Nile Basin Initiative
Initiative du Bassin du Nil

PART II DSS CONCEPTUAL DESIGN

Including DSS Requirements Assessment and Design Specifications

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Acronyms

API	Application Programming Interface
BOD	Biological Oxygen Demand
COM	Council of Ministers
CPU	Central Processing Unit
CU	Coordinating Unit
DSS	Decision Support System
EN-COM	Eastern Nile Council of Ministers
EN (Region)	Eastern Nile (Region)
ENSAP	Eastern Nile Subsidiary Action Programme
ENTRO	Eastern Nile Technical Regional Office
GIS	Geographic Information System
IWRM	Integrated Water Resource Management
MCA	Multi-Criteria Analysis
NB	Nile Basin
NBI	Nile Basin Initiative
NEL-COM	Nile Equatorial Lakes Council of Ministers
NEL (Region)	Nile Equatorial Lakes (Region)
NELSAP	Nile Equatorial Lakes Subsidiary Action Programme
NGO	Non Governmental Organization
Nile-COM	Nile Council of Ministers
Nile-IS	Nile Information System
Nile-SEC	Nile Secretariat
Nile-TAC	Nile Technical Advisory Committee
OLAP	On-Line Analytical Processing
PHP	Hypertext Pre-Processor
PMU	Project Management Unit
RBO	River Basin Organization
SAP	Subsidiary Action Program
SQL	Structured Query Language
SVP	Shared Vision Program
SVP	Shared Vision Program
WRM	Water Resource Management
WRPM	Water Resource Planning and Management
XML	Extensible Markup Language

Executive Summary

The basic purpose of the Nile Basin DSS is to provide a framework for sharing knowledge, understanding river system behavior, designing and evaluating alternative development scenarios, investment projects, and management strategies; and to support informed, scientifically based rational decision making. As such its primary objective is to create *"... a shared knowledge base, analytical capacity, and supporting stakeholder interaction, for cooperative planning and management decision making for the Nile River Basin"*. It is intended to improve the overall net benefit from harnessing the Nile, and develop economically efficient, equitable, environmentally compatible and sustainable strategies for sharing the benefits. In doing so, the DSS should help to *"enhance the capacity to support basin wide communication, information exchange, and identifying trans-boundary opportunities for cooperative development of the Nile Basin water resources"*.

The range of decisions that the DSS will support has been specified on the basis of an initial situation assessment followed by a detailed analysis of specific concerns emerging from a comprehensive stakeholder consultation exercise. The concerns raised at the different workshops (in the nine riparian countries as well as two at the sub-regional level) were grouped and prioritized (see Annex A for details), and finally the following priority areas of concern were agreed at a regional workshop (Entebbe, January 2008):

- Water resources development
- Optimal water resources utilization
- Coping with floods
- Coping with droughts
- Energy development (hydropower)
- Rainfed and irrigated agriculture
- Watershed and Sediment Management
- Navigation

Water quality and climate change have been identified as cross-cutting issues to be considered in addressing the above eight priority areas of concern.

Comparison with ongoing NBI initiatives under the ENSAP and NELSAP programmes confirmed the relevance of these areas of concern.

The above areas of concern guided the identification of key functionalities and model components to be included in the core system in its initial phase of development. Its modular and open architecture will allow for future expansion of the range of decisions to be supported as needs emerge or are re-prioritised.

The DSS and its central river basin model system will directly support an open and participatory multi-criteria decision making process, considering simultaneously hydrological, socio-economic criteria and environmental criteria and objectives.

The Nile Basin DSS design is based on three major functional components:

- An information system that provides a common and shared information basis for the planning and decision making processes, locally, sub-regionally, and basin wide, directly accessible for all stakeholders;

- A modular river basin modeling system built around a dynamic water budget model and economic evaluation, that helps to design and evaluate possible interventions, strategies and projects in response to the problems and challenges identified and prioritized in the stakeholder consultations;
- Tools for a participatory multi-criteria analysis to rank and select alternative compromise solutions for win-win strategies.

These DSS components will be integrated in an open, hierarchical, modular and very flexible structure that *inter alia* will facilitate information exchange with other models and tools used or developed within the basin. A key concept is the support of the analysis of local, national issues and specific projects, yet always to evaluate their overall downstream effects and basin wide impacts.

The major design principles for the Nile Basin DSS include ease of use, flexibility, modularity, scientific excellence and advanced ICT technology, openness, transparency, compatibility and interoperability, and cost efficiency to facilitate sustainable operation.

Its main architectural features are a client-server implementation based on open source operating environments, standard interfaces, data formats, and communication protocols (e.g., http over TCP/IP, SQL, XML/HTML) that can exploit a wide range of hardware configurations but also the communication with any number of external information resources and the option for efficient web based access by a distributed user community.

The institutional structure of the implementation foresees one common set of software tools and shared, standardized common data sets that can be extended locally with data for individual scenarios, and optional problem specific add-on software, exploiting the modular architecture. These common tools and data are implemented at a central (NBI) location, two sub-regional locations (covering the White and Blue Nile sub-basins, respectively) and at the country level, together with the hierarchical data sharing, update, and access control mechanisms to ensure efficient yet safe and reliable use of the system.

The implementation process will use a rapid prototyping approach within an object oriented design paradigm that aims at an early operational prototype to ensure sufficient time for user feedback and extensive and independent testing, calibration and validation. The direct involvement of the end users and future operators and managers of the system in the implementation and testing is an important principle here. This implementation process will also require a parallel open peer review process organized around a set of directly relevant pilot applications and an associated training program intended to ensure control, responsibility, interest and ownership as the basis for trust and acceptance by all riparian countries.

1 Introduction

1.1 Development of a Nile Basin DSS within the NBI

The Nile Basin Initiative (NBI), within the framework of the Water Resources Planning and Management (WRPM) Project, has launched the consultancy services: "Needs Assessment and Conceptual Design for the Nile Basin Decision Support System" as the first step in the development of a decision support system (DSS) for the Nile Basin.

Thus, the Nile Basin DSS is one of four components of the WRPM under the Shared Vision Program (SVP) of the Nile Basin Initiative, a partnership of the ten Nile Basin countries of Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda. The WRPM project is managed from a regional Project Management Unit (PMU) located at Addis Ababa, Ethiopia.

The scope of the Nile Basin DSS component includes the Nile Basin DSS itself (consisting of an information management system, a regional river basin planning model, and a suite of analytic tools to support multi-objective analysis of investment alternatives) as well as the development of core national capabilities to assist in the evaluation of alternative development paths and the identification of joint investment projects at the sub-regional and regional level.

The Consultancy Service is divided into three distinct phases, namely the Inception Phase, the Analysis Phase and the Synthesis Phase.

During the **Inception Phase** the Consultant assessed the present situation within the Nile Basin in terms of hydrology, water availability and use patterns, environmental and socio-economic and other issues pertinent to the use of the shared Nile water resources, and produced a situation assessment report.

The present report concludes the **Analysis Phase**, in which the conceptual design of the Nile Basin DSS was developed based on the results of a needs assessments and stakeholder consultations carried out through 9 national and 2 sub-regional workshops. Training needs were also identified during the same consultation. In addition, Training and Awareness Workshops were held in each of the countries and sub-regions in order to enhance the understanding and general awareness of riparian experts in issues on IWRM and use of DSS in water resources planning and management. In parallel, an information system (the Nile Information System - Nile-IS) was developed, to be used as a common and knowledge base and and to promote communication and information exchange among the Nile Basin countries. The key findings of the first two project phases were uploaded to this system.

In the final **Synthesis Phase** (until mid-April 2008) the Consultant will formulate the DSS Development Plan, including an Implementation Plan and Training Plan, and prepare the Terms of Reference for the development of the Nile Basin DSS.

1.2 Brief Introduction of this Report

The present “main report” is intended to summarise the results of the analytical stage of the consultancy, the output of which is the conceptual design of the NB DSS. The results and the process of the stakeholder consultations are documented in Annex A while more technical details on the DSS design are provided in Annex B. Further annexes describe the training needs assessment conducted (Annex C), the institutional set-up and decision making process (Annex D) and finally the information system (“Nile-IS”) developed under this consultancy (Annex E).

In this main report, ***Section 2*** begins with a description of the DSS primary objective and intermediate goals consistent with the need for phasing the development of the DSS while maintaining stakeholder interest. The section then continues by describing the approach taken by the Consultant when developing the conceptual design and closes with a description of the DSS's functional components.

Section 3 is concerned with how the results from the stakeholder consultations were used to define the nature and focus of the DSS. It includes sub-sections describing how the consultation workshop results were analysed; the nature of decision making support that could be provided; the types of decisions to be supported by the first version of the DSS; and the models, tools and data necessary to do that.

Section 4 covers all aspects of the proposed DSS design and has six sub-sections, dealing in turn with basic design principles; software development approach; system architecture; the information management system; the river basin model system and the decision support tools.

Initial ideas for the implementation of the DSS are presented in ***Section 5***, which suggests an implementation approach and also indentifies possible challenges and risks that could constrain successful and timely implementation of the DSS. Further details on these aspects will be elebaorated during the final Synthesis Phase of the project (preparation of DSS development and implementation plan)

Section 6 closes the main text, describing the institutional implications for the DSS and the training needs of those that will be involved in its operation and management.

2 The Nile Basin: Opportunities and Challenges

The Nile, though the longest river in the world with its 3 million sq km basin area, its runoff potential is small. The basin is also prone to sever inter- and intra-annual variability of rainfall. The basin's population is expected to double every 25 years. High population growth and increased variability of rainfall is forcing many of the countries, which hitherto depend on rain fed agriculture, into irrigated farming system thus increasing overall consumptive water demand on the system.

The Nile Basin drains from South to North and can be divided into 15 sub-basins as shown in Figure 2.1. The South-North orientation of the River Nile on the African continent means that the extreme ends of its basin are subject to serious variability with respect to climate. The North for instance (Egypt and Sudan in particular), is characterised by extreme aridity and extensive desert while in the South and East strong rainfall results in lush vegetation, humid conditions and even tropical rainforest in some locations.

In an average year the basin receives some 650 mm of rainfall corresponding to around 1,900 bcm of water per year. Long-term mean annual flow at Aswan is only about 84 bcm per year[1], making the annual runoff coefficient of the basin around 4.5% (Nicol 2003). This figure is small and, for example, is just 10% of that of the Rhine. This is explained by the fact that a significant portion of the basin comprises arid and hyper-arid zones that are large in surface area yet contribute only negligibly to basin runoff. Added to this are the evaporation losses from major swamp areas which cause up to 30% of the basin's rainfall to be lost before being used for any purpose. 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 northward movement of the Inter-Tropical Convergence Zone (ITCZ) (summer monsoon) over the highlands, before retreating again, the tropical "upper easterlies," and local convergence in the Arabian Sea region. The resulting rainfall is often intense, and causes rapid runoff leading to major soil loss (Nicol 2003). In the south precipitation is also stormy and caused by convection, orthographic conditions or frontal conditions caused by the collision of dry north east boreal winds with the moist air above the Indian ocean being blown in to the region from the South.

[1] average for the period 1900-1955

Figure 2.1 **Nile Sub-Basins**

Flows moreover, are seasonal as indicated by Figures 2.2 and 2.3 which show also that the seasonal peaks arise earlier in the NEL sub-region than the EN.

Figure 2.2 Mean Monthly Flows of Selected Rivers/Catchments

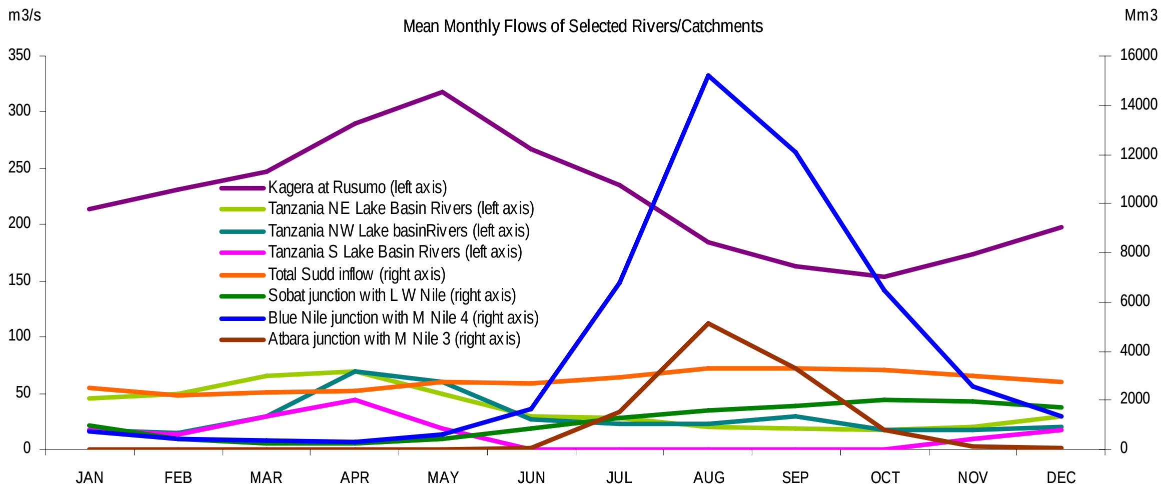
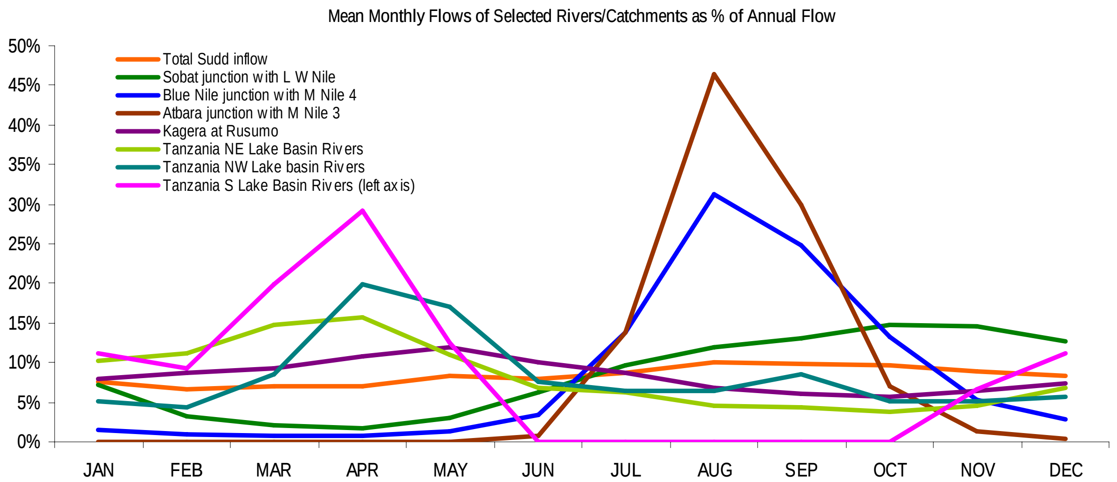


Figure 2.3 Mean Monthly Flows of Selected Rivers/Catchments as % of Annual Flows



Note: These figures, which are offered as heuristic illustrations only, have been consolidated from several data sources between them covering the period 1900 to 1997, but with no single run of data less than 77 years.

