WATER RESOURCES DEVELOPMENT: COMPETING NEEDS, ANALYSIS AND GLOBAL TREND

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1.0 INTRODUCTION: REVIEW OF WORLD WATER

Water is one of the abundant natural resources on earth, covering 75 percent of the earth surface but the amount available for human use is very limited. 97% world's water is contained in the oceans and other saline bodies of water which are not readily usable for most purposes while only 2.5% is freshwater. The greater portion of the fresh water (68.7%) is tied up in ice caps, glacier, atmosphere and soil moisture and is not accessible. Fresh groundwater comprises 29.9% of freshwater resources. Only 0.26% of the total amount of fresh water on the earth is concentrated in lakes, reservoirs, and river system and this is the most accessible for mankind supplies (Engelman and LeRoy, 1993). Precipitation in form of rainfall is the primary source of freshwater with an annual flow about fifty times the normal stock held in lakes, rivers and reservoirs (World Bank, 1995).

The total water resources in the world are estimated in the order of 43,750 km^3/year, distributed throughout the world according to the patchwork of climates and physiographic structures. At the continental level, America has the largest share of the world's total freshwater resources with 45 percent, followed by Asia with 28 percent, Europe with 15.5 percent and Africa with 9 percent. In terms of resources per inhabitant in each continent, America has 24 000 m^3/year, Europe 9 300 m^3/year, Africa 5 000 m^3/year and Asia 3 400.1 m^3/year (FAO, 2003).The annually renewable river runoff is the most important component of the hydrological cycle and has a pronounced effect on earth's surface ecology and the world economic development.

The river runoff is the most widely distributed over the land and provides a major part of water use in the world. In practice, the quantity of river runoff serves as a basis for determining the availability and deficits of water resources in a region. Much of the available surface water is limited to a number of rivers: the Amazon carries 16 per cent of global runoff, while the Congo-Zaire River Basin carries one-third of the river flow in all of Africa. The arid and semiarid zones of the world, which constitutes 40 per cent of the land mass, have only 2 per cent of the global runoff (Kuylenstierna et al., 1998). Table 1.1 shows the world largest rivers, their drainage basins and discharge rates.

Table 1.1 World Largest Rivers

Rank	Name Of River	Location Country	Drainage Basin ($1000km^2$)	Discharge Rate (m^3/s)
1.	Amazon	Brazil	6150	175,000
2.	Congo	DRC	3822	39,000
3.	Mississippi	USA	3222	17,270
4.	**Plata-Parana-Grande**	Argentina	3100	22,900
5.	Nile	East/North Africa	2802	3,000
6.	Yenis	Russia	2619	18,000
7.	Lena	Russia	2478	16,100
8.	Ob-Irtysh	Russia	2470	10,200
9.	Niger	West Africa	2092	5,700
10.	Amur	Russia	2050	9,800
11.	Yangtze	China	1827	32,190

Source: Environment Canada (1988)

Water in the environment, in global and regional and national economies, and the societies and polities in which it is embedded, is universally regarded as an essential commodity and frequently as an appreciated amenity. Such is water's fundamental place in sustaining life and livelihoods that human societies have devoted political energy and substantial economic resources in ensuring secure supplies (Allan, 1999). The management of water resources has attained a high security status and national interest (Tafesse, 2001) to the extent that water-scarce regions are increasingly looking at water as a strategic resource worth fighting over (Gleick, 1998) and which has lead to playing regional hydropolitics. However, since 1948, there were only 37 incidents of acute conflict between riparian states over water involving violence while in the same period, 295 international water agreements were signed (OSU, 2011).

Nearly 40 per cent of the world's population live in the more than 200 river basins that are shared by more than two countries (Seragelin, 1995). These basins account for about 60 percent of the earth's land area (World Bank, 1995). Africa has a large number of transboundary rivers and lakes. More than 80 rivers and lakes are shared by two or more countries (Salman, 2002). There are 54 drainage basins that cover approximately 50 per cent of the total land area of the continent of Africa. Of these, 11 rivers drain four or more states with the largest draining 10 states. No less than 6 African countries depend on water largely imported from outside their territories: Egypt, 97%; Mauritania, 95%; Botswana, 95%; Gambia, 86%, Sudan, 97%; Niger, 64% and Senegal, 34% (Douwdeswell, 1998).

