Nile Basin Remote Sensing Scoping Study

Inception Phase Report

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F I N A L

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1. Introduction

1.1 Purpose

This report is the Inception component of the Remote Sensing Scoping Project, which comprises:

A. Inception Phase
B. Analysis Phase
C. Synthesis Phase

It is anticipated to establish a Remote Sensing (RS)/Geographic Information System (GIS) unit that will operate under the aegis of the regional Decision Support System (DSS), and that will enrich the existing databases with a spatial mapping tool. The purpose of this Remote Sensing Scoping Project is to identify the need for and define the functions of the proposed RS unit.

Scope of work—Inception Phase

i) Review relevant project documents under Nile Basin Initiative (NBI) programs: the objective of this review is to understand the broader context and needs for establishing the Remote Sensing/GIS unit to support the development of the Nile Basin DSS and other NBI programs/projects.

ii) Draft and submit Inception report**:** based on the review of documents, the Consultant shall submit an inception report to the WRPM project. The inception report shall contain preliminary identification of needs for remote sensing information products, revised methodology for subsequent stages of work, an outline of the final report and a revised work schedule.

This Inception Phase report contains several acronyms that are explained further in Appendix 1.

1.2 Background

The Nile basin, which is home and source of livelihood to approximately 160 million people, is the longest river in the world having a total length of about 6700 km, traversing an extremely wide band of latitude, from 4-degree south to 32-degree north. The area draining into the Nile river system (about 3 million km^2) extends over 10 African countries (see Figure 1).

The two main river systems that feed the Nile are the *White Nile* and *the Blue Nile.* The White Nile has sources on the Equatorial Lake Plateau (Burundi, Rwanda, Tanzania, Kenya, Democratic Republic of the Congo and Uganda) and is fed by substantial flow from the Baro-Akobo-Sobat system that originates in the foothills of southwest Ethiopia. The *Blue Nile*, has sources in the Ethiopian highlands surrounding Lake Tana. The Tekeze-Setit-Atbara system also contributes to the flow of the main Nile further downstream of Khartoum.

Average annual runoff of the Nile Basin is estimated to be approximately 85 billion cubic meters (BCM). Compared to other major river basins, the Nile Basin displays sharp disparity in water availability among sub-basins. Arid portions (perhaps one-third of the area of the Basin) yield negligible flows, while the Eastern Highland of Ethiopia, comprising only 15–20 percent of the land area of the Basin, yields 60–80 percent of the annual flow in the lower Nile.

The basin is home to a diversity of ecosystems, which are threatened by high population density and limited development over decades. The outflow of the basin into the Mediterranean Sea is typically 5 to 8 BCM (being 5% to 10% of average runoff) and marginally adequate to flush the system of pollutants and to maintain the salt balance at the interface with the sea. This implies that additional *consumptive*[1] water resources development must be offset by reductions in *consumptive* use elsewhere. The relationship between land cover, water use, and the economic benefits derived from the water use, is thus crucial for effective land-use planning.

[1] Consumptive water uses—most commonly EvapoTranspiration (ET) from natural vegetation, irrigated and unirrigated crops, wetlands and free water surfaces—result in reduced availability to downstream users. Non-consumptive uses such as hydropower generation and most domestic uses, especially where treatment plants are in place, may change the location and timing of water availability, but do not change the quantity of water in the basin in a particular hydrological cycle.

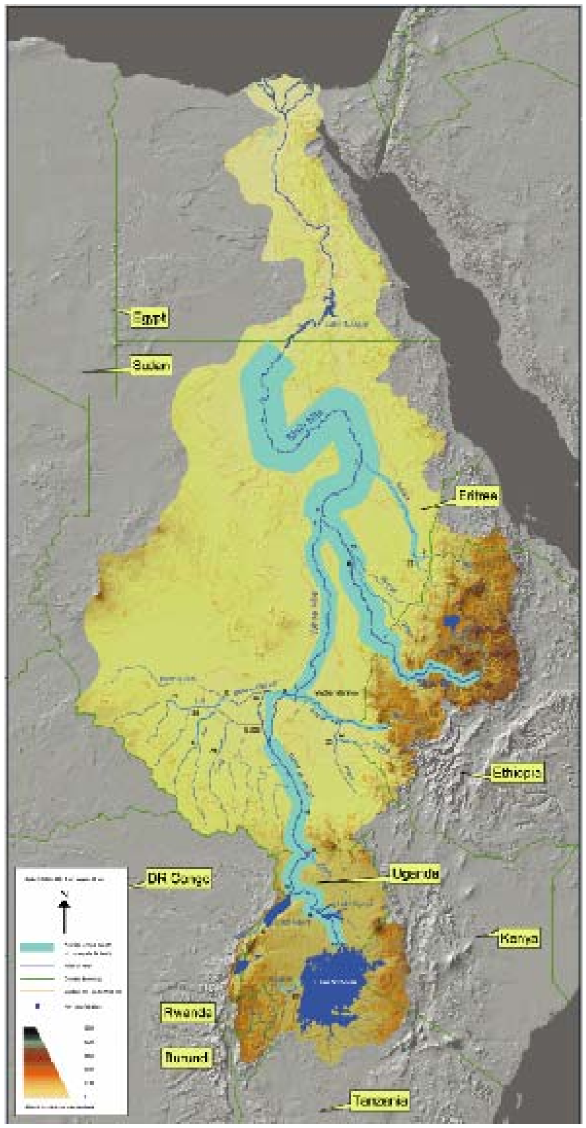

Figure 1: Geographical location of the Nile Basin and its major tributaries (source: http://www.faonile.org/nbs/bluewater_poster.htm)

1.3 Remote sensing

Remotely sensed (RS) data from satellites should be seen as complementary to conventional ground-based measurements - not as a substitute. Most analyses based on RS data also depend on ground-based measurements as additional information. RS approaches are of particular value on locations where spatial analysis of very large areas is required for policy development, large scale planning, and inter-basin or other land management decisions.

Remote sensing measurements consist of the detection and recording of reflected and emitted spectral radiation from the earth's land surface by sensors in satellites. Radiation occurs in various wavelengths (infra-red, visible, thermal, microwave, etc.) that can be interpreted individually and in combination to estimate physical processes such as rainfall or state variables such as soil moisture. When different bands of spectral reflectance are combined, it can provide information on the land cover class, crop type, wetlands, open water bodies, etc. Some of the relationships between spectral radiance and state variables are deterministic or physical. This means that they are derived from theory and physical laws (e.g. temperature in relation to topographic features can be computed directly from the Planck function without any further information). Some relationships are empirical. This means they are derived for experimental measurements and are subject to random variation (e.g. a water body will have decreasing reflectance with increasing wavelength, being a distinct feature that does not apply to land surfaces). Linking RS measurements with land surface characteristics such as deforestation, erosion, etc., and water resources such as irrigation and water quality, requires the combining of multiple RS parameters by using sophisticated interpretation algorithms.

Evapotranspiration (ET) for instance, is calculated by solving a complex energy balance algebraic function of surface albedo, vegetation cover, leaf area index, surface temperature and surface roughness. While the RS data is a 'true measurement', the calculated ET is derived by combining measurement with sophisticated modeling.

