Nile River Morphological Changes

State of the Art

[Marwa Meky, and Bakenaz. A. Zeidan]

Abstract— **River Engineering preserves environment while protecting the rivers against advanced human activities and flooding. Natural rivers and alluvial channels are shaped by interactions of sediment transport and flow rate. Because of sediment-transport processes the cross section and alignment of alluvial rivers may vary continuously with time passage. Alluvial rivers transport sediment in suspension or bed load shaping their downstream river morphology, dynamics, and ecosystems. River morphology includes the migration of issues deposited by water flow in the river channel across its floodplain. Storage and hydropower dams control the flood flows and the sediment transport capacity to the river at dam site. Morphological characteristics of the Nile River are affected by several changes; bank erosion, bank retreat, bed degradation, bed aggradation and scour around bridge piers. Morphological changes of the Nile River experiences should be closely observed and estimated in order to avoid their negative impacts. Morphological research studies are based on mathematical simulation, laboratory experimentations and field observations. The key object of this paper is to address the state of the art of morphological changes implications along the Nile River via numerical techniques.**

Keywords—**Morphology, Modeling, Alluvial, Floodplain, Nile River, Sediment Transport, Migration, Degradation, Aggradation.**

I. Introduction

River morphology is illustrated by channel types and channel forms, and is determined by such factors as flow rate, water surface slope, water velocity, depth, width of the channel, and bed materials. These affecting factors are not separated but interrelated to each other [1]. The alluvial river channel morphology affects the movement of water and sediment along it, but in the long term is formed by those processes. These implicate the scope to best be able to model how mutating flows drive morph-dynamic modification, to know the impact of the sediments on morph-dynamics, and to acknowledge the attendant need for rivers that transport bed material to disfigure laterally. Understanding the influences of environment that command avulsion (shifting of a river path) manner is significant, as well as the properties and division of floodplain sediments for portending channel migration.

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However, avulsions take place infrequently and often in distant locations. Because of these, avulsions are little directly noticed, which has made it hard to determine the influences that estimate avulsion manner. Determining these influences would increase our interpretation of fluvial avulsion precipitates in the geologic register and support relieve avulsion-related flooding hazards to societies constructed on floodplains [2]. In the last century, the Nile River has varied morphological changes tremendously due to flow rate, sediment transport and human interventions. The Nile River is a natural alluvial river so; it has many islands formed after construction some of dams. It has many meanders and bends along its alignment from headwaters to Mediterranean Sea. Sediment analysis from Nile Delta bottom confirms the linkage from the Ethiopian highlands to the Nile Delta extension back to the Oligocene [3] as Fig. 1. River morphological processes are among the most complicated phenomena in riverine environment and in the fact, that they influence on our life. Scientists have different researches to improve our least understanding for morphological changes and protect the quality of our environment and civilization. . For Nile River Morphology, previous research methodologies employed either physical modelling or Remote Sensing and GIS technologies utilizing Landsat images.

II. Aspects of River Morphology

River morphology is the study of changes of river alignment shape and bathymetry configuration. This is mainly due to erosion and sedimentation processes. Water flow and sedimentation setting up can determine the channel alignment dimensions as width, depth, meander wavelength, and gradient. There are many morphological problems such as bank erosion, sedimentation, scour around bridge piers, and flood hazards where moving from the upper to lower course. River morphology can be classified to three main processes such as degradation, widening and aggradation as table I [3].
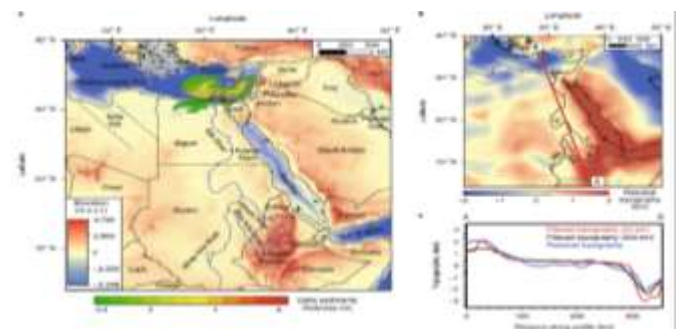

Figure 1.   The East Africa–eastern Mediterranean sediment transport system a, Topography of the Nile drainage b, Residual topography map White Nile, Blue Nile, Main Nile and Atbara River. Points A and B indicate start and end

points for river profile graphed in c. c, Comparison between topography and its residual component along the Nile profile [4].

TABLE I.   RIVER MORPHOLOGY PROCESSES

Morphological Process	Due to	Description
Degradation	Water flow increasing	Lowering bed elevation
Aggradation	Water flow decreasing	Increasing bed elevation
Widening	Water flow increasing	Increasing channel width

Fluvial geomorphology is the phenomena of the correlation between river channel forms and processes at a range of space and time scales. Fluvial morphology is conditioned by three basic elements: flow regime, sediment yield and valley characteristics. The impact of past events is also important in clarifying the present form of river alignment. Rivers are found in many various environments and take a variety of forms. Three basic channel types are detected in alluvial plains. They are straight, meandering and braided, as Fig. 2, [5].

For the river valley, the fluvial system can be generalized into three main regions as an erosional region of runoff production and sediment source, a transport region of water and sediment transport, and a depositional region of runoff delivery and sedimentation, Fig. 3, [6].

III. Theoretical Approach and Governing Equations

The flow and sediment transport process in rivers are recognized by turbulence, free-surface difference, bed variation, stage interaction, etc. The essential governing equations unsteady flow in open channels are predicted on conservation of momentum and mass in a bounded technique.

For 1- D Flows steady or quasi-steady flow model, the governing equation is the energy equation, which can be estimated by the standard step technique. For 1-D unsteady model, the most widely used numerical scheme is Preismann's four-point implicit scheme.

