Challenges of Modeling the Flows of the Nile River

F.M. Mutua[1], F. Mtalo [2] and W. Bauwens[3]

[1]Department of Meteorology, University of Nairobi, P.O. Box 30197, 00100 GPO, Nairobi, Kenya.
Email: fmutua@uonbi.ac.ke

[2]Department of Water Resources Engineering, University of Dar es Salaam, P.O. Box 35131, dare s Salaam, Tanzania. Email: mtalo@wrep.udsm.ac.tz

[3]Department of Hydrology and Hydraulic Engineering, Vrije Universiteit Brussel, Brussels, Belgium.
Email : wbauwens@vub.ac.be

Abstract

Perceptions and realities of water and conflict in basins such as the Nile vary widely. The river continues to be brought into debates about "water wars" by writers on the subject. One of the major problems with the "water wars" thesis is that it includes only a cursory understanding of "scarcity" issues, and of the actual facts and figures that underlie much of the analysis. This fact is as a result of the difficulties and subsequently the inability to be able to model the Nile flows satisfactorily due to the complexity of the geography, the hydrology and the climate – which are the major drivers of the hydrologic system of the Nile basin.

One of the main features of the Nile basin is its varied geography. The second major feature of the of the basin is the hydrological diversity of the two major tributaries of the Nile River. The Blue Nile has a huge seasonality which yields flows mainly concentrated from July to October. The total flow of Blue Nile (including its tributaries) varies greatly from a high of 15.6 BCM in August to just 0.3 BCM in April. The White Nile's average monthly maximum (October) and minimum (February) discharges vary only slightly from 1.4 billion cubic meters (BCM) to 1.2 BCM, A third major feature of the river system is caused by virtue of the river's situation in hot, arid areas where evaporation losses are high.

The north–south orientation of the River Nile on the African continent ensures extreme variability in climate between the extremes of the basin. The Nile Basin receives annually an average rainfall of about 650 mm, or a total of about 1,900 BCM per year. Long-term mean annual flow at Aswan is about 85 BCM per year, making the annual runoff coefficient of the basin to be very small (about 4.5 percent) compared to other basins of the same size in other parts of the world.

This paper explores the challenges and opportunities of modeling the flows of the Nile.

Introduction

The geography of the Nile Basin is both distinct and varied. From the most remote source at the head of the River Luvironzo near Lake Tanganyika and lake Tana of Ethiopia, to its mouth on the Mediterranean Sea downstream. The 6850-km long Nile is the world's longest river, and flows from south to north with a catchment basin covering approximately 10% of the African continent. The river spreads across 10 countries with an area of 3×10^6 km^2 (Figure 1).

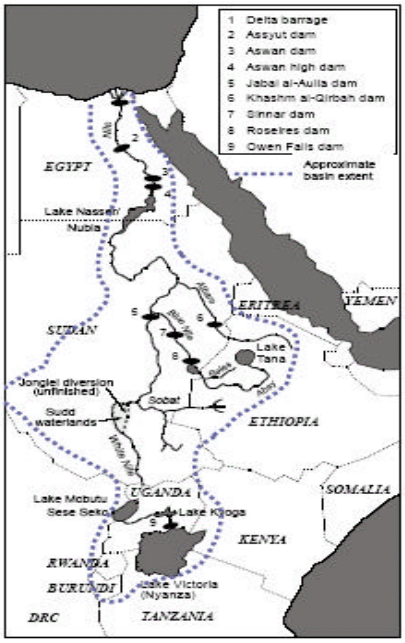


Figure (1): The Nile River basin (Nile Basin Initiative 2002)

Although all the waters in Burundi and Rwanda and more than half the waters in Uganda are produced within their boundaries, most of the water resources of Sudan (72%) and Egypt (97%) originate outside their borders (FAO, 1997). About 94 billion cubic meters (BCM) flow annually to Lake Aswan, Egypt, although only 0.4 BCM are released into the Mediterranean through the Rosetta, Damietta, and other main branches along its 40-km wide delta (Karyabwite, 2000; Varis, 2000; Nile Basin Initiative, 2002). The river has three tributaries: the White Nile, the Blue Nile, and the Atbara. The upper White Nile originates in the East African highlands of Burundi (Figure 2), flows through the now submerged Owen Falls, Lake Kyoga, Kabalega (Murchisson), and Lake Mobuttu to drain into Lake Albert.

Lake Victoria forms the first natural reservoir of the White Nile system. Its heavy rainfall is almost balanced by surface evaporation, and the lake's 23 billion cubic meters outflow mostly from the rivers draining into it, particularly the Kagera. This water flows as the Victoria Nile into Lake Kyoga, , and then into Lake Albert. Water lost through evaporation is more than balanced by rainfall over the lake and inflow from other smaller streams, notably the Semliki. The annual outflow from Lake Albert to the Bahr-El-Jabal River is about 26 billion cubic meters. Figure 2 shows the Nile River profile along its longest span.