Most RS data – especially when dealing with pixel sizes of 250 m and larger - are available in the public domain and can therefore be accessed by all stakeholders. Other remote sensing data can be purchased on the commercial market. RS data is provided in a consistent manner by public and scientific agencies across the world. This makes it feasible to study large river basins across administrative borders in a standardized and unbiased manner. Because the RS techniques are based on spectral radiances and specified algorithms, the results are scientifically credible and trusted by authorities across borders of countries.

RS data thus allow spatial mapping of processes and state variables. Because many RS data sets are archived, it is also possible to trace trends in land features such as vegetation cover, cropping patterns, and extent of wetlands. Such spatial and temporal information sets are advantageous for understanding, managing and protecting natural resources. The neutral and objective nature of remotely sensed data and analyses facilitates and encourages exchange of information and collaboration.

The following sections outline the problem areas as identified from existing reports related to the NBI, and indicate the contribution that RS data and analyses can make. In compiling this list, we tried to indicate whether the contribution that RS can make is predominantly in terms of **historical** understanding, for **real time** application, or for **plannin**g future interventions. By "historical understanding" we mean the establishment of benchmark conditions and trends. By "real time application" we mean the use of currently (real time) observed features to estimate phenomena such as hydrological impact of changes in land cover, and changes in rainfall patterns. "Planning future interventions" entail measuring and monitoring of indicators that will provide tools that can be used by managers to plan their operations. Flood forecasting or crop water stress in irrigated areas, are examples of such tools.

Our basic approach will be to collect all existing primary RS data for the Nile Basin from the public data archives of NASA, USGS, ESA and other agencies, and to store them in the regional DSS in Addis Ababa. In addition, we will apply a number of standard interpretation algorithms to produce special purpose RS products for use in the execution of the Shared Vision Program (SVP) and SAP projects.

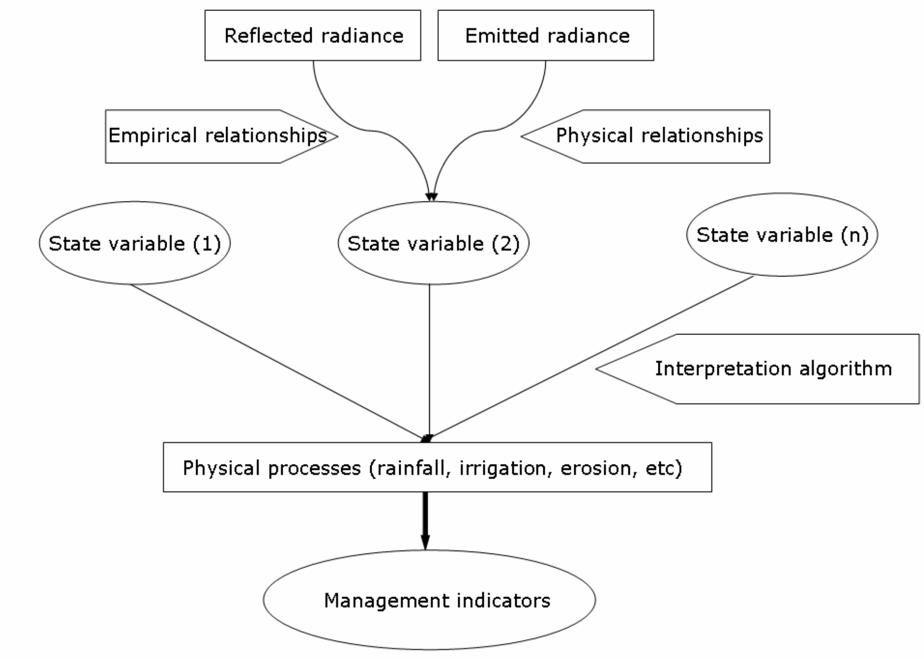

Figure 2: Schematic representation of how spectral radiances, measured by satellites, are used to infer physical processes, and indicators that can be used for the management of water, land, and agricultural resources

2. The Nile Basin Initiative

2.1 General

Increasingly evident competition for water, concerns about the slow economic progress in parts of the Nile basin, and recognition of the potential contribution of improved water management to alleviate poverty, are all factors which are attracting the attention of management authorities on an increasing scale. Various agencies have for some years been working with the basin countries towards improving water resources planning and management. These efforts culminated in the Nile Basin Initiative Shared Vision Program (SVP).

The Shared Vision Program (SVP) is a broad-based and basin-wide program of collaborative action, exchange of experience and of capacity building. The SVP comprises a limited range of essential activities to create a coordinated, and enabling environment for the implementation of the SVP.

In parallel with the SVP, there are Subsidiary Action Programs (SAPs) geared towards physical investments under the umbrellas of the Nile Equatorial Lakes Subsidiary Action Programs (NELSAP) and Eastern Nile Subsidiary Action Programs (ENSAP). The objective of these programmes is to develop the water resources in a sustainable and equitable way to ensure prosperity, security and peace for all stakeholders. This includes irrigation and drainage development, hydropower, development and trade, watershed management, sustainable management of lakes and wetland systems, river regulation, flood and drought management, pollution control and water quality management, improved water use efficiency and integrated water resources management.

The SVP Portfolio includes the following seven projects:

1. Nile Trans-boundary Environmental Action
2. Nile Basin Regional Power Trade
3. Efficient Water Use for Agricultural Production
4. Water Resources Planning and Management
5. Confidence-Building and Stakeholder Involvement (communication)
6. Applied Training
7. Socio-Economic Development and Benefit-Sharing

This inception report addresses the scope for using Remote Sensing, to contribute specifically to the Decision Support System that is to be developed as part of project 4 (Water Resources Planning and Management). RS can of course also contribute to several of the other projects listed under the SVP and for the formulation of projects under the two SAPs.

2.2 Basin-wide Shared Vision Project (SVP)

Table 1: RS data needs assessment for SVP

Projects	Goal	Physical processes	RS data needs	Historical (H), Real-time (R) or Planning (P)
Nile Trans-boundary Environmental Action	Environmental sustainability	Deforestation; Land degradation; Soil erosion; Soil salinization.	Forested area; Vegetation cover on hill-slopes; Soil salinity; Water quality.	H, P
Nile Basin Regional Power Trade	Institutionalize regional power markets	Not applicable (Na)	Not applicable	Not applicable
Efficient Water Use for Agricultural Production	Increase water productivity	Crop production; Consumptive use; Effective rainfall; Irrigation.	Irrigated area; Irrigation intensity; Biomass production; Crop type; Crop yield; Crop ET; Rainfall; Vegetation cover; LAI; Crop nitrogen status.	H
Water Resources Planning and Management	Management and protection of Nile Basin waters	Hydrological cycle; Overall water stress; Surface water allocation; Groundwater allocation.	Land cover; Rainfall; Runoff; ET (actual, potential, deficit); Net Groundwater use; Change in total water storage.	H, R P
Confidence Building and Stakeholder Involvement	Develop trust in regional cooperation	Na	Na	Na
Applied Training	Strengthen institutional capacity	Na	Na	Na
Socio-economic development and benefit sharing	Cooperative development	Na	Na	Na

A critical component of the Water Resources Planning and Management activity is the establishment of a Decision Support System. The Nile Basin DSS will provide a common, basin-wide platform for communication, information management, and analysis of Nile Basin water resources and related issues. Coupled with human resources development and institutional strengthening, the Nile Basin DSS will provide a framework for sharing knowledge, understanding river system behavior, evaluating alternative development and management schemes, and supporting informed decision-making from a regional perspective, thus contributing to sustainable water resources planning and management in the basin.

