Nile Decision Support Tool
Executive Summary

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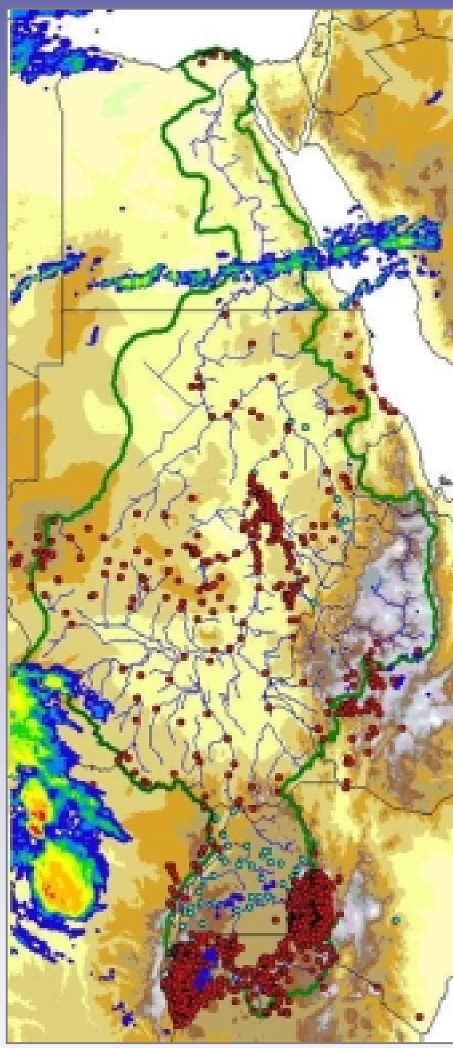

Developed collaboratively by

The Nile Basin Nations,

The Georgia Water Resources Institute at the Georgia Institute of Technology,

and

The Food and Agriculture Organization of the United Nations

June 2003

Nile Decision Support Tool (Nile DST)
Executive Summary

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In collaboration with

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and

The Food and Agriculture Organization (FAO)
of the United Nations
Nile Basin Water Resources Project (GCP/INT/752/ITA)

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The GWRI Director and project staff are grateful to the Nile Basin nations (Burundi, Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda), their focal point institutions, their Project Steering Committee (PSC) members, and their National Modelers for entrusting us to work with them in this important basin-wide project. The development of databases, models, technical reports, software, and user manuals are key but not the only project accomplishments. Even more important are the evolving contributions relating to people and the difference the project is poised to make in data and information sharing, developing a common knowledge base for policy debates, and long term capacity building.

GWRI is also grateful to the Government of Italy and to FAO for sponsoring this project and for providing dependable logistical and technical support through the FAO offices in Rome and Entebbe.

It is our hope that the Nile DST effort will contribute in some positive way to the historic process of the Nile Basin nations to create a sustainable and peaceful future.

Aris Georgakakos
GWRI Director
Atlanta, June 2003

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Nile Decision Support Tool: Executive Summary

1. Introduction and Overview

The Nile River Basin is spread over ten countries covering an area of about 3.1 million km^2, or approximately 10 percent of the African continent. The river discharge per unit drainage area is relatively small, and almost all of the Nile water is generated from 20 percent of the basin, while the remainder is in arid or semi-arid areas. The Nile Basin encompasses five main regions (Figure 1): (a) the Equatorial Lake sub-basin within the countries of Uganda, Tanzania, Kenya, Rwanda, Burundi, and Congo, (b) the Sudd, the Bahr el Ghazal, and the Sobat River Basin (in Sudan and Ethiopia), (c) the White Nile (in Sudan) connecting the Sudd with the Blue Nile, (d) the Blue Nile and Atbara Rivers draining parts of Ethiopia, Eritrea, and Sudan, and (e) the Main Nile flowing through Northern Sudan and Egypt. Each region has distinct hydrologic features, water use requirements, and development opportunities.

