FORECASTING OF WATER LEVELS AT GAUGE STATIONS DUE TO RIVER SIDE ENCROACHMENTS

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ABSTRACT

In Egypt, large areas of the River Nile floodplains get uncovered during the low stage period, a matter which encourages commitment of encroachments on them. Such encroachments come in the form of different developments such as river earth-filling, building erection or expansions of opportunistic nearby residents. The effect of these encroachments materializes mostly during higher stages where the water flow undergoes obstructions and hindrances. Accordingly, the river starts to react in different ways. It loses its ability to manage the water flow naturally. Excess flow may be kept out of floodplains by forcing extra flow downstream at higher speeds, with obvious consequences. Erosion and down-cutting will increase and the danger to downstream communities will increase. Moreover, the water levels may rise in some areas causing flooding conditions to prevail during releases of maximum discharges and resulting in heavy losses and damages to island and floodplain squatters (occupants). This research paper mainly aims to introduce a methodology that can develop a general formula at each gauge station along the river reach under study that can be used to forecast the water levels at any given values of both the discharge released through that reach and the average encroachment width committed on both or either side of the riverbank. In other words, the water level (***WL***) will be a function of the discharge (***Q***) and the proposed average encroachment width ($\boldsymbol{W}_{Enc.}$). Such a formula will be a quick and practical tool for evaluating the water level conditions in the different cases of riverside encroachments. This, hopefully, helps to make the necessary precautions and arrangements for any future unfavorable conditions that can avoid expected losses or damages.

INTRODUCTION

In Egypt, the River Nile always experiences water stage fluctuations round the year due to the different discharges released downstream Aswan High Dam in the south. These discharges change according to the planned daily requirements. Unfortunately, large areas of floodplains get uncovered during the low stage period, a matter which encourages commitment of encroachments on them. Such encroachments come in the form of different developments such as river earth-filling, building erection or expansions of opportunistic nearby residents. The effect of these encroachments materializes tangibly and evidently during higher stages where the water flow starts to undergo obstructions and hindrances.

The river starts to react in different ways. It loses its ability to manage the water flow naturally. Excess flow may be kept out of floodplains by forcing extra flow downstream at higher speeds, with obvious consequences. Erosion and down-cutting will increase and the danger to downstream communities will increase. Moreover, the water levels may rise in some areas causing flooding conditions to prevail during releases of maximum discharges and resulting in heavy losses and damages to island and floodplain squatters (occupants).

Therefore, it is important to forecast the water level conditions that may occur in the different cases of riverside encroachments. This, hopefully, helps to make the necessary precautions and arrangements that may save the country any expected losses or damages by being ready to cope with any future unfavorable conditions.

OBJECTIVE

This research paper mainly aims to introduce a methodology that can develop a general formula at each gauge station along the river reach under study that can be used to forecast the water levels at any given values of both the discharge ($\boldsymbol{Q}$) that may be released through that reach and the percent average encroachment width ($\%\boldsymbol{W}_{\text{Enc.}}$) committed on both or either side of the riverbank. In other words, the water level ($\boldsymbol{WL}$) will be a function of the discharge ($\boldsymbol{Q}$) and the proposed percent average encroachment width ($\%\boldsymbol{W}_{\text{Enc.}}$).

APPLICATION REACH DEFINITION

Reach (4) of the River Nile was specifically chosen for this study. This is because of the availability of the two sets of data (hydrographic and hydrologic data) required for model calibration purposes. It is about 408.720 km long. It extends from just downstream Assyut barrages at km (544.780) from Old Aswan Dam (OAD) far up in the south down to just upstream Delta Barrages at km (953.500) in the North as shown in Figure (1). It is worth mentioning that the geometry of the reach was represented by 200 cross sections surveyed in 2003 (the most recent hydrographic survey that was done by the Nile Research Institute where the first author works) spaced at an in-between average distance of 2 kilometers.

THE PROPOSED METHODOLOGY

The Water Surface Profiles (WSPs) along the study reach were computed using a 1-D model developed by the first author during his PhD study (2003). This is done in case 5 different discharges (25, 70, 100, 140, 180 M.m^3/day) are released through the reach for different assumed percent river encroachment widths (0 %, 5 %, 10 %, 15 %, 20 % and 25 % of the top width of the case when there is no encroachment). Five detention water levels (14.00, 14.80, 15.30, 16.00, 16.70 m) at the downstream end of the reach were used in computations corresponding to the above discharges respectively. Then, the water levels at the eleven gauge stations spread along the reach were simply computed by interpolation using their kilometers (See table (1) where the Gauge Stations & their kilometers are shown). This procedure was repeated for 3 main cases:

1. The first one takes place when the encroachment is assumed to be committed along the whole east side of the river;
2. The second is when the encroachment is assumed along the west river side; and
3. The third is when the encroachment is along both sides of the river.