In environmental terms, it is interesting to note that the basin includes a wide variety of ecosystems many of them highly water dependent such as important wetlands in Kenya, Uganda and Sudan. Equally, the basin contains three large lakes - namely Victoria, Albert and Tana. Human development has already begun however, to compromise the sustainability of key environmental assets. Reported transboundary environmental issues accordingly include:

- Cross border physical or chemical pollution arising from deforestation and soil erosion which increases vulnerability to drought; sedimentation (of wetlands, reservoirs, canals and drains); and greater floods downstream. In addition urbanization, industrialization and increased use and improper application of pesticides and fertilizers lead to increased runoff and pollution that harm downstream water users.

- Loss or degradation of wetlands and lakes – water dependent ecosystems throughout the Nile basin contribute to the stability, resistance and resilience of both natural and human systems to stress and sudden changes.
- Need for transboundary cooperation to protect key habitats. Many key plant and animal species have habitats in adjoining countries, often requiring cross-border protected areas.
- Lack of early warning systems.
- Spread of exotic and invasive water weeds. Water hyacinth and other invasive aquatic weeds have spread throughout many parts of the Nile basin, impairing the functions of natural ecosystems, threatening fisheries and interfering with transportation.
- Waterborne diseases such as malaria, diarrhea and bilharzia (schistosomiasis) are among the leading causes of death especially among the old and very young. Their spread is related to a variety of different factors such as increased breeding ground for disease vectors, growing resistance to drugs that fight these diseases, and lack of sanitation infrastructure, often compounded by the lack of adequate hygiene education.

Water use in the basin is widespread and varied and includes water supply and sanitation; agriculture (including a large livestock sector); capture and culture fisheries; hydropower generation; industry and mining; navigation and tourism. But despite the significance of the development that has already taken place, great undeveloped potential remains – and this is especially so in terms of irrigation and power generation both of which represent pressing concerns among the riparian stakeholders. Realisation of the remaining potential needs however, greater coordination and cooperation between these stakeholders. Not only is it necessary to mitigate or obviate the transboundary environmental challenges listed above; it is also necessary that future development pays due regard to changing climatic conditions and increasing scarcity/unmanageability of water; changing demographics; new economic development opportunities; food security/poverty alleviation and does in a way that promotes basin welfare and transboundary cooperation as alternatives to development trajectories that are based on purely local advantage.

Since therefore, its waters are shared between ten riparians and given the need for coordinated protection, management and development of its natural resources, nine of the riparians (Eritrea is not included as yet) have embarked on the Nile Basin Initiative. The NBI is a partnership of the riparian states of the Nile River and is answerable to the Council of Ministers of Water Affairs of the Nile Basin states (Nile Council of Ministers, or Nile-COM). The NBI seeks to develop the river in a cooperative manner, share substantial socioeconomic benefits, and promote regional peace and security. It began with a participatory process of dialogue among the riparians that resulted in their agreeing on a shared vision: to "achieve sustainable socioeconomic development through the equitable utilization of, and benefit from, the common Nile Basin water resources," and a Strategic Action Program to translate this vision into concrete activities and projects. The proposed DSS is a major, transitional deliverable of the NBI and will quickly be able to support decisions relevant to pressing investment opportunities such as those represented by i) the basin’s hydropower potential; ii) sustainable management of the Sudd wetlands; iii) the development of rainfed and irrigated agriculture potential or iv) measures to maintain navigation drafts in river reaches and lakes that are important for navigation. All of these examples are relevant to priority concerns as expressed by the riparian states in the consultation workshops and other fora.

3 Rationale for a Nile Basin DSS

3.1 General Justification

Indications are that ***cooperative development*** of the basin's water resources would lead to more efficient and sustainable development of the basin's water resources. Such an undertaking requires a sound and scientific information base coupled with analytic tools that are agreed upon by all riparians. However, there currently exist no such common information base and analytic tools that could be used to assist the countries in the ***cooperative*** planning of development schemes that would result in mutual benefits for the basin countries. The Nile Basin DSS is expected to meet this need by establishing and combining the necessary knowledge base and analytical tools to support the planning of cooperative joint investment projects.

3.2 What is a DSS?

DSS (Decision Support System) is a commonly used term with numerous, and often diverging definitions and interpretations; it refers to any and all computer based systems designed to assist decision making processes. In the context of the development of the Nile Basin DSS the following definition has been presented (Seid, A., 2007, pers. comm.):

"A DSS is a common computer-based platform for communication, information management and analysis of water resources. It provides a framework for sharing knowledge, understanding river system behavior, evaluating alternative development and management strategies, and supporting informed decision making.

The main components of a DSS are

- *an information system including GIS for the management of all data and information, including model scenarios;*
- *a analytical core for the simulation and optimization of scenarios, interventions, projects and measures or alternatives, and the (economic) evaluation;*
- *multi-criteria decision support tools for the ranking and selection of alternatives.*

For the user, this means support of the decision making process and its phases, from problem identification, the design and evaluation of alternatives, and their ranking and selection in a multi-criteria framework. The criteria generated by the models and used in the DSS include both bio-physical/environmental as well as socio-economic criteria with their associated objectives and constraints."

3.3 Benefits Expected from a Nile Basin DSS

A Nile Basin DSS is expected to support basin wide information exchange, enhance capacities and contribute to identifying transboundary opportunities for cooperative development and thus increase the overall efficiency of the management and use of the Nile Basin water resources. It will also help to deal with the challenges including extreme events (floods and droughts), environmental degration, as well as food and power production deficits or insecurity.

The basic functions of a Nile Basin DSS will be to

- provide a shared, common and agreed information basis for all the participants in decision making processes (empowerment of stakeholders) as the basis for identifying current and expected opportunities and problems (concerns);
- provide tools to design and analyse alternative strategies (combinations of measures, projects, instruments, policies) that address these problems or capitalise on the opportunities, and evaluate and compare them in terms of their bio-physical and socio-economic impacts (costs and benefits);
- provide tools and methods to rank and select these alternatives to arrive at an acceptable compromise solution for water allocation and use (a win-win strategy) that helps to generate and distribute increased net benefits from a "better" use of the Nile's vast resources.

This must be based on reliable (validated) modeling tools that can operate with the available data and information within the well defined scope of water resources management, i.e., based on dynamic water budgets and derived criteria.

The primary idea is to put an ultimately political debate on values and (conflicting) interests on a scientifically sound and rational basis for more efficient, equitable and sustainable solutions within a shared vision for the basins future development.

Typical questions that the Nile-DS is designed to address and answer could be:

- What are the downstream effects and associated costs and benefits of a large reservoir/hydropower scheme, during normal operation, during filling? What are the costs and benefits of hydropower production, flood protection, enhanced temporal availability of water for irrigation, reduced downstream water balance? Where do they accrue?
- For any given investment project, is there an overall increase in basin-wide net benefits that can lead to a win-win strategy?
- How would changes in the flow regime of the Sudd (Jonglei canal) affect downstream water availability (temporal patterns and total water budget) and associated costs and benefits?

4 Goals and General Concept of the Nile Basin DSS

4.1 Goals of the Nile Basin DSS

The primary objective of the Nile Basin DSS is *"to develop a shared knowledge base, analytical capacity, and supporting stakeholder interaction, for cooperative planning and management decision making for the Nile River Basin"*. The Nile Basin DSS is expected to be an *"agreed upon tool that will be accepted and used by all riparians in the management of the shared Nile water resources"*.

This in turn requires that the DSS:

- is a clear response to perceived needs (these needs have been assessed by the Consultant and are described in sections 3.1 and 3.2)
- provides rational and objective support to the Basin's decision makers – based on the best available data, information and estimates – thereby inspiring full confidence among the stakeholders
- is sustainable in institutional, financial and technical aspects so that it may function within the framework of *"Nile Basin collaboration as well as at the national level"*.

This is the first time the countries of the Nile Basin came together to develop such a comprehensive tool as the Nile Basin DSS. As anticipated the situation assessment and stakeholder consultations confirmed that the range of requirements for such a tool proved to be complex. As a result, to be realistic, the DSS development should evolve gradually over time in an adaptive, phased approach with initial efforts focusing on the priority concerns.

However, time and budgetary limitations mean that all this has to be implemented in an adaptive, step-wise fashion. This suggests the need for an **immediate target** defining what is a reasonable expectation of the first phase, defining in other words what is achievable while responding nonetheless to clear priority needs of the riparians, which have been so carefully wrought (in part) as a result of the comprehensive, consultative needs assessment carried out during the analysis phase of the consultancy.

It is, therefore suggested that the immediate target of the first DSS development exercise shall be ***"a water balance and allocation model, linked to a set of core models relevant to the priority areas of concern in the Nile Basin, and integrated with an information system and decision support tools for multi-criteria analysis (MCA)"***. It should be noted however, that the model will have been pre-tested and calibrated using applications based on realistic Nile Basin water management and allocation scenarios. Furthermore, relevant institutions will have had their capacities strengthened for DSS utilisation, and data will have been collated, generated and reconciled as appropriate; thus by the time that it is commissioned it will be fully operational both functionally and institutionally.

4.2 Water Resources DSS

The Nile Basin DSS is based on the concepts of Integrated Water Resources Management: „IWRM is a participatory planning and implementation process, based on sound science, that brings stakeholders together to determine how to meet society's long-term needs for water and coastal resources while maintaining essential ecological services and economic benefits" (USAID, http://www.usaid.gov/our_work/environment/water/what_is_iwrm.html). The Global

Water Partnership describes IWRM as " a process which promotes the coordination of water, land, and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital eco-systems" (GWP, 2000). These concepts are directly applicable to the Nile Basin DSS and reflected in its design.

4.3 Development and Implementation Approach

The development and implementation of the Nile Basin DSS have to consider a number of constraints, primarily the need to achieve the abovementioned targets within a very limited timeframe while meeting the basin stakeholder's key requirements and respecting the required participatory nature of the process.

4.3.1 Phasing

From the above discussion it is obvious that a phased and flexible approach is needed.

The first phase of DSS will concentrate on an operational system that addresses all the priority concerns identified by the stakeholders, but in an open architecture that facilitates future extensions.

The implementation of the system is planned in a number of consecutive and partially overlapping phases (to be described in detail in the Implementation Plan). Software adaptation, development and testing, data compilation and application building will be run in phases, and partly parallel to minimize time to operational use.

4.3.2 Links with other Developments

There are several other information systems or decisions support systems, currently under development or already existing, in the Nile basin, such as the Mara river basin model, Kagera river basin model, Sio-Malaba-Malakisi basin model as well as the Lake Victoria Water Quality Model developed during the Lake Victoria Environmental Project I.

The technical interfaces (in particular for the systems still under development) and the institutional relationships and workflows cannot be defined at this stage. Therefore, the strategy to ensure compatibility and complementarity is to design an open, modular architecture and a fully data driven implementation. These systems can all be integrated through a shared data base (network accessible), common data formats and standards, and communcation protocols. These can either be built into the respective model implementations, or addressed by a set of model specific software wrappers that provide the necessary data translation and integration of the information flow and user interface.

4.3.3 System Implementation Approach

The institutional structure of the NBI, the importance of participatory processes and ownership, and the constraints of the communication infrastructure (IT connections) in the Nile Basin require decentralized installations of the system, while it is essential to maintain the consistency of an agreed common set of software tools and data sets.

The system design is based on the assumption that the same, common system will be installed at (initially) 12 locations. These installations will use one common set of software tools and data sets but can be extended locally with data and optional problem specific add-on software for individual scenarios.

The system will be based on the adaptation and customization of existing software components, models and tools. The procedure most appropriate for the implementation under the given conditions is rapid prototyping, as a participatory approach with a maximum of user (stakeholder) involvement. A first operational prototype should be installed within one year of the implementation phase, to ensure sufficient time for user feedback and extensive and independent testing, calibration and validation. This implementation process will also require a parallel open peer review process organized around a set of directly relevant pilot applications and an associated training program intended to ensure control, responsibility, interest and ownership as the basis for trust and acceptance by all riparian countries.

4.4 Functional Components of the Nile Basin DSS

The Nile Basin DSS design is based on three major functional components:

- An information system that provides a common and shared information basis for the planning and decision making processes, locally, sub-regionally, and basin wide, directly accessible for all stakeholders;
- A modular river basin modelling system built around a dynamic water budget model end economic evaluation, that helps to design and evaluate possible interventions, strategies and projects in response to the problems and challenges identified and prioritized in the stakeholder consultations;
- Tools for a participatory multi-criteria analysis to rank and select alternative compromise solutions for win-win strategies.

4.4.1 Information Management System

At the core of the DS is a common, shared information management system implemented in one or several relations data base management systems (RDBMS) and related GIS with industry standard SQL network accessible interface. The data base design (data model) must directly reflect the object oriented design (OOD) of the DSS implementation and include OLAP (on-line analytical processing) capabilities for efficient data analysis. The data bases describe the geo-referenced physical and administrative elements of the river basin such as sub-catchments, dams and reservoirs including hydropower generation, aquifers and wells, open channels and pipelines, diversions and confluences, lateral catchments, and points of demand such as settlements, farms and irrigation districts, industries, or wetlands. Generic objects classes include crops or water technologies.

4.4.2 River Basin Model

The central analytical tool is a dynamic water budget model, implemented in an object-oriented network design (semi-distributed), that fits into the overall modular architecture: each of the nodes and reaches of the river basin representation can be hierarchically based on specific models for the corresponding object or processes, supporting the hierarchical linkage, cascading or nesting of several models. The basic model computes water supply and demand on a daily basis, and can be aggregated to monthly and annual water budgets for any node, sub-catchment, or administrative grouping. This basic core model interacts with logical pre-processors (hydro-meteorological data management, time series analysis, rain-fall runoff model, irrigation water demand[2], watershed erosion) and in turn provides the inputs for a water quality model (DO/BOD, conservative substances, first order decay, turbidity/sediments including bank and bed erosion, transport and siltation processes) and the economic evaluation of demand and supply in a cost-

[2] Including supplemental irrigation demand

benefit analysis. These models together generate the criteria describing the main issues and concerns as used in the subsequent multi-criteria analysis.