For 2- D Flows the water depth performed in the depth integrated continuity (1), providing a strong linkage between velocity and pressure (water level). When the central difference scheme is used to discretize these terms, artificial dissipations or Total Variation Diminishing (TVD) limiters are often used to suppress the numerical oscillations. Other solution methods for the Navier-Stokes equations can also be used for the 2-D shallow water , (1) to (3).

$$\frac{\partial h}{\partial t} + \frac{\partial (hU)}{\partial x} + \frac{\partial (hV)}{\partial y} = 0 \tag{1}$$

$$\frac{\partial (hU)}{\partial t} + \frac{\partial (hUU)}{\partial x} + \frac{\partial (hVU)}{\partial y} = -gh\frac{\partial z_s}{\partial x} + \frac{1}{\rho}\frac{\partial (hT_{xx})}{\partial x} + \frac{1}{\rho}\frac{\partial (hT_{xy})}{\partial y} + \frac{\partial D_{xx}}{\partial x} + \frac{\partial D_{xy}}{\partial y} + \frac{1}{\rho}(\tau_{sx} - \tau_{bx}) + f_c hV \tag{2}$$

$$\frac{\partial (hV)}{\partial t} + \frac{\partial (hUV)}{\partial x} + \frac{\partial (hVV)}{\partial y} = -gh\frac{\partial z_s}{\partial y} + \frac{1}{\rho}\frac{\partial (hT_{yx})}{\partial x} + \frac{1}{\rho}\frac{\partial (hT_{yy})}{\partial y} + \frac{\partial D_{yx}}{\partial x} + \frac{\partial D_{yy}}{\partial y} + \frac{1}{\rho}(\tau_{sy} - \tau_{by}) - f_c hU \tag{3}$$

Where x and y are the horizontal Cartesian coordinates; h is the flow depth; U and V are the depth-averaged flow velocities in x- and y-directions; z_s is the water surface elevation; g is the gravitational acceleration; T_{xx}, T_{xy}, T_{yx} and T_{yy} are the depth-averaged turbulent stresses; D_{xx}, D_{xy}, D_{yx} and D_{yy} are the dispersion terms due to the effect of secondary flow, which are important in the situations of curved channels; ρ is the density of fluid; τ_{bx} and by τ_{by} are the bed shear stresses,   determined   by

$$\tau_{bx} = \rho c_f U\sqrt{U^2 + V^2} \; ; \quad \tau_{by} = \rho c_f V\sqrt{U^2 + V^2}$$

With $c_f = gn^2/h^{1/3}$, and n is the Manning's roughness coefficient; τ_{sx} and τ_{sy} represent the shear forces acting on the water surface, usually caused by wind; f_c is the Coriolis coefficient.

For 3- D Flows Navier-Stokes (4) and (5), the momentum equations link the velocity to the pressure gradient, but the continuity equation does not directly link to the pressure and is just an additional constraint on the velocity field. Owing to such a weak linkage, the convergence and stability of a numerical solution of the Navier-Stokes equations depend largely on how the pressure gradient and velocity in these equations are evaluated.

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{4}$$

$$\frac{\partial u_i}{\partial t} + \frac{\partial (u_i u_j)}{\partial x_j} = F_i - \frac{1}{\rho}\frac{\partial p_i}{\partial x_i} + \frac{1}{\rho}\frac{\partial \tau_{ij}}{\partial x_j} \tag{5}$$

IV. MORPHOLOGICAL MATHEMATICAL MODELS

Numerical solving methods vary from the simple 1-D finite difference method to the complex 2-D and 3D finite difference, finite element or finite volume schemes.

A. Equations of 1 –D Model

For sediment transport models are separated this process to bed load and suspended load according to sediment transport modes, as Fig. 4. Sediment Transport [7]. The governing equation for the non-equilibrium transport of non-uniform sediment is:-

$$\frac{\partial (AC_{tk})}{\partial t} + \frac{\partial Q_{tk}}{\partial x} + \frac{1}{L_s}(Q_{tk} - Q_{t^*k}) = q_{lk} \quad, k = (1,2,\dots,N) \tag{6}$$

Where t is the time; x is the longitudinal coordinate; C_{tk} is the section-averaged sediment concentration; Q_{tk} is the actual sediment transport rate; Q_{t^*k} is the sediment transport capacity or the so-called equilibrium transport rate; L_s is the non-equilibrium adaptation length of sediment transport; and q_{lk} is the side inflow or outflow sediment discharge from bank 73 boundaries or tributary streams per unit channel length; each k represents a sediment size class; N is the total number of size classes.

B. *Equations of 2 –D Model*

Models for 2 -D separated to two groups, the depth averaged and width averaged. The 2 –D model for depth averaged is more often used in morphology analysis. This model applies to simulating the shallow water flow and is governed by the depth-integrated continuity and Navier-Stokes Equations. The bed deformation can be calculated using the overall sediment balance equation or the following equation

$$(1 - P'_m)\left[\frac{\partial Z_b}{\partial t}\right]_k = \alpha\omega_{sk}(C_k - C_{*k}) + \frac{(q_{bk} - q_{b*k})}{L_s} \ , \\ k = (1, 2, \dots, N) \qquad (7)$$

Where p'_m is the bed material porosity, $\partial Z_b/\partial t$ is the total bed deformation rate, α is the non-equilibrium adaptation coefficient, ω_{sk} is the settling velocity of sediment particles, C_k is the depth-averaged suspended-load concentration; C_{*k} is the suspended-load transport capacity; q_{bk} is the bed-load transport rate of k-th size class; q_{b*k} is the corresponding bed-load transport capacity.

C. *Equations of 3 –D Model*

The 3-D flow field is determined by the Reynolds-averaged momentum, continuity equations and Navier-Stokes equations for the hydrodynamic flow field. Models for 3 –D can be determined the bed change by the following equation $(1 - P'_m)\left[\frac{\partial z_b}{\partial t}\right]_k = D_{bk} - E_{bk} + \frac{1}{L_s}(q_{bk} - q_{b*k})$ (8)

Where D_{bk} is the deposition rate $(Dbk = w_{sk} c_{bk})$, and E_{bk} is the entrainment rate.

D. *Conjunction of 1-D, 2-D and 3-D Models*

In the search of River Engineering Issues, such as water intaking, navigation, river migration, river restoration, structure protection, and morphological processes, one needs to define the rate of flow, channel evolution and sediment transport that should be imitated using a 2 -D model or 3 -D model. So it may be more effective cost to use an integrated 1-D, 2-D and/or 3-D model for a long river reach if it is examined over a long time period. The final explanation, for simple parameter geometry with less significant subdomains applying the 1 –D model, and in cases of complex geometry with more significant subdomains applying the 2-D model or 3-D model. In 1-D, 2-D and 3-D models, the extreme calculation allowed for time steps are usually different so the total time step should be accurately chosen. The idea of the conjunction of 1-D, 2-D and 3-D models is explained in Fig. 5 for a general river case.

V. Morphological Modeling and Simulation

Morphodynamic models have three mainly components morphology, sediment transport and hydrodynamics. Some of the most application 1-D morphological and sediment transport models are CCHE1D, MIKE11, GSTARS3 and

HEC-RAS. CCHE1D model [8] is a 1-D model for the water quality, sediment transport, and flow simulation in a network of channels. CCHE1D predicts morphological changes and sediment yields, computing variations of the bed material degradation/aggradation and hydraulic sorting simulating and armoring processes. The layout of the CCHE1D graphical interface is explained in Fig. 6.