DSS

A DSS consists of mathematical models, data and graphical user interfaces that connect decision-makers directly to the models and data they need for informed, scientific decisions. A DSS collects, organizes, and processes information, and then translates the results into management plans that are comprehensive and justifiable

The Nile Basin DSS is expected to provide the necessary knowledge base and analytical tools to support the planning of cooperative joint projects and the management of the shared Nile Basin water resources on an equitable, efficient and sustainable manner. The RS unit will form a component of the DSS, and most likely become a part of the comprehensive knowledge base (see below).

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. It is essential that the DSS is accepted as a tool for water resource management by all riparian countries represented in the Nile Basin. Essential components of the Nile Basin DSS are:

- A Comprehensive Knowledge base;
- A River Basin Modeling System;
- A set of tools, including those used for multi-criteria analysis;
- A Basin-wide communication system;
- Human and institutional capacity building plan to enable the maintenace of the DSS.

A Nile Basin Regional Decision Support System Center is being established at the Project Management Unit (PMU), in Addis Ababa, Ethiopia to support the development and continued use of the Nile Basin DSS. The Regional DSS Center will be responsible for developing and operational use of the Nile Basin Decision Support System.

Knowledge of spatial and temporal variations of all elements of the hydrologic cycle and their relationship with vegetation, economic activities and the environment at large is an essential prerequisite for efficient and sustainable management of water resources. Sound decisions regarding resource allocation and usage, which are key elements for good water governance, require a robust and reliable knowledge base. Information gathered through non-conventional means, such as remote sensing imagery and derived products, have become fundamental components of any knowledgebase on natural resources.

2.3 Eastern Nile Subsidiary Action Program (ENSAP)

Table 2: RS data needs assessments for ENSAP

Projects	Goal	Physical processes	RS data needs	Historical (H), Real-time (R) or Planning (P)
Eastern Nile Planning Model	Sustainable development and management of Eastern Nile waters	Optimization of water allocation and economic benefits	Land cover; ET (actual, potential, deficit); Biomass production; Economic water productivity; Net Groundwater Use; Change in total water storage.	H, P
Baro-Akobo Multi-purpose water resources	Flood management, hydropower development, environmental and natural resources protection, water conservation, irrigation.	River overflow; Flood extent; Inflow in reservoir; Reservoir storage; Land degradation; Loss of biodiversity; Water logging; Irrigation; Crop production.	Land cover; Rainfall; ET; Soil moisture; Vegetation cover; LAI; Crop type; Ponding water surfaces; Lake levels.	H, P
Flood preparedness and early warning	Reduce damage and loss of life from major floods	River overflow; Inundation; Crop failure.	Land cover; Rainfall ; ET; Soil moisture; Vegetation cover; LAI; Biomass production; Ponding water surfaces; Lake levels.	H, R
Transmission interconnection	Promote regional power trade	Electricity demand; Power generation.	Not applicable	R
Regional power trade	Hydropower generation	River flow; Reservoir storage; Turbine power generation.	Rainfall; ETactual; ETpotential; Irrigated area.	R
Irrigation and drainage	Increase agricultural productivity and consolidate conservation of water resources	Irrigation and drainage; Agronomy.	Irrigated area; Irrigation intensity; Crop types; ET; Biomass production; Crop nitrogen status; Crop yield.	H, R, P
Watershed management	Increase land productivity and sustainable land cover practices	Hydrological cycle interactions with land cover practices	Land cover; Rainfall; ET; Soil moisture; Vegetation cover; Biomass production; Water quality.	H, P

2.4 Nile Equatorial Lakes Subsidiary Action Program (NELSAP)

The data needs for NELSAP are similar to those set out in Table 2 above. In addition, the NELSAP program refers specifically to co-operative inter-country and consultative in-country projects. In both cases, the impacts of a specific investment would be expected to have agreed and acceptable implications for other riparian states. In such cases, the indicators of impacts (positive or negative) may often be dependent on RS monitoring. A Special Purpose RS product (see below) could be developed to provide appropriate information on actual impacts.

3. Remote sensing data

3.1 General

In this section, we summarize the nature of RS products that are available in the public domain, evaluate the sources of the data, and then discuss additional information and analyses that can be based on the available data. The major earth observation satellites are described in Appendix 2. A distinction is made between *primary data*—the information that can be directly downloaded in processed form (e.g. surface temperature; leaf area index) and *derived information*, which is based on the integration by the user of satellite data with other data (e.g. ET; crop yield). The integration is classically done by means of interpretation algorithms. Different algorithms exist to interpret and convert *primary data* into *derived information*. Whilst there are many different algorithms for ET (e.g. EARS, SEBAL, SEBS, SEBI, METRIC, TSEB, ALEXI), there are less algorithms for rainfall. The number of soil moisture algorithms is steadily growing. Figure 3 provides an example of surface moisture values based on two different algorithms and on two different satellite measurement systems (AMSR-E and TRMM). These algorithms are a consequence of academic research conducted over the last 20 years. Comparisons of the performance of such algorithms for various themes (e.g. erosion, water quality, etc.) are well documented in the peer reviewed literature. Remote sensing as a technology combines *data* and *algorithms*.

