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FAO/UNEP Global Land Cover Network (GLCN) Topic Centre

GLCN GUIDELINES

FOR

LAND COVER MAPPING

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
UNITED NATIONS ENVIRONMENT PROGRAMME

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Executive Summary

It is often argued that the ecological footprint of mankind has reached its limits and that the Earth cannot support further population increase. Yet, the world's population of 6.4 billion (end 2004) is still rapidly growing, particularly in the least developed countries. The latest population growth projections by the United Nations estimate another 40% population growth in the next 50 years that is an increase by about 2.5 billion people, which equals the world's total population in 1950.

Global demand for food and fiber is expected to grow by 60-70% during the same period. It will be chiefly driven by growing population and increasing standards of living in developing countries. But there is a little room for further increase of arable land area and the fresh water supplies per capita are diminishing. Hence, the future increase of food and fiber production to satisfy the growing demand will have to be science-driven, global in scope and based on holistic concept including the social, economic, political, environmental and technological dimensions and respecting the interconnectivity among these components of sustainable management of the Earth's ecosystems.

FAO is spearheading this effort by introducing new, advanced concepts for sustainable development and management of land and water resources resulting in their higher productivity, effective conservation and environmental protection. An example is the development of the Global Land Cover Network (GLCN) and establishment of the GLCN Topic Centre (GLCN-TC), undertaken jointly with the United Nations Environment Programme (UNEP). The GLCN-TC is hosted by the Italian Istituto Agronomico per l'Oltremare in Florence, Italy and funded primarily by the Government of Italy.

The GLCN development was based on demands by land use planners, food security officers, land and water resources managers and environmental protection officers for more reliable and timely information on land and water resources and their changes. Land cover is one of the most reliable, objective and early indicators of natural and anthropogenic changes of environmental conditions, such as those caused by climate variability and change, natural disasters and land use. Systematic monitoring of land cover provides essential inputs to a number of societal priorities such as land use planning based on agro-ecological zoning, more effective environmental protection based on the assessment of the impact of climate change, degradation of land and water resources, deforestation, changes in wetlands and lakes areas, etc.

Land cover information has become one of the most important inputs to predictive models related to environmental protection, such as models for climate change, biodiversity and land degradation/desertification. An equally important application of reliable and timely land cover information is in the regional and national food security early warning systems. In particular, the identification of areas with food security risk benefits from the availability of baseline land cover information to which the changes in the area of cultivated land, irrigated areas, extent and severity of land degradation, and impact of natural disasters can be referenced.

One of the primary goals of GLCN is to meet the needs of the international science community for land cover data and their dynamics to address the issues related to fulfillment of the Millennium Development Goals, the Agenda 21 and the United Nations environmental conventions.

Recent advances in geo-information technologies of satellite remote sensing, geographic information systems and global positioning systems, accompanied by development of international standards for remote sensing data and derived products, modernization of remote sensing data archives and establishment of international remote sensing data networks, have created new opportunities for land cover mapping and environmental monitoring at regional and global levels.

As a result of growing demand for land cover information at global and regional levels, there is an increasing number of land cover projects designed to produce such information. However, there is an urgent need for harmonization among these projects. Although each project produces valuable information on current state of land cover and its changes, this information cannot be reliably compared because of differences in the definition of land cover classes, classification systems, mapping methodologies, and accuracy assessment procedures. Information about technical characteristics of land cover products of these projects, such as their accuracies, dates of the input remote sensing images, etc., is sometimes difficult to obtain. Thus the benefits that could be obtained from synergy among land cover mapping and monitoring activities at global and regional levels are lost.

FAO and UNEP have decided to jointly address the challenge of improving the availability of harmonized land cover information and initiated the development of GLCN with particular emphasis on the needs of developing countries. The main task of GLCN is to provide direction, focus and guidance for harmonization of land cover mapping and monitoring projects based on the innovative FAO Land Cover Classification System (LCCS).

An equally important task of GLCN is to increase the benefits from the international land cover projects to developing countries. They urgently need an access to reliable and current land cover information for sustainable development and management of their natural resources. Yet, because of the lack of the effective infrastructure that would link the international land cover projects, provide information about their products and facilitate their accessibility, they remain largely unavailable to land use policy-makers, planners and land managers from developing countries that need them most.

In order to fulfill its objectives, the GLCN conducts the following four types of activities:

- Normative and methodological, aiming at upgrading and harmonization of land cover mapping and monitoring methodologies and information products at country, regional and global levels. This task includes certification of existing land cover databases for their compliance with GLCN technical specifications. It also includes a continuing development of GLCN methodology based on changing requirements on land cover products by their end users;

- Networking - establishing effective linkages and cooperation with major land cover databases and international, governmental and commercial organizations involved in land cover mapping and monitoring activities. Its main aim is to increase the benefits from regional and global land cover mapping and monitoring initiatives to developing countries;
- Capacity building in developing countries, including provision of advisory services and organization of training courses on GLCN land cover mapping and monitoring methodology for technical staff and appraisal workshops for decision-makers. Its aim is to strengthen the national capacities for land cover mapping and monitoring in developing countries;
- Serving as the international clearinghouse for information related to land cover mapping and monitoring activities. This task involves development and management of GLCN meta-database providing information on major land cover mapping and monitoring projects.

1. Introduction

The socio-economic and environmental challenges related to population growth, rural poverty, food insecurity, and environmental degradation in most developing countries require mobilization of efforts for development of geoinformation infrastructure that would speed up provision of reliable and timely information on land and water resources needed by land use planners. Such information is an essential prerequisite for land use planning, sustainable management of renewable natural resources, environmental protection, better preparedness for natural disasters and more effective mitigation of their impacts, and realistic modeling of climate change scenarios. Yet, in developing countries the existing information is spotty, often outdated and generally unreliable. Filling the data and information gaps have become one of the development priorities.

An intelligent judgment of options on how to effectively cope with the socio-economic and environmental challenges has to be based on knowledge of current situation. Since the land cover reflects both the natural and anthropogenic causes of environmental change, it is one of the most reliable indicators of their impacts. Therefore, the availability of information on land cover and its dynamics, including the assessment of past changes and forecasting the future trends, are essential requirements for formulation of rational and economically feasible scenarios for sustainable development and management of land and water resources and environmental protection (Figs.1 & 2).

Sound land use planning should be based on a comprehensive approach, taking into account all major contributing factors, bio-physical and socio-economic, affecting the land use. Changes in land cover, which reflect in a synthetic manner the impact of natural as well as anthropogenic factors, can be monitored, evaluated and mapped by advanced geo-information technologies worldwide.

The importance of the availability of reliable information on land cover and its changes for sustainable management of the Earth's renewable natural resources was emphasized at the United Nations Conference on Environment and Development (UNCED), better known as the Earth Summit, which took place in Rio de Janeiro in 1992. Its action plan, the Agenda 21, has provided a rational basis for planning of sustainable development. The following two specific actions were listed among the UNCED priority requirements: bridging the data gap between developing and industrialized countries, and improving the availability of information. The Earth Summit recommended the use of remote sensing and GIS technologies for coordinated, systematic and harmonized collection of data on land cover and environmental degradation.

In September 2000, the United Nations Millennium Summit adopted the Millennium Declaration in which it reaffirmed its support for the implementation of the Agenda 21 and, in particular, for the principles of sustainable development. A follow-on initiative, the Road Map towards the Implementation of the United Nations Millennium Declaration, prioritized the global development objectives into a set of eight Millennium Development Goals (MDGs), which include the reduction of poverty, hunger, disease, illiteracy and gender discrimination, and adoption of principles of sustainable development. A set of indicators have been defined for each Goal and are used to track the progress in meeting the Goals. Since the land cover change is one of the most important indicators of development activities related to food security and sustainable development, an objective assessment of current state of land cover and monitoring its changes have become essential requirements for monitoring the progress of MDGs at regional and global levels.

Ten years after adoption of the Agenda 21, its progress was reviewed at the World Summit for Sustainable Development (WSSD), which took place in Johannesburg in 2002. Its participants pointed out to delays in its implementation and emphasized the growing urgency of sustainable development resulting in the increase of food production while reversing environmental degradation. They recommended the use of geo-information technologies for environmental assessment and monitoring and urged the governments to allocate additional resources for the fulfillment of the Agenda 21 and Millennium Development Goals.

Sustainable management of land and water resources and effective environmental protection have to be based on reliable, timely and location-specific information on the state of natural resources and their changes. In most developing countries, there is a wealth of information on natural resources that have been collected by government agencies with mandates for disciplines related to land and water management, which include soils, agricultural land use, forestry, rangelands, hydrology, meteorology, topographic mapping and national statistics. Yet, this information even if digitized and stored in GIS databases, is usually not compatible among different organizations and often lacks updating and accuracy assessment.

Hence, there is a need for geoinformation infrastructure that would provide a standardized reference to all spatial information products related to land and water resources. Such a geo-information infrastructure should be a component of, and thus fully compatible with the National Spatial Data Infrastructure (NSDI). It would provide a normative and methodological framework for management of geospatial data and make possible harmonization of geospatial databases maintained by different organizations. The geoinformation infrastructure would enable geospatial data exchanges among different organizations, their integration, and thus expand the range of their applications. This would facilitate development of rational plans for sustainable land and water management and environmental protection based on spatially referenced, harmonized and comprehensive information on land and water resources, climatic factors, and socio-economic conditions.

The Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Program (UNEP) have jointly undertaken development of land cover component of geoinformation infrastructure for sustainable management of land and water resources and environmental protection at global level. The development strategy is based on a holistic concept that the well-being of population, food security, and rural poverty, sustainable management of land and water resources, and environmental protection are inter-related.

Information on land cover, which reflects the biophysical and environmental parameters of land and water resources, as well as the climatic and socio-economic factors affecting the land use, fulfills the requirements for a baseline dataset to which other information can be linked. Land cover is an explicit geographic feature to which many disciplines can relate in GIS context. When the land cover mapping and land cover classification system are based on specifications that are applications neutral, the resulting land cover dataset is not a single-discipline oriented, but addresses the multi-user community. It provides a common, standardized geographic baseline dataset to which government agencies responsible for land and water management can reference their data.

Current state of land cover is the result of complex interactions among the types of land use, landforms, soils, water resources and climate. Its changes are primarily affected by changes in land use and climate variability and thus enable monitoring their impacts. Equally important characteristic of land cover information is that it can be used in a wide range of application fields, including agricultural land use planning, forestry, monitoring of watersheds, rangelands and wetlands, assessment of environmental impacts, etc. In particular, the information on land cover change provides an objective indicator for the assessment of land and water management and the state of the environment.

There is an increasing number of land cover mapping projects, based on satellite remote sensing and GIS data processing, being implemented at global, regional and country levels in recent years. However, there has been little or no compatibility among them in terms of definitions of land cover classes, map legends, image interpretation methodologies, accuracy criteria and cartographic specifications. Although these land cover maps are a valuable source of information, most of them were designed for a specific application and are difficult to compare and use in other applications that may require different land cover definitions, map legends, or mapping scales.

FAO in cooperation with UNEP and supported by the Government of Italy, responding to the requirement for the availability of standardized methodology for land cover mapping and change monitoring applicable to any geographic area and compatible with a wide range of applications, initiated development of the Global Land Cover Network (GLCN). This development has been based on the experience with implementation of the FAO Africover project for land cover mapping in East Africa. Its results include, as its spin-off product, an innovative methodology for land cover classification, the Land Cover Classification System (LCCS).

The primary GLCN objective is to improve the availability of reliable and harmonized information on land cover and its dynamics. An equally important objective is to assist developing countries to strengthen their capacities for land cover mapping and effective utilization of land cover information. In 2002, FAO and UNEP, with the support of the Italian government, organized an international workshop on strategies for global land cover mapping and monitoring in Artimino, Italy. Its participants, representing major national and international organizations involved in land cover mapping, unanimously endorsed the establishment of GLCN and invited FAO and UNEP to take the lead, in partnership with other UN agencies and international organizations, in GLCN development. Full text of the Artimino Declaration is in Annex 1.

In 2004, FAO and UNEP in cooperation with the Italian Istituto Agronomico per l'Oltremare (IAO) and the U.S. Agency for International Development (USAID), organized an international GLCN workshop at IAO headquarters in Florence, Italy. Its objectives were to formally launch the GLCN Topic Center located at IAO headquarters, establish links with relevant global and regional Earth observation initiatives, and encourage cooperation of developing countries with GLCN.

Production of GLCN Guidelines for Land Cover Mapping was one of the first activities of GLCN Topic Center. The Guidelines address the need for harmonization of information on current state of land cover and its changes based on the FAO Land Cover Classification System, which is becoming the international standard for land cover classification. They also provide a description of innovative land cover mapping methodology, which was developed and successfully used during implementation of the Africover land cover mapping project covering 10 countries with a total area of 8.5 million km^2 in East Africa. The methodology is applicable in all countries, regardless of the level of their economic development, geographic location, land cover types, or types of applications of land cover information.

2. Terminology and Definitions related to Land Cover Mapping

There is a considerable range of definitions related to land cover mapping. Although there have been several attempts for international standardization of such definitions, this process is still continuing. It was therefore necessary to clarify the terminology and definitions used in these guidelines. The definitions used are mostly based on FAO and UNEP sources, taking in account international initiatives for their harmonization.

The current state of land cover is specific to a geographic location and its physical parameters, such as landforms, soils and water, and reflects the anthropogenic and natural processes affecting the area. Since the industrial revolution, the influence of people on land cover has started to rapidly grow. Vast areas of land have been deforested, wetlands dried, and urban areas and related infrastructures started their expansion without regard to environmental impacts. This trend was further exacerbated during the twentieth century by increasing population pressure and continuing transformation of national economies through industrialization, with little attention paid to sustainable land management and environmental protection. As a result, the degradation of land and water resources became a serious problem that has been increasingly affecting fresh water supply, agricultural production and food security. The natural processes influencing land cover include climate inter-annual variability and change, and natural disasters, such as vegetation fires, wind damage, sand storms, floods, earthquakes and landslides. The impact of natural disasters has been magnified when the protective function of land cover was disturbed in ecologically sensitive sites, such as deforestation on steep hills or intensive land cultivation in climatically marginal zones.

In order to prevent misunderstanding regarding the meaning of term land cover in the context of GLCN and, in particular, to distinguish it from related term land use, the following definitions of both terms should clarify their usage in these guidelines:

Land cover - continuous mosaic of natural and anthropogenic types of the earth's surface, including vegetation, bare land, water, and man-made structures.

Land use - the purpose for which a specific earth's surface area is used by people; its socio-economic function.

Hence, the land cover and land use are closely interlinked yet distinct geo-information terms, both describing the characteristics of the earth's surface features in specific locations. Land cover describes their types, while land use describes their utilization by people.

Geo-information – location-specific information that can be processed by geographic information systems. It is usually stored in digital geographic databases and/or displayed on maps. Land cover and land use are examples of geo-information.

Land cover reflects not only variations in natural vegetation, topography, soils, soil moisture and surface water bodies, but also the type and intensity of land use and land degradation. While each area on the earth's surface can be identified by a unique land cover class, only areas used by people can be also identified by land use classes. There may be several land use classes related to the same area, identified by a single land cover class. For example, forest is a land cover term, while forest plantation, protection forest, park, wildlife refuge, hunting reserve, denote the type of forest use by people and, therefore, are land use terms. Similarly, the land cover term grassland can be associated with number of land uses, such as pastoral, agricultural, recreational. While land cover can be interpreted from remote sensing data, the interpretation of land use usually requires additional information.

There is little compatibility among land cover terms used by international land cover mapping and monitoring projects. The same land cover term, such as forest, may be based on different definitions, resulting in wide differences in the forest areas obtained from different projects. Furthermore, some projects mix the land cover and land use terms. Such a lack of uniformity in land cover nomenclature and definitions prevents reliable comparison of land cover assessments among these projects. Therefore, one of the main objectives of GLCN is to promote and assist harmonization of land cover mapping and monitoring at national, regional and global levels.

Global Land Cover Network (GLCN) – is the FAO and UNEP global initiative, funded primarily by the Government of Italy, which aims to speed-up the availability of reliable, timely and harmonized information on land cover and its changes, with the emphasis on filling the land cover information gaps in developing countries. The GLCN implementation strategy is based on linkages with existing land cover databases, cooperation with ongoing land cover mapping and monitoring projects, and the use of the GLCN Land Cover Classification System (LCCS) as the standard for harmonization of land cover products.

Other terms related to land cover mapping include land cover classification, land cover interpretation, land cover digital database and meta-database, land cover map legend, and land cover map:

Land cover classification - process of systematic grouping of land cover features into classes according to pre-selected criteria. The resulting land cover classes are an abstract, generalized depiction of reality.

Land cover interpretation - delineation and identification of land cover classes on remote sensing images, such as satellite imagery or aerial photographs. The interpretation process can be manual or computer-assisted. Its important component is field validation (ground truthing), during which the interpretation results are checked in selected field sites.

Land cover digital database – complete set of geographically referenced digital polygons defining location of land cover classes in the mapped area, their identification labels and attributes stored on a computer disk. It includes links to other geospatial and statistical information, such as socio-economic, demographic, climatic, etc.

GLCN land cover digital database – land cover digital database certified by GLCN Topic Centre that its data, their quality and accessibility comply with GLCN specifications. GLCN land cover digital database is accessible only to qualified users.

Land cover meta-database – description of characteristics of land cover data stored in database, including their types and definitions, dates, quality, cartographic parameters and terms of their accessibility. It is important to note that the meta-database is important not only to data description but also to their quality rating and certification. The GLCN land cover meta-database is freely accessible on the Internet.

Land cover map legend – subset of land cover classes that is representative for land cover in the mapped area, and compatible with a type of land cover map (e.g. general, agricultural land, forestry, wetlands, etc.) and its scale. Hence, it is dependent on the mapping scale, application and project geographic area.

Land cover map – abstract cartographic representation of land cover in the mapped area. It has defined cartographic projection, coordinate grid, scale, map legend, and source of land cover data including their dates. It can be distributed in virtual format and displayed on computer screen, and/or as paper prints.

Other, more specific terms related to advanced land cover mapping methodology developed under the framework of the FAO Africover project, like the Land Cover Classification System (LCCS), Geographical Vector Interpretation System (GeoVIS), Multipurpose Advanced Database for Environmental information (MADE), Africover Interactive Database for interpretation (AID), and Africover Database Gateway (ADG) are described in chapters dealing with these topics.