Interactive scenario analysis, but also the automatic generation of alternatives for sensitivity analysis and in a two stage optimization procedure (satisfizing) or direct mathematical programming frameworks should be considered for implementation.

4.4.3 Decision Support Tools (MCA)

The analytical core directly and automatically exports the alternatives and their descriptive criteria (including costs and benefits) to the multi-criteria analysis tools. These will include several methods, from basic interactive implementation of the Pugh method (decision matrix) with user defined weights to reference point methodology (automatic normalization between Nadir and Utopia, preferences expressed by a reference point) and the linkage (open interface) to any number of commercially available tools for stakeholder preference elicitations and subsequent ranking and selecting, including group decision making and sensitivity analysis for robust decisions.

5 Identification of Nile Basin DSS Requirements

The objective of this chapter is to summarise how the functional requirements of the DSS, at least as far as its start-up version is concerned, were defined on the basis of the consultant's investigations which included and were based largely upon a comprehensive round of stakeholder consultations convened at the national and sub-regional levels.

Primarily the Nile Basin DSS is intended to address common (basin-wide) and shared (universal) problems expressed by riparian countries or defined by regional or sub-regional stakeholders and projects. However, specific national or sub-catchment concerns can also be addressed in many respects.

In the sections below, a ***"concern"*** is understood as an issue or domain of decision making for which the DSS shall provide support.

5.1 Basin Concerns Identified through Stakeholder Consultations

A comprehensive needs assessment was undertaken using a structured workshop consultation process in the nine riparian countries and the two sub-regions. The purpose of these workshops was to allow the stakeholders to identify the most pressing, specific water sector concerns in their countries and sub-regions. The rationale, the workshop process itself, the results and their analysis are all described in detail in Chapters 3 and 4 of Annex A which can be summarised as follows.

The situation assessment carried out in Phase 1 of the study, and the 1st Regional Workshop that concluded it (Addis Ababa, October 2007), resulted in a consolidated list of 42 specific concerns that between them captured all of the concerns identified. At the request and mandate of the workshop, this list of specific concerns was reduced by the Consultant to 31 by removing those that are really, in effect, externalities, pre-conditions or objectives. Table 5.1 presents the list of 31 specific concerns that was used as a basis for the country and sub-regional level stakeholder consultations and subsequent analyses.

Table 5.1 Results from 1st Regional Workshop, Reworked by the Consultant

Specific Concerns (31)		
Biodiversity conservation	Irrigation	Water Quality - agro-chemical seepage
Conflicts in water use (pastoralists etc)	Land use, Cover change, impacts on runoff	Water Quality - eutrophication
Coping with droughts and floods;	Need to improve conservation to cope with CV e.g. through Rain water harvesting	Water Quality - pollution
Declining water levels in lakes and rivers	Optimal utilization of available water resources	Water Quality - salinisation
Drainage of Marshlands for agriculture;	Population structure/settlement patterns	Water resources availability
Drought Prediction	Rain fed agriculture	Water supply and sanitation

Specific Concerns (31)

Flood Forecasting and Preparedness	Sedimentation of hydraulic infrastructure	Water use efficiency, demand management
Improving and developing navigation potential	Sharing/exchange of real time data	Watershed degradation (Destruction of natural forests)
Increased energy demand	Soil/Bank erosion	Wetlands degradation
Increased flow variability	Tourism	
Intra- and inter-annual fluctuation;	Use of carbon credit to finance power project	

Participants at the consultation workshops were facilitated in the selection and ranking of their ten to twelve highest priority specific concerns from the above list. The workshop findings were analysed by the consultant, as described in section 4.2 of Annex A, and the results discussed at the 2nd Regional Workshop (Entebbe, January 2008). Based on this two step process (analysis and workshop) the specific concerns prioritised by the stakeholders were clustered into 8 “Areas of Concern” for use in specifying the priority functionalities for the first phase of DSS development.

These “Areas of Concern” - as agreed by participants at the 2nd Regional Workshop – are as follows:

- Water resources development
- Optimal water resources utilization
- Coping with floods
- Coping with droughts
- Energy development (hydropower)
- Rainfed and irrigated agriculture
- Watershed and Sediment Management
- Navigation

Water quality and climate change have been identified as cross-cutting issues to be considered in addressing the above eight priority areas of concern.

Climate change is of particular interest because much of the likely investment in the Basin is likely to represent either adaptation or mitigation measures in respect of climate change.

- Increased irrigation for instance is a measure that allows the agricultural sector to ***adapt*** to reduced or changing rainfall patterns;
- Climate changed induced increased saline intrusion in the northern portions of the Nile Delta may require radical farming system ***adaptation*** and/or investments (in improved irrigation technology or increased leaching provision); while
- Hydropower dams can ***mitigate*** climate change as compared with fossil fuelled thermal stations.

Just as important however; is the increasing likelihood that development partners will want climate change impacts of proposed investments to be assessed along with environmental and social impacts during pre-investment appraisal.

In the first phase of DSS development, climate change will be addressed within the framework of scenario analysis and comparison; as one of the optional models for future developments, tools for the downscaling of climate change scenarios (based on IPCC story lines) will be considered.

The above areas of concern reflect most of the priorities expressed by the national stakeholders. Accordingly, even in its first version, the DSS will be perceived as relevant at every level. However, once the DSS is up and running, its proposed modular and open architecture will allow its range of decision support tools to be extended to support new decisions as necessary.

Once the DSS is up and running, the modular and open architecture proposed (see Section 6.2) will allow its range of decision support tools to be extended to support new decisions as necessary, including tools for climate change impact assessment based on prognostic meteorological models.

5.2 Mapping of Basin Concerns onto NBI Projects

The above priority areas of concern have been mapped onto NBI cooperative projects in order to check the level of consistency between these areas of concern, identified as a result of the consultation process, and the NELSAP and ENSAP initiatives.

The NBI philosophy is that investment projects are identified and implemented at the subsidiary level. Projects currently being implemented under the NELSAP and ENSAP initiatives should therefore be consistent with the “areas of concern”.

This is reflected in table 5.2 below, which confirms a high level of consistency. The same table provides an indication of the kind of decisions that could be supported by the DSS that would be relevant to ongoing programmes and projects.

5.3 Decisions and Criteria to be supported by the DSS

In order to support decisions pertaining to planning, implementation and management of interventions in the eight areas of concern listed above, the DSS shall provide the necessary information and analytic tools as well as the necessary models to compute appropriate criteria.

Therefore, in a next step the areas of concern have been translated into DSS requirements in terms of types of decisions that should be supported, questions that should be answered and key outputs (criteria) the DSS should produce.

Tables 5.2 and 5.3 below provide examples of interventions / alternatives, decisions, questions and criteria for each area of concern.

Table 5.2 Ongoing NBI Initiatives Mapped onto DSS Areas of Concern

AREA OF CONCERN	NELSAP INITIATIVES	ENSAP INITIATIVES	POSSIBLE INTERVENTIONS / ALTERNATIVES	SAMPLE DECISIONS
Water Resources Development	NELSAP Track 3 "*People centred productive and sustainable use of in-country shared Nile water resources reaching economic cooperation*" • River basin planning and development	Water resources development is one focus of the Eastern Nile Joint Multipurpose Program	• A few, large, basin level storage structures • Small local level water harvesting schemes • Water conservation projects (loss reduction)	• Selection of investment alternatives (e.g. small number of large, basin level storage facilities, or large number of small, local level storage facilities, or a combination of various alternatives?) • Configuration of the overall (macro level) system-wide water development plan • Determination of features of development schemes (location, scale of development, size of components) • Identification of optimal operation rules (at the planning level)
Optimal water resources utilization	NELSAP Track 3 • River basin planning and development	Optimal water resources allocation is another focus of the Eastern Nile Joint Multipurpose Program Improved water conservation is a sub-focus of the Eastern Nile Joint Multi-purpose Programme	• User financed water saving equipment and infrastructure • Subsidised water saving equipment and infrastructure • Demand management by means of a basin wide, rights based; water resource pricing mechanism • Changed operating rules for large storage dams • A combination of the above	• Comparison of alternative ways of increasing system efficiency, e.g. – basin wide resource priced demand management mechanism – investments in water saving infrastructure and equipment – subsidising of increased engineering efficiency at user level – introduction of penalties for wastage – changes of operating rules for dams

AREA OF CONCERN	NELSAP INITIATIVES	ENSAP INITIATIVES	POSSIBLE INTERVENTIONS / ALTERNATIVES	SAMPLE DECISIONS
Coping with Floods	NELSAP Track 3 • Flood and drought control	Flood forecasting and preparedness are the foci of the Eastern Nile Flood Preparedness and Early Warning project	• Changed operating rules of large storage dams • Flood management infrastructure • Restored flood plain functions • A combination of the above	• Determination / selection of the most feasible flood-control schemes or mechanisms, e.g. – Changing operating rules of existing dams – Building of new dams for flood control purposes – Restoration of flood plain functions
Coping with Droughts	NELSAP Track 3 • Flood and drought control	Improved drought preparedness is a sub-focus of the Eastern Nile Joint Multi-purpose Programme	• Adapt to increasing drought conditions by increasing storage facilities • Adapt to increasing drought conditions by increasing (conjunctive) use of groundwater • Mitigate droughts by crop diversification and changing farming systems • A combination of the above	• Comparison of alternative measures to enhance the resilience of the system to drought and reduce vulnerability • Development of adaptation and mitigation strategies
Energy Development	NELSAP Track I "*Investment Projects implemented in power generation and trade and natural resources management and development delivering energy and meeting deficits for productive multipurpose use and sustainable livelihoods*" NELSAP Track 2 "*Investment projects implemented in multiple Nile water related sectors delivering benefits to ensure sustainable livelihoods*" NELSAP Track 3 • Hydro-power	Energy development is the focus of the Eastern Nile Regional Power Trade Investment Programme Increased Access to Hydro-power is a sub-focus of the Eastern Nile Joint Multi-purpose Programme	• Regional power trading based on a common grid and existing capacity • Increase the installed hydropower generating capacity • Feed into a common grid • Focus on national or sub-regional self sufficiency	• Selection of investment alternatives • Determining scale of development for new schemes • Optimisation of scheme design and operation rules to best suit emerging needs • Evaluation of hydropower compared to other possible solutions to the energy problem

AREA OF CONCERN	NELSAP INITIATIVES	ENSAP INITIATIVES	POSSIBLE INTERVENTIONS / ALTERNATIVES	SAMPLE DECISIONS
Rainfed and Irrigated Agriculture	NELSAP Track 2 • Use of modern irrigation and rainwater harvesting techniques NELSAP Track 3 • Agriculture	Irrigation and drainage are the foci of the Eastern Nile Irrigation and Drainage Study Productive agricultural use of water resources is a sub-focus of the Eastern Nile Joint Multi-purpose Programme	• Run-of-river schemes • Storage based schemes • Groundwater based schemes • Conjunctive use schemes • Complementary irrigation schemes	• Selection of investment alternatives • Prioritisation of areas for irrigation development • Determining type and scale of development for new schemes • Optimisation of scheme efficiency • Minimisation of negative impacts
Watershed and Sediment Management	NELSAP Track 2 • Re-afforestation management NELSAP Track 3 • Watershed management	Watershed degradation is the focus of the Integrated Watershed Management Program Improved management of watershed is a sub-focus of the Eastern Nile Joint Multi-purpose Programme	• Large scale terracing • Agroforestry • Sediment interception structures	• Identification of priority areas of intervention • Determining sizes of dead storage for reservoirs
Navigation	NELSAP Track 2 • Navigation for trade and tourism • Water hyacinth control		• Increase and maintain draft depths by releases from storage dams • Increase and maintain draft depths by dredging • A combination of both	• Selection between alternatives • Optimisation of operation rules (releases from storage dams) to minimise impacts on navigation potentials of rivers and lakes downstream

Table 5.3 Areas of Concern, Sample Decisions and Supporting DSS Outputs

AREA OF CONCERN	POSSIBLE INTERVENTIONS / ALTERNATIVES	SAMPLE DECISIONS	DSS QUESTIONS	DSS OUTPUTS (CRITERIA)
Water Resources Development	• A few, large, basin level storage structures • Small local level water harvesting schemes • Water conservation projects (loss reduction)	• Selection of investment alternatives (e.g. small number of large, basin level storage facilities, or large number of small, local level storage facilities, or a combination of various alternatives?) • Configuration of the overall (macro level) system-wide water development plan • Determination of features of development schemes (location, scale of development, size of components) • Identification of optimal operation rules (at the planning level)	• What are the magnitudes of demands that the storage alternatives could fulfil? • What is the yield of the upstream catchment at the point of interest for the planned scheme at different levels of reliability? • What is the impact (+/-) of the intervention alternatives on flow: system wide water balance; peak and minimum flow at designated points? • How would key environmental assets be affected due to the flow regulation resulting from each alternative? • What are the economic impacts of the alternative schemes? How many people will be displaced due to the planned storage scheme? • How would the flow regulations resulting from each alternative affect societies downstream? • Who is better/worse off for each alternative?	**Bio-Physical/Environment** • Change in volume of water available: 1. System wide (water balance) 2. At designated points in the river network (such as environmental hotspots, other points of interest) • Change in sediment movement downstream • Effect on navigable water reaches (draft, length of reaches, etc) • Change in annual dead storage volumes due to upstream sediment trapped • etc. **Socio-Economic** • FIRR/EIRR (or B/C) of alternative; or economic and financial unit costs of increased water • Impacts on Navigation (gain/loss of revenue as a result of implementing alternative) • No of people t o be located (from reservoir area)