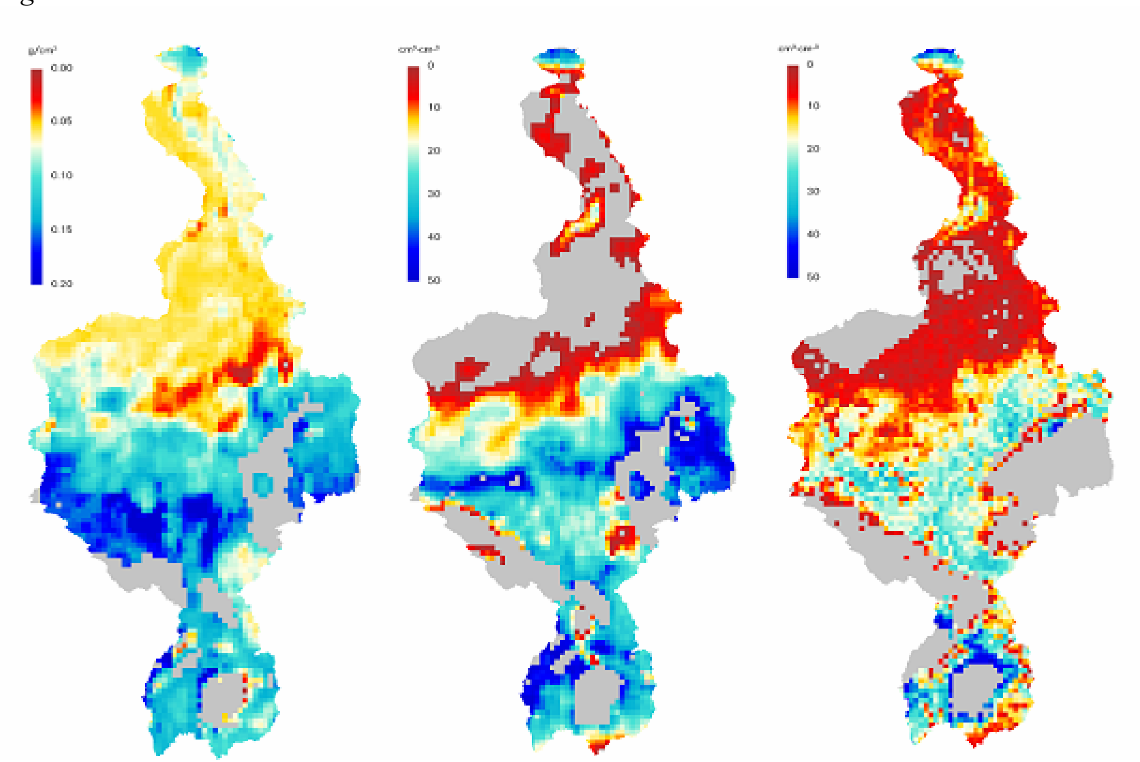

Figure 3: Example of daily surface soil moisture ($g\ cm^{-3}$) across the Nile Basin on 14 September 2003. Left and center images are both based on AMSR-E data but interpreted with different soil moisture algorithms (NSIDC (left) and VUA (center)). The right hand picture is based on TRMM measurements and the VUA algorithm

It is recommended that the DSS-RS unit base its work on RS data that is freely available. This will greatly reduce the costs of operation. A summary of free satellite data sources is provided in Table 3.

In addition to that, it is recognized that commercially available earth observation images could also facilitate the description of processes in hot spots that require more attention. The NBI has a demand driven mandate, and in certain situations this may require investments in expensive satellite imagery, provided that it serves the purpose. Commercially available satellites have the characteristic of providing high spatial detail, but at the cost of a smaller total image. Earth Observation satellites considered useful for detailed mapping are Aster, Landsat, Spot, radarsat and IRS.

Furthermore, possible links between satellite images (i.e. remote sensing) and other GIS data will be described. Existing GIS data such as the digital elevation model (e.g. SRTM), soil maps etc. could be of great help for the interpretation of the satellite measurements.

Table 3: Potentially suitable satellite systems with free access to data considered to be useful for natural resources management within NBI

Satellite	Sensor	Pixel size (m)	Path width (km)	Revisit period (days)	Suitable for
NOAA	AVHRR	1100	2800	0.5	Land cover ; Land degradation ; ET (actual, potential, deficit) ; Root zone soil moisture; Biomass production; Snowfall.
SPOT	Vegetation	1000	3000	1	Vegetation cover; Length vegetation period; Land degradation.
Terra/Aqua	MODIS	250, 500, 1000	2500	0.5	Land cover; Dominant crop types; Land degradation; Bio-diversity; ET (actual, potential, deficit); Root zone soil moisture; Flood extent; Leaf Area Index; Biomass production; Snowfall; Water quality parameters.
Aqua	AMSR-E	25000	2500	1	Surface soil moisture.
ERS	Scatterometer	50000	500	3	Surface soil moisture ; Surface roughness.
TRMM	VIRS TMI PR	5000		0.0625	Rainfall; Surface soil moisture.
Nimbus	SSMR	25 to 150	1400	1	Surface soil moisture
DMSP	SSM/I	15 to 70	1400	1	Surface soil moisture
Topex	Poseidon	2200	profiler	10	Lake water level
Jason	Altimeter	2000	profiler	10	Lake water level
MSG	SEVIRI	3000	Na	0.01	Vegetation cover; Length vegetation period; Solar radiation; Flood extent; Rainfall; ET; Root zone soil moisture.
Envisat	MERIS	300	3000	3	Land cover; Land degradation; Water quality parameters.
Envisat	AATSR	1000	2000	5	ET
Envisat	RA2	1700	profiler	16	Water levels
Grace		250000			Change in total water storage

In this chapter we also discuss Special Purpose RS products. These are derived from analysis of RS data in conjunction with other data. The products are designed to serve specific needs of the NBI such as local flood forecasting or monitoring of wetlands. Primary data and derived products will be basin-wide. This is practically feasible with low resolution imagery only. The users of the remote sensing data base are technical professionals (e.g. engineers, ecologists, agronomists) and water policy makers (including water managers). The first category of users are interested mostly in the primary remote sensing output, whereas the second group (water policy developers and water managers) have more interest in advanced products as outlined under the special products.

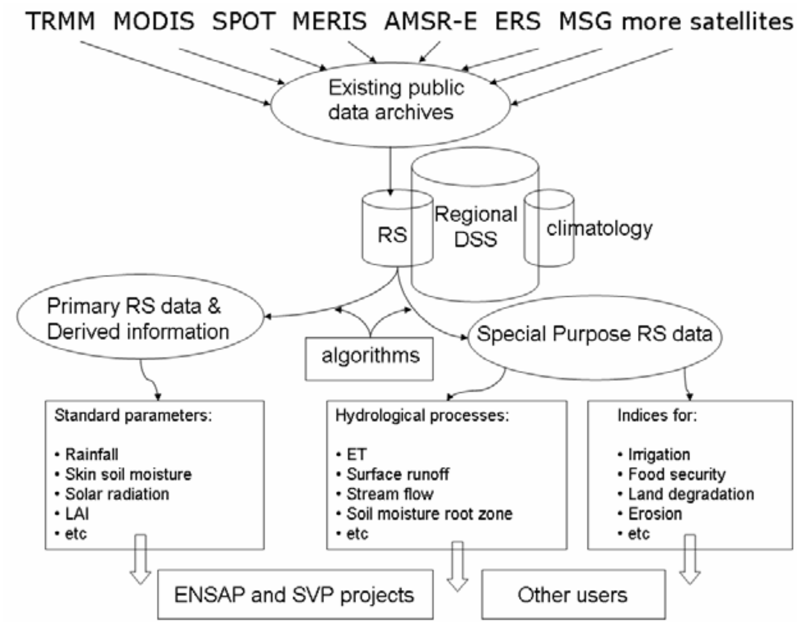

Figure 3: Structure of satellite data and algorithms to create primary data, derived information and special purpose RS data

3.2 Primary RS data

Table 4 provides an overview of operationally available primary RS data. This data is available from public websites. We recommend the use of low resolution images that can cover vast parts of the basin with a single image, and that reduces the operational running costs. That will not exclude high and very high resolution images that could assist in more spatially detailed mapping of specific features, such as crop identification, wetland habitat descriptions etc.

Appendix 3 contains a preliminary list of websites that provide links to satellite data archives. These sites will be further checked during the Analysis Phase of this study. Raw data will also be collected and inspected. The irrigated area map and the crop dominancy map have been generated before by certain institutes during special projects. The resulting products were made available to the public for sharing with more groups. Table 4 summarizes the RS data that we suggest should feed into the database of the regional DSS.