Now, at each gauge station and for different percent average encroachment widths, there are always 30 values (5 x 6) of water levels corresponding to the five discharge values assumed to be released through the study reach. By regression analysis, a formula correlating the water level, the discharge, and the percent average encroachment width was obtained for each gauge station. This formula is, then, used to compute the water level at the gauge station under interest for any proposed discharge and percent average encroachment width.

DEDUCTION OF FORMULAS AT THE DIFFERENT GAUGE STATIONS

In order to deduce the relationships that correlate the water level (***WL***), the discharge (***Q***), and the percent average encroachment width ($\%\boldsymbol{W}_{\text{Enc.}}$), the abovementioned methodology is followed. The "Roda" gauge station was taken as an example to show how the formulas were obtained.

1- Steps of Formula Deduction at "El Roda" Gauge Station (Case of East Encroachment)

a) Having the 1-D model calibrated, it is runs to compute the (WSPs) for the 5 discharges (25, 70, 100, 140, 180 M.m^3/day) assumed to be released through the study reach. This was done for each discharge (Q) when a percent average encroachment width at the east side was assumed to have the following values: (0%, 5%, 10%, 15%, 20%, 25%).

b) Using the computed WSPs, the water levels at the station were computed by interpolation for the 5 discharges in the six cases of encroachment width. For example, at Q = 25 $M.m^3/day$, the water level (WL) had 6 different values corresponding to the six values of the percent average encroachment widths imposed at the east side and so on for the remaining 4 discharges.

c) Now, 5 curves correlating the water level values and the percent average encroachment widths could be plotted for the 5 assumed discharges as shown in Figure (2).

d) Using the regression analysis, 5 trend lines with 5 2^{nd}-degree polynomial equations were drawn corresponding to the above 5 curves. The proposed equations can be in the following form:

$$WL = C1 * W_{Enc}^2 + C2 * W_{Enc} + C3 \tag{1}$$

in which:

WL = the water level at the station;
W_{Enc} = the percent average encroachment width, and
C1, C2, and C3 are constants.

e) The above constants have got different values at each discharge (Q). For example, for each (Q), there is a corresponding value for (C1), another for (C2), and a third for (C3) as shown in table (2).

f) Now, 3 curves correlating the 5 values of each constant and the 5 discharge values can be plotted as shown in Figures (3, 4, and 5).

g) Also, by regression analysis, 3 trend lines with 3 2^{nd}-degree polynomial equations are drawn corresponding to the 3 curves. The equations are in the following form:

$$C1 = B1 * Q^2 + B2 * Q + B3 \tag{2}$$
$$C2 = D1 * Q^2 + D2 * Q + D3 \tag{3}$$
$$C3 = E1 * Q^2 + E2 * Q + E3 \tag{4}$$

h) Substituting the values of constants (C1, C2, and C3) from equations (2, 3, and 4) in equation (1), the following general formula is obtained:

$$WL = [B1 * Q^2 + B2 * Q + B3] * W_{Enc}^2 + [D1 * Q^2 + D2 * Q + D3] * W_{Enc} + [E1 * Q^2 + E2 * Q + E3] \tag{5}$$

i) Again, the above steps were once repeated for the case when the encroachment was assumed to be along the river west side and a third for the case when the encroachment imposition was assumed at both sides of the river.

The above procedure was repeated for the rest of the gauge stations. Finally, a number of formulas were obtained for the gauge stations spread along the river reach under study. Then, a simple Spreadsheet Macro as shown by the flowchart in Figure (6) was designed to combine them together and help compute the water level at any gauge station during the release of any discharge through the study reach when an encroachment with any width is committed on both or either side of the riverbank. Such formulas will be a quick and practical tool for evaluating the water level conditions in the different cases of riverside encroachments. These formulas and their constants are shown in tables (3, 4, and 5).

CONCLUSIONS

1. Having such a quick tool in hand, the decision maker is able to forecast the future conditions of the water levels in the different cases of encroachment during the release of any discharge through reach (4) of the River Nile.

2. The actual water level situation and the consequent effects particularly during emergency flooding conditions can be evaluated more precisely. This helps take the necessary preparations and countermeasures.