MIKE11 model [9] is a 1 –D model for water quality and sediment transport in rivers, flood plains, irrigation canals, reservoirs and other inland water. GSTAR3.0 is a 1 –D mathematical model for imitating water flow, sediment transport and prediction of morphological changes in natural alluvial rivers. The model applies minimum stream power theory for optimum channel width and channel geometry determination as Fig. 7. GSTARS 3 model can be simulated the study developing impact of island and its stability on river morphology [10].
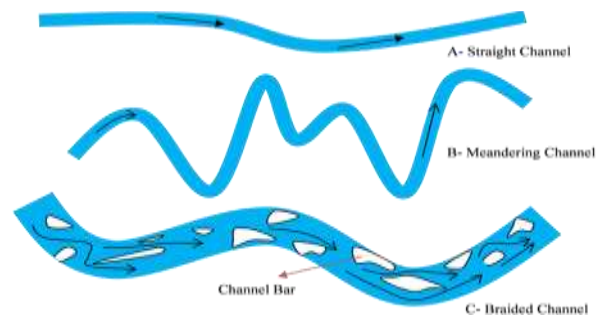

Figure 2. The forms of a river [5].

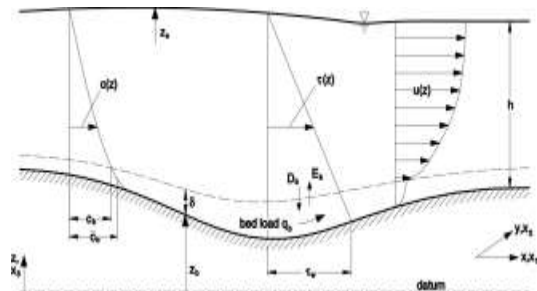Figure 3. The regions of a Fluvial System[6].

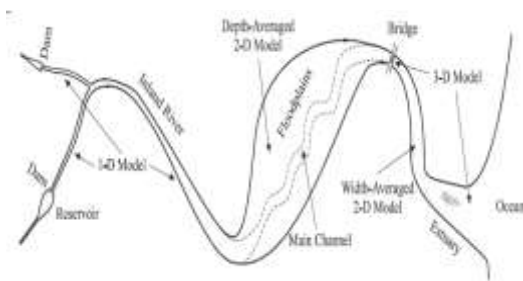Figure 4. Configuration of Flow and Sediment Transport [7].

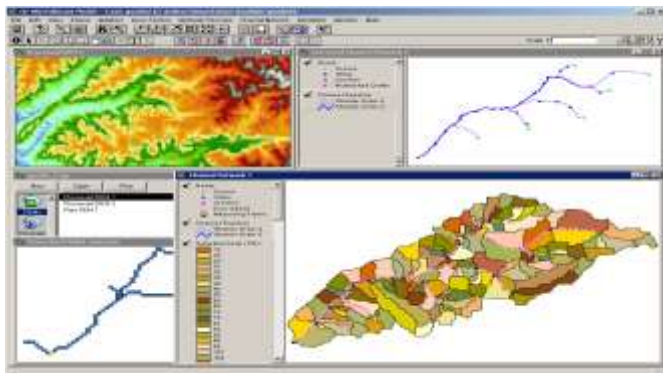Figure 5. The idea of the Conjunction of 1-D, 2-D and 3-D Models [7].

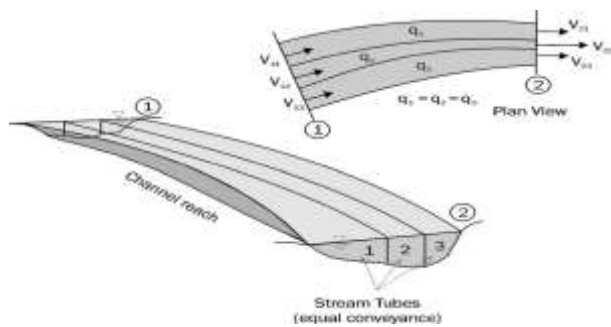
Figure 6. CCHE1D Graphical Interface [8].

Figure 7. Schematic Representations Illustrating the Use of Stream Tubes[10].
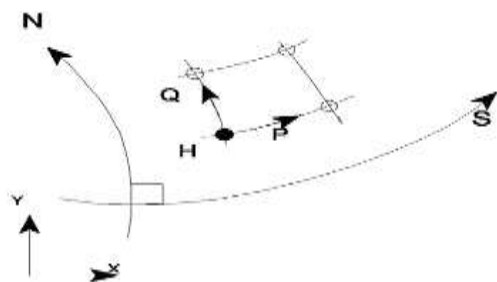

Figure 8. MIKE 21C model Curvilinear Coordinate System (N, S) [16].

HEC-RAS model [11] is a 1 -D flow model. This model can determine the corresponding water levels and perform 1-D water surface profile calculations for steady/unsteady gradually varied flow in open channels. The RMA2-SED2D model [12] consists of two uncoupled models RMA2 and SED2D. RMA2 is a 2-D depth-averaged finite element hydrodynamic numerical model. RMA2-SED2D can be used in sediment transport, scour, and deposition studies near major obstructions to river flow, such as navigation dams and bridge crossings. CCHE2D model [13] is a depth-averaged 2-D morphological, sediment transport and hydrodynamic model progressed by the Center for Computational Hydro-science and Engineering (CCHE), University of Mississippi. CCHE2D model can simulate steady or unsteady free surface flows, morphological processes and sediment transport including bank erosion, bed degradation / aggradation, channel migration and widening with and without structures. River2D model [12] is a 2-D finite element depth-averaged hydrodynamic model, which was prepared for use in natural rivers and streams. It has been developed in the University of Alberta by Steffler and Blackburn (2001). River2D do not have any sediment transport capacity however, some primitive type bed load transport capacity have been developed and added into the existing hydrodynamic model to simulate morphological changes in alluvial rivers. TWODSR model [12] is an uncoupled, unsteady 2-D finite difference based water and sediment routing model. It applies the continuity equation and Reynolds averaged Navier-stokes equations and for sediment transport it applies a 2-D expression of the Exner equation with a sediment transport function (a power function of discharge), for hydrodynamics. MIKE 21C model [14] is a curvilinear modeling system for 2-D free-surface flows with a specific emphasis on river morphology. MIKE 21C merges fully unsteady flow, bed load as well as suspended load, via a non-equilibrium transport formulation with both phase and time lag effects in the adaptation of suspended load. MIKE 21 C is based on an orthogonal curvilinear grid, as Fig. 8 shows a typical orthogonal grid with flow fluxes P and Q and flow depth H. The major cause of using an orthogonal grid in River Hydraulics issue is that one horizontal axis can follow the bank lines of the river. Apply of an orthogonal curvilinear grid produces the finite difference equations characterizing the 2-D flow become basically simpler than if a rectilinear grid was applied.