3. Rational for Land Cover Mapping

Socio-economic and environmental challenges facing developing countries at the dawn of the twenty-first century have been addressed by the United Nations Millennium Development Goals. Their achievement, which should become a top priority, requires a fundamental change of development strategies. Land use planning and sustainable management of renewable natural resources have to be based on sound databases with location-specific, reliable and timely data. Furthermore, the geospatial environmental databases should be linked to socio-economic ones (population, food security, poverty, unemployment, etc.) to allow realistic assessment of the impacts of growing population and future trends.

It is often argued that the ecological footprint of mankind has reached its limits and that the Earth cannot support further population increase. Yet, the latest population growth projections by the United Nations estimate another 40% increase from the present 6.4 billion (end 2004), that is an additional 2.5 billion people, which corresponds to the world's total population in 1950, before the population level stabilizes in about 50 years. Practically all this increase will occur in the developing countries, with the least developed ones having the largest population growth. The demand for food and fiber is expected to grow by 60% - 70% during the same period.

The assurance of food security for growing population in developing countries has therefore become a major concern. The first Millennium Development Goal, the eradication of extreme poverty and hunger, is linked to sustainable rural development because the extreme poverty is the most serious in rural areas of developing countries. Since there is a little room for further extension of cropland areas, the future increase of agricultural production will primarily depend on intensification of land use in the existing croplands. Reliable baseline data on current land cover and its changes are urgently needed for rational planning of land use intensification. The land cover data are also needed for agro-ecological zoning, which should be part of sustainable land use planning, because it optimizes the use of agricultural land based on its biophysical characteristics, environmental and socio-economic conditions, while preventing its degradation.

Another problem affecting primarily developing countries and addressed by the Millennium Development Goals is the growing shortage of fresh water. Over one billion people in developing countries are currently without safe drinking water. The World Population Institute estimates that this number may increase to 2.5 billion people in the next 25 years because of continuing population growth, increase of water use and contamination of water supplies. Timely information on changes of surface water bodies and monitoring of land use and vegetation cover in watersheds provide essential inputs to sustainable management of fresh water resources.

The population growth, poverty, food insecurity, growing shortage of fresh water and environmental degradation are closely interconnected. Hence, the land use planning, in the framework of sustainable development, should be based on holistic approach, integrating the demographic, socio-economic and environmental factors.

Rapid advancements of geo-information technologies in recent years have caused them to become critical components of sustainable development strategies. These advancements have enabled development of more effective methodologies for mapping and monitoring of the Earth's surface at regional and global levels, processing and integration of vast amounts of geospatial and socio-economic data, and their conversion into information products. Furthermore, they enable user-friendly data access and provide innovative visualization and modeling tools, thus facilitating their effective utilization in the land use planning process.

Since the land cover reflects the effects of both, natural and anthropogenic processes on the Earth's surface, it is an objective indicator for the assessment and monitoring of their combined impacts. Land cover provides continuous, seamless and location-specific information on the Earth's surface features of the area. It reflects the effects of land use and natural disasters, as well as the impacts of climate variability and change. These inherent characteristics of land cover make it particularly suitable to provide baseline data for realistic design of sustainable rural development strategies based on the assessment of land supporting capacity for agricultural production, food security and rural poverty situation and trends. Furthermore, the land cover dataset serves as a logical common reference layer for geographic databases used for rural land use planning, sustainable management of land and water resources and environmental protection. Therefore, the availability of reliable and timely information on land cover and its changes has become an essential requirement for sustainable rural development, management of renewable natural resources and environmental protection.

Changes in land cover are often an early indication of emerging environmental issues. For example, the extensive vegetation damage in Central Europe that started to appear in the so called black triangle (highly industrialized area near the borders between Czech Republic, Germany and Poland) in 1960s and about twenty years later resulted in total destruction of forests, lead to identification of atmospheric pollution and resulting acid rain as its source.

While land cover changes are location-specific, they may have regional or even global consequences. For example, shrinking of the area of Aral Sea due to water diversion for irrigation of newly established cotton plantations in 1960s have intensified sand storms that are affecting vast areas in central Asia. Similarly, extensive deforestation of tropical forests has resulted in a loss of biodiversity and also affected climate, with global consequences. Hence, systematic assessment of land cover and monitoring its changes is important for early detection of environmental "hot spots" and facilitates identification of their sources.

However, it has to be understood that the land cover information by itself, although essential, is not a sufficient input to the above tasks. It has to be integrated with other relevant geo-information layers reflecting the environmental, social, cultural, political and economic factors affecting rural land management and environmental protection. These additional geo-information layers may include information on landforms (in the form of DTM), soils, water resources, climate including inter-annual climate variability, land use including farming systems and forest management procedures, population density including age groups and health statistics, rural poverty and employment patterns, etc. Several models have been developed for effective integration of such diverse inputs to facilitate land use planning.

In most countries, all the above inputs, except of information on current land cover and its changes, are available. They are collected and managed by government organizations with mandates for respective disciplines. Some of these inputs may also be available from non-governmental organizations. However, there are usually no organizations with the explicit mandate for systematic, country-wide mapping of land cover and monitoring its changes in developing countries. Ad hoc land cover mapping and monitoring activities are typically undertaken by a number of organizations, such as remote sensing centers, surveying and mapping organizations, agricultural and forestry institutes, with no harmonization of methodologies and little cooperation among them.

In the past, such sectoral modus operandi for implementation of land cover mapping projects served its purpose and provided required information to respective organizations. However, with the rapid advancement of geo-information technologies, in particular remote sensing and GIS, such approach is not any longer effective and efficient. Rational land use planning requires a holistic approach, based on integration of land cover information with geospatial and socio-economic data, their joint analysis and modeling. Furthermore, the high priority global tasks, in particular the United Nations Agenda 21 and the Millennium Development Goals, which address the need for the increase of food security, eradication of extreme poverty, improved access to fresh water, sustainable management of renewable natural resources and environmental protection at global level, have set new standards for the type, availability and quality of geospatial information required for their implementation.

New paradigm for land cover mapping is clearly required that would account for these new developments and effectively respond to new challenges. It should facilitate harmonization of land cover mapping procedures across sectoral barriers and national borders, increase flexibility of land cover classification to support diverse applications worldwide, enable effective integration of land cover data and other types of geospatial data with socio-economic data, and provide links to attribute information. In order to address these challenges, the FAO and UNEP, with the support by the Italian Government, jointly established a Global Land Cover Network Topic Centre (GLCN-TC) in Florence, Italy. The GLCN-TC will establish links and cooperation with the existing land cover databases, promote and assist harmonization among land cover mapping projects and standardization of land cover classification based on the GLCN Land Cover Classification System (LCCS). One of its most important activities will be provision of training and advisory services on GLCN land cover mapping and monitoring methodology to developing countries and countries with economies in transition. When the GLCN is fully operational, it will contribute to reduction of current duplication of effort in land cover mapping and monitoring activities.

The societal benefits of timely access to the harmonized information products of land cover mapping and change monitoring projects can be summarized as follows:

- Inputs to sustainable land use planning, including agro-ecological zoning;
- Improved preparedness for natural disasters, assessment and mitigation of their impacts (e.g. agricultural drought, floods, wind damage, forest fires, pest infestations, etc.);
- Inputs to food security regional and national early warning systems;
- Assessment and mitigation of impacts of climate variability and change;
- Inputs to greenhouse gas accounting and carbon management;
- Monitoring changes in croplands, including irrigation, abandoned fields, conversion to other land uses;
- Assessment and change monitoring of surface fresh water bodies and their watersheds, including fresh water wetlands;
- Assessment and monitoring of forest cover, including the extents and rates of deforestation, reforestation and afforestation;
- Assessment and monitoring of land degradation;
- Monitoring land erosion and accretion in coastal areas;
- Monitoring the extent of urban sprawl.

4. Overview of Land Cover Mapping

Land cover mapping has evolved in response to increasing needs by growing population for reliable inventories of natural resources, land use planning and environmental protection over the course of the twentieth century, in particular its latter part. However, its origins can be traced to Swedish botanist Carolus Linnaeus who devised a classification system for plants in mid-18th century. By contrast, the classification of land cover, which includes vegetation as well as abiotic features of land surface, is a relatively new development. It started with the use of aerial photographs during the 1920s. One of the earliest large area land cover map was produced for forest assessment in Canada in early 1920s. Over the next 50 years, the main users of land cover maps were managers of natural resources and geologists. Only in the latter part of the twentieth century, the land use planners and environmental officers have joined the ranks of major users of land cover maps. Rather surprisingly, already in 1949, the International Geographic Union (IGU), at its Congress in Lisbon, recommended to initiate the world land use mapping based on harmonized specifications (the terms land use mapping and land cover mapping were interchangeable at that time). The IGU initiative succeeded only partially because compilation of a global land use/land cover map based on aerial photographs was too difficult, time consuming and expensive.

The real advent of land cover mapping based on aerial photographs occurred during the 1950s. Hierarchical land cover classification schemes were developed for the main application disciplines and photointerpretation keys designed for all major land cover classes. The purpose of photointerpretation keys is to harmonize the interpretation results produced by different photointerpreters and thus to reduce the effect of subjectivity, increase the accuracy of visual interpretation and enable more reliable assessment of land cover changes. One of the largest land cover mapping project based on aerial photographs was the World Bank – funded land cover mapping of Indonesia in the mid-1970s.