AREA OF CONCERN	POSSIBLE INTERVENTIONS / ALTERNATIVES	SAMPLE DECISIONS	DSS QUESTIONS	DSS OUTPUTS (CRITERIA)
Optimal water resources utilization	• User financed water saving equipment and infrastructure • Subsidised water saving equipment and infrastructure • Demand management by means of a basin wide, rights based; water resource pricing mechanism • Changed operating rules for large storage dams • A combination of the above	• Comparison of alternative ways of increasing system efficiency, e.g. – basin wide resource priced demand management mechanism – investments in water saving infrastructure and equipment – subsidising of increased engineering efficiency at user level – introduction of penalties for wastage – changes of operating rules for dams	• Where in the basin exist opportunities for enhancing the physical and/or economic efficiency of water use? • How would water utilization be enhanced if available storage is operated in a coordinated manner? • What are the investment implications for making water more economically mobile? • What are the economic benefits accruing to each alternative?	**Bio-Physical/Environment** • Net gain in water availability at basin and specific locations • Impact (+/-) of contemplated alternative on downstream water flow **Socio-Economic** • Net financial and economic productivity of water at basin level • FIRR/EIRR (or B/C) of alternative; or economic and financial unit costs of increased water
Coping with Flood	• Changed operating rules of large storage dams • Flood management infrastructure • Restored flood plain functions • A combination of the above	• Determination / selection of the most feasible flood-control schemes or mechanisms, e.g. – Changing operating rules of existing dams – Building of new dams for flood control purposes – Restoration of flood plain functions	• What would be the impact of contemplated alternatives on flood peaks and areas of inundation? • What are the flood peaks at designated points of interest, with and without planned interventions? • How much flood damage can be avoided if storage reservoirs can be operated differently? Which operation rule produces the least flood damage? • Which parts of the basin are flood prone? What is the type of land-use practiced in these areas? • What the economic costs and benefits of each alternative?	**Bio-Physical/Environment** • Peak flow conditions at designated points along the river network • Changes to inundation patterns at designated flood prone areas • Changes to the annual hydrograph and regime cycles that would impact capture fisheries **Socio-Economic** • FIRR/EIRR (or B/C) of alternatives

AREA OF CONCERN	POSSIBLE INTERVENTIONS / ALTERNATIVES	SAMPLE DECISIONS	DSS QUESTIONS	DSS OUTPUTS (CRITERIA)
Coping with Droughts	• Adapt to increasing drought conditions by increasing storage facilities • Adapt to increasing drought conditions by increasing (conjunctive) use of groundwater • Mitigate droughts by crop diversification and changing farming systems • A combination of the above	• Comparison of alternative measures to enhance the resilience of the system to drought and reduce vulnerability • Development of adaptation and mitigation strategies	• What are the inflow and climatic conditions in the short and medium term? (rainfall and flow forecasting) • What are the degrees of vulnerability to drought (for different parts of the basin) • How would performance of the system improve with respect to coping with drought if managed differently? (for example, if more flow regulation is provided?) • How would the system respond to anticipated shortages • What are comparative costs and benefits of adaptation versus mitigation measures? • What are the economic benefits accruing to each alternative?	**Bio-Physical/Environment** • Information on severity of drought (Drought index and comparisons with earlier events) • Predictions of flow conditions for short to medium term • Operational updates on status of water availability in the basin (reservoirs, lakes, river flows, etc) • Effect on availability of water during times of drought **Socio-Economic** • FIRR/EIRR (or B/C) of alternatives
Energy Development	• Regional power trading based on a common grid and existing capacity • Increase the installed hydropower generating capacity • Feed into a common grid • Focus on national or sub-regional self sufficiency	• Selection of investment alternatives • Determining scale of development for new schemes • Optimisation of scheme design and operation rules to best suit emerging needs • Evaluation of hydropower compared to other possible solutions to the energy problem	• How much generation capacity is available in the Nile Basin (by country)? • How much energy can be generated for a given configuration (of storage and power plant)? • What are the economic benefits accruing to each alternative? • How would existing hydropower generation schemes be affected due to the planned alternative (energy produced, unit cost, etc) • What is the overall system-wide benefit in terms of energy generation under the various alternatives? • What are the tradeoffs (sectoral and by country) necessary under each alternative?	**Bio-Physical/Environment** • Increase in energy supplies (GWh/y); contemplated alternative and system wide **Socio-Economic** • Unit costs of energy • FIRR/EIRR (or B/C) of alternatives including tradeoffs with other alternatives (thermal, etc) and sectors (irrigation, flood control, etc)

AREA OF CONCERN	POSSIBLE INTERVENTIONS / ALTERNATIVES	SAMPLE DECISIONS	DSS QUESTIONS	DSS OUTPUTS (CRITERIA)
Rainfed and Irrigated Agriculture	• Run-of-river schemes • Storage based schemes • Groundwater based schemes • Conjunctive use schemes • Complementary irrigation schemes	• Selection of investment alternatives • Prioritisation of areas for irrigation development • Determining type and scale of development for new schemes • Optimisation of scheme efficiency • Minimisation of negative impacts	• Which parts of the basin rely on rain fed agriculture (spatial information)? And which parts rely on irrigation? • What is the productivity level of agriculture in the Nile Basin? For rain fed and irrigated agriculture; what are the contributions of each to food security in the basin? • What are the crop water requirements for major growing areas in the Nile Basin? • What is the effect on environmental/riparian streamflows for the various alternatives? Is there a hidden economic cost? • How much water is required for the specific irrigation developments in question? What is the trade-off with other uses (by sector and u/s – d/s) • What are the economic benefits accruing to each alternative	**Bio-Physical/Environment** • Distribution of crop growing areas (rain fed and irrigated, spate) • Crop water requirements for selected points of interest • Effect in flow at designated points (environmental stream flow) and overall system water balance **Socio Economic** • Impact on human livelihoods • Economic productivity of water at basin or sub-basin level • FIRR/EIRR (or B/C) of alternatives

AREA OF CONCERN	POSSIBLE INTERVENTIONS / ALTERNATIVES	SAMPLE DECISIONS	DSS QUESTIONS	DSS OUTPUTS (CRITERIA)
Watershed and Sediment Management	• Large scale terracing • Agroforestry • Sediment interception structures	• Identification of priority areas of intervention • Determining sizes of dead storage for reservoirs	• Which watersheds of the Nile Basin are most severely degraded? How does this relate to population pressure? • What is the sediment yield distribution by basin/watershed? • What are the social impacts of each alternative? • What are the economic benefits accruing to each alternative	**Bio-Physical/Environment** • Change in sediment movement (quantity) • Change in reservoir/canal sedimentation downstream • Changes in channel morphology downstream • Change in erosion rate • Effect on water availability 1. System wide water balance 2. Change in peak/minimum flow downstream **Socio Economic** • FIRR/EIRR (or B/C) of alternatives
Navigation	• Increase and maintain draft depths by releases from storage dams • Increase and maintain draft depths by dredging • A combination of both	• Selection between alternatives • Optimisation of operation rules (releases from storage dams) to minimise impacts on navigation potentials of rivers and lakes downstream	• Which parts of the river system are navigable and what are their characteristics (length of reach, width, depth, minimum depth requirements, etc) • What is the likely impact of an upstream development (water abstraction, flood releases, flow regulation) • What are impacts of anticipated climatic variability on navigable reaches and lakes for each alternative? • What are the economic benefits accruing to each alternative	**Bio-Physical/Environment** • Impacts on navigation potential of navigable reaches and water bodies **Socio Economic** • FIRR/EIRR (or B/C) of alternatives

The requirements resulting from this analysis have been translated into a set of core models and evaluation routines that can, together with the (geo)statistical analysis and report generation tools, describe the individual alternatives and produce the required outputs.

At this stage it was necessary to introduce expert experience to select a set of models, tools and criteria that can realistically be implemented within the first phase of DSS development. The list of required models is provided in section 5.5 below while a list and description of criteria these models can directly and reliably produce is provided in section 5.6 of this report.

5.4 Support to Decision Making Processes the DSS can Provide

The Nile Basin DSS will support various types of decisions and various steps of the decision making process. It will provide support in the following

- **Problem identification level**: Primarily supported by the information systems functions that highlight any observed or predicted deviations from the expectations and goals;
- **Definition of alternatives / actions:** Both the simulation models and the associated data base (of measures, instruments) are used to define scenarios or strategies for simulation or optimization;
- **Definition of criteria / indicators**: Criteria can be selected from a pre-defined master list that can be reliably produced by the available set of models;
- **Evaluation of alternatives**: The evaluation in terms of the criteria is embedded in the simulation models, including the economic assessment; criteria will be combined and weighted through the (participatory) definition of a preference structure.
- **Selection**: the selection of a preferred alternative from the feasible set generated by simulation (scenario analysis) or by simulation based optimization (automated scenario generation) is supported by the system's MCA tools using the user defined preference structure.

5.5 Model and Tool Requirements

The Nile Basin DSS will support decisions in the field of the eight areas of concern in the following way, with associated criteria for evaluation and ranking (MCA):

- **Water resources development**: Basic dynamic water budget model and economic evaluation - all hydrological and economic criteria;
- **Optimal water resources utilization**: As above, with MCA tools supporting the evaluation of optimal utilization based on user-defined preferences and criteria, to be agreed upon through a participatory process;
- **Coping with floods**: Flood damage estimation in the water budget model, reach/routing results and control node based evaluation;
- **Coping with droughts**: Water shortage penalties computed by the core models, yield losses from the irrigation water demand model;
- **Energy development (hydropower)**: Hydropower production as a function of reservoirs in the dynamic water budget model, economic criteria of the cost/benefit analysis;
- **Rain fed and irrigated agriculture:** Irrigation water demand model, farm/irrigation nodes in the dynamic water budget model, economic evaluation and criteria;
- **Watershed and sediment management**: Rainfall-runoff model including watershed erosion (lateral catchment representation in the water budget model); GIS-coupled database of

watershed characteristics for estimation of watershed degradation levels; sediment routing models;

- **Navigation:** Addressed by reach level low-flow constraints in the dynamic water budget model; can be evaluated with user defined penalties for non-compliance at control nodes that monitor flow against minimum flow targets;

and for the cross-cutting issue of water quality:

- **Water quality**: dynamic water quality model (DO/BOD, conservative tracers, first- and second order decaying substances) including basic sediment transport processes (turbidity, bank and bed erosion, siltation), that operates as a downstream model using the flow data from the water resources model.

The system will include tools for scenario analysis (answering WHAT IF questions), for optimisation (automatic generation of alternatives, simulation based optimization) and for the evaluation of the alternatives in terms of the user selected criteria (hydrologic, socio-economic, environmental).

5.6 Data Requirements

Data availability is certainly a constraint that needs to be addressed in a systematic manner. Among the key activities are

- agreement on a data sharing protocol between the riparian states, and
- strengthening of the national monitoring systems (see Annex B, section 2.3, for details).

However, for the core models, the basic hydro-meteorological and geophysical data are largely available from public sources. These data include, for example, runoff data sets from FAO (close to 40 data sets); global Digital Elevation Models; satellite imagery for land cover; climate and meteorology data (e.g., NOOA/NCEP: National Centres for Environmental Prediction), so that the basic dynamic water budget model can be calibrated and validated for the entire Nile basin and major sub-basins. These will be major tasks in the application building phase and testing of the initial DSS development.

For specific models beyond the core and for high-resolution models, special data compilation exercises will be needed to obtain the data necessary to run, calibrate and validate these models.

6 Nile Basin DSS Functionality Design

The Design of the Nile Basin DSS describes the organization of the proposed Nile-Decision Support software system into

- the initial set of modules/components/classes or other units
- the behaviour and functional responsibilities of units
- the interaction between these components, including the different users.

The DSS design, related architecture and implementation proposal (Implementation plan of the DSS Development plan and TOR inputs) are based on

- general considerations of the DSS processes the system will support;
- the results of the project's analysis phase, the main concerns (issues) identified by the stakeholders, and the institutional, technical, and data constraints that need to be considered.

6.1 Basic Design Principles

6.1.1 Basic Questions related to the DSS design

The basic questions related to the DSS design can be summarized as follows:

What will the system be used for?

A decision support system for integrated water resources management primarily has to support decision making processes. This includes the iterative steps of:

- Structuring the problem and providing a shared information background to all participants in the decision making process (stakeholders);
- Defining a preference structure, which involves the selection of (multiple) criteria, and the definition of (multiple) objectives and a priori constraints;
- Designing alternatives in terms of combinations of instruments (technological, economic, regulatory), that hold promise to meet the constraints and contribute to the objectives;
- Evaluate the performance of the system for these alternatives in terms of the preference structure (multiple criteria);
- Rank the alternatives, and eventually select a preferred (optimal, compromise) solution acceptable within the rules of the decision making process and its participants.

What will be the output of the system and how it shall be used to serve the intended purposes?

The output of the Nile Basin DSS corresponds to the basic components, which in turn mirror the main steps in the decision making process and MC analysis:

- Answers to any and all interactive queries put to the information system in the form of interactively designed reports, including the possibility to export selected data sets for processing with (local) third party tools;
- Model generated scenarios/results including their evaluation, uncertainty and sensitivity analysis for model results;

- Ranking of alternatives for specific decision problems according to the user defined preference structure (MCA and decision support proper).

How will the user interact with the system?

The system will be used by various types of users, who will perform different tasks. These groups are defined in section 7 of this report.

A hierarchical structure of the user interface and reports generated will provide different levels of detail and technicality for different users. All of them, however, will access the system through the same primary graphical user interface (GUI) and visualization tools (primarily graphs, diagrams and topical maps): Interactive, menu driven (selection from pre-defined menus of context sensitive options, point-and-click, drag-and-drop interface. The open architecture and interfaces will also support the use of external tools for data visualization including animation.

System access will be distributed (web browser as the primary client software) and can be either local (LAN or local PC/workstation/server) or remote through the Internet, but using the same standard protocol (http).

6.1.2 Basic Principles of the DSS Design

The DSS design described below is based on the following principles:

- **Ease of use**: the primary objective is to support decision making processes by diverse groups of stakeholders, which requires ease of use or useability. A consistent, intuitive, largely graphical, user interface includes a fully interactive and menu driven implementation, easy to learn extensive (data driven) configuration and adaptation options, embedded help- and explain functions, and error correcting.
- **Flexibility:** A DSS supports individual and institutional **learning processes**, which implies continuous change of users and user requirements. Adaptability, customization, continuing development and support for easy upgrades are all required features. Flexibility also means that the system must be scaleable for a wide range of problems from local to basin wide while retaining the same logic and methods wherever possible,
- **Scientific excellence**: a key concern when using complex software tools for decision support is **trust**. This must be based on access and openness for inspection, the ability to analyse any results in terms of the underlying, data, assumptions, and methods, full and easily accessible documentation including relevant parts of the source code.
- **Openness, transparency**: also related to the issues of trust, but equally to ease of use and the shared information basis for all stakeholders and participants in the decision making process (empowerment by information, Agenda 21, chapter 40) is the principle of openness. All data, assumptions, and processes used must be open for inspection and sufficiently documented.
- **Modularity:** the above requirements necessarily lead to a high degree of modularity, with multiple, alternative and complementary tools, models and methods, easy to exchange or add, but also the possibility to customize different versions of the system for different|(local) use easily with different sets of components.
- **Advanced technology**: as a complement to scientific excellence of the methods and tools, the use of **advanced yet appropriate** technology is the basis for the usability requirements. The very rapid development of ICT makes a forward looking strategy mandatory.