Delft3D Model [15] 2-D or 3-Dhydro-dynamic (and transport) simulation module would be used to simulate the water flow. The set of partial differential equations in combination with an appropriate set of initial and boundary conditions is solved on a finite difference grid, for the numerical aspects.

VI. The Nile River System

The Nile is one of the world's great rivers. For millennia, this individual waterway has fed various livelihoods and an series of ecosystems [17] The Nile River flows 6,853 kilometers long, northward through the tropical climate of eastern Africa and into the Mediterranean Sea, the river passes through eleven countries as follow Tanzania, Uganda, Rwanda, Burundi, the Democratic Republic of the Congo, Kenya, Ethiopia, Eritrea, South Sudan, Sudan and Egypt [18], Fig. 9.

VII. Dams Control the Nile River

The river morphology is often the result of natural impacts in combination with the effects of structures. As well as human activities, natural events, such as gravel mining dams, and hydropower projects, can also strongly deactivate the normal patterns of flow and sediment transfer and even compromise the morphological and ecological functionality [19]. Dams control the Nile River with their consequences are the responsible of the Nile morphological changes as; river bed degradation, bank erosion and suspended sediment changes. Water structure locations in the Nile are indicated in Fig. 10 and table II. Omar Et Al (2014) [20] showed that the river morphological changes restraint to dams can be predicted and analyzed only with an integrated approach including sediment, water the interaction between groundwater and surface water, and possibly also vegetation.
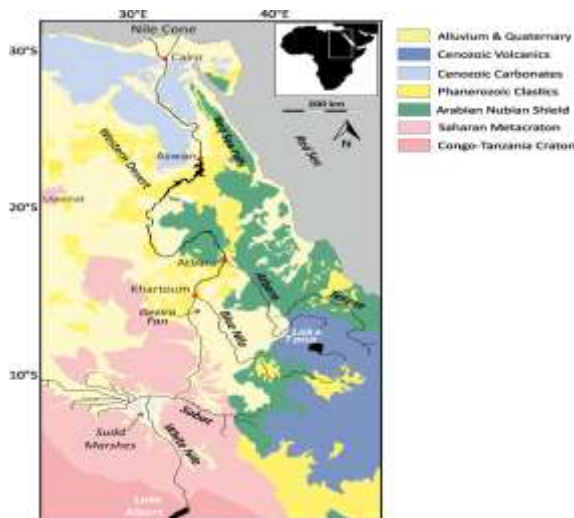
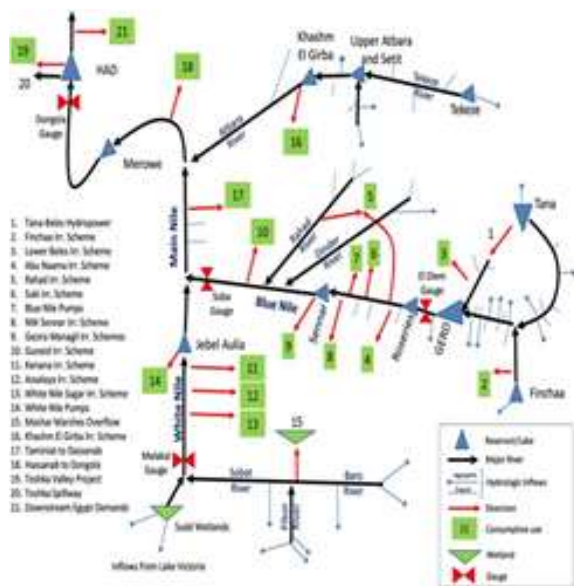Figure 9. Map of Nile River [21].

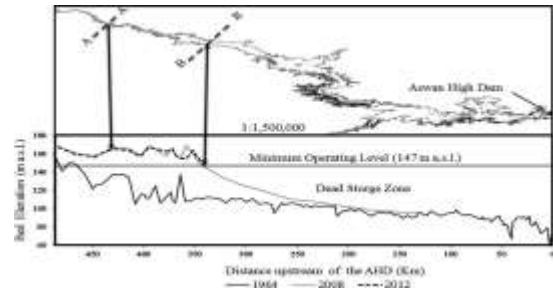Figure 10. Water Demand and Infrastructure Locations in the Nile [22].

Figure 11. Changes in the elevation of the AHDR for 1964, 2008 and 2012 [23].

Construction of dams on many of rivers all over the world must be the greatest performance of human beings in river development and greatest trouble to the stream ecology. Most of dam reservoirs have many such as flood control, hydropower, water supply, irrigation, fisheries, navigation, recreation, and environmental requirements. For the Nile River system there are all types of dams: single-, twin-, and multi- (more than two) purpose reservoirs. Nile tributaries creating from the Ethiopian Highland load large amounts of sediment evaluated at about 160 -180 million tons annually. Many of this sediment is clay and silt transported in suspension during the rainy season. Dam reservoirs built on these tributaries are exposing disturbing loss in capacity due to sedimentation. For example, the Aswan High Dam Reservoir (AHDR) which is the third largest man-made reservoir in the world. It was created as a product of the building of the Aswan High Dam (AHD) across the Nile River. This reservoir has two partitions a riverine partition and a lacustrine partition. The reservoir water level started to increase on construction of the AHD in 1964. In 2016 El-Shazli and Hoermann (2016) [23] illustrated that the AHDR storage capacity evaluated by the DEM decreased by 12% over the period 1964–2013. This lowering was at most in the live storage capacity, the dead storage capacity, and a little in the flood control zone. The sediment deposition exceeded the dead storage zone in the area located between 337.5 and 487 km upstream of the AHD, as Figs. (11:13).

The concentration of sediment decreases from 3000 ppm to just around 40 ppm, before and after AHD respectively. Fig. 14 shows the longitudinal profile and suspended sediment distribution along AHD reservoir. The total deposited sediment volume is estimated to be 2.5 billion m3 in the period 1964-1995. This reflects that the average rate of sediment deposition annually is 140 million m3 i.e. the rate of sedimentation is 0.1 %. It has been noticed that almost all the sediment deposition occurs in the Nile reach between 345 km and 430 km south of the dam site [24].

TABLE II. DAMS AND WATER CONTROL STRUCTURES ON THE NILE RIVER [25].