Towards water conflict prevention and resolution, members of international communities do convene from time to time to deliberate and initiate binding action on the issue of water. This has yielded more than 300 treaties to deal with specific international water issues and 2,000 treaties have water provisions (Gleick, 1993, Engelman and LeRoy., 1993). The availability of sufficient water resources is one of the major crises with overarching implications for many other world problems especially poverty, hunger, ecosystem degradation, desertification, climate change, and even world peace and security (Khan and Hanjra, 2009).

2.0 COMPETING NEEDS OF WATER RESOURSES

Water is not only essential to sustain life; it also plays an integral role in the ecosystem support, economic development, community well-being, and cultural values (Gleick, 1998). Water is unprecedentedly value laden. The values and beliefs attached to water can easily be observed in the way it is cherished, treated and revered in the custom, religion and cultural practices in different parts of the world. About 30 diseases have been identified to be linked to unsafe water. The transmission mechanism and preventive strategies are enumerated in UNICEF (1999). Good quality water therefore is the most potent means of improving health and enhancing life expectancy. Access to adequate safe water is cornerstone in public health (Walker et al., 2002) and is the most effective means of implementing healthcare policies and poverty alleviation throughout the world (Catley-Carlson, 1988).

Over the recent years, the issue of water and issues coming from its management have become central within debate worldwide, at all levels: economic, institutional, political and social. The central nature of the "water question" worldwide can be traced to a multiplicity of reasons, but one in particular represents, with direct efficacy, the reason for which the study of problems linked to water and potential policy approaches for solving them have become so fundamental today and, even more so, for future and this is the fact that although renewable, water is a scarce resource. As the World Bank has noted, water can be diverted, collected, purified, packaged, transported and transformed, however, it cannot be manufactured. This simple observation leads to complexity of handling and managing water as a resource which represents one of the greatest challenges that society faces today on a global scale (Barilla Center for Food & Nutrition, 2009). The competing water needs are categorized into two as shown in Table 2.1. The change in the amount of water available and water demands are likely to lead in many cases to increase competition for resources. Competition for water resourses among sectors, regions and countries, and associated human activities is already occurring. About 40% of the world's population live in regions that directly compete for shared transboundary water resources (Hanjra and Qureshi, 2010). Competition for or conflicts do arise between users, regions, and countries, and the resolution will depend on political and institutional arrangements in place ro resolve. Water supply and quality are intimately connected, yet traditional scientific boundaries between climatology, hydrology, limnology, ecology and the social sciences fragment understanding and treatment of water systems.

Table 2.1 Basic Competing Water Needs

Water Needs	
Off-stream	In-stream
Municipal	Hydropower generation
Industrial	Navigation
Agricultural	Recreation
Commercial	Ecosystem

Conflicts are not synonymous with armed or violent acts rather it is a situation of disagreement over access and the right of distribution of water. Thomasson (2004) arrives at the following definition of a conflict after synthesis of various definitions: “A conflict is a social situation in which at least two actors try to, at the same time, gain access to the same set of resources”. Another supposition is that conflict per se does not have to be negative. Most societies have institutions that deal with conflicts such as legal systems, democratic or participative procedures, etc. It is when these systems are either not in place or do not work that conflicts can become detrimental for large groups in the affected societies.

The human impacts on the quality and quantity of fresh water can threaten economic prosperity, social stability, and the resilience of ecological services that aquatic systems provide. As societies and ecosystems become increasingly dependent on static or shrinking water supplies, there is a heightened risk of severe failures in social systems and complete transformations of ecosystems. Rising demand for fresh water can sever ecological connections in aquatic systems, fragmenting rivers from floodplains, deltas, and coastal marine environments. It also can change the quantity, quality, and timing of freshwater supplies on which terrestrial, aquatic, and estuarine ecosystems depend (Jackson, et. al., 2001)