Launch of the first civilian Earth observation satellite, the Earth Resources Technology Satellite (ERTS-1) later renamed Landsat-1, in July 1972, has started a new satellite era of land cover mapping. While the meteorological applications of satellite remote sensing had started about a decade earlier, it was the success of Landsat program that has provided the basis for the assessment, mapping and monitoring of the Earth surface from satellites. Growing network of EO satellites, increasing range of ground detail (at present 1m to 1km) that can be recorded by their remote sensing systems in number of spectral bands, provide unprecedented opportunities for the operational use of remote sensing in the LCLU assessment, mapping and monitoring projects. The efficiency of satellite remote sensing and the compatibility of satellite image data with the requirements of land cover and land use mapping at scales ranging from 1:1 million to 1:50 000 have been demonstrated by a number of projects implemented in industrialized and developing countries.

Similarly as with aerial photography fifty years earlier, foresters and geologists were the first ones who pioneered the application of new satellite remote sensing technology to land cover mapping. They were soon joined by specialists from other disciplines including agriculture, land use planning, water resources and environment. USA and Canada spearheaded the early development of satellite remote sensing mapping and monitoring applications because they had a plentiful supply of data. The other countries obtained better access to satellite remote sensing data only in the second half of the 1970s and during the 1980s when over twenty ground receiving stations for satellite remote sensing data were built around the world. France launched the first European Earth observation satellite, the SPOT-1, in February 1986, joined in the following years by the former Soviet Union, India, Japan, Canada, the European Space Agency, China and Brazil. The overview of the latest status of satellite remote sensing systems that are currently (late 2004) in operation and compatible with land cover mapping at regional and global levels, is in Annex 3.

Another important development for land cover mapping occurred in 1980s when the second generation of Earth observation satellites, starting with Landsat-4 launched in 1982, produced images of the Earth's surface with finer resolution (30 m instead of 80 m) and in more spectral bands (seven instead of four). These improvements of satellite images allowed better discrimination of land cover classes and their characteristics. Furthermore, in the second half of 1980s, the new geoinformation technologies, the geographic information systems (GIS) and global positioning systems (GPS) started to be incorporated in land cover mapping methodologies. The integration of remote sensing data with relevant geospatial data from other sources in GIS and their georeferencing by GPS have contributed to significant increase of information obtainable from satellite remote sensing data and to higher accuracy of remote sensing products. These developments led to higher effectiveness and efficiency of land cover mapping and monitoring based on remote sensing data, GIS and GPS (chapter 8).

The main obstacle of satellite remote sensing, overcast sky, has been overcome with successful operation of imaging radar satellites. Their remote sensing system, the synthetic aperture radar (SAR) emits microwaves that penetrate clouds and records the backscatter from the Earth's surface and its vegetation cover. Such an all-weather capacity of SAR system makes them the remote sensing systems of choice in humid tropical zones and for monitoring of natural disasters when frequent coverage is necessary. For example, in Zaire or parts of Indonesia (e.g. Kalimantan) it may take several years before a good quality satellite optical image is recorded because of persistent cloud cover.

There was yet another technical innovation that profoundly changed the methodology of land cover mapping. It was the development of land cover classification system (LCCS) during implementation of the FAO Africover project in the second half of 1990s. It has introduced an entirely new concept of land cover classification based on diagnostic criteria of land cover rather than on land cover classes. This freed the land cover classification from its dependency on specific application and geographic area and made it universally applicable. It also eliminated the problems with differences in land cover class definitions because the diagnostic criteria rather than the classes are defined. Land cover classes compatible with any definitions can be derived from LCCS land cover diagnostic criteria. For this reason, the LCCS is ideally suited to facilitate harmonization of other land cover classification systems, which is becoming increasingly important in order to assure consistency among land cover inputs to global environmental assessment and monitoring systems and other global initiatives.

Development of LCCS was followed by development of a suite of software modules for computer-aided interpretation of land cover from satellite images (GeoVIS, AID and AIMS); land cover database (MADE) that stores a complete set of land cover classes for each country as well as their diagnostic criteria and thus allows formation of new classes at different levels tailored to users requirements; and advanced database gateway (ADG) that enables production of customized land cover products based on reconfiguration of land cover polygons not only by class name (as it is usual in GIS) but also by diagnostic criteria of land cover classes The GLCN suite of software modules is described in section 9.2 and a detailed description of LCCS is in section 10.

In 2002 FAO jointly with UNEP initiated development of Global land Cover Network (GLCN). Its main purpose is to increase the availability of existing land cover data, pursue their harmonization, promote their effective use and assist developing countries with strengthening their capacities for land cover mapping and monitoring. GLCN is coordinated by its Topic Centre, which is being established at the Italian Istituto Agronomico per l'Oltremare in Florence, Italy. The GLCN-TC will develop cooperation with custodians of major land cover databases for implementation of the above tasks.

Considering the increasing need for information on land cover and its changes at a country, regional and global levels, the benefits of land cover mapping based on advanced geo-information technologies of satellite remote sensing, GIS and GPS can hardly be overemphasized. There is no realistic alternative to these technologies for land cover mapping at scales 1:100 000 to 1:250 000.

5. FAO Africover Project

The Food and Agriculture Organization of the United Nations (FAO) initiated the development of the Africover project in the beginning of 1990s in order to increase the availability of reliable land cover information, based on uniform mapping specifications, for the whole continent of Africa. By the end of the 1980s, planning of FAO projects for development and improved management of land and water resources in Africa had become an increasingly difficult task because of lack of reliable information on current land cover and land use. In particular, the FAO Food Security Early Warning System, the Nile River Basin project, the Lake Chad Basin project, the African Rangelands Assessment and Monitoring project and the Forest Resources Assessment project needed baseline land cover information for realistic planning of their activities.

Design of the Africover project is modular, to allow its implementation either at the sub-regional or a country level. Its original design was based on the following five sub-regional modules:

Naformátováno: Odrážky a číslování

a) East Africa – 12 countries, 9 582 907 km^2 (includes Democratic Republic of Congo);
b) North Africa – 4 countries, 5 017 440 km^2 (excludes Egypt, which is part of the module #1);
c) Sahelian – 9 countries, 5 307 820 km^2 (includes Cape Verde);
d) West and Central Africa – 15 countries, 5 066 955 km^2 (includes Sao Tome & Principe);
e) Southern Africa – 13 countries, 5 350 747 km^2 (includes the Indian Ocean countries Madagascar, Mauritius, Comoros and Seychelles).

The Government of Italy funded the implementation of the Africover East African module (Africover-EA), which started in 1997 and was completed in 2004. Although the Africover-EA module originally included 12 countries with a total area 9.6 million km^2, the following ten countries with a total area 8.5 million km^2 decided to participate in its implementation: Burundi, Democratic Republic of Congo, Egypt, Eritrea, Kenya, Rwanda, Somalia, Sudan, Tanzania and Uganda. Total cost was 9.6 million Euros, or 1.13 Euro per 1 km^2.

The Africover-EA project was initially hosted by the Regional Centre for Mapping of Resources for Development (RCMRD) in Nairobi, Kenya, which was its regional counterpart organization. The RCMRD became custodian of regional land cover database developed by the project after its completion. Participating East African countries appointed the Africover National Coordinators in order to assure a close link with the project. At the regular meetings organized by the project, they obtained briefings on its progress and exchanged experience with its implementation related to their respective countries. The project also established a training facility at RCMRD for training national technical officers in its innovative software modules for land cover classification, interpretation and mapping, including the Land Cover Classification System, interpretation of satellite images and field validation of interpretation results. Upon project completion, each country participating in its implementation received a complete digital land cover dataset of its national territory.

While negotiations regarding the implementation of other sub-regional modules are on-going, it soon became obvious that some prospective sponsors preferred a more flexible approach, allowing them to select a country or group of countries according to their priorities and available budget. Revised concept of the Africover project implementation accommodates this requirement and allows the project implementation at a country level as long as the Africover concept and technical specifications are followed. FAO prepared a templet project document for implementation of the Africover project at a country level.

Five Africover scenarios were developed for project implementation at a country level. They differ according to the level of country involvement:

a) Project inputs by GLCN Africover staff are limited to training in the Africover specifications and software modules for land cover classification interpretation and mapping. Implementation of all project activities is done by the country;
b) GLCN Africover staff selects the satellite imagery, supervises its geometric rectification and enhancement and provides training as in (a). Remaining project activities are implemented by the country;
c) GLCN Africover international consultant provides training and supervises the implementation of all project activities in the country;
d) As above with the exception of development of GIS database. That task is contracted by GLCN to an international company;
e) International company implements the whole project according to Africover specifications. GLCN certifies that the specifications were sustained and the Africover label can be used for the project products.

It is expected that the majority of countries will adopt the scenario (c), in which the international consultant supervises the project implementation. Only the Republic of South Africa will likely select the scenario (a) for its proposed updating of the "South African National Land Cover (NLC) Database" project. This project provides a standardized, baseline inventory of LCLU at 1:200 000 scale for the whole of South Africa, including Swaziland and Lesotho, based on Landsat-TM imagery recorded in 1994-95. It is expected that the proposed follow-up project, is based on Africover methodology.

Projects implemented at a country level, regardless under which scenario, will obtain the Africover certification only after it is assured that their land cover products comply with the Africover specifications. This policy will assure the homogeneity of the Africover database for the whole continent of Africa and uniformity of its land cover mapping products in terms of their thematic content and accuracy.