The Nile Decision Support Tool has been developed as part of the Nile Basin Water Resources Project (GCP/INT/752/ITA) in collaboration with the Nile focal point institutions. The model purpose is to assess the benefits and tradeoffs associated with various basin wide water development and management options. The guiding principles for the development of the Nile DST are outlined below:

- The *data of the Nile DST should be shared and agreed upon* by the Nile Basin nations;

- The Nile DST should be based on *sound and current scientific and engineering approaches* able to handle the Nile Basin size, natural complexity, and range of development and management options; It should also include functionalities useful for users of varying technical backgrounds and experience, from novice to advanced;

- The Nile DST should be a *neutral* decision support tool; Thus, its overriding purpose should be to objectively assess the benefits and tradeoffs associated with various water development and sharing strategies that may interest the Nile Basin partners individually or as an interdependent community of nations;

- The Nile DST should be *sustainable and adaptable* as future needs arise; The implications of this are twofold: First, the Nile DST should be based on *widely supported* computational technology and should be *expandable* to incorporate new data and applications; Second, *effective technology and know-how building* mechanisms should be implemented during the Nile DST development as well as for the long term.

The Nile DST includes six main components: database, river simulation and management, agricultural planning, hydrologic modeling, remote sensing, and user-model interface. Each component has been described in detail in separate technical reports and user manuals. The purpose of this report is to provide an executive summary of these documents. The report is organized in 7 sections. Sections 2 to 6 outline the project accomplishments and future opportunities with respect to each Nile DST component. Section 7 provides a longer term vision of potential Nile DST benefits and impacts.