Increasing water demand and resultant discharge of wastewater are leading to gradual decline in surface water quality in most world regions. This deterioration in quality also damages the aquatic ecosystem which provides many other benefits directly (such as fish for food) or indirectly (such as providing habitats for other organisms). Until recent decades, the indirect benefits of aquatic ecosystems have been ignored and the traditional approach to managing water resources has tended to simplify the hydrological cycle and consider the water body in isolation of its surrounding catchment (Jewitt, 2002; Chapman, 2010). Global demand for water has tripled since the 1950s whereas fresh water supply has been declining (Gleick, 2003). Half a billion people live in water-stressed or water-scarce countries and by 2025 it is estimated that the number will grow to three billion due to an increase in population. Irrigated agriculture is the dominant user of water; accounting for about 80% of global water use (Molden et al., 2007). The continued increase in demand for irrigation water over many years has led to change water flows, land clearing and therefore deteriorated stream water quality.

Addressing these environmental concerns and fulfilling urban and industrial water demand will require diverting water away from irrigation which reduces irrigated area and its production with consequential impact on future food security (Hanjra and Qureshi, 2010). Conflicts from the competing demand for water resources are traditionally solved through the instrument of legislation, prices, subsidies, priority rights and demand management. However, the solution to resolving the competing needs is cooperation. The UNESCO DG put it succinctly at the Rio+20 conference in 2012 that with transboundary river basins and aquifer systems representing almost half the earth’s surface and water cooperation is vital to peace. Cooperation is necessary to deal with issues such as water allocations, upstream and downstream impacts of water pollution and water abstraction, construction of infrastructures, overexploitation, deciding on financing management of water resources and water services (UN, 2013). The water cooperation is gradually getting attention among the world communities.

3.0 ANALYSIS OF WATER RESOURCES

3.1 Inflow Hydrology and Modeling

An assessment of the available water resources is a pre-requisite to undertaking an analysis of the demand stress on the water resources and adoption of appropriate management strategies to avoid adverse environmental effects and to be able to reconcile conflicts between users (Xu and Singh, 2004). The water supply planning and management philosophy has been based largely on the concept of firm yield which should exceed demand by some reasonable margin of safety (Carbezas and Ralph, 1986). Inflow hydrology is an important aspect of reservoir operation studies. The persistence of high and low flows often described by their correlation affects the reliability with which a reservoir of a given size can provide a specified yield (Loucks et al., 1981).

Multipurpose water resources planning emerged as a result of increase in the competing and conflicting water uses due to rapid population growth and rising expectations of a better life (Matondo, 2001). The reservoir capacity together with operating policies determines the extent to which stream flows can be stored for later release. The primary purpose of a reservoir is to provide a means of regulating surface water flows. The storage-yield relation is the traditional approach commonly used in the determination of the required capacity of storage reservoir. The storage yield relationship is determined by applying mass curve technique introduced by Rippl in 1883 (Buras, 2000) to the available historical streamflow record. The important performance criteria for water resources include reliability, resilience, safe-yield, and probable maximum flood.

Stochastic streamflow models introduced by Sudler, 1927; Barnes, 1954; Fiering, 1967 and others (Vogel, 1987) provide flexible tools that can be used to circumvent the shortcomings of the use of the historical required storage alone. Essentially, synthetic streamflow forecasts derived from such models are also used to estimate the reliability or probability with which a storage reservoir can deliver scheduled quantities of water. The probability distribution of the required storage capacity (K) of a reservoir to supply a prespecified release has been derived using stochastic streamflow models by Fiering, 1967; Vogel, 1985; Wallis and Matales, 1972; Vogel and Stedinger, 1987 (Philipose and Srinivasan, 1995).

Various modeling approaches exist to treat the stochastic nature of streamflows records; however two most common approaches are the deterministic and stochastic. The purpose of streamflow modeling is to determine suitable operating rules with particular emphasis on rules for over-year rather than within-year storage operations. A decision has to be taken on whether to use the historic flow record:

1. as a deterministic time series of reservoir inflows records;
2. to generate a set of synthetic streamflow sequences for a deterministic monte-carlo; or
3. to derive statistical parameters of the underlying population of streamflows records in order to develop a stochastic model of the reservoir inflows.