5.1 Africover Project Objectives

The primary objective of the Africover project is to provide reliable land cover information, based on systematic and harmonized land cover classification system and uniform mapping specifications, for the whole continent of Africa. Such information is lacking in Africa and yet it is urgently needed for planning and implementation of sustainable development and management of natural resources and environmental protection.

5.1.1 Overall Objective of the Africover Project East African Module (Africover-EA)

Overall objective of the Africover-EA project was to improve the availability of reliable, timely and location-specific land cover information in ten East African countries covering an area of 8.5 million km^2. The reliable and timely land cover information is an essential input to food security early warning systems, sustainable management of natural resources, agro-ecological zoning and land use planning, environmental protection and rehabilitation, climate change assessment and international humanitarian and development projects.

Odstraněno: twelve

Odstraněno: 5

5.1.2 Specific Objectives of the Africover–EA Project

Naformátováno: Odrážky a číslování

Naformátováno: Odrážky a číslování

a) Development of technical specifications and methodology for land cover mapping of Africa compatible with scales 1:100 000 to 1:250 000;

b) Provision of reliable land cover information for ten participating East African countries, based on Landsat TM/ETM images and Africover methodology for land cover interpretation, classification and mapping;

c) Field validation and accuracy assessment of land cover products;

Naformátováno: Odrážky a číslování

d) Development of land cover digital database, referenced to uniform geodetic datum, cartographic projection and co-ordinate system for participating East African countries;

e) Development of Africover-EA meta-database and Internet website;

f) Strengthening the land cover mapping and monitoring capacities of participating African regional and national organizations, based on remote sensing, GIS and GPS geoinformation technologies and Africover innovative suite of software modules.

Naformátováno: Odrážky a číslování

5.2 Concept of Africover Project Implementation

Many international land cover mapping projects in developing countries prioritize the tools rather than the product. They establish GIS laboratories and provide training but produce only limited new datasets. The new facilities are often underutilized after the project termination. Building the land cover mapping and monitoring capacities in developing countries is necessary, but without assuring that they are utilized, it is a waste of effort and funding.

The main product of the Africover project is reliable information on the current status of land cover in each country. The information is in the form of digital land cover database from which land cover maps can be produced according to users' specifications at scales ranging from 1:100 000 to 1:250 000. In addition, the project outputs include the methodologies and facilities for land cover mapping, such as the suite of innovative software modules for land cover interpretation, classification, database development and mapping; trained national personnel in their operational applications; and strengthened land cover mapping capacities of regional and national organizations that participated in project implementation. The last two outputs are important for keeping the newly established land cover database updated and allowing the implementation of project follow-on activities, such as the land cover mapping at larger scales in selected areas.

The implementation of Africover-EA project was based on close cooperation with the relevant African regional and national organizations. Furthermore, two International Working Groups were established by the project to assure that its methodology was scientifically sound and subjected to international review:

- Africover International Working Group on Geodesy and Cartography;
- Africover International Working Group on Land Cover Classification and Map Legend.

The Africover Working Groups were involved in its preparatory activities, including the specification of land cover information requirements (land cover classes, classification accuracy and mapping scales); geodetic and cartographic specifications (geodetic reference datum, cartographic projection and co-ordinate system) and specifications for field validation of preliminary interpretation results (field validation methodology, sampling design and frequency).

In order to increase the usefulness of Africover products, they have to fulfill the following three criteria:

a) *Accessibility*: the Africover land cover products have to be accessible to all qualified users. Meta-database would be included on the Africover Internet website to facilitate the dissemination of information on the availability of Africover products. They would be distributed at a nominal charge covering only their actual reproduction and handling costs;

b) *Consistency*: production, storage and distribution of Africover land cover products would follow the same specifications in all African countries;

c) *Quality and reliability*: field validation of interpreted land cover classes would assure the thematic accuracy of Africover major land cover classes over 70%.

Implementation of all Africover project modules is guided by the following principles:

- Thematic content of land cover digital database is applicable to such key applications as sustainable land use planning, food security assessment and environmental protection;
- Its geometric accuracy is compatible with requirements of land cover mapping at 1:250 000 scale and related GIS data integration, processing and modeling;
- The main project product is the GIS-based land cover database from which digital and hard copy mapping products can be generated by their end users when required. After project completion, the regional land cover database is maintained by counterpart regional organization (Regional Centre for Mapping of Resources for Development in Africover-EA module) and the country-level databases by national organizations that participated in Africover project implementation;
- Africover meta-database provides description of Africover land cover products and terms of their accessibility. It is included on the Africover Internet website;
- The Africover methodology is user-friendly to facilitate the capacity building for land cover classification, interpretation and mapping in the regional and national organizations in Africa.

5.3 Africover-EA Project Outputs

The following main outputs were produced by the Africover-EA project and handed over to its counterpart organizations:

- ➢ Digital, seamless and geo-referenced land cover database and associated meta-database;
- ➢ Consistent land cover legend compatible with mapping scales 1:100 000 to 1:250 000;
- ➢ Suite of Africover software modules for land cover classification, interpretation and mapping;
- ➢ Archive of satellite images used by the project;
- ➢ Archive of field validation results;
- ➢ Africover-EA training and reference materials;
- ➢ GIS, GPS, image analysis and cartographic equipment (hardware and software);
- ➢ Trained national officers who participated in project implementation;

- ➢ Increased technical capacities for land cover mapping at participating African regional and national organizations;
- ➢ Established links and closer cooperation among participating African organizations.

The AFRICOVER digital land cover database consists of two main components:

- Base map layers;
- Land cover layer.

The base map layers, consisting of cultural features including the national and administrative boundaries, settlements, roads, dams, etc.; hydrographic features; dominant topographic features; coastlines; and geographic names, were compiled from the existing topographic maps. Their updating was based on manual interpretation of Landsat-TM/ETM false-color images displayed on computer monitor. All information selected for inclusion in the basemap layers was edited, digitized, geometrically corrected and transformed into UTM cartographic projection.

The land cover layer was compiled from recent satellite remote sensing images. The Africover-EA project selected the Landsat-TM&ETM multispectral images, with 30m pixel size and 185x170km scene size, as the main data source for land cover mapping. RADARSAT-1 SAR standard or wide mode image products (30m pixel size, 100x100km or 150x150km scene sizes) were used in areas with persistent cloud cover.

5.4 Lessons Learned

The Africover project is an important component of the global effort to establish the reliable databases of natural resources, monitor their changes and forecast their trends. Its East African module provided the venue for developing and testing new innovative methodology for land cover mapping. This methodology, which enables global harmonization of land cover classification, interpretation and mapping procedures, consists of a suite of software programs that define an advanced land cover mapping concept based on universally valid diagnostic attributes of land cover rather than on locally specific land cover classes. Another departure from standard mapping procedures is that the principal output is a digital land cover database and the mapping and modeling products from this database are defined by their end users. The new methodology, developed in the framework of the Africover project, is being accepted as an international standard for land cover mapping by growing number of organizations. . A similar project, based on Africover classification and mapping methodologies is being formulated in Asia (Asiacover).

The magnitude of the Africover project is documented by the following examples. Land cover classification by Africover project in Kenya resulted in 30 000 mapping units (final land cover polygons), representing 100 land cover classes. The land cover pattern of Somalia consists also of 30 000 mapping units, representing 73 land cover classes. The tasks of such magnitude would require much longer time to complete if the LCCS had not been developed.

6. FAO-UNEP Global Land Cover Network (GLCN)

Development of Global Land Cover Network and establishment of GLCN Topic Centre (GLCN-TC) was undertaken jointly by FAO and UNEP. The GLCN development was supported unanimously by participants of the Expert Consultation on Strategies for Land Cover Mapping and Monitoring, which was jointly organized by FAO and UNEP with cooperation of the Government of Italy at Artimino-Florence, Italy, 6-8 May 2002. The GLCN-TC is hosted by the Italian Istituto Agronomico per l'Oltremare in Florence, Italy and funded primarily by the Government of Italy.

GLCN development was based on demands by land use planners, food security officers, land and water resources managers and environmental protection officers in developing countries for reliable, timely and harmonized information on current state of the environment and its changes. Land cover is an objective and early indicator of natural and anthropogenic changes of environmental conditions, such as those caused by climate variability and change, natural disasters and land use. There is an increasing number of land cover mapping and monitoring projects undertaken, yet there is hardly any compatibility among them.

GLCN Topic Centre is establishing links with the existing land cover databases and facilitates their harmonization based on LCCS. It continues development of innovative GLCN methodology for land cover mapping and monitoring based on advanced geo-information technologies and a suite of software packages for land cover classification and image interpretation that was developed in the framework of the Africover project. An important function of GLCN-TC is strengthening the capacities of developing countries and countries with economies in transition for land cover mapping and monitoring.

6.1 GLCN Overall Objective

The overall objective of GLCN is to increase the availability of reliable and harmonized information on land cover and its changes at the global level, with particular emphasis on developing countries. The importance of such information was emphasized at both World Summits on Sustainable Development (Rio de Janeiro 1992 and Johannesburg 2002). Its availability is essential to sustainable development and management of renewable natural resources, environmental protection and mitigation of natural disasters, and thus to the achievement of the United Nations Millennium Development Goals of environmental sustainability, increased food security and reduced rural poverty, particularly in developing countries.