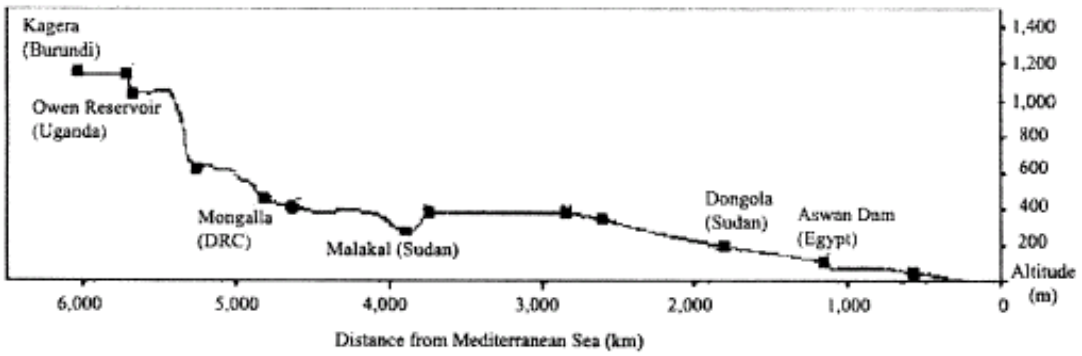


Figure (2): Nile river profile from Kagera to the Mediterranean Sea (adapted from Karyabwite, 2000).

The seasonal (torrential) tributaries of the Bahr El-Jabal supply the Nile with nearly 20 percent of its water. The outflow from the Bahr El -Jabal varies little throughout the year because of the regulatory effect of the large swamps and lagoons of the Sudd region. Though half of its water is lost, at this stage ,to seepage and evaporation, the flow from the Sobat River into the main stream just upstream of Malakal nearly makes up for the loss.

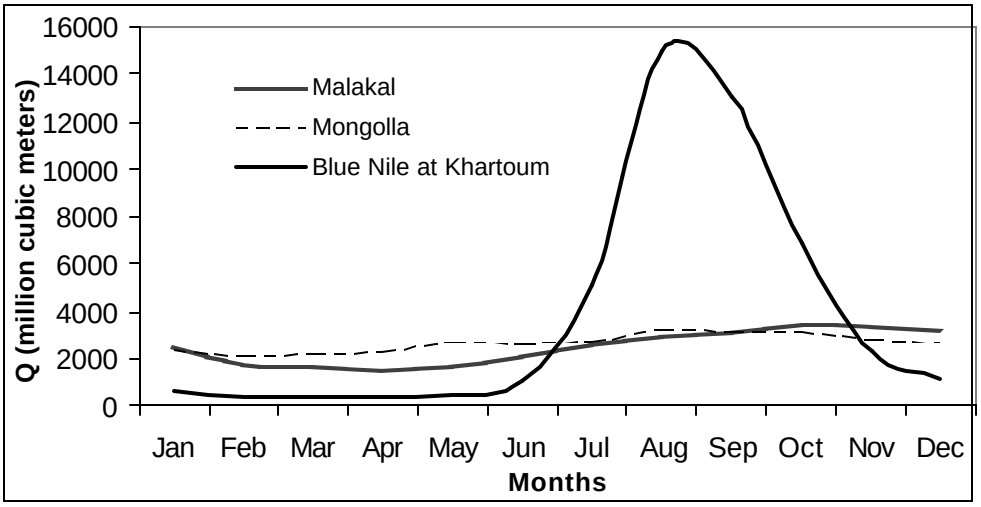
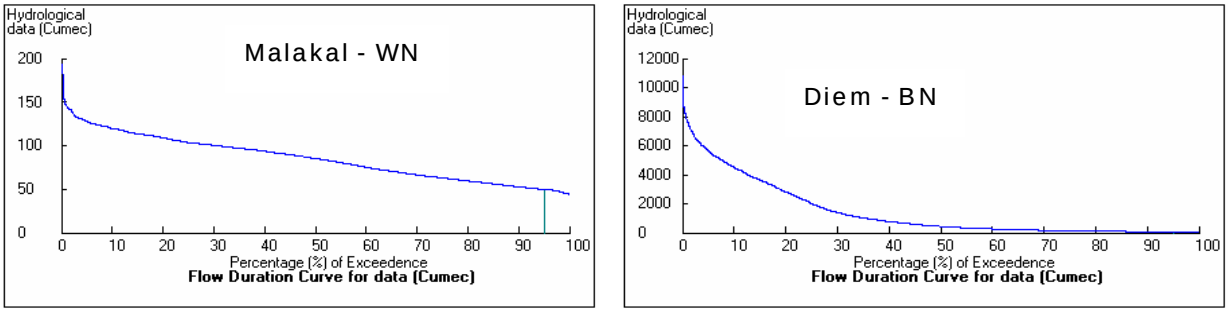