- **Compatibility, interoperability**: integration of components, and interoperability with external information resources, models, tools, data bases, monitoring networks etc. All require adherence to industry standards.
- **Cost efficiency**: this is a major prerequisite for the **sustainability** of any ICT solution. This includes not only the basic hardware and development or license costs, but more importantly the costs of continuing training, maintenance, further development.

6.2 Software Development Approach

6.2.1 Software Design and Development Methodology

The choice of software design and development methodology for the Nile Basin DSS development and the corresponding systems architecture and implementation is based on the requirements and constraints derived from the stakeholder workshops and interviews, and basic project characteristics. The choice of approach for software development is based on the main characteristics of Nile Basin DSS, which include:

- participatory implementation and a high degree of innovation,
- a heterogeneous and distributed group of stakeholders,
- approximate initial user specifications from a diverse user group,
- a complex and partially-structured application domain, and
- the non-commercial nature of the product.

The basic software development methodology adopted for the Nile Basin DSS demonstrator development and integration is **rapid prototyping**[3] within an **object oriented design and development methodology** as described in Rumbaugh OMT (Rumbaugh et al., 1991).

Prototyping is preferably used as a development method in cases where the users find it difficult to explain what is required of the software in a sufficiently technical language to allow precise interpretation. While the user requirements analysis (for a detailed description of the Analysis phase, please refer to Appendix A) provides general and high-level guidelines, in particular on aspects of required (and also desirable but not essential) functionality related to key concerns, and describes application scenarios (interventions) in some detail, it lacks the technical details that could be used as the basis for a more structured design approach

6.2.2 Modular, Open Architecture

All DSS components will be integrated in an open, hierarchical, modular and very flexible structure that *inter alia* will facilitate information exchange with other models and tools used or developed within the basin. The basic system must be designed to be easy to expand beyond the initial functionalities by adding models and tools that share the same basic utilities, data bases and core components.

“Open architecture” refers to a system/software architecture that is open for modifications and additions by virtue of using only (a) industry standard (b) fully documented interfaces (API), protocols, and data formats. The use of industry standard where applicable - including basis such as OSI and standards of communication protocols and data formats, but also more specific application oriented standards such as OpenGIS, OpenMI, Dublin Core Metadata, etc. - is an

[3] see http://en.wikipedia.org/wiki/Software_development_process for an introduction to rapid protyping in software development

important element to guarantee interoperability with external information resources, models, tools, data bases, monitoring networks etc.

This is closely related to the requirement of modularity (individual semi-independent modules). A component-based design methodology facilitates development, testing, customization, upgrading and adjustment according to evolving user needs.

6.2.3 Open Source Tools vs. Commercial Software

While the use of Open Source tools may appear of great advantage, the integration of different models, tools, utilities into a well designed and consistent system with a common user interface is beyond the constraints of the time table specified (30 months).

Therefore, it is suggested to start from a commercial product that meets the requirements of the core system and the overall open architecture as much as possible (according to the checklist of required and desirable features) seems necessary, with additional developments to adapt to the specific NBI needs.

Maintaining open and well documented interfaces (as required) will make the future integration of Open Source tools easily possible; and (at least partial) access to the source code of any solution proposed for either future development or at least detailed documentation is one of the desirable features for the TOR.

6.2.4 Development Standards

The requirements of ISO 9000-3 for software design are straight forward and rather general:

- The activities should be carried out in a disciplined manner.
- Input and output should be specified, and design rules and internal interface definitions should be examined.
- A systematic design methodology appropriate to the type of software being developed should be used (application specific methodology).
- Past design lessons learned should be used, and past mistakes avoided.
- Product design should facilitate testing, maintenance, and use.
- The product of the design phase should be subject to review.

These requirements will be reflected in the implementation plan and ToR.

6.2.5 System Components and Object Classes

The main components of the system can be grouped into

- Objects (data) organised in a set of object oriented data bases (implemented in industry standard RDBMS) and
- Services (functions) that operate on these objects and produce derived information products.

The object classes that define the core of the information system content directly represent the real-world objects in the river basin. They also relate to the main elements of the core models like Nodes (including sub-catchments) and Reaches (river segments). A major feature (see “flexibility” above) is that the list of object classes is open, new classes and their list of attributes (and certainly new instances within a class and their attribute values) can be dynamically configured (data driven without any changes to the code) to guarantee an open data base structure and flexible interface for any and all optional third party components.

Typical examples of basic IWRM object classes that directly relate to the basic core of models include a set of geo-referenced classes:

- (Sub-)Catchments or watersheds
- River segments or reaches, pipelines; (gravity flow or pumped) associated data are cross-sections, roughness (routing parameter) and rating curves.
- Reservoirs (natural lakes or with an-made storage dams) with their associated geometry
- Monitoring stations and associated time series of observations (hydrological, meteorological, combined); from the monitoring data, model input time series can be extracted, edited (e.g., scaled) and used in the models as named data sets as part of a model scenario.
- Hydraulic structures (weirs, confluences, …)
- Aquifers, and associated springs (natural flow), wells, well fields (pumped);
- Wetlands
- Settlements, farms, irrigation districts, industries/enterprises, tourist resorts
- Water and waste-water treatment plants.

Generic (non-georeferenced) object classes include, for example:

- Scenarios including all the related characteristics and descriptions of externalities and interventions
- Crops (with their physiological and economic/yield data)
- Water technologies (the technical elements and their techno-economic data that make up the Interventions to generate alternatives for the DM process);
- Pollutants (and their model relevant attributes like solubility, partition coefficients, persistence, toxicity)
- Aquatic species, wetland fauna and flora
- Variables (attribute definitions with name, synonyms, display name, unit, legal value ranges and definition, explanation, questions in support of editing functions, modification dates, source, ownership/access class, et.c) and optional Rule references (see below) for dynamic instantiation (estimation by rule-based inference);
- Rules. First order production rules of the form
```
IF   condition
     [AND/OR condition]
THEN conclusion
```
  that can be used for inference with a simple backward chaining inference engine for the estimation of values from circumstantial (indirect) evidence, classification tasks, symbolic modelling, etc.)
- Problem and error reports, FAQ, manual pages
- User profiles, access information and privileges, access rights
- Distance learning resources (lectures, tests, evaluations)

Each of these classes maintains an open list of attributes that can be numerical, symbolic, or both (hybrid). Each class, and each instance (member such as a specific reservoir) is defined by the values of these attributes, where the structure (set of attributes) is inherited from the parent class. A special set (and TABLE in the data base) corresponds to the META data for each object and attribute; typical META DATA elements (like for any other attribute, the list is open and can be configured at the application level, data driven).

6.3 System Architecture

6.3.1 System Structure and Components

The system is structured in terms of its major functional components or modules, and their relationship with each other and the user. The structure of the DSS reflects the major elements of the decision making process.

The three main groups of components are:

- The **information system (IMS)** represented by a set of (relationally) linked **databases** (RDBMS) that provide an object oriented and hyperlinked view of the Nile basin and its main functional components in hypermedia formats; the information systems includes a set of tools for **data management, pre and post processing, analysis, display and reporting**; most object (classes) in the system are geo-referenced, which makes a **GIS** a central component between the information system and the analytical tools. The information system also provides inputs to the analytical tools (model inputs, initial and boundary conditions) and manages model outputs, thus also supporting the cascading and nesting of models where the output of one model can (automatically) be used as the input for another.
- The **analytical tools or models**, that represent the basic functions of the river basin and will primarily be used for scenario analysis (answering WHAT IF questions), for the automatic generation of alternatives (automated scenario analysis, simulation based optimization in a two-stage procedure linked to the MCA below), and for the evaluation of the alternatives in terms of the user selected criteria (hydrologic, socio-economic, environmental). A fully integrated set of embedded models and tools that comprise the river basin modelling system will be complemented by external models that may be linked to this core for specific applications.
- The **DSS tools proper** that perform the ranking and selection of alternatives, and, depending on the MCA method used, with tools for structuring the problems, elicitation of preferences, support for group negotiations, analysis of robustness and sensitivity, all designed to support a participatory decision making process.

These three groups of components are embedded in a common user interface (based on http and a web server such as Apache), with common multi-layered access control. The components exchange data automatically to eliminate the need for manual data processing tasks, and also are supported by a range of systems management, maintenance, and configuration tools. The components are integrated seamlessly so that the user needs to make minimal interventions during an application session.

The primary communication between linked (cascading) models is through the shared data base: models results can be exported to the data base, model inputs can be retrieved from the data base. The management of the data sets including model scenarios (compound data sets that include (network) configuration information, model and scenario specific parameters, GIS data (fields) and numerous time series which are either derived from monitoring time series (observed or synthetically generated) or produced by other models or pre-processors.

6.3.2 Cilent-Server Architecture, System Installation and Communication

The DSS will be deployed as multiple installations of the same, identical software and shared data in different locations (NBI, sub-regional centers, national DSS centers). While each of these installations is, in principle, self-contained and stand-alone, they can interact by directly using functions and services (through their URL) in any other installation (see figure 6.2 below).

Technically, the Nile Basin DSS is structured as a **client-server** system using **http** as primary communication protocol for any combination of local and remote access (figure 6.1): A web client (browser) as graphical user interface uses http as the data transfer protocol over the general Internet protocol layers TCP/IP. Within any HTML page (interpreted by the web client) other protocols (such as ftp, smtp, ssh, scp) can also be used as required.

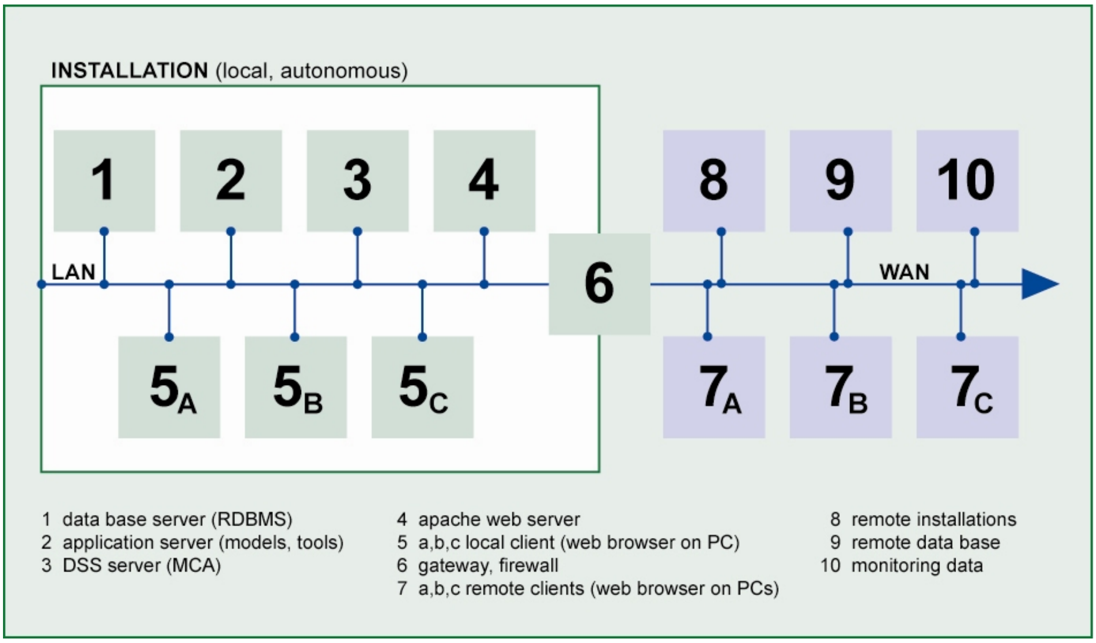
Server side tools include PHP and numerical models and tools in any language that can either

- Communicate with the **shared data bases through SQL**, including a blackboard (also implemented on the common RDBMS) for the coordination of interactive sessions in a multi-user environment);
- Generate HTML code for the client (standard PC with any standard web browser like MS Internet Explorer of Mozilla/Firefox), directly through cgis in C/C++ or PHP (server side); where appropriate, Java applets can be used for increased client side (graphic) interaction. Client pages in dynamic HTML include Javascript code for local interaction beyond HTML.

Use of standard PCs as clients facilitates integration of all Office (MS Office or OpenOffice) applications through **cut and paste** operations in addition to the possibility of **server-side integration** through:

- Data import/export in Office compatible formats such as CSV;
- Direct access of client-side applications to the SQL data bases with ODBC;
- Server side integration through standard interfaces, shared data base, cgi wrappers that execute third party (binary) code;

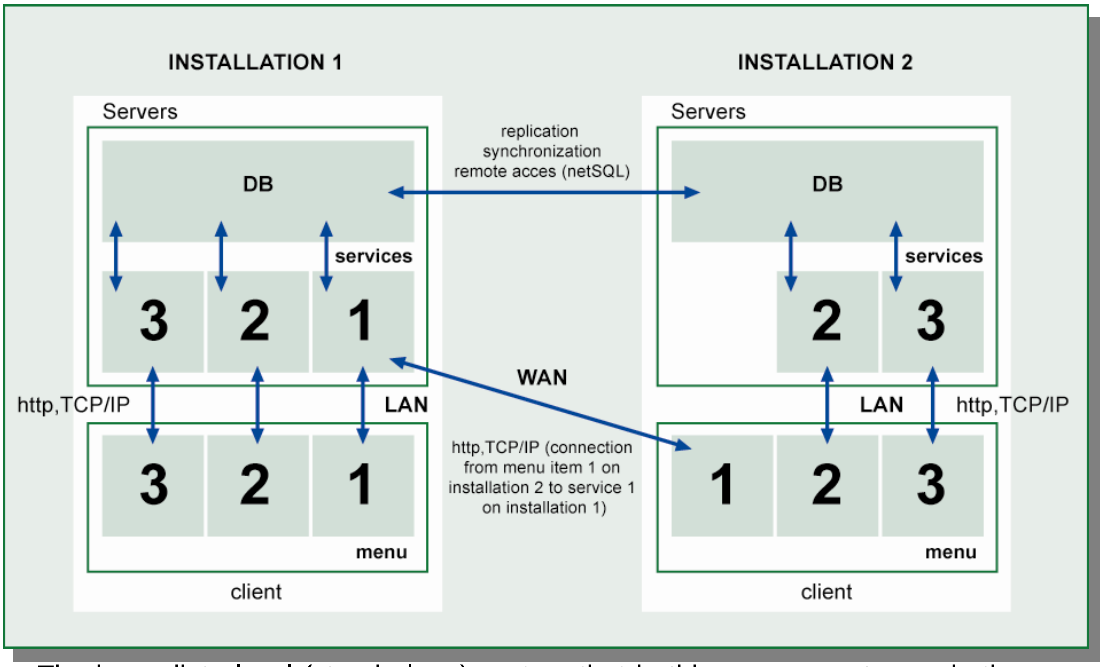
Figure 6.1 **A web based client-server architecture**



Access to interactive application and their interfaces through embedded OS emulators like VMware (virtual machine and virtual server) that basically can provide a web-accessible multi-user Windows environment on any (platform) server including a local machine with a non MS operating system.