Table 4: Available primary remote sensing data from operational and freely accessible data archives

Water Management	**Land Management**	**Agricultural Management**
Precipitation	Digital Elevation Models	Irrigated area map[2]
Solar radiation	Land cover	Crop dominancy map[3]
Surface soil moisture	Vegetation cover	Net primary production
ET[4]	Fraction Absorbed PAR	
Lake levels	Net Primary Production (NPP)	
Chlorophyll	Surface albedo	
Suspended sediment	Leaf Area Index	
Change in total water storage	Erosion parameters	

3.3 Derived information from RS and other sources

Advanced management tools can be developed by combining different sets of primary RS data to produce information on land cover characteristics along the value chain. (see Table 5). Ground measurements can be used for input into RS algorithms and for verification of their accuracy. GIS data layers on terrain elevation, soil type, basin delineations and administrative boundaries can be used as well for the further enhancement of the product.

Table 5: Potential value added information derived from combinations of primary RS data

Water Management	**Land Management**	**Agricultural Management**
ET (1 km)	Land cover change	Crop type
ET by land cover type	Vegetation cover change	Crop yield
Root zone soil moisture (1 km)	Biomass production	Crop ET
Water generation (P>ET) or consumption (P<ET)		Crop water productivity
Stream flow		Crop coefficient
Net groundwater use		
Beneficial/non-beneficial water use		

3.4 Special Purpose RS indicators

RS data describe certain conditions and processes by means of state variables, and it is not feasible to measure these processes directly (see Figure 3). Water policy makers and water managers, however, need to make quantitative assessments of their management goals. Some of their goals are for example, equitable and productive use of irrigation water; restricting

[2] Prepared by IWMI based on a suite of satellites
[3] Prepared by a USA research institute
[4] Forthcoming from NASA at 8 km resolution

deforestation; and reducing soil erosion. These “value added” indicators will not require special detailed development and modeling.

We believe that the provision of Special Purpose products will increase the utilization and value of the remote sensing data base. Although input costs will be higher and require a technically skilled staff of the DSS-RS unit; the final product will enhance the usage of remote sensing as an alternative source of data. Well formulated Special Purpose products will facilitate real-time applications such as prediction of flood events based on RS rainfall data and modeled rainfall/runoff relationships. Drought based flood predictions using ETdeficit (ET_{pot}-ET_{act}) are further examples of such Special Purpose products.

Special Purpose products will no doubt change over time as experience grows and new opportunities and challenges emerge, but some examples are listed below:

- Prediction of flood events (based on rainfall and soil moisture)
- Early warning system for droughts (based on cloud cover, rainfall, ETdeficit, soil moisture)
- Irrigation performance (based on irrigation intensity, crop yield/ET, ET/water supply)
- Food security (based on crop yield, total production, rainfall, floods)
- Wetland sustainability (based on reduction of wetland area, duration of ponding, level of soil moisture)
- Erosion stability (based on reduction of vegetation cover on hill slopes, number of rainy days)
- Land degradation (based on reduction of vegetation cover and soil moisture)
- Biodiversity (based on uniformity of vegetation cover and land wetness)
- Water quality (suspended sediments and chlorophyll)

4. Methodology for subsequent stages of the consultancy

This inception report has outlined the potential contribution of RS analysis to the goals of the NBI and the two SAPS in terms of basic data collection, preparation of basin-wide derived products, and preparation of Special Purpose products. The range of information retrievable from earth observation systems has been summarized and recommendations have been made about the appropriate sources. This was a first round of surveys on data needs and RS data availability. It is considered to be a start for verification with various stakeholders in the basin.

In the next report (Analysis Phase) we will present a selection of actual analyses of data which the DSS centre will find useful because it will show results in real terms and illustrate potential RS products. The available remote sensing data will be further screened in terms of operational availability and the accuracy of the primary data. The new DSS-RS unit to be established can deliver more exciting products, tailored for the SVP and SAP projects, if value components are added. Added value in terms of information products and special purpose RS will require the involvement of special algorithms. The consultant will collect and review relevant literature that describes the testing of different algorithms. The Analysis Phase will also provide comments on gaps between NBI data demands and potential RS data products.

Algorithms for hydrology

Reviews of remote sensing applications in hydrology and water management have been compiled by Engman and Gurney (1991), Schmugge and Becker (1991), Engman and Chauhan (1995), Petty (1995), Bastiaanssen (1998) and Schultz (2000). Journal articles dealing with reviewing the state of the art of remote sensing for agricultural water management are Vidal et al. (1995) and Bastiaanssen et al. (2000).

During the Analysis Phase visits will be made to remote sensing institutions with an international orientation that are located in the Nile Basin (e.g. UN in Nairobi, FAO in Kampala, and others). This will be in addition to the collection, retrieval, testing and judging of RS data. The consultant will travel to Rwanda, Uganda, Kenya and Ethiopia between November 28 to December 8. The possible role of these institutes will be assessed and reported upon. They could for instance provide some of the routine products, conduct special analysis with historic data sets, or provide training to the stakeholders that are encourage to use the remote sensing data in the DSS. Although the provision of public RS data sets is a great step forward for modeling water resources in data scarce environments, it requires a certain level of expertise to retrieve and import these data. Training and backstopping will be required to prevent that the RS databases fail on sound maintenance and usage. The Analysis Phase will be executed during December 2007 to February 2008 and a summary of the main activities is presented in Table 6.

International RS focused programs in Africa are increasing. Among them are Artemis (FAO), Africover, Crop Explorer of the Foreign Agricultural Service (FAS-USDA), AMESD (EU), etc. The websites of these international programs will be visited and their data will be evaluated. If needed, the consultant will contact these groups and discuss options for data exchange.

In the final phase (Synthesis), after consideration of responses to the first two reports, we will set out the implications for the proposed RS Unit in terms of data acquisition and storage capacity, data processing systems (standardized and Special Purpose); staffing, and training. This will provide the basis for a detailed budget and work plan for the component. An outline of the final report is provided in Appendix 4. The Synthesis Phase will be executed during March 2008.

Table 6: Overview of the project activities to be undertaken by the consultant

Phase	Time	Period (days)	Activity	Visit Addis Ababa
Inception	1-Oct	1	Contract signature; project planning design	
Inception		0	NBI provides relevant documents and materials to be studied (send CD-ROM to consultant)	
Inception		4	Study documents, NBI programs and DSS data structures	
Inception		3	Identify current and project future needs for remote sensing (or spatial) information products	
Inception	5-Nov	3	Inception report	
Analysis	3-Dec	7	Visit Addis, Nairobi, Entebe and Kigali	x
Analysis		2	Identify needs for remote sensing information product	
Analysis		2	Inventory world wide available remote sensing data	
Analysis		2	Inventory publicly available satellite data archives	
Analysis		1	Formulate standard remote sensing products	
Analysis		2	High level assessment of RS contributions	
Analysis	11-Feb	9	Initiate pilot activities on archiving and processing of remote sensing imagery	x
Analysis		2	Determine the hardware/software and human resources requirements for the proposed unit	
Analysis		2	Identifying potential contributions and essential functions of the unit	
Analysis	10-Mar	6	Draft Final Report	
Synthesis	17-Mar	12	Training and awareness workshop	x
Synthesis	31-Mar	2	Final Report	
TOTAL		60		

5. Summary and conclusions

During the Inception Phase, the available NBI documents have been studied and the consultant has familiarized himself with the general over-arching Nile Basin issues and aims of the NBI. Because of the relatively low outflow to the Mediterranean Sea (there is a minimum environmental flow requirement being currently met), additional *consumptive* water resources development must be offset by reductions in *consumptive* use elsewhere. The relationship between land cover and water use is thus of fundamental importance, as well as whether the use of water resources provides acceptable economic benefits. The general problems of the Nile Basin has been analyzed and re-expressed into a suitable number of state variables and physical processes that need to be quantified for understanding the extent of the problems and the kind of solutions feasible. The data needs assessment resulted into a list of land surface features that could potentially be provided by RS data (see inset). A tighter coordination of data needs and data delivery between the RS unit and the Regional DSS is warranted. More discussion is required to specify the technical data flow procedures of the DSS and how the RS data fit into that. The latter issue needs attention during the three visits to Addis Ababa, as foreseen under this project.