Structure Name	Location	Structure Name	Location
Delta Barrage	Egypt	Aswan High Dam	Aswan, Egypt

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| Aswan Low Dam	Egypt	Khashm-el-Girba Dam	Atbarah, Sudan
Assuit Barrage	Egypt	Roseires Dam	Blue Nile, Sudan
Sennar Dam	Blue Nile, Sudan	Tekezé Dam	Tigray, Ethiopia
Nag-Hamady	Egypt	Merowe High Dam	northern Sudan
Jebel Aulia Dam	White Nile, Sudan	Burdana	Sudan, Setit
Owen Falls Dam	(Lake Victoria), Uganda	Isimba Dam	White Nile, Sudan
(GERD)	Blue Nile, Ethiopia		

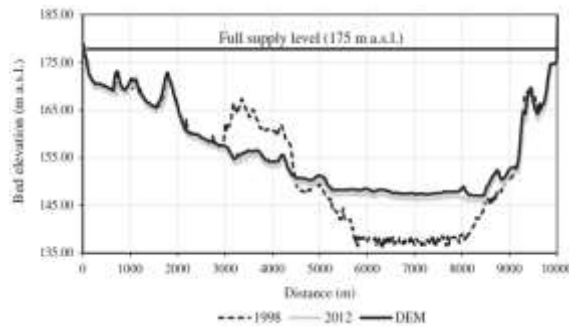Figure 12. Upstream face of cross-section (A–A) at 431 km upstream of the AHD for 1998 and 2012 [23].

Figure 13. Upstream face of cross-section (B–B) at 337.5 km upstream of the AHD for 1998 and 2012 [23].
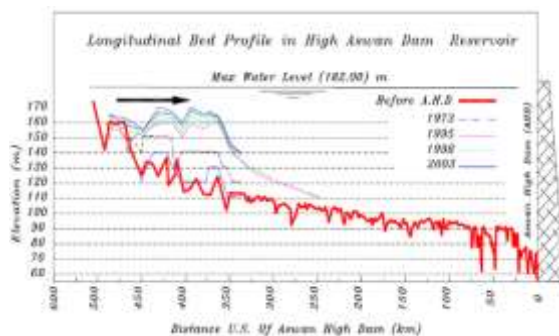

Figure 14. Longitudinal Bed Profile in AHD Reservoir [24].

VIII. Nile River Morphological Changes

The watersheds of Nile river suffer heavily exposed to soil erosion and land degradation due to expanded dry seasons in some parts of the basin, geological nature and pouring rain, resulting large quantities of sediment in the drainage systems. This produces land degradation in the watershed, the lands in Ethiopia Highlands in the east, and in the south around upstream Victoria Lake. In addition to, the deposition of sediment in the reservoirs and irrigation systems downstream lead to serious lowering in storage capacities of reservoirs and hence leading to hydropower generation issues, banks flooding and ultimately negatively impact on the socio-economic lives of the users, environment and ecosystem in general [24].

Many of the sediment in the flow of Nile from the Ethiopian Highlands through the Atbara and Blue Nile river. On the other hand, several research studies summarized that all types of land degradation occur in Ethiopia: soil erosion by wind and water. On the other hand, stream bank erosion, mass movement, biological, physical and chemical degradation are also occurring in the highlands.

The sediment load at El Diem (the entrance of the river to Sudan) in the Blue Nile, Fig. 15, to be 140 million tons per year. Also their assessment of the sediment load at Aswan High Dam in Egypt was 160 million tons taking into respect the amount of sediment transported by Atbara river.

Natural rivers are exhibited to morphological variations due to many factors as the sand encroachment. The moving of sands of different sizes (fine and medium) occupies great areas of the banks of the Nile river system particularly in northern Sudan, as shown in Fig. 16 which demonstrated how the sand encroachment choked the Nile river path.

River bank erosion is one of the most serious problems in river morphology. The process of river bank erosion is a natural process that is unavoidable, therefore the right protection measures must be selected and designed to provide effective, efficient, and durable works after construction. It is a source of sediment in the Nile system especially in the Main Nile as Figs. 17& 18. Fig. 18 shows irrigation canal buried with sand dunes.

The majority of investigated components which close to the Upper Continental Crust, their relative distribution points to the presence of fragments of igneous rocks mostly originating from the Ethiopian Plateau, as the Blue Nile transports about 70% of the all Nile sediments [26].

River Nile meandering lead to change of the morphology and islands river. Ahmed and Fawzi (2011) [27] used Landsat imagery acquired on 1987– 2000 and field observations for study area was Sohag and El-Minia, Egypt. The Landsat images analysis showed that the migration of river path with time and space. Some islands disappear completely in their study area, whereas other new islands appear in other places, Fig. 19.
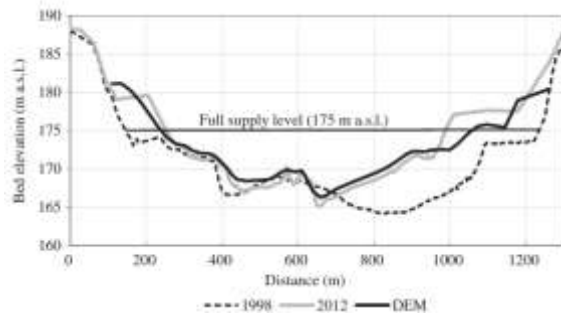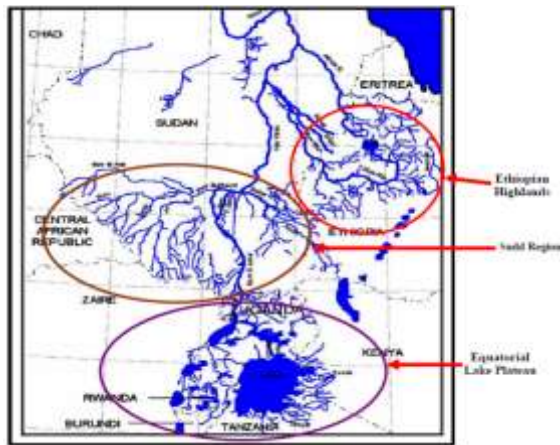
Figure 15. Map of The Three Main Watersheds of the Nile [24].

Figure 16. Sand Nile River Bank in the Sudan Northern State [24].

Figure 17. Bank Erosion in the Main Nile [24].