All **information resources** in the system are defined as objects which provides for a unified management of data and functions (models, tools). They are identified by a URL (universal resource locator) so that they can be configured (data driven) on any installation and flexibly accessed from different locations (Figure 6.2):

Figure 6.2 **Optional sharing of services between installations**



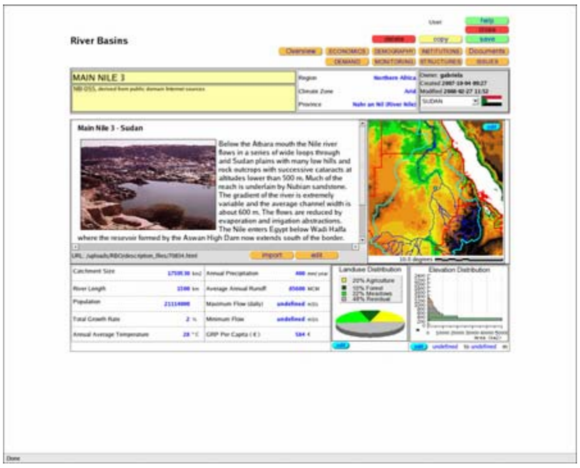
- The immediate local (stand alone) system that in this case operates as both server and client;
- A local area network (LAN Intranet) from a local database of web server;
- The Internet or WAN at any arbitrary (server) location that is network accessible.

This basic **architecture meets all the basic design concepts** enumerated above. It can be implemented both as a local, stand alone system, as a central powerful server/cluster for remote access and use by any web client, or as any combination of local and remote (in possibly several locations) information resources, data sets and models. However, any one of the installations share exactly the same code (all or a clean subset), the only differences are in the configuration data that define the locations (URL) of individual information resources (local or remote).

The implementation uses a number of (logical) servers that can be implemented on one single or several (possibly distributed) CPUs in one or more computers (clusters); these logical or software servers include:

- Object data base server (any industry standard RDBMS supporting SQL);
- Web server such as Apache (platform independent)
- Application server consisting of a set of cgi (common gateway interface) programs for the individual models and tools.

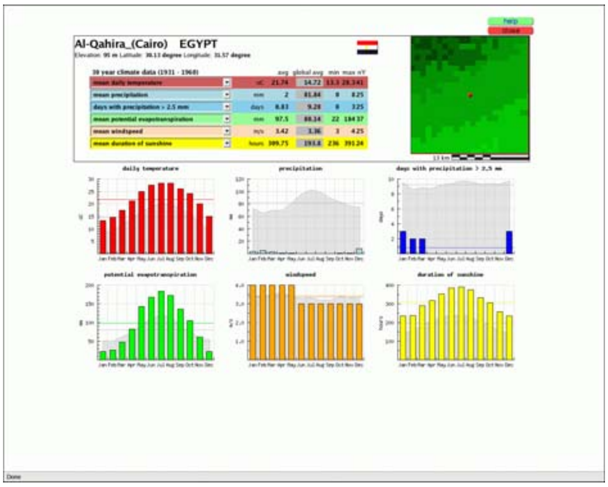
6.4 Information Management System



The information management of the NB DSS is based primarily on a common data base, implementing and object oriented design (OOD) on any industry standard relational database management system (RDBMS, e.g., ORACLE, Sybase, MySQL, PostgreSQL).

The data base is used to store

- all shared, common basin data, GIS layers, time series data, and links to the Document Management and Information System (Nile-IS); a set of basic objects to be represented and related to the water budget Model's network architecture is described above;
- any local data sets beyond the common, shared core data.
- model scenarios, parameters, model results; while primarily produced "locally" they can be exported for analysis at the next higher (sub-regional and basin wide) level, or provide inputs for any downstream scenarios;
- user management and access information and control;
- Ccordination between cascading models and data within a given interactive session (maintaining multi-user capabilities) using a blackboard architecture.



The main required features of the MIS are hypertext and multi-media support, an object oriented structure, compatible with the basic core model design, open architecture (see above) compliance with industry standards, open data and entity relationship model, and OLAP support. Operationally, the main requirement is tight integration with the model and DSS system including the automatic loading of data and management of scenarios and results.

6.4.1 Synchronization between Installations

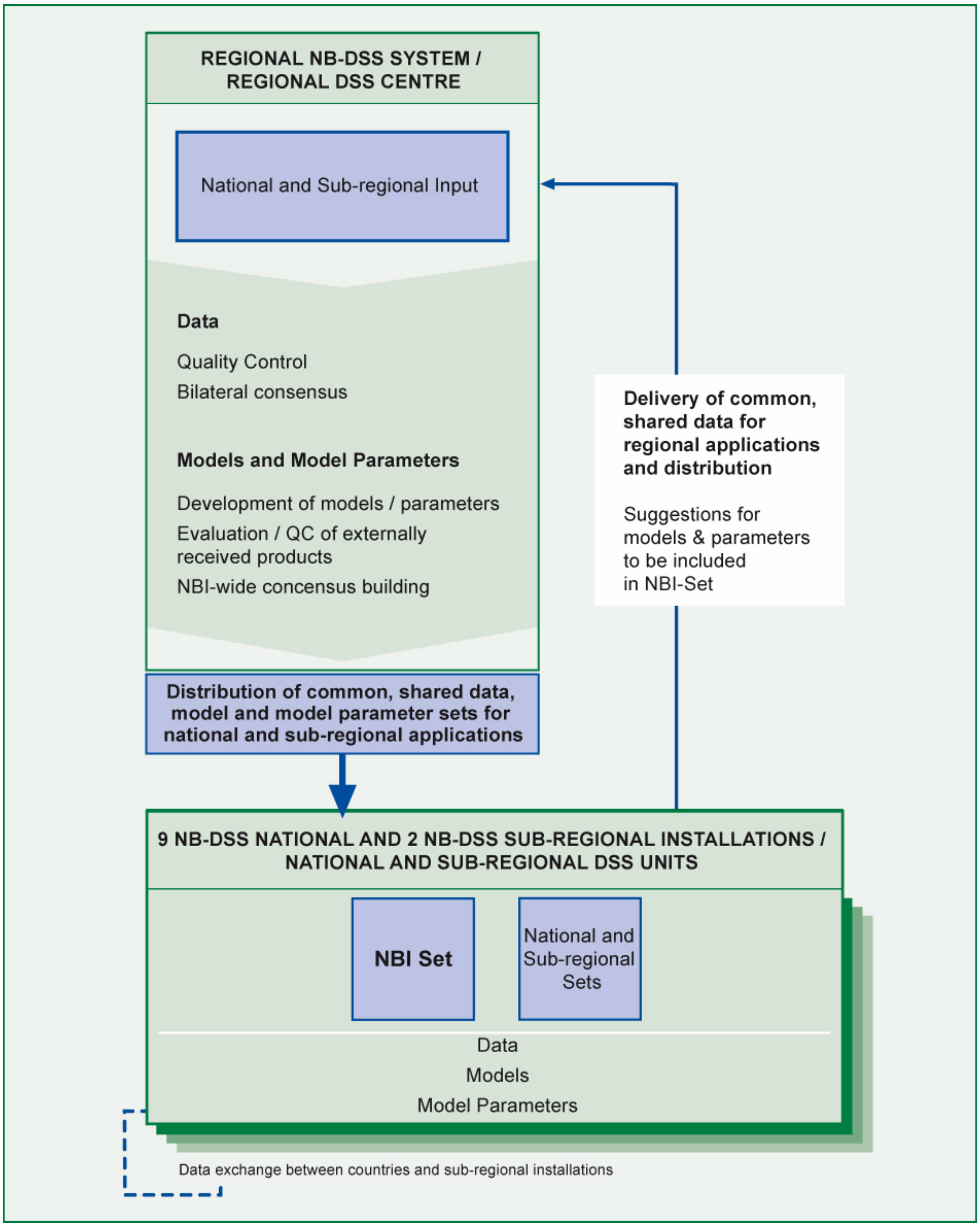
The NB DSS is planned as a single, common shared software system and common data base, with software-copies and data-replica at the national level, at the regional level and at the basin level. This requires careful consideration of the synchronization of any updates and modifications using the following principles:

- Common data sets, once approved by an editorial process to be defined, are distributed as read-only from the central NBI installation to sub-regional and national, basin level systems;
- Local data sets can be freely added and edited, including model scenarios; for the systems can be remotely accessed, all data sets are strictly controlled by user/owner and

group access privileges, i.e., read-only for any and all external/guest users; users (data owners) can freely determine access to their own data sets (data sharing).

- Any data or model scenarios/results that are to be included in the common approved, read-only shared data set have to be submitted to the next higher level for approval in an editorial peer review process before distributing them to all installations.
- Depending on the communication network capabilities, these synchronization tasks can be network based and fully automatic (updates are subject to the approval/acceptance of the respective local systems administrator) or by conventional distribution of electronic update media such as DVD.

Figure 6.3 **Distribution / Exchange of Data, Models and Applications**



6.5 River Basin Model System

The central modelling component is a dynamic water budget and linked water quality model including economic evaluation of the costs and benefits of water supply and use at different levels of temporal and spatial aggregation.

The central model uses a topological network representation of a river basin and any number of sub-basins or catchments, defined as NODES and REACHES (segments) (following Figures below) Nodes and reaches are objects, their behaviour described by data set from the information system, linked core models, and the basic dynamic water resources model itself.

6.5.1 Advantages of Network Representation

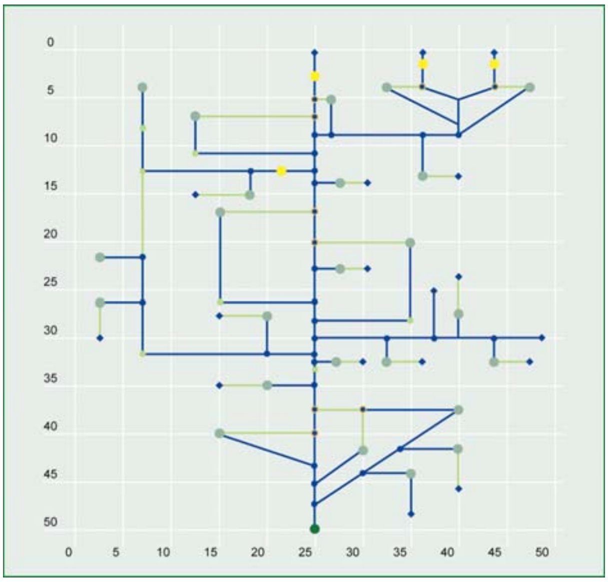
The main advantage of the network representation is its flexibility to adapt to arbitrary sized catchments; possible strategies include the ability to integrate nested models in order to analyze the basin at different levels of detail in a given application.

Model nesting refers to a method where the aggregated output from one model (application) of high resolution is used as the (point) input of another application of the same model with lower resolution but wider (spatial) coverage, i.e., a zooming in and out possibility to maintain both detail and coverage at workable levels over a large area. As an example, consider a detailed water budget mode of a sub-catchment represented by numerous nodes; the (aggregate) output (runoff) from that sub-catchment can be introduced as a single (sub-catchment or start) node in a model of a larger downstream basin.

Cascading of models describes the linkage of different models, where, for example, the output from the rainfall-runoff model is used as an input to the water budget model.

Since nodes of the network are represented as objects, this provides the possibility to add **new methods of analysis** (within the existing modeling environment as (user selected) alternative methods to "instantiate" the objects in the current (scenario) context. Since in the proposed client-server architecture this can be done by reference to any (user defined and provided) URL, the system is open for any additional method that interacts with the base model through the shared data base.

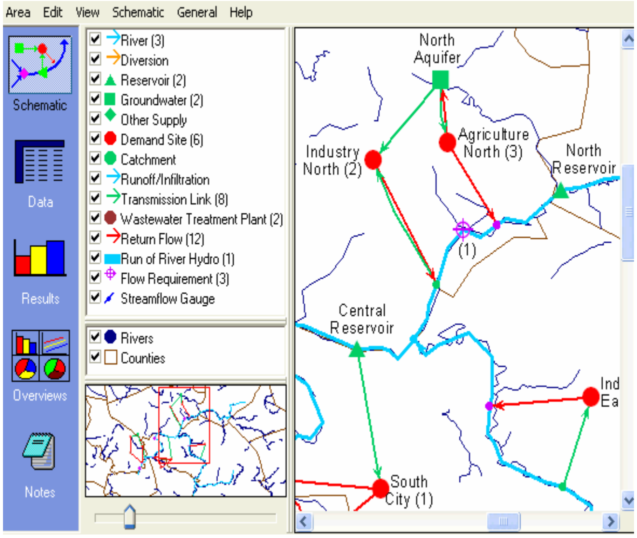
6.5.2 Basic Elements of Network Representation



While the detailed list of functional components that constitute a network representation of a river basin (dynamic water budget model) is adaptable, the list below provides some indicative examples and a minimal core of (object) components:

- <u>Start or input nodes</u>, that can represent
  - Sub-catchments (One more linked Hydrological Response Units, defined by time series of runoff which can in turn be generated by the linked rainfall-runoff model
  - Desalination, water harvesting
  - Springs, wells and well fields

- Demand nodes, representing areas of water use:
  - Settlements
  - Agricultural use (irrigation districts, livestock farming)
  - Commercial and industrial uses
  - Backdrop of GIS layers
  - Wetlands
  - Associated (waste)water treatment plants
- Structural components:
  - Confluences
  - Abstractions or bifurcations
  - Dams and reservoirs (with multiple abstractions/outflow for multi-purpose use including hydropower production) or natural lakes;
  - Falls and cataracts (relevant for navigation and water quality)
  - Geometry node (for geo-referencing and diagram design)



- End nodes (outflow from the basin simulated)
- Reaches (open channel) and associated lateral catchments, floodplains, pipelines (supporting pumped flow and negative slopes)
- Aquifers (underlying any number of nodes and reaches that can interact by seepage, extraction, infiltration and exfiltration); groundwater recharge (artificial)

6.5.3 Embedded Models (Core)

The network architecture of the basic dynamic water budget model facilitates the integration of a basic set of related models that describe individual functions elements (nodes) in more detail. These models are primarily linked through the exchange of input/output time series, sharing the same common object data base.