Standard RS derived features required to support the execution of SVP and SAP projects

Primary data	*Information products*
Land cover	Ponded water surfaces
Vegetation cover	Irrigation intensity
Dominant crop types	Snowfall
Solar radiation	Root zone soil moisture
Rainfall	Evapotranspiration
Surface soil moisture	Biomass production
Leaf Area Index	Crop yield
Net Primary Production	Soil salinity
Lake levels	Net Groundwater Use
Chlorophyll	Surface runoff
Suspended sediment	Crop water productivity
Surface albedo	Snowfall
Change in total water storage	Length vegetation period
	Crop type
	Crop coefficient

The basic approach envisaged is to collect freely available satellite data with pixel sizes of 250 m and larger. These satellite data are available from existing operational data archives. The images should cover the entire Nile Basin for a systematic collection of RS data. GIS experts, hydrologists, ecologists, agronomists and engineers – apart from water managers and policy makers – should be able to retrieve the data through the regional DSS. While the technicians may be interested in primary data, policy makers are likely to be interested in special purpose indicators. There is thus a differentiated user community, and this needs to be addressed in the products that the DSS-RS unit is going to deliver (see Figure 3).

The existing websites of NASA, USGS and ESA, among others, that provide these RS parameters will be further studied during the Analysis Phase. Basin-wide raw data will be collected and imported into GIS systems. The quality of the primary data will be checked. Only data that meets certain standards will be recommended for further usage under the Regional DSS. Examples of these primary datasets will be presented to high level policy makers for assessing their opinion and view.

Remote sensing data will become more meaningful if primary data are further interpreted into information products and special purpose indicators. This interpretation can be achieved after a brief literature review of the available algorithms. The role of interpretation algorithms was overlooked at the start of this consultancy. Further to studying the world wide available remote sensing data and the publicly available satellite data archives, available algorithms will be described during the Analysis Phase.

The new DSS-RS unit requires proper education and training for the staff members that will operate in various specialized fields ranging from erosion monitoring to irrigation management. The training and awareness program is a first step in that direction. The contents of the syllabus to be created for the participants is outlined in Appendix 5. Continuous technical assistance may be required to make the RS unit a success. The operational experiences from the FAO Nile office and FAS-Crop Explorer could be a great asset for defining practical issues in the DSS-RS unit.

The publication of maps on water use efficiency, surface runoff and the changing area of wetlands will certainly create discussions and may be contentious. There will always be supporters in favor publication of information, and opponents who have interest to hide that information. A wealth of information will become available if the DSS-RS unit is going to function as defined in the current blueprint. Information sharing is a fact of modern society. The information should therefore be based on publicly available data, as accurate as possible, and thus become a cornerstone of building trust among the Nile riparian countries. Since remote sensing measurements are necessarily a hybrid between measured and modeled parameters, the results need to be compared with data obtained through field visits. Remote sensing will never replace conventional field data collection schemes, but be complementary to ground-based systems such as hydro-meteorological stations. The ToR does not describe the issue of validation explicitly, and the consultant proposes to spent time and efforts on minimally required field measurements during the Analysis Phase.

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Appendix 1: List of acronyms

AATSR	: Advanced Along-Track Scanning Radiometer
ALEXI	: Atmosphere Land EXchange Inverse
AMESD	: African Monitoring of Environment for Sustainable Development
AMI	: Active Microwave Instrument
AMSR-E	: Advanced Microwave Scanning Radiometer-Earth Observing System
AMSU	: Advanced Microwave Sounding Unit
ASAR	: Advanced Synthetic Aperture Radar
ASTER	: Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATSR	: Along-Track Scanning Radiometer
AVHRR	: Advanced Very High Resolution Radiometer
AWIFS	: Advanced Wide Field of View Sensor
DMSP	: Defence Meteorological Satellite Program
EARS	: Environmental Analysis and Remote Sensing
ENCOM	: Eastern Nile Council of Ministers
ENSAP	: Eastern Nile Subsidiary Action Program
ENTRO	: Eastern Nile Technical Regional Office
ERS	: European Remote Sensing Satellite
ESA	: European Space Agency
ET	: Evapotranspiration
ETM	: Enhanced Thematic Mapper
FAO	: Food and Agricultural Organization
FAS	: Foreign Agricultural Service
FEWS	: Food Early Warning System
GERB	: Global Earth Radiation Budget
GIS	: Geographic Information System
GMS	: Geostationary Meteorological Satellite
GOES	: Geostationary Operational Environmental Satellite
IDEN	: Integrated Development of the Eastern Nile
INSAT	: Geostationary Indian Satellite
IRS	: Indian Remote Sensing Satellite
IWMI	: International Water Management Institute
LandSAF	: Land Surface Analysis Satellite Application Facility
LISS	: Linear Imaging Self-Scanned Sensor
MERIS	: Medium Resolution Imaging Spectrometer
METRIC	: Mapping EvapoTranspiration at high Resolution with Internalized Calibration
MODIS	: Moderate Resolution Imaging Spectrometer
MSG	: Second Generation Meteosat
MSS	: Multi-spectral Scanning System
NASA	: National Aeronautic Space Administration
NILECOME	: Council of Ministers of Water Affairs of the Nile Basin States
NELSAP	: Nile Equatorial Lakes Subsidiary Action Programs
NOAA	: National Oceanic and Atmospheric Administration
NBI	: Nile Basin Initiative

NDVI	: Normalized Difference Vegetation Index
PMU	: Project Management Unit
PR	: Precipitation Radar
RA	: Radar Altimeter
RS	: Remote Sensing
SAP	: Subsidiary Action Programs
SAR	: Synthetic Aperture Radar
SEBAL	: Surface Energy Balance Algorithm for Land
SEBI	: Surface Energy Balance Index
SEBS	: Surface Energy Balance System
SEVIRI	: Spinning Enhanced Visible and near Infrared Imager
SSMR	: Scanning Multichannel Microwave Radiometer
SSM/I	: Special Sensor Microwave Imager
SPOT	: System pour l'Observation de laTerre
SVP	: Shared Vision Program
TSEB	: Two-layer Surface Energy Balance
TM	: Thematic Mapper
TMI	: TRMM Microwave Imager
TOPEX	: The Ocean Topography Experiment
USGS	: United States Geological Survey
TRMM	: Tropical Rainfall Measuring Mission
VIRS	: Visible and Infrared Scanner
WPRM	: Water Resources Planning and Mangement

Appendix 2: Earth observation satellite systems for general applications in land and water management

Since the launch of earth observation satellites with the purpose of describing land surface processes during the 1970s, a suite of different sensors have been brought to space. One has to distinguish between spectral radiometers (that measures radiation in a specific part of the spectrum) and the satellite platform or 'mission' that can be considered as the engine that pushes the radiometer forward. For good reasons, one satellite often hosts multiple spectral radiometers.