Figure 18. Irrigation Canal Buried with Sand Dunes in the Northern State – Sudan [24].
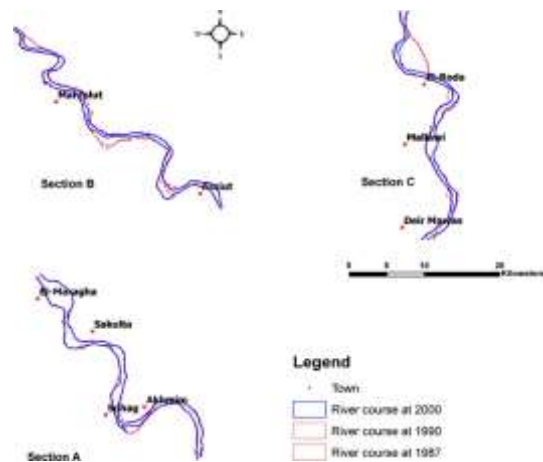

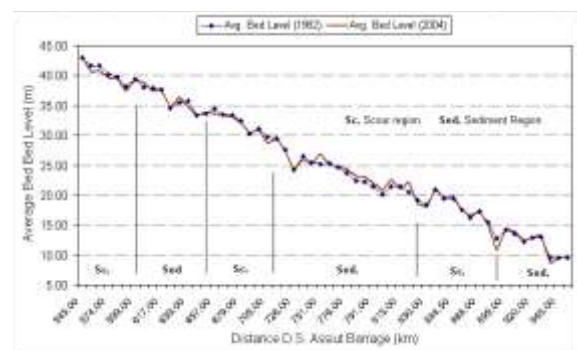Figure 19. Migration of the River Course with Time [27].

Figure 20. Longitudinal Bed Profile of the Fourth Reach 1982, 2004 [28].

IX. Nile River Morphological Models

Dalia, (2012) [28] and Ali Et Al, (2017) [29], applied GSTARS3 which was considered the most suitable model to simulate the water surface profile and the sediment transport in the Fourth Nile River reach located between Assiut Barrage and the Delta Barrage. The model was calibrated and verified using different sediment equations. The model results showed good agreements compared with actual measured data. Dalia (2012) showed that the longitudinal bed profile of the Fourth Reach 1982, 2004, Fig. 20. From this figure, it is clear that the occurrence of bed change is almost a sequence of scouring followed by sedimentation along the reach starting from D.S. Assiut barrage. Dalia found that the deposition had more frequent occurrence than erosion on the bed for the whole reach during the past decades and also in the future.

Negm Et Al (2017) [30], used 2D hydrodynamic mathematical model (CCHE2D) to simulate the morphological changes in Damietta branch and predict the effect of high flows on water velocities and geometrical changes at different cross sections under increasing discharge from 60 to 80 Mm3/day. They found that for the 80 Mm3/day scenario, the bed level at the outer curve increased from 1.0 to 3.8 m, and the eroded volume was 12,921.90 m^3 compared to the base

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scenario of 60 Mm3/day. Some of sections their width were decreased and other were increased as Fig. 21.

Sobeih Et Al (2017) [31], used Delft 3D predict the morphological changes. Two alternatives of navigational paths were proposed the first is in the east channel for Korimat Island where many activities as the intakes of water and power plant exist, while the second path is in the west channel where the channel is narrow and most the flow pass through its. Two cross sections were selected in east and west channel at the same line of that cross lines which integrated the grid as shown in Fig. 22. They showed that the dredging is not the negative solution, but the lack of study to organize which leads to appear some problems a long time.

In 2020, El Saeed Et Al [15] applied Delft 3D model to simulate the flow pattern, assess morphological changes in the river confluence and bed topography under wide range of natural conditions at three different years 1982, 2003 and 2016. Their area study at km 27 from El Roda gauge, near El Marzeek bridge, Egypt, as Fig. 23.

They explained that at year 1982 the velocity has maximum value distributed downstream the confluence along the cross reach, while at year 2003 and 2016 the maximum velocity concentrated toward the main channel, Fig. 24.

x. Nile Morphological Research Studies

Mousaa A.M.A. (2010) [32], studied the morphological changes of reach four of Nile River that is located between Assuit and delta barrage from 1982 to 2004 by using rating curves analysis and cross sections comparisons. By comparing cross sections during the period from 1982 to 2004, he found that lowering in water level at some of sections in upper part of study area due to degradation and changing in the area of cross sections water level due to aggradation. Fig. 25 shows that for different flood scenarios there is a large drop in water level for year 2004 than 1982 due to a huge degradation because this gauging station is just downstream Assuit Barrage causing a lowering of bed level and then a lowering of water level.

Mousaa Et Al (2010) [33], applied GIS to illustrate the morphological changes at length of 4km from 906 to 910 km including Aswan Bridge. He showed that there were degradation and deposition at the different positions for the study cross sections, the study length became shallower and wider in its northern part than it was on the past because the deposition effect. Also at the place where the Aswan Bridge was constructed there was no change in bank for the both sides, but there was a scour around the bridge piers. Fig. 26, shows the changes that occurred to the bed during the period from 1982 to 2007.

Abdallah and Stam (2012) [34], estimated and predicted the Sudanese Eastern Nile reservoirs sedimentation for Roseires and Sennar reservoirs on Blue Nile and Girba reservoir on Atbara River have been carried out. He applied two grey system prediction models, namely Discrete Grey Forecasting Model "DGM (1, 1)" and Verhulst Model. The

average sedimentation volume as shown in Fig. 27 is estimated as measured in Eldiem and upstream Girba dam on Blue Nile and River Atbara respectively where some of scattered suspended sediment of years (1970,73,75,93,94,2000-2009) are available. The models showed as well a rapid decreasing of Sennar storage capacity while Roseires reservoir showed slow storage deterioration mainly in last five years. Girba reservoir flushing process keeps the storage capacity deterioration at the acceptable rate.

Ahmed and Fahmy (2015) [35], illustrated the development of water surface levels for Nile River as an index for bed degradation or sedimentation since AHD construction, the study area was the second river reach which extends from downstream of the new Esna barrages at km 167.830 downstream of Old Aswan Dam (OAD) until upstream of the new Naga - Hammady barrages at km 362.820 downstream of "OAD". They noticed that to monitor such variations in water surface levels and consequently possible sedimentation or degradation through the second Nile River reach after "HAD" construction, the daily recorded observations for water surface levels and the corresponding flow discharges along the study reach were employed to produce stage discharge rating curves as the best and accurate technique to fulfill such purpose, Fig. 28.

Raslan and Salama (2015) [36] explained that the reach between Aswan and new Esna barrages in Egypt was found out in terms of islands development and morphology changes. They illustrated analysis before and after the operation of AHD. They indicated that islands areas have decreased after the operation of AHD. Where the suspended sediment transport has been reduced after the construction of AHD from 3800 ppm to 129 ppm during the flood period, Fig. 29.They demonstrated that the width of the island had increased near the downstream from 1006 m in 1939 to 1272 m in 1982, Fig. 30.