The first approach is the simplest but it depends on the flow records that are sufficiently long and climatologically representative. Its disadvantage is that reservoir releases and operating rules are determined from a single time series of flows. It is difficult to check the robustness of the prescribed policy to events that are more extreme than witnessed during the historic record. Despite this limitation, deterministic approach is used in the majority of simulation models and in many early applications of optimization models (Draper, 2001). In general a time series may consist of only deterministic events, only stochastic events, or a combination of the two.

Most often, a hydrologic time series will be composed of a stochastic component superimposed on a deterministic component. Ultimately, design decisions must be based on a stochastic model or a combination of stochastic and deterministic models. This is because any system must be designed to operate in the future. A stochastic model is a probabilistic model having parameters that must be obtained from observed data. Stochastic stream flows are neither historical flows nor predictions of future flows, but they are representative of possible future flows in a statistical sense (Yurekli and Ozturk, 2003).

3.2 Streamflow Models

Streamflow is essentially a random variable and based on this assumption, it is possible to develop a synthetic flow record by statistical methods (Linsley et al., 1992). The sequential extension of a historic flow record can also help with the assessment of future water resources and with their management by simulation of the behaviour of a water resources system (Shaw, 1988). Time series analysis and synthesis are used to model most streamflow records. A number of stochastic models have been considered in the literature for synthetic generation and forecasting of hydrological processes (Karamouz et al., 2003; Philipose and Srinivasan, 1995; Loucks et al., 1981; and Fortin et al., 2004 etc). Thomas and Fiering in 1962 used the markov chain model for generating monthly streamflow using the following recursion equation known as Lag-one single period Markov model (Raghunath, 2006) :

$$q_{i+1} = \bar{q}_{j+1} + b_j\left(q_i - \bar{q}_j\right) + Z_i S_{j+1}\sqrt{(1 + r_j^2)}$$

Where:

$q_i \; and \; q_{i+1} = the \; flows \; in \; the \; i^{th} \; and \; (i + 1)^{th} \; month \; from \; the \; start \; of \; the \; synthetic \; sequence$

$\bar{q}_j \; and \; \bar{q}_{j+1} = the \; mean \; monthly \; flows \; in \; the \; j^{th} \; and \; (j + 1)^{th} \; month \; of \; annual \; cyle \; (ie \; 1 \leq j \leq 12)$

$z_i = a \; random \; deviation \; of \; the \; flows \; for \; the \; (j + 1)^{th} \; month$

$r_j \; = correlation \; coefficient \; between \; flows \; in \; the \; j^{th} \; and \; (j + 1)^{th} \; months$

$b_j \; = regression \; coefficient \; for \; estimating \; flows \; in \; the \; (j + 1)^{th} \; from \; j^{th} month$

$b_{\boldsymbol{j}} = \; r_j \times \; S_j + 1/S_j$

$S_j and \; S_{j+1} = standard \; deviation \; during \; the \; j^{th} \; and \; (j + 1)^{th} \; season$

Hydrologic processes such as streamflow are often well represented by stationary linear models such as autoregressive (AR) and autoregressive moving average (ARMA) models. These models are usually capable of preserving the historical statistics such as mean, variance, skewness, and covariance (Fortin et al., 2004; Phillipose and Srinivasan, 1995 and Shaw, 1988). AR models have their development going back to the application of Thomas Fierring and Markov Lag-1 models. They can be classified into two (Karamouz et al., 2003):

- AR models with constant parameters which are typically used to model annual series.
- AR models with time variable parameters, which are typically used for modeling of seasonal (periodic) series.