Figure (3): Mean Monthly Distribution of Flows at different locations on the Nile Basin (FRIEND[1]-Nile)

Figure 4 below shows the flow-duration-curves for some selected stations on the Nile river. The storage characteristics of the white Nile are clearly depicted in Malakal due to the Sudd swamps upstream.

[1] FRIEND is an acronym for **F**low **R**egimes in **I**nternational **E**xperimental **B**asins and **N**etwork **D**ata. The FRIEND concept is a worldwide UNESCO initiative which is intended to fulfill some of the objectives of the International Hydrology Program (IHP). The FRIEND in the Nile Basin is also supported by Flemish Government through UNESCO.



(NB: WN = White Nile and BN = Blue Nile)

Figure (4): Flow-Duration-Curves for some selected locations on the Nile River (FRIEND-Nile)

The White Nile provides a regular supply of water throughout the year. During April and May, when the main stream is at its lowest level, more than 80 percent of its water comes from the White Nile. The White Nile obtains its water equally from the rainfall on the East African Plateau of the previous summer and the drainage of southwestern Ethiopia through the Sobat (the Baro and the Pibor) that enters the main stream below the Sudd. The annual flood of the Sobat, due to Ethiopian summer rains, is responsible for variations in the level of the White Nile. Rains swell its upper valley beginning in April causing inundation over the 500 Km of plains through which the river passes, delaying the arrival of the rainwater in its lower reaches until November-December. Relatively small amounts of the mud carried by the Sobat's flood reach the White Nile. On an annual average, the White Nile contributes about 15% of the flow in the main Nile (Karyabwite, 2000).

The Blue Nile plays an overwhelming part in bringing the Nile flood to Egypt. It receives two tributaries in Sudan (the Rahad and the Dinder), both of which also originate in Ethiopia. The regime of the Blue Nile is more rapid in the passage of its floodwater into the main stream. The river level begins to rise in June, reaching a maximum level at Khartoum in about the first week in September.

The Atbara River draws its floodwater from the rains on the northern part of the Ethiopian Plateau, as does the Blue Nile. But while the floods of the two streams occur at the same time, the Blue Nile remains perennial, and the Atbara, shrinks to a series of pools in the dry season.

The rise of the Blue Nile causes the first floodwaters to reach central Sudan in May with the maximum occurring in August, after which the level falls again. The rise at Khartoum averages more than 6 meters. When the Blue Nile is in flood it holds back the White Nile water, turning it into an extensive lake and delaying its flow. On an annual average, the Blue Nile and the Atbara contribute more than 85% of the flow in the main Nile (Karyabwite, 2000).

The peak of the flood does not enter Lake Nasser until late July or August, when the average daily inflow from the Nile rises to some 0.711 billion cubic meters. Out of this amount the Blue Nile accounts for almost 70 percent, the Atbara more than 20 percent and the White Nile 10 percent. In early May the inflow drops to its minimum; the total discharge of 0.045 billion cubic meters per day comes mainly from the White Nile and the remainder from the Blue Nile. On the average, about 85 percent of the water in Lake Nasser comes from the Ethiopian Plateau, and the rest is contributed by the East African Lake Plateau system. Lake

Nasser has an enormous storage capacity, more than 168 cubic kilometers, although the content of the reservoir varies with the extent of the annual flood upstream. Because it is situated in a very hot and dry region, Lake Nasser can lose up to 10 percent of its volume to evaporation annually when it is full, decreasing to about one-third that amount when it is at minimum capacity.

The Nile Basin's climate range varies between extreme aridity in the north (Egypt and Sudan in particular) to tropical rainforest in Central and East Africa and parts of Ethiopia. On the Ethiopian massif, the key contributor of Nile flows, the *kiremt* rains produce the main June to November spate. This spectacular phenomenon is the combination of three mechanisms: the move of the Inter-Tropical Convergence Zone (ITCZ) (summer monsoon) over the highlands, before retreating again, the tropical "upper easterlies," and local convergence in the Red Sea coastal region. The resulting rainfall is often intense, and causes rapid runoff leading to major soil losses.

Changes to the pattern and movement of the ITCZ cause major shifts in rainfall across Ethiopia and neighboring countries, particularly in association with the varied topography in the region. In some years the northeastern highlands of Ethiopia are particularly badly affected by low and unpredictable rainfall patterns, contributing to severe crop failure, and at times major famine.