Hekal (2018) [37] evaluated the dynamic morphological equilibrium status of Fourth Reach of the River Nile between Assuit and Delta Barrages throughout the period between 1982 and 2004 of the River Nile. He collected water surface profiles with three discharge values of 1982, Fig. 31. He concluded that the more the discharge released, the less the average equilibrium percentage. He illustrated that the morphological changes were registered at different x-secs along the study reach by registering the water areas of the x-secs of year 2004 and subtracting them from those of x-sects of year 1982, and samples of x-secs that experienced the four cases, Fig. 32.
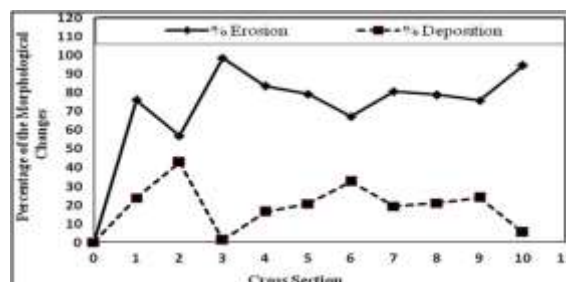

Figure 21. The percentage of the morphological changes at cross sections from 1 to 10 along the Reach of the Damietta branch,[30].
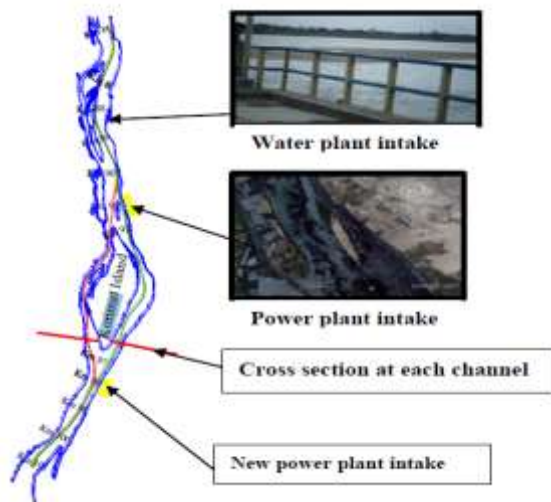
Figure 22. The Navigational Paths Alternatives for the Study Region& Cross Sections at Each Channel of Island [31].
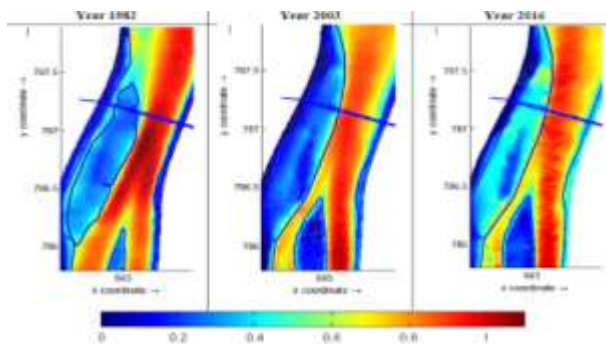

Figure 23. Area Study [15].

Figure 24. The Depth-average Velocity for Maximum Flow at 1982, 2003 and 2016 [15].

XI. River Morphological Challenges

River Morphology is modifying permanently through time. river's responses Prediction to created changes is a difficult issue, because efficient variants in this phenomenon are relative and react to the changes in river technique.

Migration of meandering river process lead the planform morphology and floodplain rivers. Monitoring and planning for river changes are some of the most important challenges for management a meandering river alignment. The channel migration model presumes that the river is able to set its alignment, slope, width, and depth between the boundaries of non-erodible of the river valley. These settings happen so that the sediment transport capacity of the river equivalents the upstream sediment rate without erosion or deposition along the river bed.

Randle (2006) [38] used model to simulate channel migration by computing bank erosion with equation. This equation was based on dimensional analysis and the use of empirical coefficients and it predicted the rate of bank erosion and channel migration. Its model predicted that the initial direction of channel migration was in the lateral direction, across the floodplain, Fig. 29.
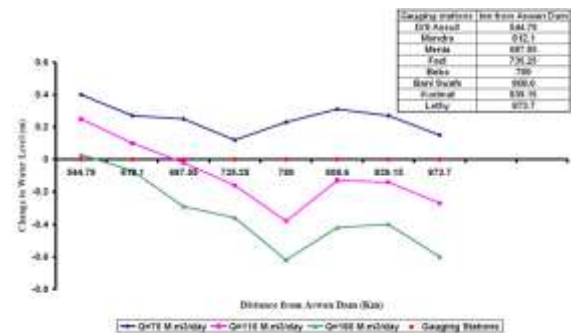

Figure 25. Change in water level between the years 1982 and 2004 at all gauging stations of Reach Four of the Nile River at different discharges [32].
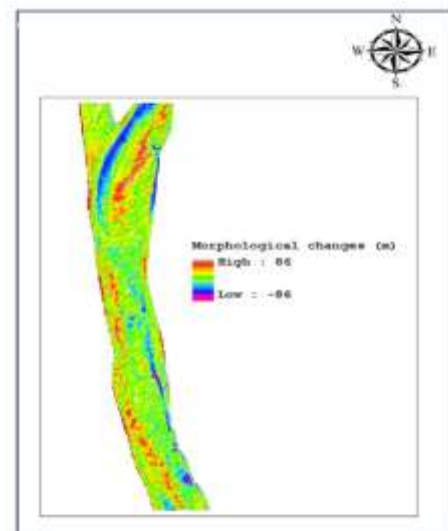

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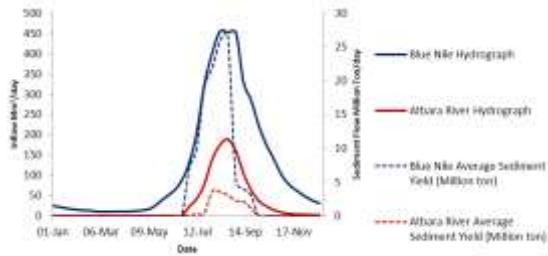Figure 26. Morphological changes between 1982 and 2007 [33].