3. The application of such a methodology can be extended to cover the other reaches of the River Nile and other open channels. In this way, a better management of water levels along rivers can be achieved.

REFERENCES

Hekal, N.T.H., 2003. Evaluation of Nile Flood Effects Downstream Flood Control Structures in Egypt, Ph.D. Thesis, Ain Shams University, Egypt.

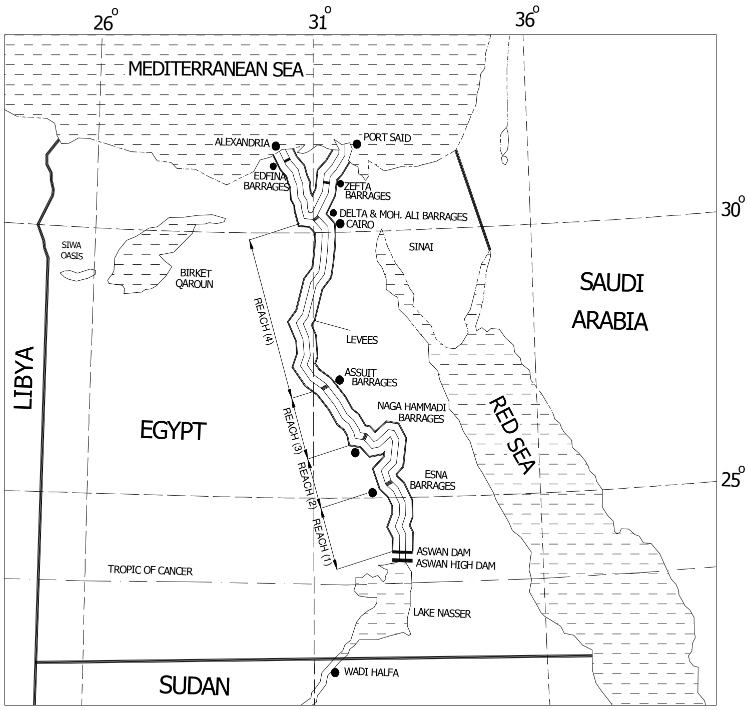

Figure-1: A map showing the River Nile through Egypt and its four Reaches

Figure (2): Relationship between Water Level and % Encroachment Width at the River East Side

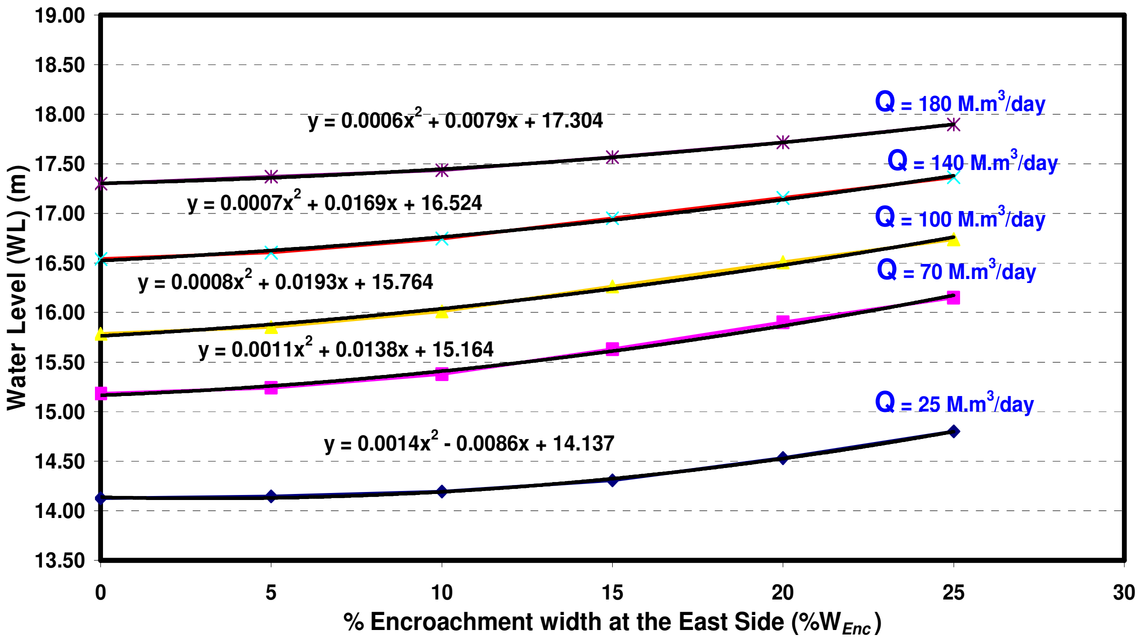

Table (1): Gauge Stations along Reach (4) and their kilometers.