Despite the fact that satellite radiometric measurements, after 30 years of research and applications, became common instruments to describe the state variables of the atmosphere such as cloud cover, water vapor content and aerosols in weather prediction and climatological studies, the applications in the water resources community are unfortunately limited. This can be partially attributed to water manager's focus on local scale, rather than large scale water management issues. Climatic processes cover continental scales, are more appropriate scales for satellite applications.

Growing recognition of the river basin as the basic unit for integrated water resource management, has resulted in renewed interest to describe hydrological processes and water management with satellites. It is expected that in the coming decade, satellites will be used more commonly to describe or predict key hydrological phenomena such as floods, droughts, groundwater processes, water productivity, etc. Space programs of NASA and ESA now dedicate more attention to measurement of hydrological processes in large river basins. They are moving their interests from global scale to river basins. It is therefore a good opportunity to explore technical technical opportunities in this field.

It is convenient to discern the various radiometers by their spectral interval:

- Visible and near-infrared radiometers (0.3 – 3.0 μm)
- Thermal-infrared radiometers (3.0 – 15 μm)
- Passive microwave radiometers (0.1 – 30 cm)
- Active microwave radiometers (0.1 – 30 cm)

Remote sensing in land and water resources management can be broadly grouped into three different categories:

a. monitoring of basin scale flow processes with the emphasis on rainfall, soil moisture, ET and river flow;
b. identification of local agricultural and ecological practices;
c. surveying field layout, plot boundaries and legislative aspects;

Category (a) requires repetitive image collection, and is therefore often based on lower resolution images (250 to 1100 m) with a potential repeat cycle of one day. MODIS is an excellent new option in this category because it is with 36 bands an imaging spectrometer (31 bands in the visible and near-infrared part of the spectrum) that acquires images twice daily. The morning overpass is on Terra and the afternoon overpass is on Aqua (see Table 1). The 2nd generation

Meteosat satellite (MSG2) was launched successfully on December 21 (2005), and this sensor provide multi-spectral images (12 channels in the visible and near-infrared part of the spectrum) with an intermittency of 15 minutes only ! Its positioning above the African equator makes this imager suitable for monitoring the hydrological processes in the Nile Basin.

Table 1: Selected visible and near-infrared radiometers and their associated satellite platforms

Satellite	Radiometer	Launch year	Pixel resolution	Revisit period	Number of bands	Swath width
				(days)		(km)
Landsat	MSS	1972	80 m	16	4	185
NOAA	AVHRR	1982	1100 m	1	2	2500
Landsat	(E)TM	1984	30 m	16	6	185
SPOT	XS	1986	10 to 20 m	23	4	60
IRS	LISS	1988	5 to 25 m	24	4	141
SPOT	Vegetation	1998	1000 m	1	3	2200
Terra	ASTER	1999	15 to 30 m	23	9	60
Terra	MODIS	1999	250 to 1000 m	1	31	2500
Ikonos	-	1999	1 to 4 m	variable	4	15
Quickbird	-	1999	1 to 4 m	variable	4	62
Aqua	MODIS	2002	250 to 1000 m	1	31	2500
Envisat	MERIS	2003	300 m	3	15	1500
IRS	AWIFS	2004	56 m	5	4	350
MSG-2	-	2005	1000 m (at equator)	continuously	13	geo-stationary

Category (b) is based on multi-spectral images designed for earth resources monitoring at field scale (15 to 30 m). Visible and near-infrared radiometers with a spatial resolution of approximately 20 meter are very common and useful to discern land cover classes, crop types, soil types and bio-physical parameters such as leaf water content, fraction of photosynthetical radiation (fPAR) etc. Landsat, SPOT and IRS images specified in Table 1 are often used for this purpose. There are costs involved in acquiring these images.

Category (c) needs the involvement of very high-resolution images (1 to 5 m) suitable to detect small objects on the earth surface. Commercially available very high resolution visible and near-infrared radiometers with a spatial resolution of 0.5 to 3 meter can be used for precision farming (e.g. N-applications, malfunctioning irrigation devices) and to detect topographical features such as canals, bridges etc. Ikonos and Quickbird imagery typically belong to this category of images.

Thermal-infrared applications in hydrology and water resources management are typically related to the determination of energy balances and evapotranspiration. The first publications in this field stem from the 1960s and 1970s (e.g. Jackson et al., 1977). Water depletion by evaporation is important for understanding the processes resulting from ET (beneficial & non-beneficial) as well as it provides an indication of water stress experienced by vegetation. *Table 2* describes the space and time domains related to the retrieval of thermal infrared data, being required for ET computations.

Skin temperatures that can be derived from thermal infrared measurements can also be used for the determination of precipitation. The latter technology is also known as the cold cloud duration (Dugdale and Milford, 1986) which is based on the fact that top cloud temperatures are related to the amount of precipitable atmospheric moisture present in the clouds.

Table 2: Thermal infrared radiometers and accompanying satellite platforms

Satellite	Radiometer	Launch year	Pixel resolution	Revisit period	Number of bands	Swath width
				(days)		
Meteosat[5]		1977	5000 m	30 minutes	1	geo-stationary
NOAA	AVHRR	1982	1100 m	01	3	2500 km
Landsat	(E)TM	1984	60 to 120 m	16	1	185 km
ERS	ATSR	1996	1000 m	23	2	1500 km
Terra	MODIS	1999	250 to 1000 m	1	5	2500 km
Terra	ASTER	1999	15 to 90 m	23	5	60 km
Aqua	MODIS	2002	250 to 1000 m	1	5	2500 km
Envisat	AATSR	2002	1000 m	1	2	2500 km
MSG-2	GERB	2005	3000 m	15 minutes	1	geo-stationary

The category of microwave satellites can be divided into passive and active systems. The strong advantage of microwave technology is that microwaves penetrate through the atmosphere under all weather conditions. Contrary to images acquired with optical sensors, microwave satellites are ‘weather’ proof. Microwaves with different frequencies are available in operational satellites and they range from longer wavelengths 1.42 GHz (L-band) 21 cm, via 5.3 GHz (C-band) 5.6 cm, 6.6 GHz 4.5 cm to smaller wavelengths 37.0 GHz 0.81 cm.

Passive microwave remote sensing is based on the measurements of emitted radiation from the land surface in the centimeter wave band, and is largely determined the physical temperature and the emissivity of the radiating body. The microwave emissivity is a strong function of the surface soil moisture conditions and the vegetation optical thickness and roughness. The basic capabilities of passive microwave technologies for soil moisture are well understood after more than 20 years of research. Space borne passive radiometers have, however, a very large pixel size, which makes them suitable only for regional scale applications (such as operationally monitoring land wetness throughout the entire Nile Basin).