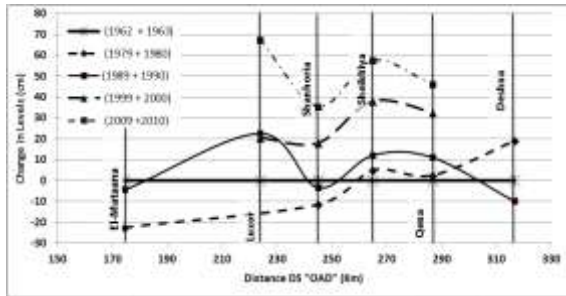Figure 27. Blue Nile and Atbara River sedimentation [34]

Figure 28. Variation of Water Surface Levels along the Study Reach [35].
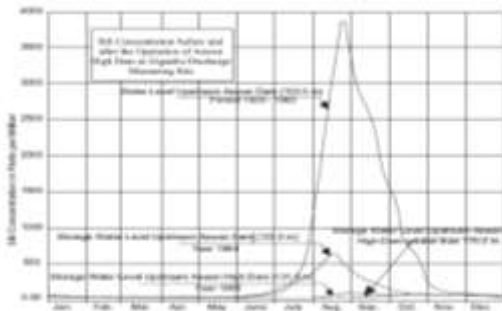

Figure 29. Suspended sediment concentration before and after operation of High Aswan Dam [36].
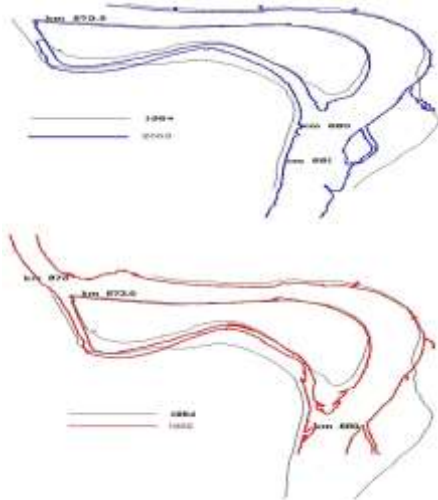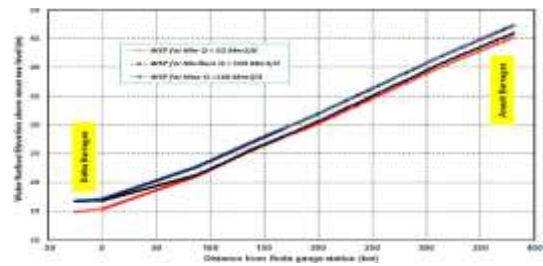

Figure 30. Development of El-Mansouria Island [36].

Figure 31. Water Surface Profiles corresponding to discharges of 62, 100, and 168 Mm3/day during 1982 [37].
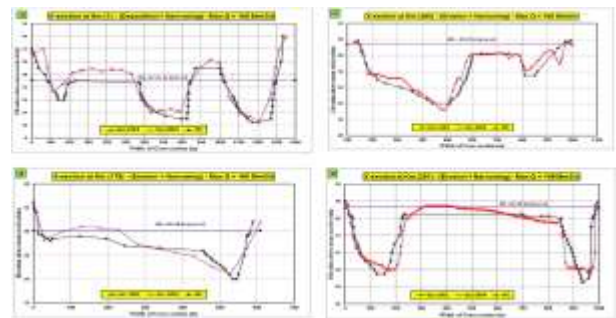

Figure 32. Samples of x-secs experiencing river bed and plan form changes at Max Discharge of 168 Mm3/day [37].
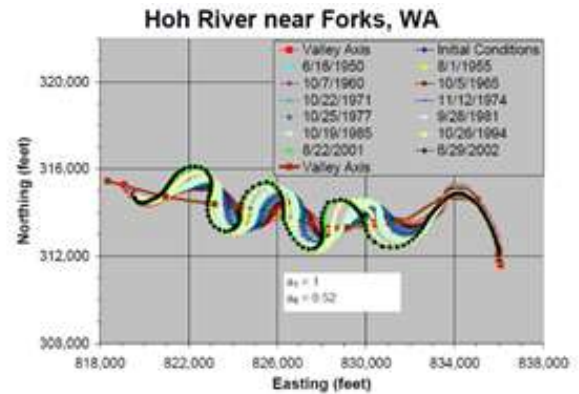

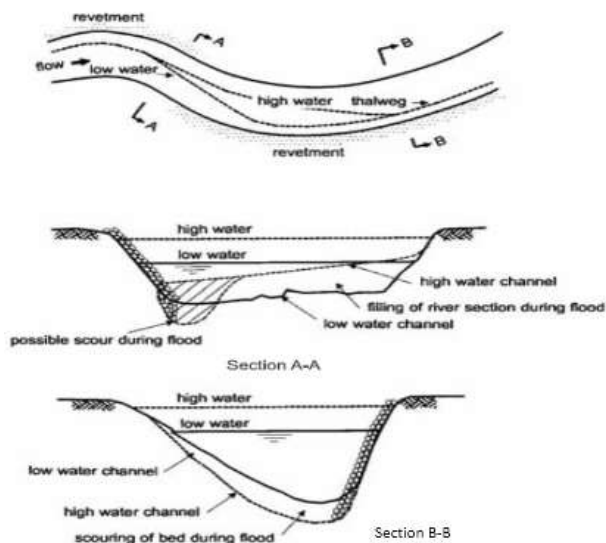Figure 33. Predicted Channel Alignments for the Period 1950 to 2002 [38].

Figure 34. Example for River Morphology Changes [39].

Channel processes in river morphology are erosion, transportation and sedimentation. The erosion of bank or bed material and the deposition of this material somewhere else should be surveyed with reference to the following: Long term Degradation and Aggradation due to variations in boundary conditions; Channel Migration upstream and downstream of the river works; Channel Cross Section Changes due to seasonal variations (Sedimentation Transport); and Location of Existing Revetments of river training works [39]. Figure 31 illustrates an example for river morphology changes for two consecutive bends of a river channel and how the cross sections are influenced by changes in flow rate that is pointed in sections A-A and B-B. Section A-A illustrates how the cross section dimensions varied as the discharge varied. Commonly the cross section fills during high discharge and scours during low discharge as indicated in section B-B.

XII. Summing up

Natural rivers and alluvial canals are sensual to human interference that may vary flow rate and rate of sediment transport. Morphology is defined as the science of structure or form. Morphological changes inside the channel were calibrated by comparing the depths and cross-section shape with years. Hydromorphological estimation is a key foundation for river management and should construct on the increasing understanding of geomorphological processes.

Numerical models supply the basis for understanding the conditions of hydrodynamic and geomorphic in river ecosystems and are a worthy tool towards solving complex problems in river and environmental engineering. The integrated multi-dimensional models having 1-D, 2-D and 3-D models are predictive tools in decision support systems, which are to have wider and wider applications in policy making, management planning and engineering designs to select the best management practices and the optimal design to satisfy all constraints of environment, ecology systems.

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