Gauge Station	Km From Old Aswan Dam
El Roda	927.00
El Ekhsas	914.50
El Lethy	900.20
El Korimat	865.60
Beni Sweif	835.10
Beba	815.50
El Sheikh Fadl	761.75
El Menia	714.05
El Mandra	638.60
El Maabda	602.70
DS Assuit Barr	571.20

Table (2): Values of Constants (C1, C2, and C3) Corresponding to Different Values of Discharges (Q)

Q ($M.m^3/day$)	C1	C2	C3
25	0.0014	0.0086	14.1370
70	0.0011	0.0166	15.1640
100	0.0008	0.0193	15.7640
140	0.0007	0.0169	16.5240
180	0.0006	0.0079	17.3040

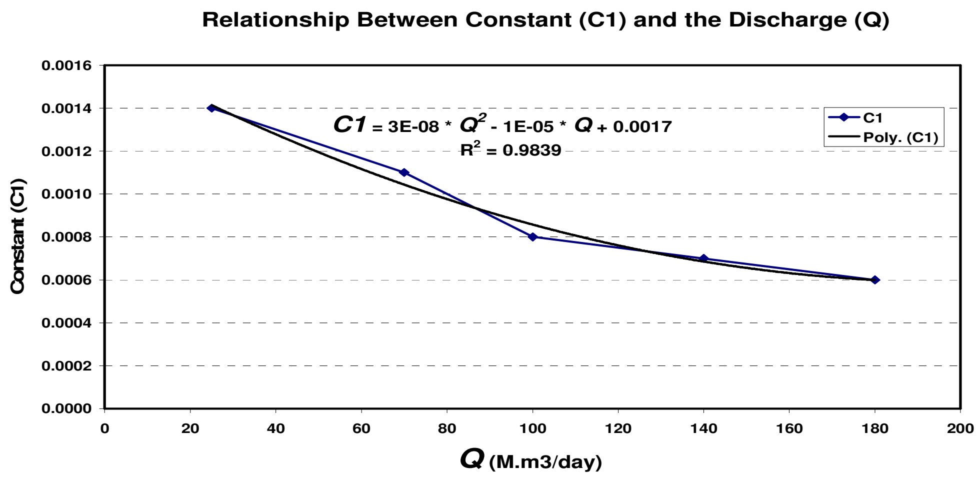

Figure (3)

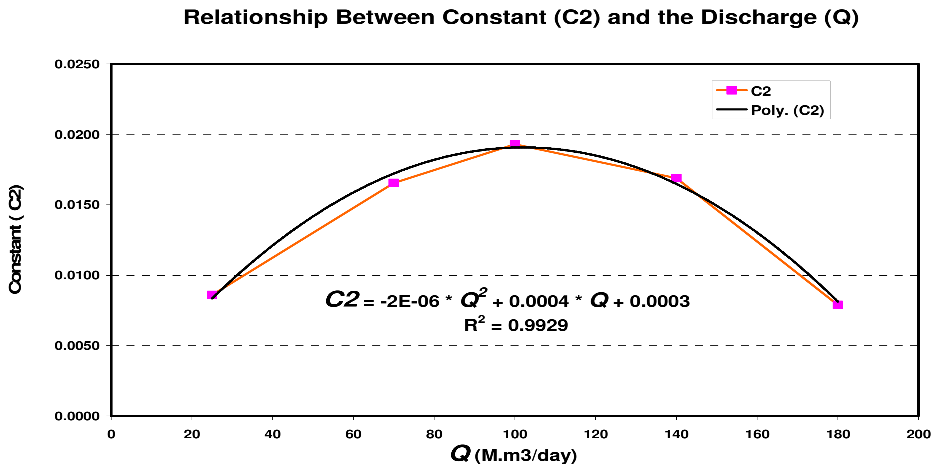

Figure (4)