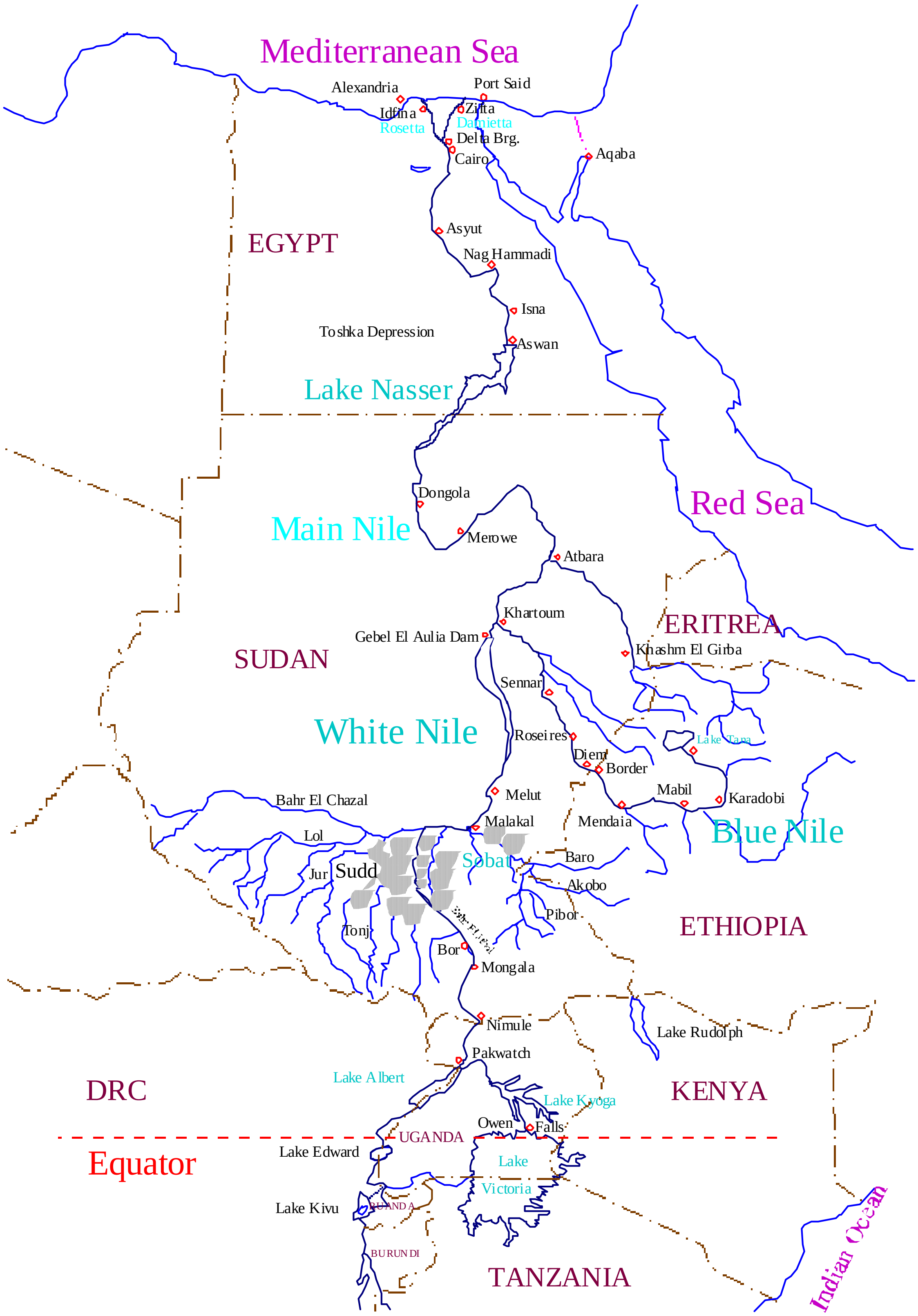

Figure 1: The Nile River

2. Database

2.1 Nile DST Database: Accomplishments

Flexible and Expandable Database Design

The Nile DST database is an object-oriented, databasing structure developed to (**1**) house all types of data (existing as well as future) required by a comprehensive water resources decision support tool and (**2**) to optimize data entry, access, visualization, and analysis. It is important to emphasize that to support the process of water resources planning and management, the data base is designed with the ability to grow, namely, to accept new data, regardless of its type and size. Further, this tool is capable of visualizing and analyzing the data in efficient and meaningful ways.

Database Contents

The Nile DST database is of considerable size. In fact, it is not one but many databases. Each of the Nilotic countries has painstakingly provided an MS Access database of station data with measurements of more than 30 parameters. In addition to this, the project has compiled some 3 years of remotely sensed data that covers the entire basin. The temporal resolution of the remotely sensed data is 30 minutes, and the special resolution is approximately 5 km x 5 km. Derived data products are also included in the database including climatic zone data that is based on the original station data and is used in the Nile DST agricultural planning module. Finally, the entire database used in the Lake Victoria Decision Support System has been incorporated in the Nile DST database. All together, this data represents some 37 GB of information, the largest such collection ever compiled for the Nile Basin.

Data Visualization

The data visualization tool in the Nile DST provides a seamless system to look at all of the databases. At its heart is a tree-style exploring tool (data tree) that at once shows the entire contents of the Nile DST database and, equally importantly, allows the user to navigate down to greater and greater levels of detail. Due to the database's sheer size, the data tree is necessary to promote user awareness and understanding of the database. Each database in the tool has a geo-referenced component and time series component. The geo-referenced data is viewed in the mapping tool, which holds a geographic information system (GIS). The mapping tool incorporates the ESRI Inc. Map Objects mapping plug in to ensure compatibility of the system with industry standard GIS files. The time series data is viewed in the charting tool, which features a powerful chart and aggregation and statistics calculators. Together, the charting tool, mapping tool, and the data tree work seamlessly to provide the user with an ability to view any piece of information in the system quickly and meaningfully.

Data Analysis

The data analysis tool provides powerful data manipulation capabilities for current and future applications. The user can instruct the Nile DST to take information from its databases in user specified forms, operate on the data, and construct maps of the output. One example of this is the generation of mean areal precipitation (MAP) estimates over user-specified areas. This process requires spatially defining the watershed of interest, defining a grid that covers this watershed, deriving from stations a time series for each of the grid cells in the watershed, and then aggregating each of the time series into one time series that represents the precipitation for the entire watershed. Traditionally, this process takes a spreadsheet program, a database program, and a GIS program, and a user who understands how to transfer data between them. The data analysis tool brings all of this together into one graphical map. The benefits of this tool are wide ranging. First, the tool greatly reduces error and processing time. More importantly, the MAP process described above is but one example in an extensive set of analyses that a user can build. Finally, the tool allows the user to save the graphical map of the analysis, which is a built-in method of journaling analyses, a task rarely done well in water resources planning.