The minimal set of (initial) models that constitute the tightly integrated core of simulation tools consists of

- The dynamic **water resources network model with embedded economic evaluation**, generating dynamic water budgets, demand/supply data for distributed and sectoral water use. This basic, main or core dynamic water budget model system includes a number of components as embedded process models such as direct rainfall and evapotranspiration, routing (open channel and pipelines, gravity flow and pumped), confluence and diversions (abstraction points) including the representation of alternative water allocation strategies, storage and reservoir release, water use and interaction with groundwater such as conveyance losses (evaporative and seepage at demand nodes) etc. These processes are transparently embedded with the model system and accessible through the menu driven interface system (the model manager, see below). A simple (mass budget) lumped or semi-distributed representation of groundwater coupling and interactions (conjunctive use scenarios, seepage, infiltration and exfiltration processes) must be included to complete the water budget approach. More complex 3D groundwater flow and transport models can be linked as external components (see below). Aggregation to different geographical and administrative units (sub-catchments and riparian countries) as well as economic sectors is an important requirement. The basic dynamic water budget model does include **reservoirs**

and multi-purpose reservoir management (represented by multiple, individually controlled abstractions or outflow) as well as **hydropower production** at a planning level (daily timestep with optional monthly aggregation).

- Dynamic **rainfall-runoff model** with lumped, semi-distributed and gridded (GIS based) options, integrated in the DSS for different parts of the basin (subject to data availability). The model provides inputs to nodes representing sub-catchments, or lateral inflow to reaches. These inputs consist of one or more time series of flow; they can include, depending on the implementation strategies, estimates of non-point source pollution in particular sediment erosion from upstream catchments. The same modelling approach can be used to represent lateral inflow to the reaches of the primary network water resources model. In its embedded version, a lumped representation for each lateral catchment based on a runoff-coefficient and empirical methods like the Universal Soil Loss Equation (USLE) in its numerous variants can be used. A closely related topic here is flood management, prediction of flood plains and inundation areas. Relevant concepts include flood damage based on GIS overlay analysis with land use, and the extent of the flood plain, duration of the flooding; related aspects include inundation fisheries and agricultural use of the receding flood. This in turn is thematically linked with any specific wetland management simulation, see below. Operational real-time flood forecasting is beyond the scope of the basic model set (primarily due to the real-time data requirements) but can be linked through the external model integration strategies. Please note that the rainfall runoff model will only be used in parts of the Nile basin that do have precipitation above 10 mm/year.
- **Meteorological models** generating distributed hydro-meteorological data or forecasts. These can be either diagnostic (statistical pre-processors) or prognostic (non-hydrostatic) 3D dynamic models or; in particular for the regional to local downscaling of global scale climate change models (based on IPCC scenarios), a 3D prognostic model (e.g., MM5, WRF) will be required, but can also be integrated as an external code or computational service (see below); the use of meteorological for medium term forecasts is related to the management of droughts, together with methods of alternative supply and demand management. Depending on the scale and time horizon, this is positioned between the interpretation of internal hydro-meteorological data fields and the more long term climate scenarios and impacts (see below).
- An associated network wide dynamic **water quality model** (DO/BOD, conservative tracers, first- and second order decaying substances) including basic **sediment transport** processes (turbidity, bank and bed erosion, siltation) that operates as a downstream model using the flow data from the water resources model; please note that the details of turbidity erosion (bank, bed) and sediment transport including (reservoir) siltation will require a dedicated external modelling approach with considerable data requirements.
- 1D **hydraulic models** required for at least parts of the river system and in conjunction with sediment modelling.
- **Irrigation water demand** estimation/scheduling (provides input to nodes representing irrigation areas) and associated crop data (FAO CROPWAT or similar).

The set of tightly integrated models is implemented with a common (style) user interface, shared variable (including the criteria for the MCA) definitions, scenario management, and post-processing, directly and transparently coupled with

- The information system for the management of all model inputs, outputs, and scenarios;
- The DSS tools proper (MCA) for the ranking and selection of model generated alternatives (scenarios).

6.5.4 External Models

Specific (external) models extending the basic river basin modelling functionality will be required to address all issues and concerns beyond the basic set of main concerns, provide more detail (functional, spatial temporal) for the analysis. These models are not directly required as "embedded" functions of the river basin simulation system and can therefore be implemented either as specific developments (tightly coupled) or as third party external software solutions using any one of the integration methods described. The decision on the level of integration must be based on a careful analysis of stakeholder requirements, but also of considerations on costs and data availability. In many cases, a scientifically credible treatment of the problems and processes listed below will require some research and development effort, and dedicated data compilation. These optional external models include:

- Detailed reservoir management and optimization, including specific tasks related to power generation (e.g. hourly operational scheduling and control, power distribution systems). Please note that the basic planning level representation of reservoirs and hydropower production is already included with the core dynamic water budget model. Another important aspect of lakes and reservoirs is water quality (nutrient cycle, algae primary production, fish population dynamic, macrophytes), which would be the basis for any fisheries management models.
- Urban/industrial water demand (activity based including medium to long-term prediction capabilities based on growth rates for socio-economic driving forces), water distribution, sanitation;
- Water and wastewater treatment, related sewer systems, coupled to the river and lake/reservoir water quality models (see above)
- Non-point source pollution and watershed erosion (detailed distributed GIS based modelling);
- Near-field water quality downstream of major point sources such as major cities or wastewater treatment plants, also for highly transient (spill) events (e.g., flash floods in mining areas).
- Groundwater flow and transport model (e.g., 2D vertically integrated finite difference; complex 3D codes such as the "standard" MODFLOW can be considered as external third party codes, see below);
- Lake (or reservoir) water quality, nutrient budget, primary production including macrophytes (papyrus, water hyacinths), fish population dynamics; the will require the integration of a semi-distributed or fully 3D hydrodynamic model with an ecological model which in turn could be linked to a model for (economic) fisheries management;
- Wetlands; while basically included in the main river basin model as a demand node (similar to an irrigation district) or a lake (but with increased evapo-transpiration rates due to intensive macrophyte vegetation) additional aspects and process for wetland management, e.g., linked to biodiversity, and embedded in a framework of socio-economic pressure, will warrant a specific wetland model. Due to the combination of complex biophysical processes with both ecological and socio-economic variables, a semi-quantitative approach such as cross-impact modelling could be used.
- Climate change impacts: this primarily involves the downscaling of global climate change (GCM) model results to regional and local scales. Using any one of the numerous CCM models that simulate the IPCC development scenario, their output will be used as initial and dynamic boundary conditions for prognostic (non-hydrostatic) hydro-meteorological model systems such as MM5 or WRF. They generate detailed fields of hydro-meteorological data that can drive the rainfall-runoff models and river basin modelling system described above.
- Sediments (erosion, sedimentation) beyond a simple semi-empirical treatment of catchment erosion and turbidity in the open channel flow using a non-linear threshold

equation for bank- and bed erosion and sedimentation including siltation of reservoirs, a detailed treatment will require very detailed 3D hydromechanical modelling tools.

- Biodiversity is of obvious concern in the Nile Basin. However, a realistic simulation of impacts of water resources development project on biodiversity is beyond the current state of the art in environmental modelling, beyond a simple relationship with ecological niches (defined by any or all of the state variables of the models listed, i.e., water budget elements and water quality) empirically related to individual species. Only qualitative approaches (see SIA/EIA below) seem feasible with the information available.
- Impact assessment (SIA, EIA) Strategic and Environmental Impact Assessment is a major tool for the analysis of water resources management projects, in fact mandated by most countries and all donor agencies. Support for at least screening level EIA based on checklists and linked to the data bases is a mandatory component. A range of typical methods and a rule-based approach using intelligent checklists (web-based) are described in the references below.
- Regional development, demographics. A final topic that covers the major socio-economic driving forces is regional development modelling, demographics, and input-output modelling; this can provide estimates on water demand as well as waste water generation tat directly feed into the water resources and water quality models. Again, a very wide range of possible model approaches and solutions exists, and will require a dedicated research and development effort.

6.5.5 Model and Scenario Management

The coordination of the operations of the integrated model system is based on the object-oriented design and implementation (see above). All components, i.e., models, (user specific) scenarios, and data sets (model inputs and outputs) are objects that share the same descriptive elements (Meta-data) so they can be visualised, selected, imported and exported between the functional components (models and analytical tools) including the MCA.

Wherever the results of one model can be used by another one, these results (mainly time series of hydro-meteorological variables, water supply and demand data, water quality data) they can be exported as a named data set (with automatically generated Meta-data) to the common data base. For the use of any downstream model, they are retrieved (multi-attribute ranking, filtering, and selection, parallel map display for georeferenced objects) from the data base by the common (model and scenario management) tools that organize the data and scenario objects. Examples of these links are:

- Hydro-meteorological time series (primarily temperature, precipitation) from the meteorological models (diagnostic pre-processor, prognostic forecasting model) to the rainfall-runoff, water resources, and irrigation water demand model;
- Time series of runoff from the semi-distributed rainfall-runoff model to the water resources model
- Water demand time series from the irrigation model to the water resources model
- Distributed pollution load and erosion from the catchment model to the water quality and water resources models
- Flow field (time series of flow for all network reaches) from the water resources model to the water quality model.

One important link is the automatic export of alternatives (summary of model results in terms of the user defined criteria) to the DSS tools (MCA). These alternatives can be generated individually by scenario analysis. Alternatively, simulation based multi-stage optimization tools can run the river basin model system with automatically generated parameter combinations (representing alternative sets of decision variables or instruments) **in the core set of tools**. This can use straight forward Monte Carlo simulation, adaptive heuristics, or genetic algorithms to generate large sets of alternatives. Feasible alternatives (meeting all a priori specified constraints) are then exported to the MCA tools for a second, participatory ranking and selection procedure.

6.6 Decision Support Tools (Multi-Criteria Analysis)

The NB DS includes specific MCA tools. The main concern here is their integration with the simulation models, so that model generated alternatives can be exported for further processing the MCA automatically, transparently and error free.

A basic requirement here is that the criteria to be considered are indeed computed by the models; A master list of agreed upon criteria will have to be defined, from which users can choose any subset to be considered for any particular scenario; an indicative example of such a basic set of model generated criteria is given below, grouped into (1) bio-physical and environmental criteria; (2) socio-economic criteria. Please note that water quality or environmental criteria can be covered by defining benefits or penalties for meeting or exceeding reference standard at control nodes:

1. Bio-physical and environmental criteria
    - Supply/Demand ratio
    - Reliability of Supply
    - Performance of reservoirs, diversions
    - Allocation efficiency
    - Water Shortfall
    - Content Change
    - Flooding days and extent
2. Socio-economic criteria
    - Economic efficiency
    - Benefit/Cost
    - Net benefit
    - Total Benefit
    - Total Cost

Please note that these criteria can be computed for the entire basin, any sub-basin or country, and different economic sector as well as for any individual node. For details, please refer to Appendix B.

6.6.1 MCA Methods

A number of alternative MCA methods are described in the Annex B. The maintain the necessary flexibility, and also support methodological pluralism, at least two methods that can be used efficiently independent on the number of alternatives and criteria are recommended for implementation:

- Basic decision matrix or Pugh Method (REF) with subjective, user defined weights on the criteria selected;

- Reference point methodology with automatic normalization between NADIR and UTOPIA, and implicit weights expressed by a preferred solution (reference point); the default reference point is UTOPIA.

Alternative methods to determine weights based on pairwise comparison of alternative and criteria (outranking, for details see Appendix B) can be included as third party external components.

6.7 References and a selected Bibliography

References and a selected bibliography are given in Annex B.

7 Institutional Framework

For an efficient, informed and effective NB-DSS there will need to be a consistent institutional concept that can facilitate transboundary collaboration at **basin/regional** as well as at **sub-regional** and **national** levels.
There are essentially two types of coordination platforms which apply at each of these levels:

- Technical, environmental and economic considerations
- Political and administrative considerations

The interconnection of these is given in Figure 7.1. Note that there is also the important public/stakeholder consultation platform, which has been included in the figure, but crosses over both platforms. The figure is set out as a matrix indicating both the type of platform (on the vertical axis) and the geographical level, regional/national level (on the horizontal axis).

It will be difficult to keep a balance on the relevance of the committees and centres, against the cost and practicality of setting up 'too many committees/centres'. The proposed framework allows for multi-tasking of activities/roles to take place where possible.