6.2 GLCN Immediate Objectives

a) To provide direction, focus and guidance for harmonization of land cover mapping and monitoring projects at national, regional and global levels in order to achieve compatibility among their products through the promotion of LCCS as the new standard classification system;

b) To establish cooperation and linkages with organizations managing major land cover databases, both in public domain and commercially operated;

c) To develop a global land cover meta-database providing information on the existing land cover databases and characteristics of their datasets, major ongoing land cover projects and related activities;

d) To provide assistance to developing countries with institutional capacity building for land cover mapping and monitoring based on a suite of GLCN software packages: LCCS, GeoVIS, MADE, AID and ADG;

e) To increase benefits from the existing land cover databases, international land cover projects and associated activities to developing countries by facilitating the accessibility of their products and advising on their uses;

f) To continue development of new, advanced land cover mapping and monitoring methodologies and data products, tailored to priority applications such as the increase of food security, reduction of rural poverty, environmental protection, and mitigation of natural disasters;

g) To promote the use of GLCN methodologies for land cover mapping and monitoring at global, regional and country levels.

6.3 GLCN Topic Centre

In order to fulfill the above objectives, the GLCN Topic Centre was established to serve as an international clearinghouse for information on land cover mapping and monitoring projects. It conducts the following four types of activities:

- Normative and methodological, aiming at upgrading and harmonization of land cover mapping and monitoring methodologies and information products at country, regional and global levels. This task includes certification of existing land cover databases for their compliance with GLCN technical specifications. It also includes a continuing development of GLCN methodology based on changing requirements on land cover products by their end users;
- Networking - establishing effective linkages and cooperation with major land cover databases and international, governmental and commercial organizations involved in land cover mapping and monitoring activities. Its main aim is to increase the benefits from regional and global land cover mapping and monitoring

initiatives to developing countries;

- Capacity building in developing countries, including provision of advisory services and organization of training courses on GLCN land cover mapping and monitoring methodology for technical staff and appraisal workshops for decision-makers. Its aim is to strengthen the national capacities for land cover mapping and monitoring in developing countries;
- Serving as the international clearinghouse for information related to land cover mapping and monitoring activities. This task involves development and management of GLCN meta-database providing information on major land cover mapping and monitoring projects.

In order to coordinate its activities with related international initiatives, the GLCN Topic Centre established a close cooperation with the following global Earth observation programs: the Global Terrestrial Earth Observing System (GTOS), the Integrated Global Observing Strategy (IGOS), and the Global Earth Observing System of Systems (GEOSS). Their descriptions are in sections 7.1, 7.2, and 7.3.

6.4 GLCN Core Components

Schematic flowchart of the configuration of GLCN linkages and feedbacks is in Figure 1. The operation of GLCN Topic Centre is built upon three core components:

- GLCN global land cover meta-database
- Methodological development
- Capacity building in developing countries

The GLCN global land cover meta-database serves as a gateway to land cover databases managed by international organizations (databases at global and regional levels), governmental organizations (national level databases) and commercial organizations (special interest areas). It only links with the databases certified by the GLCN Topic Centre for their compliance with GLCN specifications. In particular, their land cover classes should have unambiguous definitions to allow their translation into the GLCN Land Cover Classification System that provides a common reference to global land cover classifications, be geo-referenced, and their classification accuracy validated.

Methodological development is based on feedbacks from end-users of land cover products, new developments in geo-information technologies, and “best practices” learned during implementation of the Africover and other major land cover mapping and monitoring projects. The information requirements by end-users of land cover products determine their types and formats. In many cases, the development of land cover products involves integration of land cover data with other types of geospatial data (e.g. with digital terrain model data for assessment of land cover dynamics in watersheds) and, increasingly, with socio-economic data (e.g. with data on population, poverty levels, production of staple food crops per person, etc.).

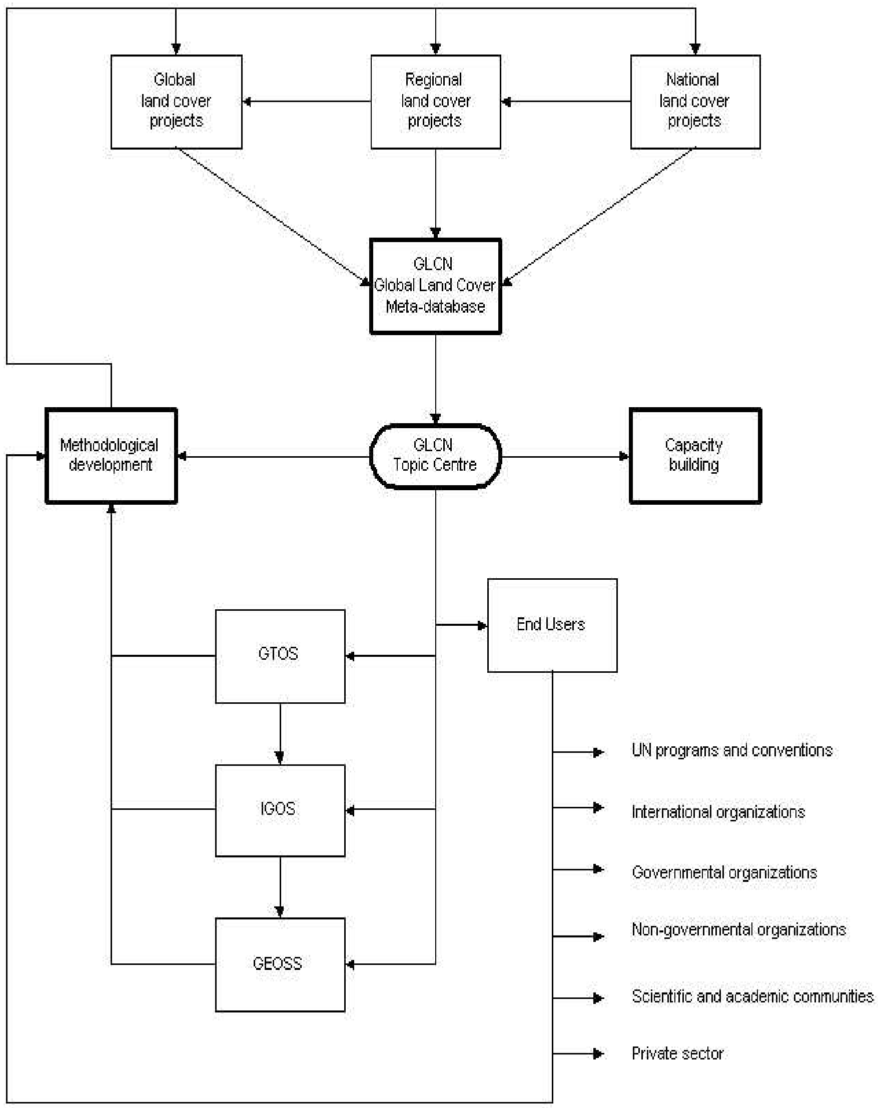

Figure 1. Configuration of GLCN-TC linkages and feedbacks

Capacity building for land cover mapping and monitoring is focused on developing countries and countries with economies in transition. The capacity building activities include the provision of advisory services, organization of training courses for technical staff (e.g. Land Cover Classification System, on-screen interactive image interpretation, field validation of land cover interpretation, database management), appraisal workshops for decision-makers, and implementation of pilot studies.

There are six main groups of end-users of GLCN land cover products. They include the United Nations programs, conventions and treaties; international organizations; governmental organizations; non-governmental organizations; scientific and academic communities; and private sector. Their feedback is important for further development of GLCN methodology, to assure that the GLCN land cover-based products reflect the information needs of their users.

6.5 GLCN Critical Tasks

The GLCN tasks, which are critical to its success and therefore their implementation requires particular attention and close monitoring, include the following ones:

a) Establishing the links between GLCN Topic Centre and the end-users of land cover-based geo-information products. Feedback from end-users of these products and understanding of their information requirements are essential prerequisites to further improvement of GLCN methodology and usefulness of GLCN products.

b) Strengthening the national capacities for land cover mapping and monitoring in developing countries and countries with economies in transition.

c) Inventory of existing land cover databases at global, regional and country levels. Assessment of their datasets characteristics, in particular the procedures used for land cover classification, definitions of land cover classes, field validation of image interpretation results, and quality assessment.

d) Negotiating access to existing major land cover databases managed by international and national organizations.

e) Harmonization of land cover datasets of the existing databases, which usually involves the translation of land cover classification into LCCS and re-assessment of data quality.

f) Development of new types of information products for sustainable management of renewable natural resources, based on integration of land cover data with other geospatial data, such as topographic, soils, climatic, etc., and with socio-economic data, such as population, poverty, food security, etc.

7. GLCN Links with International Earth Observation Initiatives

GLCN has become a global clearinghouse for harmonized information on land cover and its changes, and the focal point for provision of assistance to strengthen the capacities for land cover mapping and monitoring of the developing countries and countries with economies in transition. For the fulfillment of these tasks, it is closely cooperating with major international initiatives for Earth observation, mapping and monitoring. The GLCN provides the links to major land cover databases that were certified to comply with GLCN specifications.

The international scientific community established the following programs for sustained and consistent observation and change monitoring of the Earth's land surface: the Global Terrestrial Observing System (GTOS), the Integrated Global Observing Strategy (IGOS) and, the most recently, in 2003/2004, the Global Earth Observation System of Systems (GEOSS). The GLCN is becoming the land cover mapping and monitoring component of these global Earth observation programs. Furthermore, the modalities of GLCN participation in the cross-cutting themes of these programs, such as the capacity building, harmonization of environmental observations and data products, and development of models for the assessment of impacts and prediction of trends, are being considered at present (end 2004).