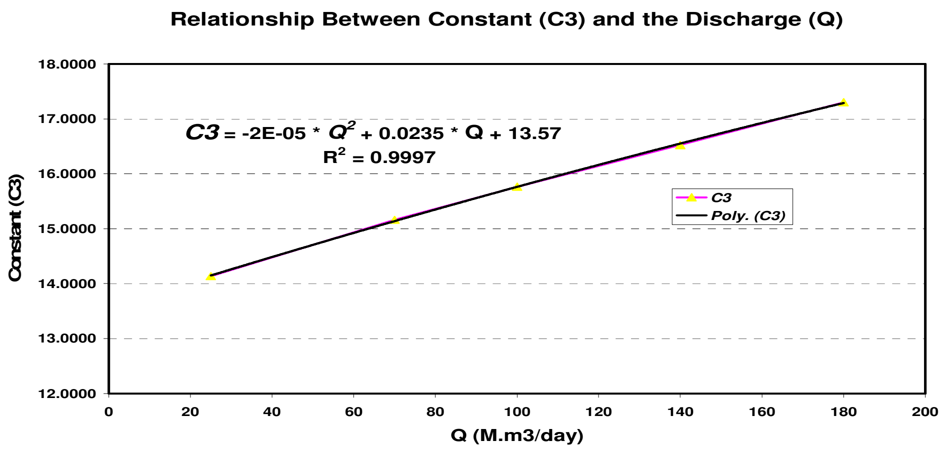

Figure (5)

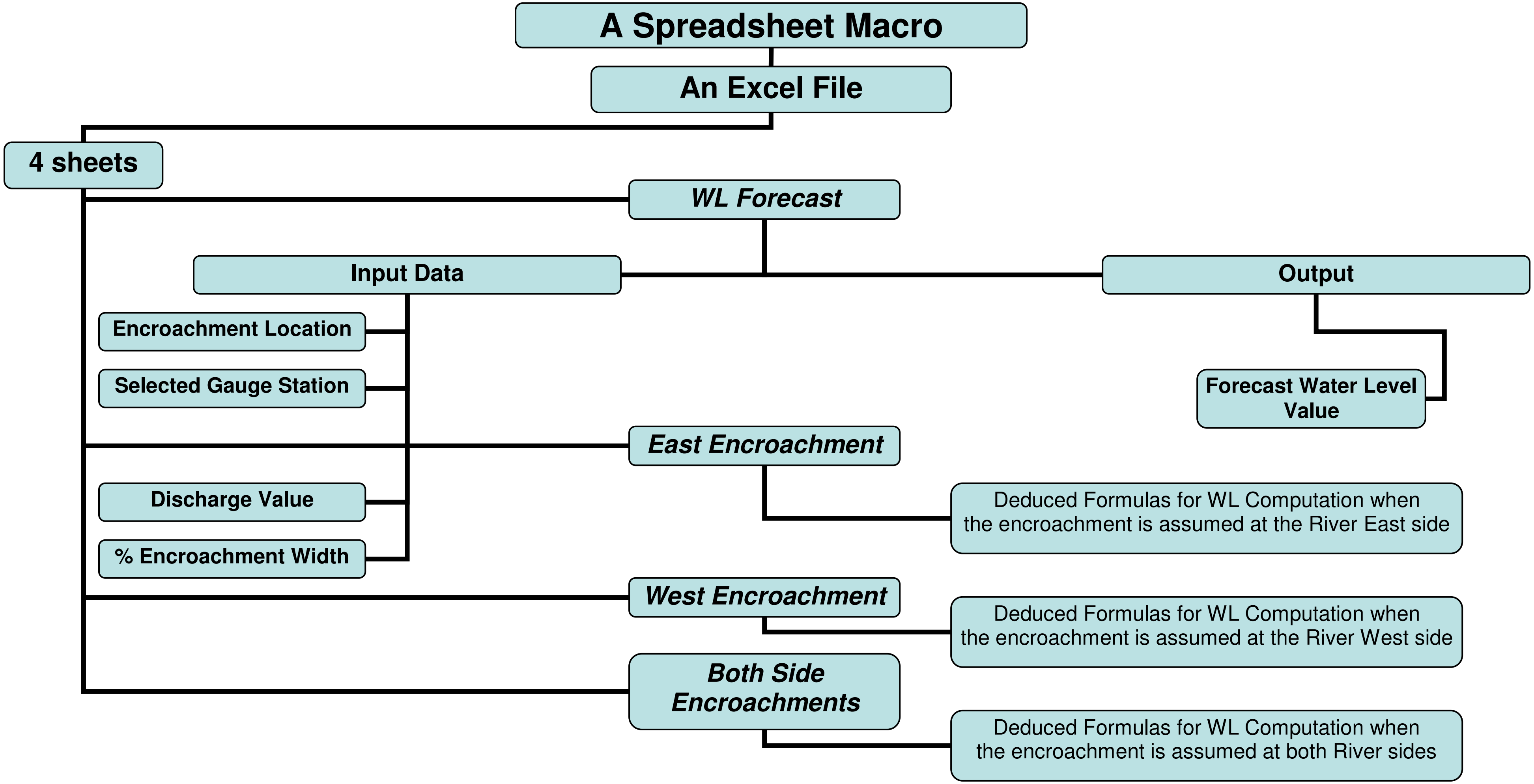

Figure (6): A flowchart showing the components of the Spreadsheet Macro designed to compute the water levels at gauge stations.