One of the key factors affecting this rainfall variability is the El Niño–Southern Oscillation (ENSO), the occurrence of positive anomalies in sea surface temperatures over the central and Eastern Pacific Ocean, which can have dramatic global impacts on regional weather systems. In the case of the Nile, studies have shown significant correlation between the ENSO index in May and Ethiopia's *Kiremt* rainfall. The Nile floods are significantly lower than average in all El Niño years, but a strong relationship developed only after 1830 and continues up to the 1980s (Nicol, 2003).

These variable rainfall patterns in recent years have prompted major efforts at better forecasting in the basin. In particular, the successive years of low rainfall during the mid-1980s, with floods in some years barely half a "normal" year, led to a 13% decline in the level of Lake Nasser/Nubia to such an extent that by the time a major rainfall event occurred in August 1988 the turbines were just short of being turned off.

This experience had the dual impact of illustrating how vulnerable Egypt could be to successive low flows in the absence of the High Dam, but also the importance of a more integrated, basin-wide management regime for Egypt's water security. Successive low-flow years would require more than one massive structure to help achieve greater water security in the future; upstream augmentation of flows would also be important.

Nearly all of the river's water is generated on an area covering 20% of the basin, while the remainder is arid or semiarid regions with minimal water supplies and very large evaporation losses (Karyabwite, 2000). The north–south orientation of the River Nile on the African continent ensures extreme variability within the basin. The Nile Basin receives annually an annual average rainfall of about 650 mm (about 1,900 BCM per year). The mean annual flow out of the basin (as measured at the Aswan) is about 85 BCM per year, making the annual runoff coefficient of the basin around 4.5 percent. This figure is small and, for example, is just 10 percent of that of the Rhine. This is mainly due to the fact that the expansive parts of the basin belonging to the arid and hyper-arid zones contribute only negligibly to basin

runoff. With losses from major swamp areas as well, up to 30 percent of the rainfall the basin receives is lost to the atmosphere mainly through evapotranspiration.

Socio-Economic Factors in the Nile Basin

The Nile riparian countries experience frequent occurrence of droughts and a host of other hazards including epidemics. Figure 4 shows the frequency of occurrence and distribution of various types of hazards in the region.

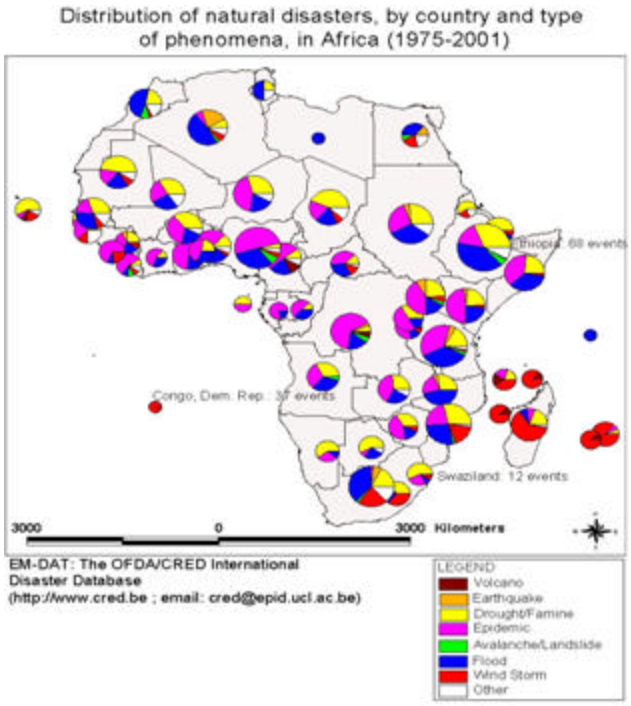


Figure (5): Distribution of "natural" Hazards in Africa (http://www.em-dat.net/)

For a long time, this has continuously acted as a catalyst for impoverishment and intensification of the vulnerability to future drought hazards. This is worsened by the fact that the majority of the population in the basin depend on subsistence rain-fed farming which is highly vulnerable to the high climate variability within in the basin (Baecher et al, 2000, FAO 1977, FAO 2000 Howell and Allan 1994). Understandably, poverty is widespread in the basin. In most cases, the water resources of the Nile are under-utilized for lack of proper opportunities and technologies (FAO 1997). The following tables summarize some of the important socio-economic factors of the Nile riparian countries. In these tables, the notation DRC represents Democratic republic of Congo.