The basic form of the AR model of order p, (AR, p), with constant parameters is (Philipose and Srinivasan, 1995):

$$Z_{v,\tau} = \sum_{j=1}^{p} \phi_{j,\tau} Z_{v,(\tau-j)} + \varepsilon_{v,\tau} \qquad \text{(Eqt. 3.2)}$$

Where the subscript v and τ denote the year and the period, respectively, $\{Z_{v,\tau}\}$ is the time series suitably transformed and standardized and has an expected value equal to zero, $\phi_{j,\tau}$ are the autoregressive parameters and $\{\varepsilon_{v,\tau}\}$ is the error term (white noise) and assumed to be uncorrelated. The general structure of ARMA model is given as (Philipose and Srinivasan, 1995):

$$Z_{v,\tau} = \sum_{j=1}^{p} \phi_{j,\tau} Z_{v,(\tau-j)} + \varepsilon_{v,\tau} - \sum_{j=1}^{q} \vartheta_{j,\tau} \varepsilon_{v,(\tau,j)} \qquad \text{(Eqt. 3.3)}$$

Where $\vartheta_{j,\tau}$, the moving average parameters and the other notations are the same as for AR. Once ARMA is fitted to a time series, the synthetic generated values conserve the statistical properties of the historical data (Karamouz, et al., 2003).

3.3 Spatial Hydrology Models – A GIS Supported Modelling System

Geographic information system (GIS) is a broad, complex and rapidly-evolving technology highly suitable for spatial and temporal data analyses and information extraction. It is an information system with a database consisting of (1) observations on spatially distributed features, activities or events; (2) procedures to collect, store, retrieve, and display such geographical data (Miloradov and Marjanovic, 1998). A spatial hydrology model is one which simulates the water flow and transport in a specified region of the earth using GIS data structures. The motivation for using such models includes (Xu and Singh, 2004):

1. for a variety of operational and planning purposes there is need to estimate the spatial variability of resources over large areas at a spatial resolution finer than the one that can be provided by observed data alone.
2. water management require the knowledge of the effects of land-use and climate variability and change over a large geographic domain and,
3. there is an increasing need for using hydrologic models as a base to estimate point and non-point sources of pollution loading to streams.

4.0 DEVELOPING AND MANAGING RIVER BASINS: GLOBAL TRENDS

4.1 Integrated Water Resources Management (IWRM)

Water resources management is in a difficult transition phase, trying to accommodate large uncertainties associated with climate change while struggling to implement a difficult set of principles and institutional changes associated with integrated water resources management (Stakhiv, 2011). The consensus that water management has social, economic, environmental, and security ramifications began to gain mainstream attention in the 1990s. At the 1992 International Conference on Water and the Environment (ICWE) in Dublin, participants proposed guiding principles for an integrated, more holistic approach to water stewardship.

Integrated Water Resources Management strategies seek more balanced consideration of both supply and demand dynamics, coordinating between multiple uses, stakeholder claims, and ecosystem needs including geographic areas. Policymakers increasingly view the approach as not only a better way to manage water, but also as a more effective means to spur cooperation between riparian states. IWRM is based on the philosophy that all uses of water are interdependent and that water exists both as a social and economic good (Michel et al., 2002). It is considered a path to bring many elements within the development schemes together toward a unified land-water planning and management (Ahmad et. al., 2012).

The world summit on sustainable development (WSSD) held in 2002 in Johannesburg set a target for all countries to prepare integrated water resources management and water efficiency plans by 2005. Thus the Nigeria integrated water resources management commission (NIWRMC) was established six years after. It is a Federal Government of Nigeria organization with the following mission: “to provide sustainable, effective, efficient and equitable management of Nigeria’s water resources through local, regional and national actions and cooperation”. The new integrated approach to sustainable water supply requires greater knowledge and understanding of technological, social, economic and ecological dimensions of water resource management and how they are interrelated. Developing the capacity to engage in integrated sustainable development planning from community level to the highest national decision-making level remain a major challenge in Nigeria and many other African countries (Gbadegesin and Olorunfemi, 2009). At the fourth World Water Forum in Mexico in 2006, Yemen, Tunisia, Palestine, Morocco, Jordan, and Egypt were recognized as the most successful MENA countries and territories to formally incorporate IWRM into their national water policies. While the Algeria, Kuwait, Iraq, Oman, and Qatar meanwhile were judged to be the least successful in meeting the Johannesburg goals.