Training

To this point, there have been two training workshops on the database. The first took place in Dar es Salaam, Tanzania in June, 2002. The workshop concentrated on describing the design principles of the database. Participants were lead through database principles to final database design. An alpha version of the software was displayed to show the implementation of the design. The second workshop took place in Entebbe, Uganda in February, 2003. In that workshop, the beta version of the software was installed on computers, and the participants went through extensive and realistic exercises of data access, visualization, and general manipulation. Since the second training workshop, significant database capabilities have been added to the Nile DST software. The opportunity to provide training on the recent database features has not yet realized.

Technical Report and Manual

A detailed technical report and manual describing the methods used, application range, and software usage have been developed and provided as part of the final deliverables.

2.2 Nile DST Database: Future Opportunities

The Nile DST database system is a technical tool that the Nile water professionals can use to comprehensively compile, quality control, and analyze existing and future data sets. Some of the future opportunities and recommendations are listed below:

- *Training*: As mentioned earlier, new important database features have recently been added to the Nile DST on which the national modelers have not yet received training. These features include (**1**) the Data Analysis Tool and (**2**) a versatile and user-friendly data entry system. As described in the "Accomplishments" section, the data analysis tool represents a powerful component of the database system that enables the Nile water professionals to perform extensive and complex data-related functions. The data entry system facilitates adding data to existing stations, adding new stations within a database, and even adding new databases.

- *Database extension:* The Nile DST database contains all data provided to Georgia Tech during the project tenure. However, due to time constraints, very useful hydro-meteorological data (a good part of which exist in digital form) have not been provided and are not included in the Nile DST. It is recommended that this data be compiled and added to the Nile DST database to insure their preservation and beneficial use.

- *Data Quality Control:* There is a clear need to systematically quality control the data in the national data bases and in the Nile DST. The reader is referred to Georgia Tech's reports on "Remote Sensing" and "Hydrology" where these issues are discussed at length. Data quality control would have to be done primarily by the countries with Georgia Tech or other experts establishing systematic protocols and procedures. Country engineers, knowledgeable in the history of data collection, would provide the only sound basis for data infilling and verification. The Nile DST database system would provide an effective tool to consistently implement the quality control process.

3. River Simulation and Management

3.1 Nile DST River Simulation and Management: Accomplishments

The Nile DST River Simulation and Management system aims at simulating the Nile response under different hydrologic, development, and management scenarios. Thus, its overriding purpose is to objectively assess the benefits and tradeoffs associated with various water development, sharing, and management strategies that may interest the Nile Basin partners individually or as an interdependent community of nations. Tradeoffs exist among water uses in the same country and across the Nile countries. The river basin planning and management Nile DST component has several unique features:

Data

The database of this module includes extensive data in five major categories: (**a**) River network configuration, (**b**) river hydrology, (**c**) existing and planned hydro facilities, (**d**) water use, and (**e**) reservoir/lake regulation rules. Data can be viewed, added, or modified as necessary through a user-friendly interface. The actual river system is represented by a network of river nodes, reaches, and reservoirs, each with its own attributes. River nodes represent locations of local inflow and/or water withdrawals and returns. River reaches represent physical river segments and their water transport characteristics. Reservoirs represent man-made or natural lakes that may support various water uses including water supply, flood control, drought management, hydropower, and others.

Models

The Nile-DST river simulation and management model simulates the flow of water through the various system nodes, reaches, and reservoirs. In keeping with its planning purpose, the model time resolution is 10-days. The simulation model includes a routing model for each river reach and regulation rules for each reservoir. Two types of reservoir regulation rules are included: (**1**) Simple static rules and (**2**) dynamic multi-reservoir coordination rules. Simple reservoir regulation rules define reservoir release as a function of reservoir elevation, inflow, irrigation demand, time of the year, or some combination of these parameters. The Nile-DST user can select and define any of these options. These regulation rules are very common, but they are simple because they relate reservoir release to a few parameters of the same reservoir and, possibly, of nearby reservoirs. Dynamic multi-reservoir coordination rules are also possible and are available through the system optimization model. System optimization encompasses four sub-models pertaining to (**a**) streamflow forecasting, (**b**) river and reservoir simulation, (**c**) reservoir optimization, and (**d**) scenario assessment.