Table (1): Some of the Social Factors in the Nile riparian Countries
(http://www.jnrlse.org/pdf/2003/E02-15.pdf#search='case%20study%20nile%20conflict%20resolution')

Country	Climate	Rainfall (mm)	Present Utilization		PG (%)	AG (%)	LE (yrs)	Infant Deaths in 1000 live births	% of Food imports	Agric as % of GDP	Availability of other resources
			BCM	% of flow							
Burundi	tropical	1000–1500	NA‡	NA	2.9	1.7	49.5	110	18	56	none
DRC	tropical	1500–2000	NA	NA	1.9	2.7	61.6	57	20	30	minerals, oil hydropower,
Egypt	desert	<200	59–60	79	1.9	2.7	61.6	57	31	17	oil, Suez Canal industry
Ethiopia	NA	NA	<0.6	0.5	2.9	-2.1	47	122	17	41	gas, hydropower
Kenya	60% tropical, 30% savannah, 30% semi-arid	NA	NA	NA	3.8	3.4	61	64	10	28	hydropower and tourism
Rwanda	tropical	1000–1500	NA	NA	3.4	-1.1	52	112	9	38	none
Sudan	desert/savannah	400–1500	16	20	2.8	0.8	51.8	99	18	37	oil
Tanzania	savannah/desert	NA	NA	NA	3.6	3.8	55	97	7	59	hydropower
Uganda	tropical	1000–1500	NA	NA	3.4	-0.5	53	94	8	67	hydropower

LE= Life Expectancy
PG= Population growth
AG= Agricultural Growth
† Refer to Exhibit 6 for further information related to GDP and GNP.
‡ NA, not available.

Table (2): The relative ranking of the Nile riparian countries according to the Helsinki Rules (http://www.jnrlse.org/pdf/2003/E02-15.pdf#search='case%20study%20nile%20conflict%20resolution')

Indicator		Burundi	DRC	Egypt	Ethiopia	Kenya	Rwanda	Sudan	Tanzania	Uganda
Country share in area of Nile basin, %		9	7	1	3	6	8	2	5	4
Country water in contribution to the Nile		2	6	8	1	3	2	7	4	5
Climate		9	7	1	3	4	8	2	5	6
Utilization	Past	5	5	1	4	5	5	2	5	3
	Present	4	4	1	3	4	4	2	4	4
Social needs	Life expectancy	8	4	1	9	2	7	6	3	5
	Infant mortality	6	3	1	8	2	7	5	5	4
Economic needs	Income	6	7	1	9	3	4	2	8	5
	Total debt	5	3	2	6	6	8	4	1	7
	Total population 1990	9	3	1	2	6	8	5	4	7
	Average annual growth of population 1987-2000	5	6	8	6	1	2	7	3	4
	Average annual growth of agriculture 1980-7	5	3	4	9	2	6	7	1	8
	Cereal imports	9	4	1	2	5	8	3	6	7
	Food production per capita, index, 1985–1988	3	4	2	5	5	6	5	5	1
	Percentage of labor force in agriculture, 1985–1988	1	7	9	6	5	2	8	4	3
	Agriculture as percentage of GDP 1988	3	7	8	4	7	5	6	2	1

Country share, 1 = largest Present use, 1 = greatest, 4 = least Total debt (% GDP), 1 = largest debt, 8 = smallest Cereal imports, 1 = largest importer

Country water contribution, 1 = greatest Life expectancy, 1 = longest, 9 = shortest Total population, 1 = largest, 9 = smallest Food production index, 1 = highest

Climate, 1 = dry, 9 = wet Infant mortality, 1 = lowest, 9 = highest Average annual population growth, 1 = highest

Past use, 1 = oldest, 5 = newest Income, 1 = highest, 9 = lowest Average annual growth in agriculture, 1 = highest

Table (3): Water resources and availability per person (Karabywite, 2000).

Country	IRWR†	ARWR‡	Dependency ratio%	Per capita IRWR in 1994	Per capita ARWR in 1994
	km3/yr			m3/inhabitant	
Burundi	3.6	3.6	0	579	563
DRC	935	1019	8.2	21973	23211
Egypt	1.7	58.3	96.9	29	926
Eritrea	2.8	8.8	68.2	815	2492
Ethiopia	110	110	0	2059	1998
Kenya	20.2	30.2	33.1	739	1069
Rwanda	6.3	6.3	0	833	792
Sudan	35	88.5	77.3	1279	3150
Tanzania	80	89	10.1	2773	2998
Uganda	39.2	66	40.9	1891	3099

† Internal Renewable Water Resources.

‡ Actual Renewable Water Resources.

§ Dependency ratio represents the extent to which the supply of a country's renewable water resources is dependent on sources external to its political boundaries and can be calculated using the equation (ARWR xIRWR)/ARWR × 100.