Active microwave radar technologies have a spatial resolution that is compatible with the optical satellites. Active microwave systems have a radar antenna beam that illuminates the ground. Due to the satellite motion and the along-track (azimuth) beam width of the antenna, each target element only stays inside the illumination beam for a short time. This process is equivalent to a

[5] Meteosat is the geostationary satellite over Africa and Europe. America has GOES, Asia has INSAT and Fyuing and Australia has GMS

long antenna (so called Synthetic Aperture) illuminating the target. Active microwave systems are therefore often referred to as SAR systems. A summary of operational systems is provided in Table 3.

Table 3: Selected microwave radiometers and accompanying satellite platforms

Satellite	Radiometer	Launch year	Pixel resolution	Revisit period	Frequency	Swath width
				(days)		
Nimbus passive	SSMR	1978	25 to 150 km	17	37 GHz (25 km) 6.6 GHZ (150 km)	1400 km
DMSP	SSM/I	1987	15 to 70 km	17	86 GHz (15 km) to 19 GHz (40 x 70 km)	1400 km
Topex	Poseidon altimeter	1992	2.2 km	10	14 GHz	-
TRMM passive	TMI	1997	9 km X 16 km	2	10.7 GHz to 86 GHz	760 km
Radarsat Active	-	1995	8 to 100 m	24	5,3 GHz	50 to 500 km
ERS Active	AMI	1991	12.5 m	23	5.3 GHz	100 km
ERS Active	Scatterometer	1991	50 km	3	5.3 GHz	500 km
Jason	Poseidon altimeter	2001	2 km	10	14 GHz	-
JERS Active	SAR	1992	12.5 m	46	1.275 GHz or 23 cm (L band)	75 km
Envisat	ASAR	2002	150 m	3	c-band	405
Envisat	RA2 altimeter	2002	1.7 km	16	13.6 GHz (KU band)	

Appendix 3: Selected websites for satellite image data retrieval

Agriculture

- Landsat images http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp

Climatology

- Climate http://www.iwmi.cgiar.org/WAtlas/atlas.htm
- Reference evapotranspiration http://www.iwmi.cgiar.org/WAtlas/atlas.htm

Flood and Drought

- MODIS Flood maps http://earthobservatory.nasa.gov/NaturalHazards/natural_hazards_v2.php3?img_id=12688
- ERS Scatterometer http://www.ipf.tuwien.ac.at/radar/ers-scat/home.htm
- Population density http://grid2.cr.usgs.gov/globalpop/africa/
- Radarsat for flooded areas http://visibleearth.nasa.gov/search.php?q=floods

Geography

- Africover http://www.africover.org
- Digital Elevation Model http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp
- IGBP Land cover http://www.igbp.kva.se
- IKONOS high resolution http://www.spaceimaging.com
- Landsat images http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp
- Landsat mosaics http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp
- MODIS Image http://modis.gsfc.nasa.gov
- SPOT Vegetation http://www.spot-vegetation.com

Water balance

- Meteosat animation http://meteosat.e-technik.uni-ulm.de/
- Nimbus http://sheba.geo.vu.nl/users/jeur/richard.htm
- TOPEX/Poseidon altimeter http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/
- TRMM monthly rainfall http://trmm.gsfc.nasa.gov/images_dir/avg_rainrate.html

This list is tentative and will be further completed during the Analysis Phase

Appendix 4: Table of contents Final Report RS Scoping Study

Chapter	Topic
1	Introduction - NBI data needs on basis of documents - NBI data needs on basis of personal interviews - Difference/complementary between DSS and RS - Role of GIS
2	Role of existing international RS institutes present in Nile Basin - Inventory of institutes - Inventory of operational products - Possible cooperation with DSS-RS unit
3	Summary of review papers - Interpretation algorithms (ET, soil moisture etc.) - Management indicators (irrigation, erosion etc.) - Coupling of RS with hydrological basin models
4	Standard business processing of primary RS data - list of parameters - examples of applications in Nile basin
5	Standard business processing of information products - list of parameters - examples of applications in Nile basin
6	Standard business processing of Special Purpose indicators - list of parameters - examples of applications in Nile basin
7	Ground validation - collection of field measurements (rain, stream flow, meteo) - inspection of land cover classes and crop types - gathering secondary agricultural data (acreage, yield)
8	Data organization RS unit - hard/software requirements - link with DSS and GIS data - data formats - data accessibility and sharing protocol - quality control - retrieval procedures for outsiders - protocol of other DSS downloadable products
9	Human resources - Number of staff - Tasks of staff - Recruitment plan - Supervision plan - Educational plan
10	Electronic dissemination - weekly overview of maps - weekly hydrological bulletin - weekly report on thematic anomalies

Appendix 5: Proposed Syllabus for the training/awareness workshop

The training and awareness workshop will aim at two different audiences. One audience is considered to be technicians with a background in GIS/RS and water management issues. The second audience are managers and policy makers. The list of participants will be jointly discussed with the Regional DSS unit.

Chapter	Topic
1	Introduction - Primary data - information - indicators
2	Summary of textbook lectures - radiation physics - water management - land management - agricultural management - guiding texts and graphics - Question and answer session
3	Available earth observation satellites for basin management - Pixel size, repeat cycle, swath width - Thematic applications - Specification of websites
4	Hydrological processes - Rainfall - Soil moisture - ET - Runoff - Net Groundwater Use - Crop yield
5	Interpretation algorithms - Irrigation performance - Food security - Land degradation - Deforestation - Wetland sustainability - Erosion
6	Examples created under this consultancy
7	Demonstration of RS outputs in various SVP and SAP projects
8	CD-ROM with sample data

Appendix 6: References studied

NBI, The Nile Basin Decision Support System, a Concept Paper

NBI, Integrated Development of the Eastern Nile (IDEN), Project Identification Document, Summary (18 March 2001), ENCOM

NBI, SVP, Water resources planning and management, project document, March 2001, Council of Ministers of Water Affairs of the Nile Basin States

NBI, NESAP, Strategy for Scaling up NELSAP investment projects, endorsed by NEL-COM, 16 March, 2005

NBI, Efficient water use for agricultural production (EWUAP) project, October 2007

NBI, SVP, Launch of the water resources planning and managent project

NBI, Development of a proposal for institutional strengthening project 2008-2010, consolidated consultation document

Shahin, M., 1985. Hydrology of the Nile Basin, Developments in Water Science 21, Elsevier Science Publishers, Amsterdam: 575 pp.

Sutcliffe, J.V. and Y.P. Parks, 1999. The hydrology of the Nile, IAHS special publication no. 5, IAHS Press, Institute of Hydrology, Wallingford, Oxfordshire, UK: 179 pp.

WaterWatch, 2005. Rapid remote sensing assessment for flood and water resources management in the Eastern Nile

WaterWatch, 2006. Remote sensing for evapotranspiration estimation to support a scoping study on Eastern Nile multi-purpose development options (including i. wetland evaporation in the Baro-Akobo basin, ii determination of water surface area and evaporation losses from Jebel Aulia reservoir and iii identification of irrigated area and evapotranspiration of summer and winter crops in Sudan)