Selected Applications

The Nile-DST river simulation and management model can be used to provide answers to various important questions. Typical applications are listed below:

- Value of various regulation, hydro-power, and irrigation projects along the White, Blue, and Main Nile branches; Such assessments could quantify the incremental benefits from individual development projects as well as the combined benefits from various project configurations;
- Implications of reservoir regulation rules for local, upstream, and downstream riparians;
- Marginal value (gain or loss) of irrigation with respect to hydropower at various basin locations;
- Irrigation versus hydropower tradeoffs for each nation, region, and the entire basin.

The Nile-DST utilizes several assessment criteria of possible interest to the Nile Basin nations. These criteria include

(i) severity and frequency of shortages with respect to user-specified water supply targets;
(ii) water withdrawals and losses over user-selected regions and times of the year;
(iii) reservoir and lake level drawdown and spillage statistics;
(iv) in-stream flow availability at user-selected river nodes and reaches;
(v) flood and drought severity and frequency;
(vi) annual and firm energy generation statistics.

Training

As with the rest of the Nile DST, there have been two training workshops on the river simulation and management model. The training in Dar es Salaam, Tanzania (June, 2002) concentrated on methods for river flow forecasting, routing, and simulation, and on reservoir regulation. The workshop in Entebbe, Uganda (February, 2003), was a hands-on training experience where the national modelers defined and run various scenario assessments. At the end of the workshop, the national modelers presented their assessments to the first evaluation mission and demonstrated good command of the model functions. However, following the last workshop, additional optimization features have been added to the Nile DST.

Technical Report and Manual

A detailed technical report and manual describing the methods used, application range, and model usage have been developed and provided as part of the final deliverables.

3.2 Nile DST River Simulation and Management: Future Opportunities

The river simulation and management model is the centerpiece of the Nile DST as it is designed to support water sharing policy debates with factual information. Although the model is presently able to perform this function, its value for the Nile countries can be maximized with additional training and the inclusion of more data.

- *Training*: Two national modelers have been trained from each country and have demonstrated good understanding of model capabilities. However, the model can assess a plethora of development scenarios, water sharing strategies, and management options and there has not been enough time to cover all of its features and capabilities. Furthermore, the purpose of the Nile DST is to convert data and models into information and understanding of the issues, and this requires systematic model usage by several competent individuals. There is a clear need to continue the training and capacity building process until a large enough human resources pool has been created that can adequately support the information needs of the decision makers.

- *Additional Data:* All Nile river reaches have been modeled to the extent that the data have allowed. However, additional data clearly exist that can easily be incorporated to increase the model spatial resolution and assessment range. To this end, a better representation of the Sobat river and its tributaries, the Blue Nile in Ethiopia, and the Main Nile in Egypt would add simulation accuracy and perhaps reveal more interesting water sharing options and strategies.

4. Agricultural Planning

4.1 Nile DST Agricultural Planning: Accomplishments

The Nile DST Agricultural Planning module has been developed as an integrative tool useful for various analyses relevant to crop production and irrigation in the Nile Basin. The main purpose of this component is to assess the crop yield potential and irrigation needs at different locations within the Nile basin. This information can be used to define meaningful scenarios for the assessment by the river simulation and management model. The software integrates several different technologies into a user-friendly form. These technologies include databases, geographic information systems, advanced crop growth models, optimization techniques, and agricultural management tools. In its present form, the Agricultural Planning module can be used for the following applications:

Applications

- Crop growth and production can be simulated for 11 crops at any point in the Nile Basin based on historical meteorology;
- The optimal quantitative relationship between crop yield and irrigation (the "crop-water production function") can be determined as a continuous function from rainfed to fully irrigated conditions;
- Optimized irrigation schedules can be found for all points on the crop-water production function;
- By simulating for multiple years of climatic data, variability of crop yield and irrigation needs can be determined;
- Irrigation management for individual farms or irrigation districts can include information on yield-irrigation relationships, irrigation schedules, and sensitivity to other parameters provided by the module; and
- Long-term planning decisions can include agricultural assessment results for questions of water availability and sharing.

Training

Training relevant to the Nile DST Agricultural Planning module has been conducted during both training workshops in June 2002 (Tanzania) and February 2003 (Uganda). Training in Tanzania included the following methodological aspects:

- Physical science of soil-plant-water systems,
- Physiologically based crop models,
- Irrigation planning and management techniques,
- Optimization of irrigation systems, and
- Vulnerability of agricultural systems under climate variability.