A major challenge that is confronting water resource planners in the Nile River basin is the treaty-fixed volume of annual water in the system, 84 billion cubic meters at Aswan according to the 1959 Egypt-Sudan treaty (Waterbury, 1979), serves the needs of one of the world's most rapidly growing populations. Since 1900, the population of Egypt, the largest of the ten riparian states of the Nile River basin, has grown from 10 to 65 million; second-most populous Ethiopia has also grown to 60 million. The total population sustained by the waters of the Nile River and its tributaries is projected to reach 300 million by 2025.

Egypt has traditionally been the major user of Nile River water. Under the 1959 treaty, Egypt was allocated 55.5 billion cubic meters (BCM) per annum, and the Sudan, 18.5 BCM. Ethiopia was not a party to the 1959 treaty, but its rapidly growing population and its desire for industrialization suggest that Ethiopia's need for Nile River water will increase significantly. Other riparian states, such as Uganda, currently use little Nile River water; but they, too, will demand a greater share in the future. Major projects being planned or in progress will expand water demand beyond the nominal 84 BCM per annum. The most noteworthy of these are the Western Desert project and Sinai Canal and Siphon in Egypt, and Ethiopia's plan for a series of dams on the Blue Nile.

With today's population and water constraints, all other Nile states are net importers of food. While the management of Nile River water could be improved, the projected rise in population will create difficulties even under the most efficient allocation scenario. Thus, everything possible must be done to manage the limited Nile River waters in an optimal way.

Challenges of hydrologic Modeling in the Nile Basin

Efficient utilization of the water resources in the Nile Basin demands a good understanding of the past and current hydro-climates but also how these interact with the geography and

geology of the basin to produce the hydrologic characteristics of flow that is observed at different sections of the basin. It is difficult to accomplish this demand due to the following challenges:

- The wide variety of all the drivers of the climate, the geography and the geology and consequently the wide variety of the hydrology of the basin
- Lack of communication and persistence of local and transboundary conflicts
- Widespread Poverty and high persistence of drought. This causes frequent famine hazards which divert the national attention and resources to emergencies. In these circumstances, water resources monitoring and assessment take low priorities.
- Weak national commitments (policies) to hydro-climatic monitoring
- Contentious issues in the past Nile treaties which weaken effective communication and information exchange between the riparian countries (Gleich 2000, Inventory of Conflict and Environment 1997, Howell and Allen 1994)
- Poor technologies in water resources monitoring and assessment

Examples of hydrologic Modeling in the basin

Notwithstanding, many attempts have been made to model the flows in the Nile basin at different spatial scales ranging from small to medium sized basins in individual riparian countries to the whole river basin hydrologic models.

Catchment models

In most cases, the modelings of the small to medium sized basins in individual riparians utilize the conventional catchment hydrologic models. The models which often include input-input, conceptual and occasionally hydrodynamic models are used either in isolation or in some simple combination using catchment data.

Preliminary results from the Rainfall-Runoff Modeling (RRM) Component of the FRIEND-Nile project have shown that data limitations notwithstanding, the simple input-output hydrologic models (the Galway Flow-Forecasting Systems Models) perform well in small humid or strongly seasonal catchments, particularly those which do not have strong water storage characteristics. In the sub-humid catchments where evaporation exceeds rainfall for extended periods of time, the conceptual models perform much better.

Table (4): Performance (Nash-Sutcliffe R^2) of different types of catchment models in the Nile Basin (FRIEND-Nile)

Period	**Model** / **Basin**	**SLM**	**LPM**	**VGFM**	**SMAR**	**ANN**	**SWAT**	**SMARG**
Calibration	Nzoia	60.0	67.0	64.0	68.0	54.0		**72.2**
	Sondu	44.0	67.0	49.0	68.0	67.0		**67.4**
	Simiyu	32.3	39.4	49.9	46.5	52.7	**58.3**	**59.8**
	Blue Nile	77.8	**92.1**	91.2	90.5	91.8		
	Awash	52.0	72.0	53.0	72.0	51.0		
Verification	Nzoia	**49.0**	44.0	45.0	43.0	41.0		41.3
	Sondu	34.0	42.0	21.0	45.0	**68.0**		58.1
	Simiyu	24.8	31.6	41.8	31.0	40.9	**58.8**	**62.1**
	Blue Nile	76.0	**91.1**	89.0	89.2	90.7		
	Awash	47.0	64.0	55.0	79.0	39.0		