East Side Encroachment

Station	Q	% $W_{E.Enc}$	Constants for (C1) B1	B2	B3	C1 ($C1=B1*Q^2+B2*Q+B3$)	Constants for (C2) D1	D2	D3	C2 ($C2=D1*Q^2+D2*Q+D3$)	Constants for (C3) E1	E2	E3	C3 ($C3=E1*Q^2+E2*Q+E3$)	$WL=C1*(\%W_{Enc}^2)+C2*(\%W_{Enc})+C3$
El Roda	130	5	0.00000003	-0.00001	0.0017	0.000907	-0.000002	0.0004	0.0003	0.0185	-0.00002	0.0235	13.57	16.287	16.40
El Ekhsas	130	5	0.00000003	-0.000007	0.0012	0.000797	-0.000001	0.0002	0.001	0.0101	-0.00004	0.0301	13.86	17.097	17.17
El Lethy	130	5	-0.00000002	0.000005	0.0004	0.000712	0.00000005	-0.000002	0.0062	0.006785	-0.00004	0.0306	14.578	17.88	17.93
El Korimat	130	5	0.00000009	-0.00002	0.001	-7.9E-05	-0.000001	0.0003	0.0052	0.0273	-0.00011	0.0438	16.066	19.901	20.04
Beni Sweif	130	5	0.00000004	-0.000002	0.00008	0.000496	0.0000001	-0.00002	0.0047	0.00379	-0.0001	0.0415	18.442	22.147	22.18
Beba	130	5	0.00000008	-0.000009	0.0005	0.000682	-0.000001	0.0003	-0.0044	0.0177	-0.0001	0.0473	19.964	24.423	24.53
El Sheikh Fadl	130	5	-0.0000002	0.00002	0.0003	-0.00048	0.000005	-0.0008	0.0246	0.0051	-0.0001	0.0465	24.508	28.863	28.88
El Menia	130	5	0.0000001	-0.00001	0.001	0.00139	-0.000002	0.0003	-0.0018	0.0034	-0.00006	0.031	28.88	31.896	31.95
El Mandra	130	5	0.000000008	0.000001	0.0005	0.0007652	0.0000001	0.00002	-0.00006	0.00423	-0.000006	0.0221	36.133	38.9046	38.94
El Maabda	130	5	-0.000000009	0.000008	0.001	0.0018879	-0.000002	0.0003	-0.0037	0.0015	-0.0001	0.0481	38.978	43.541	43.60
DS Assuit Barrages	130	5	-0.00000009	0.00004	-0.0027	0.000979	0.000001	-0.0005	0.0692	0.0211	-0.00006	0.0371	41.334	45.143	45.27

Table (3): The deduced formulas computing water levels at the different stations along Reach (4) when the encroachment is at the East Side.

			Constants for (C1)			C1	Constants for (C2)			C2	Constants for (C3)			C3	
Station	Q	% $W_{E.Enc}$	B1	B2	B3	$C1=B1*Q^2+B2*Q+B3$	D1	D2	D3	$C2=D1*Q^2+D2*Q+D3$	E1	E2	E3	$C3=E1*Q^2+E2*Q+E3$	$WL=C1*(\%W_{Enc}^2)+C2*(\%W_{Enc})+C3$
El Roda	130	5	0.00000006	0.000007	0.0004	0.002324	0.0000003	0.00003	0.0015	0.01047	-0.00002	0.0243	13.545	16.366	16.48
El Ekhsas	130	5	0.00000007	0.000009	0.0009	0.003253	-0.000001	0.0002	-0.0019	0.0072	-0.000045	0.03055	13.848	17.059	17.18
El Lethy	130	5	-0.00000001	0.000009	3E-06	0.001004	-0.0000009	0.0002	0.0041	0.01489	-0.00004	0.0305	14.572	17.861	17.96
El Korimat	130	5	-1E-11	0.000006	0.00005	0.000829831	-0.0000006	0.0001	-0.0041	-0.00124	-0.0001	0.0438	16.078	20.082	20.10
Beni Sweif	130	5	0.00000009	-0.00002	0.001	-7.9E-05	-0.000002	0.0004	0.0073	0.0255	-0.0001	0.0414	18.427	22.119	22.24
Beba	130	5	-0.00000004	0.000007	0.0002	0.000434	-0.000003	0.0007	-0.0085	0.0318	-0.0001	0.0471	19.965	24.398	24.57
El Sheikh Fadl	130	5	-0.0000002	0.00003	-0.0003	0.00022	0.000003	-0.0001	0.0041	0.0418	-0.0001	0.0468	24.512	28.906	29.12
El Menia	130	5	0.00000003	-0.000004	0.0006	0.000587	-0.000001	0.0002	-0.0044	0.0047	-0.00006	0.031	28.88	31.896	31.93
El Mandra	130	5	0.0000001	-0.00001	0.0004	0.00079	-0.000005	0.001	0.0095	0.055	-0.00005	0.035	35.681	39.386	39.68
El Maabda	130	5	-3E-09	0.000004	0.0001	0.0005693	-0.0000003	0.0001	-0.0029	0.00503	-0.0001	0.0473	39.004	43.463	43.50
DS Assuit Barrages	130	5	-4E-09	0.000005	0.0004	0.0009824	0.0000002	4E-07	-0.0008	0.002632	-0.00007	0.0385	41.286	45.108	45.15