7.1 Global Terrestrial Observing System (GTOS)

The Global Terrestrial Observing System (GTOS) is one of three major global monitoring systems established in mid-1990s as a follow-up to the Earth Summit. The other two systems, complementary to GTOS, are the Global Ocean Observing System (GOOS) and Global Climate Observing System (GCOS). All three systems are interlinked. Close coordination of their implementation is an essential requirement for the achievement of their objectives. GTOS was established in response to a growing need for a systematic, long term monitoring of changes in the natural and managed ecosystems at a global level. Its Scientific Secretariat is hosted by FAO. GTOS plan of operation includes a global network of some 100 field sites and transects, covering all the major terrestrial ecosystems. Its hierarchy of observational levels includes the Earth observation satellites, aerial platforms and surface-based systems. Satellite observations play a vital role in the following three areas:

(a) Monitoring changes in land cover and land use over large areas;
(b) Extrapolating local observations from GTOS field sites to larger areas;
(c) Ensuring a consistent set of measurements worldwide.

The GTOS data management is based on distributed concept and implemented at three levels: (i) the field sites (national level); (ii) the regional and thematic centers; and (iii) the global coordinating centre, managing the GTOS meta-database. An important characteristic of GTOS concept is its 2-way information flow: from the national field sites to regional and global databases, as well as the feedback to national sites in order to provide a wider context for analysis of local measurements. Global harmonization of GTOS measurements and data management at all three levels are high priority requirements.

7.2 Integrated Global Observing Strategy (IGOS)

The Integrated Global Observing Strategy (IGOS) was initiated by the Committee on Earth Observation Satellites (CEOS) and international organizations involved in global Earth observations at the first IGOS Workshop in Seattle, USA, in March 1996. In 1998, thirteen international organizations involved in environmental observations established the IGOS Partnership (IGOS-P). At present (end 2004), it consists of fourteen international organizations. The IGOS-P focuses on the improvement of the Earth observations in order to produce better environmental information for decision-making. Its implementation strategy involves identification of specific application themes, formation of partnerships among international organizations involved in observation activities related to selected themes, harmonization of their methodologies and integration of satellite-based and *in situ* observations for development of more effective environmental information products.

Of particular interest to GLCN is a proposed new IGOS-P Theme, the Integrated Global Observations of the Land (IGOL). Fundamental to this theme is the characterization, monitoring and understanding of land cover and land use change and their drivers. When IGOL is approved, it provides a basis for cooperation between IGOS-P-IGOL and GLCN-TC.

In addition to AGOL, there are two IGOS-P cross-cutting Themes, which are also of interest to GLCN-TC and provide basis for collaboration: Data Integration and Capacity Building. These two Themes are already being implemented. Regarding the Capacity Building Theme, it plans to develop a comprehensive capacity-building methodology. Its development would benefit from GLCN experience in capacity building for land cover mapping in East Africa.

7.3 Global Earth Observation System of Systems (GEOSS)

Development of a comprehensive, coordinated and sustained Global Earth Observing System of Systems (GEOSS), based on existing programs and projects, is one of the most important Earth observation initiatives aiming to increase its efficiency and effectiveness. The GEOSS initiative has its origins at the 2003 G8 Summit, which took place in Evian, France. One of the results of this Summit was the G8 Action Plan "Science and Technology for Sustainable Development". The G8 Action Plan focused its priorities on the following three areas:

- Coordination of global observation strategies;
- Cleaner, sustainable and more efficient energy use;

- Agricultural sustainability, productivity and biodiversity conservation.

For the fulfillment of the first priority task, the G8 Action Plan set up the following goals:

- Develop close co-ordination of our respective global observation strategies for the next ten years; identify new observations to minimize data gaps;
- Build on existing work to produce reliable data products on atmosphere, land, fresh water, oceans and ecosystems;
- Improve the world-wide reporting and archiving of these data and fill observational gaps of coverage in existing systems;
- Favor interoperability with reciprocal data-sharing;
- Develop an implementation plan to achieve these objectives by next spring's Tokyo ministerial conference (the Second Earth Observation Summit).

In July 2003, the First Earth Observation Summit was held in Washington, D.C., U.S.A. Its participants, representing 34 countries, the European Union and 25 international organizations acknowledged the G8 decision to strengthen international cooperation on global observation and recommended the development of a comprehensive, coordinated and sustained Earth Observation System, built upon existing systems. At the Second Earth Observation Summit, which was held in April 2004 in Tokyo, Japan, 49 countries, the European Union and 29 international organizations adopted the Framework Document for a Global Earth Observation System of Systems (GEOSS). Its 10-Year Implementation Plan is expected to be adopted at the Third Earth Observation Summit to be hosted by the European Commission in Brussels, in February 2005. GEOSS will link the existing Earth observation systems in order to increase the effectiveness and efficiency of systematic, long-term Earth observation, to eliminate the observation redundancies and to minimize the observation gaps. Its overall objective is to translate the observations into tangible environmental and societal benefits, including those benefiting developing countries.

8. Geo-information Technologies for Land Cover Mapping and Monitoring

New geo-information technologies introduced in the second half of last century have fundamentally changed methodologies for mapping and monitoring of the Earth. Development of powerful computers capable of processing and storing vast amounts of digital data, coupled with deployment of Earth observation and positioning satellites continually recording the Earth's surface and allowing fast determination of correct positions, have provided opportunities for more effective mapping and monitoring of large areas regardless of their accessibility. In particular, these developments enable, for the first time, mapping of land cover from the original, rather than derived, data and continuous monitoring of its changes at regional and global scales.

Geo-information technologies used for land cover mapping and monitoring include: remote sensing from Earth observation satellites, geographic information systems, and global positioning systems. These technologies have become indispensable components of development strategies for sustainable management of land and water resources and environmental protection. GLCN Topic Centre is following new developments in geo-information technologies, testing their usefulness for implementation of GLCN mapping and monitoring projects and incorporating them into GLCN methodology when appropriate.

8.1 Remote Sensing from Earth Observation Satellites

Images of the earth's surface, continually recorded by Earth's observation satellites with optical and microwave remote sensing systems, have enabled better understanding of land cover patterns and their associations over large areas. In particular, they have increased the effectiveness and efficiency of mapping land cover, monitoring its changes, and assessing the impacts of land use and natural disasters. Satellite remote sensing is the only geospatial data source, which can economically provide the repetitive coverage of the Earth's surface at regional and global levels.

Number of Earth observation satellites and the capacities of sensors in their remote sensing payloads have been growing. The United States, France, Russia, India, Japan, Canada and the European Space Agency have been operating long-term Earth observation programs for civilian applications. Several other countries have launched Earth observation satellites in recent years, for example the Chinese-Brazilian Earth resources satellite series CBERS (CBERS-1A in 1999 and CBERS-1B in 2003), but these are either experimental programs or the availability of their data is limited.

The first civilian Earth observation satellite, the Landsat 1, was launched in July 1972. While the meteorological applications of satellite remote sensing started about a decade earlier, it was the success of Landsat program that provided the basis for mapping, assessment and monitoring of land cover from images of the Earth's surface recorded by satellite remote sensing systems. The near-continuous sets of Landsat Multi-Spectral Scanner (MSS) images with 80 m spatial resolution and Landsat Thematic Mapper (TM) images with 30 m spatial resolution in the visible and near infrared spectral bands have been available since 1972 and 1982 respectively. They enable assessment of land cover changes that have occurred since 1972.

There are two Landsat satellites in operation at present (November 2004): Landsat 5, launched in March 1984, well passed its projected operational life and Landsat 7 with the Enhanced Thematic Mapper Plus (ETM+) remote sensing system, which was launched in 1999 but suffered the malfunction of its ETM image formatting mechanism in 2003, resulting in gaps of image coverage in each scene. The problem has been solved by filling the image gaps through mosaicking the scenes using image data from several orbits acquired within weeks of each other.

In August 2004, in order to assure the continuity of Earth observations with Landsat-type remote sensing system, the U.S. Government approved its inclusion in the sensors' payload of the planned new generation of the U.S. Earth observation satellites, the National Polar-orbiting Operational Environmental Satellite System (NPOESS). The first NPOESS-Landsat mission is scheduled for 2009. There may be a "bridging" mission with Landsat-type remote sensing system to prevent a gap in Landsat coverage.

The multispectral images recorded by Landsat 5 TM and Landsat 7 ETM remote sensing systems with 30 m spatial resolution in the visible and near infrared spectral bands were the primary input data used by the Africover project for image interpretation and development of land cover database. The combination of their low cost per km^2, 30 m spatial resolution and the availability of multispectral images, have made the Landsat TM and ETM images particularly suitable for land cover mapping at the country-wide, regional and global scales. (Annex 3).

At the end of 1990s, the NASA-led international program called the *Mission to Planet Earth* started to deploy the *Earth Observing System (EOS)* series of satellites for systematic, long-term observation of the Earth's surface and its atmosphere from space. In December 1999 the *Terra satellite*, the flagship of EOS, was launched. Its primary remote sensing system, the *Moderate Resolution Imaging Spectroradiometer (MODIS)* records data of the Earth's surface in 36 spectral bands with spatial resolution ranging from 250 m in two spectral bands (red and near infrared), 500 m in 5 spectral bands, to 1 km in 29 spectral bands. Its sister satellite, the *Aqua satellite*, launched in May 2002, also has the MODIS remote sensing system in its sensor payload.