On the other hand, in the arid catchments where rainfall is extremely episodic (Wadis in Sudan and Egypt) the event-based HEC-HMS model seems to work well. Other models such as Soil-Water Accounting Tool (SWAT) and HSPF (for WMS) were also available for use in the RRM. The SWAT has so far proved to have a good potential in modeling the flows in some catchments of the Lake Victoria basin. However, the researchers were not able to apply the HSPF model successfully due to some of the following reasons:

- The model data requirement is too heavy. Data on soils and river cross-sections is often not available in most of the catchments in the basin
- The model is "Hard-wired" and even very simple modifications are impossible to implement
- There had not been adequate opportunities to create a strong capacity in the use of the model.
- License limitations

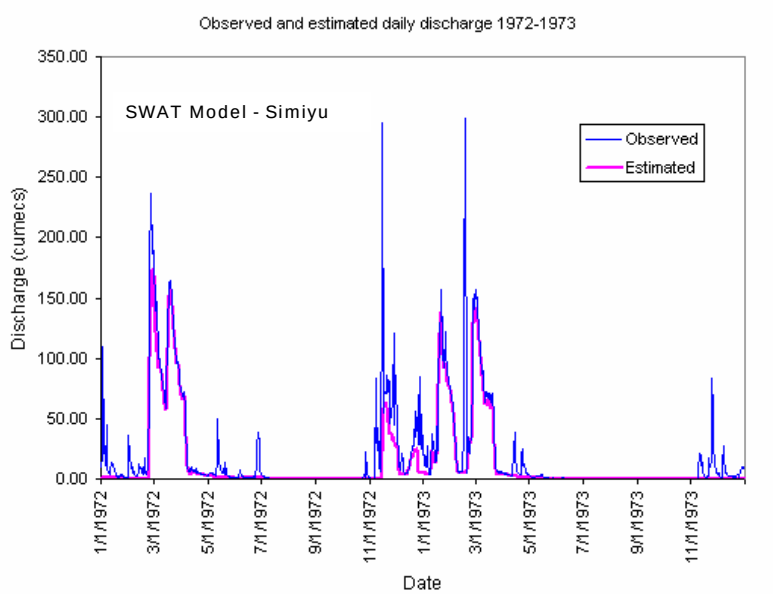


Figure (6): Application of the SWAT Model

The application of the SWAT model in one of the medium sized catchments could not capture the extremes, especially the short-duration floods as illustrated in Figure 6.

Obviously, the "hard-wired" types of models which are often accompanied by strict license limitations have little chance of success in the Nile basin due to the huge hydrological diversity. It is recommended that emphasis should be invested in modified or tailor-made models which are flexible and can be adjusted for local conditions. This should indirectly provide better opportunities for capacity building in catchment modeling in the Nile Basin.

Regional hydrologic models

In general, lack of data either due to conflicts within/between some riparians or mistrust between some riparians has been some of the major hindrances in the development of large-scale or basin-wide models for the Nile basin. The Institute of Hydrology (Center for Hydrology and Ecology) in Wallingford UK was the only institution that continued doing serious transboundary (hydrological) research in the Nile basin during the periods when inter-

riparian collaborations were at their lowest levels. There are many detailed publications on the hydrology of the Nile which were spearheaded by researchers who were based in the Institute of Hydrology. However, In the recent past, there have been many initiatives that have focused on a greater regional cooperation in the Nile basin. These efforts have considerably eased the mistrust that previously existed between the riparians. The WMO-UNDP Hydro meteorological Survey of the Upper Nile basin Project successfully illustrated the vital importance of riparian collaboration in turning conflict potential into potential for cooperation. This paved the way for more collaboration amongst the Lake Victoria riparian countries, such as the Lake Victoria Environmental Management Project, the Nile Basin Research Project and the Nile Basin Initiative (http://www.gefweb.org/COUNCIL/council7/wp/lakevic.htm)

Basin-wide hydrologic models

The climate, geography, and geology of the Nile basin vary greatly from one place to the other, even within very short distances of less than 100 Km. The correct hydrologic representation of the basin would therefore require a cascading combination of many distributed models (input-output, water balance and hydraulic) which when connected would form the basin-wide model or basin simulator. Obviously, due to the size of the basin and the limitations of data exchange protocols, a detailed Nile simulator, while theoretically plausible, is practically impossible not only due to computational restrictions but also due to the real problem of data scarcity. Consequently, many assumptions and approximations have to be made in the cascade of the Nile Simulator components in order to have an operational model. This greatly comprises the accuracy of the model. Consequently, such a model would have limited usage in engineering and design applications where high accuracy is demanded. However, such approximate simulators are useful in planning and in conflict resolution where possible options and scenarios are the key requirement. By necessity, one of the main requirements in a Nile Simulator is the simplicity and appearance of the outputs from the simulator.