4.2 River Basin Development Organization

The basic functions that comprise water resources management (see Table 4.1) can be performed by a variety of actors and at multiple levels. From a hydrological perspective, performing certain functions at the basin level makes good sense such as planning water resources development, allocating water between competing uses, flood control, monitoring and enforcing water quality and quantity standards, water-related decision-making coordinating, data collection, and mobilizing financing to support basin development and management activities. This becomes imperative since each basin is unique; however there is enough commonality of hydrological, geomorphologic and ecological characteristics for them to serve as widely applicable, non-ephemeral, operational landscape units for planning and management, and for maintaining environmental quality and pursuit of sustainable development (Barrow, 1998).

It is at the river basins that multiple uses advantage can take place such as planning, monitoring, reconciling competitive use and coordinating the activities of independent agencies and other interest groups. Many countries have continued to maintain national or state control of water resources development and allocation using the basin as a unit of planning, while decentralizing other functions to the basin or sub-basin level (Molle et. al., 2007). This practice has the advantage of ensuring that water allocations are in line with national development priorities and, in countries where inter-basin transfers are the norm, may be a necessity.

However, it has the disadvantage of giving basin stakeholders little or no say in allocation decisions. While the complexity of integrated management of sizable river basins may invite centralization and technocracy, the need for participation suggests decentralization and more local operations. Countries have found many different ways to strike a balance between these imperatives. This balance has shifted over time from more centralized (ie during the basin development phase when construction of large-scale water infrastructure demanded technical expertise and massive mobilization of public funds) to more decentralized, as the focus shifted towards improving productivity, allocating water among users competing for a limited supply, or addressing pollution and degradation of important ecosystems (Molle et. al., 2007).

Table 4.1: Essential Water Resources Development and Management Functions

Data collection	Collecting, managing and communicating data regarding water availability, demand and quality to support different basin functions
Planning	Formulating medium- to long-term plans for developing and managing water resources in the basin
Water allocation	Defining mechanism and criteria by which water is apportioned among use sectors, including the environments
Facilities construction	Designing and constructing hydraulic infrastructure
Facilities maintenance	Maintaining hydraulic infrastructure
Operation and management	Ensuring that dams, navigation and water distribution infrastructure, and wastewater treatment plants are properly operated
Prevention, monitoring and enforcement	Monitoring and control of water pollution, salinity levels and groundwater extraction; and enforcing relevant laws and regulations to prevent degradation/overexploitation and restore ecosystem
Water disasters preparedness	Protection against floods and developing emergency works and coping mechanisms
Conflicts resolution	Providing mechanisms for negotiation and litigation
Ecosystems protection and conservation	Defining priorities and implementing actions to protect ecosystems, including awareness campaigns
Coordination	Harmonizing policies and actions undertaking in the basins by state and non state actors relevant to land and water management
Mobilizing resources	Ensuring financing for other functions, for example collecting water user fees or water taxes

Source: Barilla Center for Food & Nutrition (2009)

The trend across the world is the involvement of public and private sector actors in basin planning and management from environmental agencies and civil society or interest groups to regulatory bodies and service providers for agricultural, municipal, tourism and industrial water users. The appropriate institutional arrangement for a particular basin depends on its scale (transboundary, national, local); the stage of basin development; the main water management challenges to be addressed; and the existing social, economic, political and institutional environment. There are no universally applicable solutions while the criteria for successful functioning of basins organizations are listed in Table 4.2 (Molle et. al., 2007). The challenge then is to define institutional arrangements that can coordinate between actors and decision-makers operating at different scales; local, basin, national, transboundary. However, physical and socio-political diversity settings preclude defining universal guidelines for addressing this challenge.

Table 4.2 Criteria for Successfully Functioning Basin Organizations

A well-defined mandate and the legal, political, and administrative power to carry it out. In particular it needs to be clear at what level decision-making authority is vested and mechanisms for resolving conflicting interests between levels.
Adequate staffing and capacity building, especially for environmental issues, which are often new and informed by limited data availability.
Strong, broad-based political and stakeholder support
Sustainable funding---BOs need to be financed, whether out of user or polluter fees or through government subsidies

Source: Barilla Center for Food & Nutrition (2009)

5.0 CONCLUSION

The author chronicled the competing needs, analysis and global trend aspects of water resources development with the aim of broadening and provoking thoughtful discussions with a view hopefully of finding long term solutions to water resources development in a cooperative and considerate manner.

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