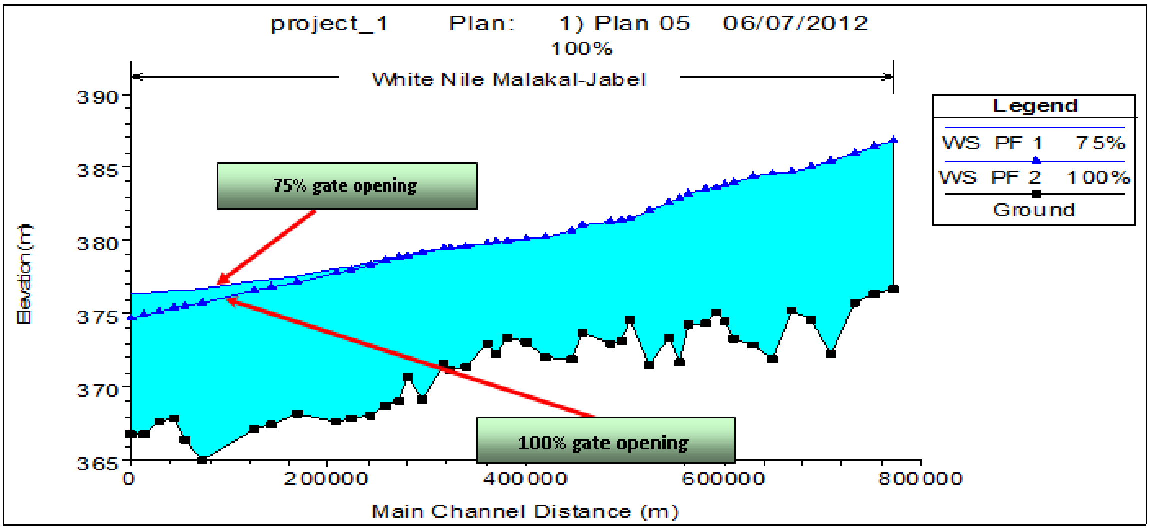

Figure 11. Water surface profile along the White Nile between Malakal and Jebel Aulia Dam For two cases of Gates Opening

7 CONCLUSIONS

In this study, actual historical flow data of the White Nile reach from Malakal to Jebel- Aulia dam is used in Hec-Ras model for simulating the hydraulic performance. The study has identified the locations along the White Nile that face flooding for 7 scenarios and current condition. Results have shown flood protection is required at the specified areas for each scenario. Even in the current conditions, the Nile suffers from flooding problems in about 154.9 km of its length. Therefore it needs urgent protection at the specified locations. With the implementation of the upper-Nile projects, about308.0 km and 131.0 km from the left and the right banks will overflow and need protection.

The minimum gate openings of Jebel Aulia Dam to avoid dam overtopping are estimated for 7 scenarios. When the downstream water level is minimum, the minimum gate opening to pass the max discharges is 2.44 m for the 50 gates.When the downstream water level is maximum, the minimum gate opening is 4.10 m. Respecting the recommended minimum gate openings, the 50 gates of Jebel Aulia Dam are enough to pass the max discharges for all upper Nile Projects, and no needs to use the spare gates. The protection levees worksrecommended along the White Nile banks should be implemented in parallel with the Upper Nile projects implementation

REFERENCES

Afifi, A. K & Ezzat, M. N (1995) Nile Control and Conservation Projects, Nile Water Sector report, MWRI, Egypt

Eizel-Din, M.A. & Saghayroon, E.(2010) Trap Efficiency of Reservoirs on the Nile River, a technical report, Ministry of Irrigation, Khartoum, Sudan

El-Sayed, M. (2013) Impact of proposed upper Nile projects on the hydraulic performance of the white Nile and jebel aulia dam operation rules", MSc. Thesis, Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University, 2013

Elzawahry A.E..M., Bekhit H.B.M. (2016) Impacts of the Upper Nile Mega Projects on the Water Resources of Egypt. In: Negm A. (eds) The Nile River. The Handbook of Environmental Chemistry, vol 56. Springer, Cham• Print ISBN978-3-319-59086-8• Online ISBN978-3-319-59088-2

Mission E. I (1961) Estimating the Areas and Contains of Gable- Aulia Reservoir, Technical report by the Egyptian irrigation mission in Sudan, MWRI, Egypt

Mission E. I (1970) Jebel Aulia annual report, Technical report by the Egyptian irrigation mission in Sudan, MWRI, Egypt, 1970-1971

MWRI (2000) The National Water Resources Plan 2017, technical report by Planning sector, MWRI, Egypt

MWRI (1936) The Working Arrangement for Operating the Jebel Aulia Dam with Notes Revised, Technical report, Egypt

NWS (2000) Nile Basin Encyclopaedia 1912-2000, Nile Water Sector, MWRI, Egypt

PJTC (1961) First Annual Report1960/1961, Permanent Technical Joint Commission for Nile Water, Sudan

Samah, A. H. (1974) Notes about the White Nile Efficiency "From Lake No to the Mouth of the White Nile", MWRI report, Egypt