A number of basin simulators have been developed for the Nile basin. Some of the more popular ones are:

- The Nile Decision Support Tool (Nile DST) (http://www.faonile.org/)
- The Nile Simulator (http://www.isr.umd.edu/CELS/research/nilesim/paper.html) - NileSim.

Each of these Nile simulators uses a unique conceptual algorithm (analogue) for the basin. The analogue for the NileSim is shown in the figure below:

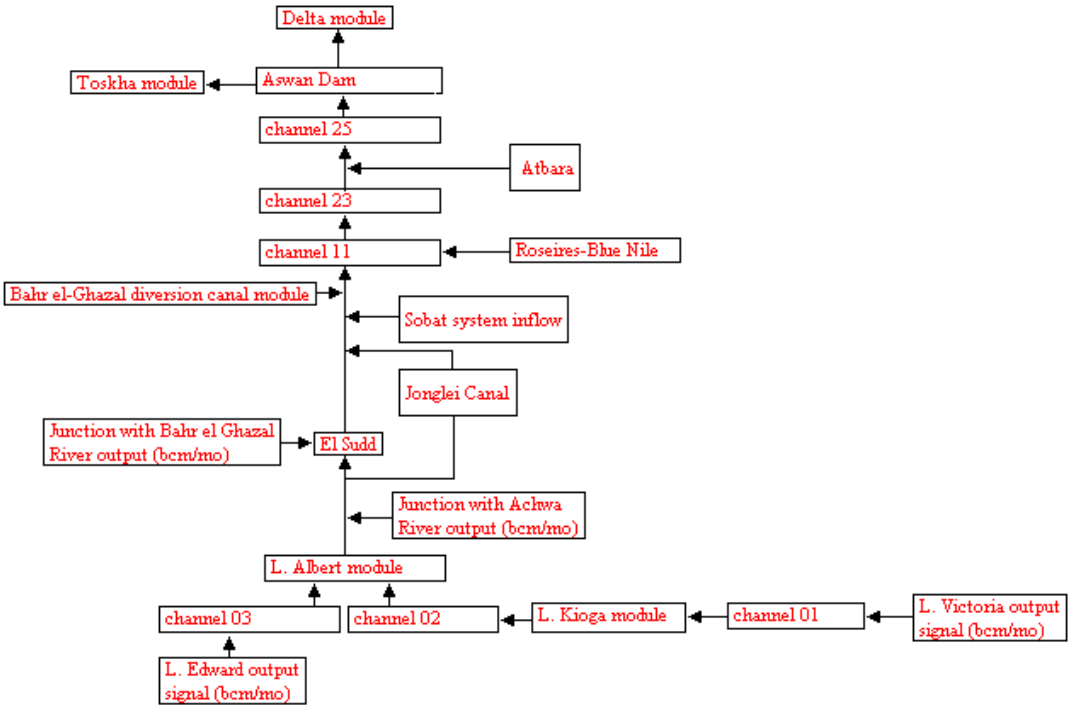


Figure (7): A Simulator-Analogue for the Nile Basin

In both the Nile DST and the NileSim, the user sees a GUI that shows a full-screen image of the Nile River basin from the Equatorial Lakes and Ethiopia to the delta. While the simulator program is a complicated set of the algorithms, the user only interacts with the GUI.

Conclusions

The Nile basin is comprised of many countries with many contrasting attributes such as wealth, climate, topography, religion, race, customs and traditions. There is no other basin in the world with this rich diversity. Unfortunately, this diversity has been the cause for many conflicts and deteriorating communication between the riparian countries in the basin. The water resources in the basin comprise of a huge potential, yet it is now barely sufficient for all in the basin. It is projected that the Nile basin countries will start experiencing acute water scarcities by the year 2025 particularly due to environmental changes and population growth (Varis 2000, Nileriver.com 2002). This calls for a turn-around in the way the peoples of the basin have been managing this resource. The most logical point to start is to commence with the improvement of national water resources monitoring and assessment programs and to intensify efforts that lead to effective and long-lasting information-sharing mechanisms between the riparian countries. This will pave way for a better understating of the temporal and spatial distribution of the water resources in the basin and would, more importantly provide a better insight into the sensitivity of the Nile system to different operational or management scenarios of water resources development in the basin. Obviously, hydrologic modeling is indispensable in this process. Efforts should be made to model the cascade of the headwater and middle basins as well as the downstream channel flow characteristics. It is important to note that the "hard-wired" types of models which are often accompanied by strict license limitations have little chance of success in the Nile basin which has such a huge hydrological diversity. It is recommended that emphasis should be invested in modified or tailor-made models which are flexible and can be adjusted for local conditions. This should

indirectly provide better opportunities for capacity building in catchment modeling in the Nile Basin.

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