Table (4): The deduced formulas computing water levels at the different stations along Reach (4) when the encroachment is at the West Side.

					Both Side Encroachment									
El Roda		*Constants for (C1)*			*C1*	*Constants for (C2)*			*C2*	*Constants for (C3)*			*C3*	
Q	% $W_{E.Enc}$	B1	B2	B3	$C1=B1*Q^2+B2*Q+B3$	D1	D2	D3	$C2=D1*Q^2+D2*Q+D3$	E1	E2	E3	$C3=E1*Q^2+E2*Q+E3$	$WL=C1*(\%W_{Enc}^2)+C2*(\%W_{Enc})+C3$
130	5	0.00000006	-0.000009	0.0019	0.001744	-0.000004	0.0008	-0.0301	0.0063	-0.00001	0.0234	13.578	16.451	16.53
El Ekhsas		*Constants for (C1)*			*C1*	*Constants for (C2)*			*C2*	*Constants for (C3)*			*C3*	
Q	% $W_{E.Enc}$	B1	B2	B3	$C1=B1*Q^2+B2*Q+B3$	D1	D2	D3	$C2=D1*Q^2+D2*Q+D3$	E1	E2	E3	$C3=E1*Q^2+E2*Q+E3$	$WL=C1*(\%W_{Enc}^2)+C2*(\%W_{Enc})+C3$
130	5	0.00000006	-0.0000006	0.0007	0.001636	-0.000003	0.0006	-0.01	0.0173	-0.00004	0.0299	13.858	17.069	17.20
El Lethy		*Constants for (C1)*			*C1*	*Constants for (C2)*			*C2*	*Constants for (C3)*			*C3*	
Q	% $W_{E.Enc}$	B1	B2	B3	$C1=B1*Q^2+B2*Q+B3$	D1	D2	D3	$C2=D1*Q^2+D2*Q+D3$	E1	E2	E3	$C3=E1*Q^2+E2*Q+E3$	$WL=C1*(\%W_{Enc}^2)+C2*(\%W_{Enc})+C3$
130	5	0.00000008	-0.000007	0.0007	0.001142	-0.000003	0.0006	-0.0096	0.0177	-0.00004	0.0301	14.581	17.818	17.94
El Korimat		*Constants for (C1)*			*C1*	*Constants for (C2)*			*C2*	*Constants for (C3)*			*C3*	
Q	% $W_{E.Enc}$	B1	B2	B3	$C1=B1*Q^2+B2*Q+B3$	D1	D2	D3	$C2=D1*Q^2+D2*Q+D3$	E1	E2	E3	$C3=E1*Q^2+E2*Q+E3$	$WL=C1*(\%W_{Enc}^2)+C2*(\%W_{Enc})+C3$
130	5	0.0000001	-0.00002	0.0012	0.00029	-0.000003	0.0005	-0.0036	0.0107	-0.0001	0.0434	16.074	20.026	20.09
Beni Sweif		*Constants for (C1)*			*C1*	*Constants for (C2)*			*C2*	*Constants for (C3)*			*C3*	
Q	% $W_{E.Enc}$	B1	B2	B3	$C1=B1*Q^2+B2*Q+B3$	D1	D2	D3	$C2=D1*Q^2+D2*Q+D3$	E1	E2	E3	$C3=E1*Q^2+E2*Q+E3$	$WL=C1*(\%W_{Enc}^2)+C2*(\%W_{Enc})+C3$
130	5	0.00000008	-0.000006	0.0012	0.001772	-0.000001	0.0002	0.0081	0.0172	-0.0001	0.0419	18.414	22.171	22.30
Beba		*Constants for (C1)*			*C1*	*Constants for (C2)*			*C2*	*Constants for (C3)*			*C3*	