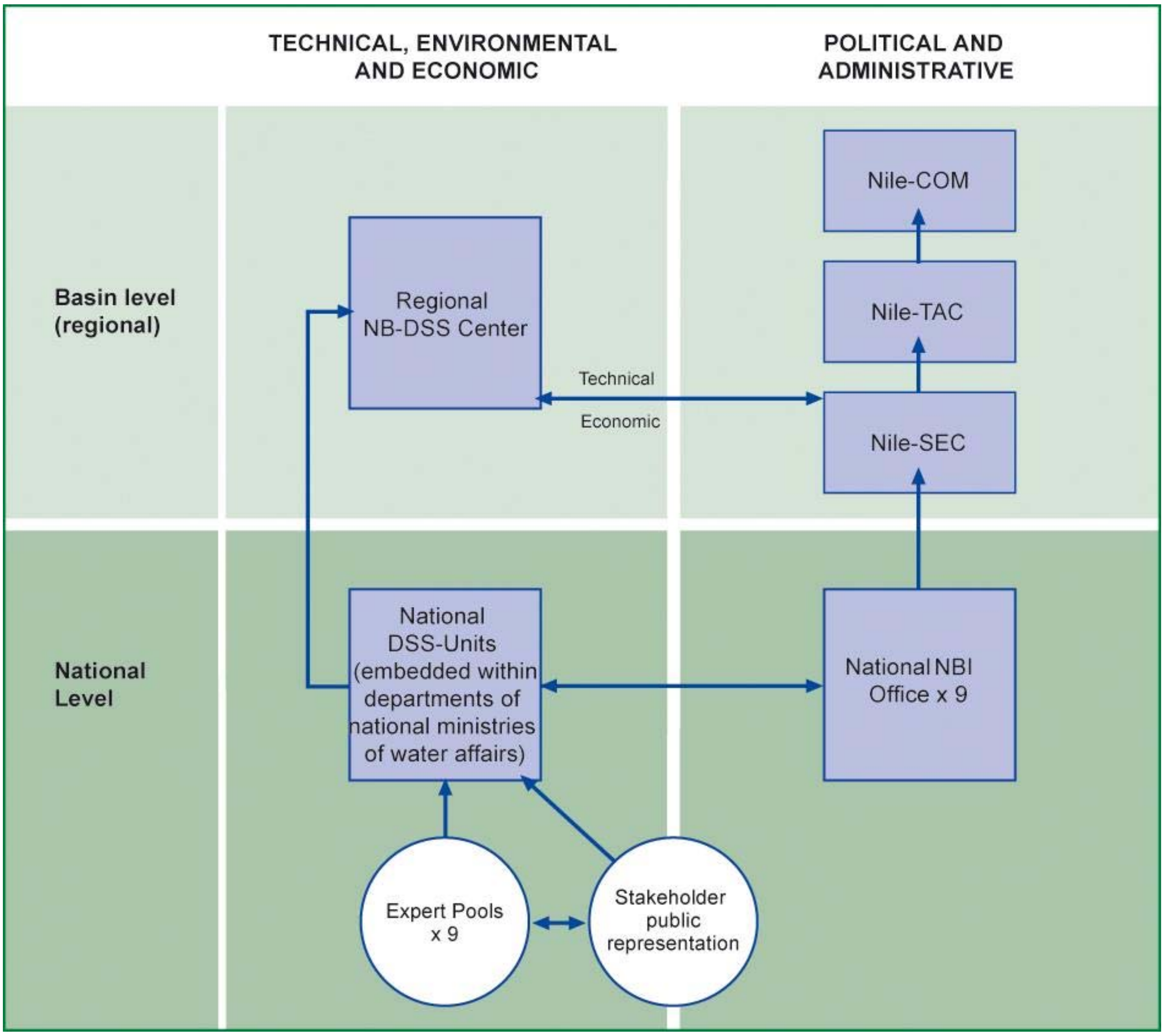
Within a proposed cooperation platform, the functional requirements of the DSS depend on institutional interaction at different levels, namely the:

- Regional level
- Sub-regional level
- National level

The complete establishment and roles of the institutional framework will evolve as the agreement on data and information sharing is prepared and the '*proposed institutional strengthening project'* takes place (between now and 2010). It is important that roles and functions are clearly defined so that overlap is avoided in accordance with each organization's mandate.

Please do consider that Figure 7.1 presents the institutional framework in a rather general form. More links could be made with the consequence of difficulties in the interpretation of different levels and arrows signalizing different forms of institutional links.

Figure 7.1 Proposed Institutional Framework for the NB-DSS



National DSS-Specialists and DSS Counterpart Staff are already operational in all riparian counties. The offices of the DSS Counterpart Staff are in general part of the line Ministry for Water Resources Management. The Consultant recommends establishing the National DSS-Units within the Ministries for Water Resources Management operated by a team including the National DSS-Specialists and DSS Counterpart.

Similar to the regional and national levels, on the sub-regional level Sub-regional DSS-Units should be established. The physical locations of such units can be decided by the Nile-TAC and other relevant decision makers. At operational stage, the location and staffing of the Regional DSS-Centre and Sub-regional DSS-Units shall be decided by the Nile-TAC and other relevant decision makers.

The Nile Basin countries are currently developing agreement on data and information sharing. The agreement shall, among others, lay down the roles/responsibilities of relevant NBI institutions and riparian countries with respect to provision of data and maintenance of databases. However, the proposed lines of collaboration in terms of sharing and distribution of common shared data, models and model parameter sets (see Figure 7.1) should be followed.

In the following sections the roles and functions of institutions within the recommended institutional framework are briefly introduced, but a more detailed description can be found in Annex D – Institutional Set-up and Decision Making Process of this report.

Nile Basin Council of Ministers for Water Affairs:

The Council of Ministers to provide policy guidance and operates for the whole of the Nile Basin; it is supported by Nile-TAC and Nile-SEC at the political and strategic level and provides decision making authority.

Regional Nile Basin-DSS-Centre

As laid out in the initial thought of the Nile Basin countries, the Regional NB-DSS-Centre shall assume the responsibility for providing the technical core team and modelling tools to support transboundary water management. The centre shall be accountable to the Nile-SEC/Nile-TAC/Nile-COM through the arrangements in a permanent River Basin Organisation (RBO).

The country representation in the staff developing and operating the DSS is a sensitive issue, which was mentioned frequently in the various consultations and workshops during the Analysis Phase of this assignment. A greater role for the National DSS-Units in the DSS development process as well as in the operational use stage is envisaged to build trust.

Quasi-Steering Committee Function

Existing NBI institutions such as

- Nile-COM, Nile-TAC and Nile-SEC at the regional level;
- EN-COM and NEL-COM at the sub-regional level;
- and National DSS-Office at the national level

steer the operation of the National DSS-Units, Sub-regional DSS-Units and Regional NB-DSS-Centres.

Sub-regional DSS-Units

It is anticipated that the principle of subsidiarity shall be maintained through which the sub-regional arrangements (EN- and NELSAP) shall continue to identify, prepare and implement investment projects. Sub-regional DSS-Units could be established with the existing arrangements of ENTRO and NELSAP-CU.

Primary roles of these two units shall be to support development of cooperative projects at subsidiary level, i.e. provide necessary technical support for planning of cooperative projects. Further, they provide technical capacity building (in coordination with the regional centre). The Regional DSS-Centre, having a basin-wide focus, shall be instrumental in integrating data and models to support investment decisions at subsidiary level.

Similar as with the Regional DSS-Centre, the country representation in the formation of Sub-regional DSS-Units is a sensible issue, which need special attention.

National DSS-Units

There should be a National DSS-Units in each of the NB countries which is embedded within appropriate departments of national ministries of water affairs. Those are responsible for operational use of the DSS for planning and management of cooperative projects, but also for collating and analysing technical, environmental and economic information/data, see Figure 7.1.

National DSS-Units facilitate the use of the DSS in the planning and management of cooperative projects. National DSS-Units are the core units in Nile Basin countries and shall serve as repository of the DSS at country level. They are accountable to the ministries within which they are established. It should be noted that arrangements may differ by country.

During the development of the DSS, the National DSS staff shall contribute as appropriate to activities, such as selection of consultants, review of development progress, training and selection of case studies.

National DSS-Units are provided with technical advice by National DSS Offices and will in turn provide political and administrative advice to the sub-regional and regional levels.

Stakeholder Forum(s)

There will be a communications role for the National DSS-Units which has the function of providing information to, and collecting from, all stakeholders and public representatives (see stakeholder public representation shown in Figure 7.1). In future the National and Regional DSS Networks will become part of the stakeholder public representation.

The application of the Nile Basin DSS is meant to assist in important processes and consequently impact on the socio-economic and environmental development of the entire Nile basin. It supports long-term development of the regions which will go hand in hand with political processes; national and regional ones. The involvement of a wider stakeholder group is important for the legitimization of such decision making processes. The exclusion of stakeholder groups, which benefit and/or bear the negative affects from decisions, will in the long run result in negative drawbacks, which should be avoided.

At all levels of operation, from local to basin-wide, it is important for the DSS to be open and transparent and continuously work with stakeholders. This can be achieved through a number of additional supporting means, such as regular multi-stakeholder forums as well as through partnerships with civil society or NGOs on particular activities.

8 Training Needs

The Training Needs Assessment was carried out during the Stakeholder Consultation Missions in the nine countries. The Assessment had a national focus in the light of a regional DSS, and therefore has been carried out at national level.
The objectives of this were:

- Assessment of the existing skills in the nine countries
- Assessment of the relevance of the proposed training modules and training contents for the nine countries on a country specific basis
- Identification of the Training Needs for further development of the training plan
- Development of comprehensive data and information to be discussed with the Client during the Sub-regional Workshop in Entebbe in order to reach agreement for the development of the training plan

The training needs differ according to which function a specific individual has in dealing with the DSS. Together with the Client the following definitions have been agreed:

- ***Managers***
  are the responsible administrators of the DSS-Centres and have direct connection to Decision-Makers. Managers are not Decision-Makers but are responsible for the whole decision-making processes.
- ***Operators***
  are the system administrators and responsible for the administration of the data, database, communication and user administration as well.
- ***Professionals***
  Professionals will be hired by NBI to build and manage the models. They can be also involved in the planning processes as well.
- ***Decision Makers***
  are the representatives of certain groups of beneficiaries and are directly involved in the decision-making processes.
- ***Data Providers***
  supply data to the DSS data bases.
- ***Other Users***
  are persons interested in getting more information on the Nile Basin and can use the IS via Internet portal.

The results show that all proposed possible training modules were considered by the participants as relevant. The central conclusions of the Training Needs Assessment and the Training Workshops are the following:

The intensity of the needed training will differ from country to country; therefore a modularised structure of the Training Plan is recommended. It is necessary to train a ‘critical mass’ of trainees for ensuring that the DSS technology, awareness and use is internalized at institution level and is sustainable after the end of the project.

The Training Needs Assessment has furthermore strongly contributed to the raising of awareness among the stakeholders in terms understanding of the different user levels and target groups and hence the necessity for differentiated training needs according to the target groups and the functions of the different individuals working with, supporting and deriving information from the

DSS. The value and advantages of the DSS for focused and result oriented discussions and decision-making in the various national and transboundary political areas has also been introduced to the stakeholders. In future, focused discussions will be enhanced within the NBI and its national components.

It has emerged that also other institutions, at national and international level offer training courses in the basin with DSS relevant content. Considerable synergies can so be generated in the future, which means that the efficiency of training and capacity building is notably enhanced.

Already existing and planned training activities of the NBI itself should be focused and bundled, increasing the overall efficiency of the trainings and capacity building activities.

The direct relevance of the Training Needs Assessment for the elaboration of the Training Plan is evidenced. The discussions during the Analysis Phase resulted in the understanding that two areas of training will be covered by professional service providers:

- the specific software training will be delivered by the software supplier (to be included in the tendered package)
- the training related to the development of applications, calibration and fine tuning of the models to be used will be supplied also by the respective service provider (also to be included in the tendered package)

Awareness raising trainings for decision makers and the high administrative levels are very important, since the knowledge about the potential of the DSS for the future transboundary and national policy dialogues, hence, decision-making should be enhanced.

9 Moving toward Implementation

The implementation of the NB DSS has to consider a number of constraints, primarily the very limited timeframe, but also the required participatory nature of the process. In consequence, the main elements of the implementation have to include:

- A rapid prototyping approach based on the adaptation and customization of existing software components, models and tools; a first operational prototype should be installed within one year of the implementation phase;
- Concurrent engineering, where different elements of the system can be developed in parallel, which requires a careful definition of all interface, data formats and protocols.
- A components based approach, where individual modules can be tested as fully functional tools in their own right to speed up development and testing.
- Build upon existing systems.

9.1 Implementation Approach

The detailed description of the systems implementation plan and associated detailed technical specifications will be provided in a separate report (DSS Development Plan).

The procedure most appropriate for the implementation of the above architecture, but also a participatory approach with a maximum of user (stakeholder) involvement is rapid prototyping in a middle-out approach (e.g., Rumbaugh et al, 1991).

The Nile Basin DSS technically consists of **several installations of the same, common systems** – for 9 countries, 2 sub-regions and the NBI itself.

On one hand there is a hierarchical relation between these components, which would suggest a technical solution based on a centralised client / server architecture, with the NBI providing the more sophisticated components (e.g. database, GIS) to be used by its partners, with central administration, maintenance and development.

On the other hand there are several facts suggesting alternative solutions:

- unpredictable quality of IT-connections (reliability, latency, bandwidth)
- demand for full-equipped systems on the national and sub-regional level for dealing with proprietary data
- complexity of managing the service of different system configurations
- decreasing costs of hard- and software components.

The recommended alternative is therefore to install 12 more or less identical systems at the NBI, sub-regional and national levels.

Sharing the same, identical client-server architecture, these systems can be operated as completely autonomous local systems, with data base (and optional software) updates from a central installation, or they can access any and all of the services from the central (or any other installation).

In this case, to assure

- consistency concerning data, models and parameters throughout the NBI;
- quality control of NBI-wide used information;

- general acceptance of NBI-DSS based decisions

the system needs a careful replication, update and synchronization strategy based on a master-slave concepts where the central server (at NBI) distributes any update.

9.2 Data Flow, Exchange of Models and Model Parameters

The underlying principle is that there is a central master installation that at any time holds the one and only set of information (data, models, model parameters) valid for the whole NBI and this NBI-set is only distributed by the central NBI-DSS to the local installations. The data of this common, central and NBI installation will be delivered mainly by the national authorities, but can also come from the sub-regions or maybe even the NBI itself. It will be the task of the NBI to check the quality (completeness, consistency, plausibility) of any data submitted and reach consensus about necessary changes. Only quality assured data can then be made available for distribution/replication NB-wide, based on the emerging Data Exchange Protocol.

9.3 Implementation Plan

The Implementation Plan for the Nile Basin DSS will be based on the Design Principles and the Systems Architecture defined above, including descriptions of:

- **The Procedure** A step by step guide to the process for using the method for design and implementation.
- **The Framework** which refers to the set of available building blocks, the hardware and software environment used for the implementation.
- **Evaluation criteria** The metrics, measures and design rules that are used to evaluate the design and implementation created using the procedure.
- **Notation and terminology** (ontology) providing a common, standard language and symbolism for the design and documentation process (such as UML, e.g., Albir 1998).

9.4 Potential Challenges and Risks to be Considered

Risks in the implementation process will be addressed in the DSS Development / Implementation plan. They are primarily related to the long-term sustainability of the system in terms of licensing, documentation, support, institutional capacities, etc. Specific concerns include:

- Contractual possibilities of long-term support, maintenance, extended warranty beyond the basic project duration
- Access to source code for inspection, further development, under a non-disclosure agreement, as an “insurance” (put in escrow against consultant’s bankruptcy), etc.
- Integration of local staff in the development, consultants location versus on-the job-training for local staff.
- License requirements and possible constraints in the distribution of software editions.

These concerns will be addressed primarily through a set of required features and criteria in the Implementation Plan and TOR.