Training in Uganda included hands-on usage of the model to develop crop water production functions and perform sensitivity analysis on parameters affecting crop yield. Such parameters were related to hydro-meteorological data, soil types, and planting dates.

Technical Report and Manual

A detailed technical report and manual describing the methods used, typical applications, and model usage have been developed and provided as part of the final deliverables.

4.2 Nile DST Agricultural Planning: Future Opportunities

- *Training:* Previous training aimed to engage the national modelers most of whom have a water resources and hydrology background. While these professionals are interested in the water aspects of the model, the Nile DST Agricultural Planning system is a tool with functions especially meaningful to agricultural engineers and scientists. Availing the model to agricultural professionals would increase its utility and impact. It is recommended that a training strategy be developed to engage agricultural professionals in the training process. In time, these professionals would enhance the model application range to local crop varieties and conditions and ensure its sustainability.

- *Data:* The Agricultural Planning module has been developed to use the Nile DST Database as fully as possible. In some cases, important meteorological data have not been available in the database, and a system of climatic zones was developed to fill in average regional values for unavailable parameters. Continued additions of meteorological data, from both the past and future, will allow for more accurate and comprehensive assessments. Furthermore, results from crop experiments have been used when available to verify the crop models. Continued collection of this data from agricultural experiment stations in the region will allow for continued calibration and verification of model parameters.

- *Model Extensions:* In its present form, the Agricultural Planning module is capable of producing results for many types of analyses. Further tools can be added to increase its capabilities. Particularly, an economic valuation module can be included to analyze net profits from agricultural operations by considering factors such as crop prices, costs of water and other inputs, profit goals, and risk analysis.

5. Hydrologic Modeling

5.1 Nile DST Hydrologic Modeling: Accomplishments

Data, Models, and Applications

Hydrologic watershed models provide the means to describe the response of river basins (streamflow and soil moisture) to different conditions of rainfall and temperature. A hydrologic model has been developed in a generic form and has been applied to selective Nile sub-basins where data allowed. A detailed technical report has been provided describing the modeling method, the input data preparation process (step by step), and the model outputs. The model applications are particularly instructive, showing the significance and necessity of good quality hydrologic and hydro-meteorological data. Thus, including other existing data and the need for data quality control are clearly illustrated. Notwithstanding data limitations, the hydrologic model is applicable to any basin for which suitable data can be assembled.

Training

Hydrologic training has been provided at the two training workshops, with methods emphasized in the first and model usage in the second. However, due to workshop time limitations, the time allotted to this module has been insufficient to cover all software features and hydrologic modeling issues.

Technical Report and Manual

A detailed technical report and manual describing the hydrologic model, typical applications, and software usage have been developed and provided as part of the final deliverables.

5.2 Nile DST Hydrologic Modeling: Future Opportunities

- *Training and Nile DST Ownership:*   As mentioned above, the national modelers would benefit from additional hydrologic model training. However, the hydrologic model also presents an excellent opportunity to develop model "ownership" on the part of the national experts. This is because the development of valid hydrologic models requires that the national modelers and their agency colleagues systematically review and assess all relevant data, basin-by-basin. This process would be tedious but would provide full appreciation of the existing data quality and their importance in modeling applications. The Nile DST data analysis tool can be used to facilitate this process.

- *Data Monitoring Based on Modeling Needs:*   To this point, no real connection has been established between the two major project components of data monitoring and model development. The hydrologic model (as well as the remote sensing model to be discussed next) presents an excellent opportunity to assess where data is needed from a modeling standpoint. This connection is crucial and it will help prioritize monitoring needs with the highest payoff or maximize the value of monitoring investments.

6. Remote Sensing

6.1 Nile DST Remote Sensing: Accomplishments

Data, Models, and Applications

A fairly comprehensive remote sensing data set was availed to the project only recently. In spite of these delays, a remote sensing component has been developed and is included in the Nile DST. Two remote sensing rainfall estimation procedures have been calibrated and validated, and a comprehensive assessment has been made for all regions of the Nile Basin. The results are very interesting (**1**) demonstrating the value of remote sensing information for rainfall estimation, and (**2**) delineating the areas of the Nile Basin where estimation accuracy is fairly reliable (e.g., Lake Victoria basin, Ethiopia) and those where better ground data are clearly needed. An application over the Lake Victoria and its watershed shows that remote sensing can enhance the value of conventional data and support water resources assessments and management.