Q	% $W_{E.Enc}$	B1	B2	B3	$C1=B1*Q^2+B2*Q+B3$	D1	D2	D3	$C2=D1*Q^2+D2*Q+D3$	E1	E2	E3	$C3=E1*Q^2+E2*Q+E3$	$WL=C1*(\%W_{Enc}^2)+C2*(\%W_{Enc})+C3$
130	5	0.00000006	-0.000008	0.0011	0.001074	0.0000002	2E-06	0.0151	0.01874	-0.0001	0.0474	19.954	24.426	24.55
El Sheikh Fadl		*Constants for (C1)*			*C1*	*Constants for (C2)*			*C2*	*Constants for (C3)*			*C3*	
Q	% $W_{E.Enc}$	B1	B2	B3	$C1=B1*Q^2+B2*Q+B3$	D1	D2	D3	$C2=D1*Q^2+D2*Q+D3$	E1	E2	E3	$C3=E1*Q^2+E2*Q+E3$	$WL=C1*(\%W_{Enc}^2)+C2*(\%W_{Enc})+C3$
130	5	-0.0000003	0.00004	-0.00007	6E-05	0.000008	-0.0011	0.0385	0.0307	-0.0001	0.0468	24.496	28.89	29.05
El Menia		*Constants for (C1)*			*C1*	*Constants for (C2)*			*C2*	*Constants for (C3)*			*C3*	
Q	% $W_{E.Enc}$	B1	B2	B3	$C1=B1*Q^2+B2*Q+B3$	D1	D2	D3	$C2=D1*Q^2+D2*Q+D3$	E1	E2	E3	$C3=E1*Q^2+E2*Q+E3$	$WL=C1*(\%W_{Enc}^2)+C2*(\%W_{Enc})+C3$
130	5	0.0000002	-0.00002	0.0016	0.00238	-0.000002	0.0004	-0.0069	0.0113	-0.00006	0.031	28.88	31.896	32.01
El Mandra		*Constants for (C1)*			*C1*	*Constants for (C2)*			*C2*	*Constants for (C3)*			*C3*	
Q	% $W_{E.Enc}$	B1	B2	B3	$C1=B1*Q^2+B2*Q+B3$	D1	D2	D3	$C2=D1*Q^2+D2*Q+D3$	E1	E2	E3	$C3=E1*Q^2+E2*Q+E3$	$WL=C1*(\%W_{Enc}^2)+C2*(\%W_{Enc})+C3$
130	5	0.0000002	-0.00003	0.001	0.00048	-0.000005	0.001	0.0123	0.0578	-0.00006	0.0349	35.676	39.199	39.50
El Maabda		*Constants for (C1)*			*C1*	*Constants for (C2)*			*C2*	*Constants for (C3)*			*C3*	
Q	% $W_{E.Enc}$	B1	B2	B3	$C1=B1*Q^2+B2*Q+B3$	D1	D2	D3	$C2=D1*Q^2+D2*Q+D3$	E1	E2	E3	$C3=E1*Q^2+E2*Q+E3$	$WL=C1*(\%W_{Enc}^2)+C2*(\%W_{Enc})+C3$
130	5	-0.00000001	0.00001	0.0011	0.002231	0.0000007	-0.0001	-0.0004	-0.00157	-0.0001	0.0477	38.985	43.496	43.54
DS Assuit Barrages		*Constants for (C1)*			*C1*	*Constants for (C2)*			*C2*	*Constants for (C3)*			*C3*	
Q	% $W_{E.Enc}$	B1	B2	B3	$C1=B1*Q^2+B2*Q+B3$	D1	D2	D3	$C2=D1*Q^2+D2*Q+D3$	E1	E2	E3	$C3=E1*Q^2+E2*Q+E3$	$WL=C1*(\%W_{Enc}^2)+C2*(\%W_{Enc})+C3$
130	5	0.00000005	0.000001	0.001	0.001975	-0.000003	0.0008	-0.0163	0.037	-0.00007	0.0378	41.286	45.017	45.25

Table (5): The deduced formulas computing water levels at the different stations along Reach (4) when the encroachment is at Both Sides.