Training

Training on this model has been limited to remote sensing methodologies during the first training workshop in Dar es Salaam, Tanzania (June 2002). Due to data delivery delays, the model was not part of the Nile DST at the time of the second training workshop in Uganda (February, 2003).

Technical Report and Manual

A detailed technical report and manual describing the remote sensing method, comprehensive data quality control, basin-wide assessments, and model usage have been developed and provided as part of the final deliverables.

6.2 Nile DST Remote Sensing: Future Opportunities

The remote sensing model and its value for the countries has shown to have significant promise and can be improved in the following ways:

- *Training:* Detailed review of the assessments and hands-on training has not been conducted and is recommended.

- *Data Availability and Quality:* First, important gaps in the already acquired satellite data can be filled with data obtained directly from Eumetsat, the management agency of the Meteosat satellites. These are voluminous data, and their acquisition may a few months. However, compiling a long data base of satellite images (e.g., 1980 to present) would enable very useful long term assessments and the development of hydrologic models in rain gage scarce areas. Second, rain gage data availability and poor quality affect model calibration, especially in regions featuring strong variations in precipitation patterns. Any further improvement of the remote sensing rainfall estimation procedures will depend strongly on quality control and expansion of the available data. These data needs can only be filled by a concerted effort of the national agencies.

- *Modeling Improvements:* Such improvements can potentially include (1) seasonal re-calibration of the remote sensing parameters based on extended data records and (2) implementation of more sophisticated remote sensing methods such as the Georgia Tech Remote Sending procedure that also incorporates information from the TRMM (tropical rainfall measuring mission) satellite.

7. Conclusions

This report provides an executive summary of the Nile DST development work conducted under the Nile Basin Water Resources Project (GCP/INT/752/ITA) consistent with the project terms of reference. Much has been achieved under this project, despite its limited time and resources. The Nile DST is not only a tool that can provide scientifically valid facts and information to the Nile Basin decision makers, but it also represents a foundation for further developments as well as vehicle for capacity building.

Further Assessment Capabilities: At its present form, the Nile DST assessments are expressed in quantities of river flow, water supply, food production, and energy generation. Building on these developments, it is now possible to introduce the next layer of assessment capabilities that can translate these physical outputs into economic and social benefits and impacts. Furthermore, a water quality component can be added to enable fully integrated assessments.

Long Term Capacity Building: While the purpose of the above-mentioned training activities is to ensure that a core modeling group has sufficient expertise to effectively use the Nile-DST, long term capacity building aims at steadily expanding this human resource pool in size as well as in scientific and engineering knowledge. Although the Nile-DST is a useful tool for the Nile Basin countries, its most important impact could be as an educational and capacity building instrument. As described earlier, the Nile DST incorporates several science and engineering disciplines, from database and software development to meteorology, hydrology, agricultural science, remote sensing, and policy assessment, and represents an extensive knowledge base upon which to build formal college and professional education programs.

In this regard, engaging existing or planned water resources centers (e.g., centers that may be established under NBI) represents an excellent follow-up opportunity. These centers could include country professionals from agencies, universities, NGO’s, etc., and could take on the responsibility to maintain and continue to develop these technical tools and data bases. Center personnel would be knowledgeable in data analysis, quality control, and the theory and use of the modeling tools. As new data and models are developed, center engineers and scientists would release new versions to the country agencies, perform the installations, and conduct training for the national professionals.

In collaboration with the universities in the region, Georgia Tech and other institutions of higher learning could contribute courses and seminars (on-site or via distance learning means); educate scientists and engineers at the Masters and Ph.D. levels (abroad as well as in the region); establish joint degree programs in meteorology, hydrology, water resources, agricultural planning, environmental science, and socio-economics; and bring to bear a lasting mechanism for capacity building and the continuous development of technical professionals. In time, the centers would provide valuable services to the Nile Basin countries and would produce the human resources necessary to develop sound and sustainable water sharing and management policies.