The MODIS image data recorded in the red and near-infrared spectral bands with 250 m spatial resolution are particularly suitable for continuous monitoring of land cover changes at reconnaissance level over large areas. They also enable generation of vegetation index data, which is an important criterion of vegetation health.

Environmental monitoring based on MODIS images with 250 m ground resolution facilitates the early detection of environmental "hot spots" such as natural disasters sites (forest fires, wind and pests damage, floods, etc.), agricultural drought, illegal deforestation, land degradation, air pollution/acid rain vegetation damage, water pollution in rivers, lakes and coastal areas, etc. The follow-up assessment of identified “hot spots” should be based on high resolution image data (Annex 3).

8.2 Geographic Information Systems (GIS)

Geographic information systems (GIS) facilitate harmonization of geospatial data from diverse sources, their referencing to GLCN geodetic datum and coordinate system, integration of land cover data with other types of geospatial data in GIS database, their combined analysis and production of cartographic, statistical and modeling products. In particular, they enable transformation of the input geospatial data into information required by end-users.

Integration of geographically referenced land cover data with other geospatial data, such as topographic, pedologic, hydrographic, climatic, land use, land degradation and others in GIS database, and their joint analysis, result in the increase of quantity and quality of derived information. Some GIS software packages provide a mathematical modeling capacity for forecasting, such as the agricultural drought forecasting, environmental impact assessment of planned construction projects, etc. They also enable the analysis of trends, such as trends in land use changes, land degradation or deforestation. Thus, GIS facilitate the transformation of data into information, knowledge and, ultimately, decisions.

In recent years, the geographic information systems greatly enhanced their effectiveness and user-friendliness. However, it should be remembered that the usefulness and impact of GIS processing depend on the availability and quality of input data. Even the most sophisticated GIS are useless if no reliable input data are available. The main limits of GIS in developing countries are the scarcity of suitable input data and expertise of GIS operators, rather that the capacity of GIS hardware and software. That is why GLCN Topic Centre aims to support capacity building for land cover mapping and monitoring in developing countries and increase the availability and quality of land cover data through linkages with major land cover projects and harmonization of their land cover products.

An important part of GIS, its core, is its database where all geospatial data are archived, validated, referenced to common geodetic datum, integrated, linked to attribute data and managed by database management system (DBMS) to be useful. The DBMS supports the combined analysis of geospatial data in either vector or raster formats and socio-economic data related to food security, rural employment, poverty, health, demographic age distribution, etc., which are usually available in tabular format. Joint processing of these two discrete types of data is needed for modeling of land use trends, forecasts of food security and fresh water supplies, planning of sustainable development and biodiversity protection.

GIS database design has to be compatible with land cover information products specified by their end-users. At the country level, the primary end-users are the land use planners and managers responsible for sustainable management of renewable natural resources and environmental protection. At the regional and global levels, the primary end-users are the managers and scientists involved in implementation of international treaties, such as the Millennium Development Goals, Agenda 21, United Nations Framework Convention on Climate Change and its Kyoto Protocol on Climate Change, United Nations Convention to Combat Desertification, United Nations Convention on Biological Diversity, and United Nations Forest Forum.

The database design also includes a definition of geodetic framework to which all spatial datasets are transformed. It consists of geodetic datum (dimensions of reference ellipsoid, origin and orientation of the coordinate system), cartographic projection, and specifications for data accuracy and size of the minimum mapping unit (MMU). The MMU defines the smallest area that is stored in the database as a separate entity. Any polygon having smaller area than the MMU would be aggregated. The concept of MMU is only related to vector-based GIS databases. In the raster-based GIS database, the smallest raster cell becomes *de facto* the MMU. The GLCN specifications for geodetic framework are in chapter 9.

The accessibility to land cover databases vary, with some being freely available on the Internet while others, usually the country-level ones, restrict the access to users approved by owners of these databases. The GLCN meta-database, which provides inventory of major national and international land cover databases and describes the types and characteristics of their datasets and the terms of their accessibility, is freely accessible on the Internet.

8.3 Global Positioning Systems (GPS)

The satellite-based GPS hand-held receivers are increasingly used for quick determination of accurate geographic locations. They have become the standard equipment for field surveys and are particularly useful in areas lacking good quality maps. For example, they greatly facilitated the field land cover validation surveys in East Africa for the Africover project by allowing accurate positioning of validation sites.

At present (2004), there is only one global positioning system fully operational: the United States NAVSTAR GPS. The Russian system GLONASS operates in degraded mode with just few of its original 21 satellites still active. Its next generation, the GLONASS-M, is being developed. The European Union (EU) and the European Space Agency (ESA) are developing the European GPS, Galileo, which will be based on 30 satellites orbiting at an average altitude of 23,200 km. The Galileo system will become operational in 2008. In June 2004 the EU and USA signed an agreement that assures the full compatibility and interoperability between Galileo GPS and NAVSTAR GPS. As a result, the same GPS receivers will be able to receive the satellite signals from both systems, thus increasing the reliability of GPS positioning. Japan and China are also considering development of their own global positioning systems.

The NAVSTAR GPS consists of 24 active satellites and 4 spares orbiting at an average altitude of 20,200 km. The first NAVSTAR GPS satellite was launched in 1978. The semi-operational use of GPS started in the mid-1980s but the system became fully operational only in 1993 when all 24 satellites were in orbit. Reception of time signals from four satellites is needed for accurate determination of coordinates. Since at least four satellites are continuously overhead, GPS hand-held receivers enable determination of coordinates, even in the most remote locations, with horizontal and vertical accuracies in the range of 10 m–20 m, within few minutes of operation. The coordinates are referenced to the World Geodetic System datum of 1984 (WGS 84), with the option to choose among a suite of prerecorded local datums. It is also possible to reference the coordinates to user-specified mapping datum. The accuracy of coordinates determination can be increased to about 1 m by the use of differential technique, when two GPS receivers are used simultaneously. One of them, the "mother station" is on fixed location with known coordinates, while the other one, the "rowing station" is used for precise determination of coordinates in new location.

Continuity of GPS operation and further improvement of NAVSTAR GPS will be provided by a new generation of satellites, which deployment has already started. The new system will become fully operational in 2010, when all 24 new satellites are in orbit.

9. GLCN Land Cover Mapping Methodology

GLCN land cover mapping methodology has been developed and tested in the course of implementation of the FAO Africover project. This project was a trailblazer in the application of advanced geo-information technologies, the satellite remote sensing, geographic information systems (GIS) and global positioning systems (GPS) to land cover mapping at 1:200 000 scale of an area over 8.5 million km^2 in East Africa. The suite of innovative software programs for land cover classification, computer-aided interactive image interpretation and digital mapping, developed by the project, has established a new paradigm for land cover mapping and created a considerable attention worldwide. The GLCN land cover mapping methodology, which is based on these developments, provides enabling tools for more effective and efficient land cover mapping at global, regional and country levels. Another FAO regional land cover mapping project, similar to the Africover project, and based on the same methodology, is being formulated in Asia: the Asiacover. A schematic flowchart of GLCN land cover mapping methodology is in Figure 2.

9.1 Basic Principles of GLCN Land Cover Mapping Methodology

Development of GLCN land cover mapping methodology has been guided by the following principles:

- *Land cover provides a geographic reference to other geospatial data.*

  Land cover is an explicit geographic feature to which other disciplines can reference their data. GLCN land cover mapping is not a single discipline oriented (forestry, agriculture, surface water bodies and wetlands, etc.), it is application-neutral and thus addresses a multi-user community;

- *Importance of standardization.*

  Standardization has become an essential requirement for effective integration of data from diverse sources, to support multi-user applications of land cover information products and compare land cover assessments produced by different projects. The standardization of GLCN land cover mapping is based on innovative Land Cover Classification System (LCCS);

- *User-friendliness.*

  Users' information requirements determine the type of GLCN land cover products and specifications for their development. The GLCN mapping methodology is designed to maximize the users' involvement in products development;

- *Users form the land cover classes and map legends.*

  The users form themselves the land cover classes through a selection of classifiers best suited for their applications, develop map legends and produce the land cover

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maps according to their specifications. The GLCN land cover mapping methodology is the only one that provides users with such a flexibility;

- *GLCN database is the primary land cover mapping output.*

  The main GLCN land cover mapping outputs are the geo-referenced land cover database and associated meta-database rather than a paper map;

- *Accessibility of GLCN land cover data.*

  The GLCN meta-database provides the link between GLCN database and general public. The meta-database is included on GLCN Internet website to facilitate the dissemination of information on the type and availability of GLCN land cover data products;

Odstraněno: for land cover infomation produced by the AFRICOVproject

- *Quality of GLCN land cover data.*

  All data have to be validated and labeled before their inclusion in the GLCN database. The validation is based on field identification of land cover classes in field validation sites;

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- *Consistency of GLCN land cover data.*

  Production, storage and distribution of GLCN land cover products follow the same specifications worldwide, regardless of their application.

9.2 GLCN Suite of Software Modules for Land Cover Mapping

GLCN land cover mapping methodology is based on a suite of integrated software modules for land cover classification, image interpretation and development of geographically referenced digital land cover database (Figure 2):

- Land cover classification is based on the innovative GLCN *Land Cover Classification System (LCCS)*, which is being adopted as the international standard for land cover classification. The LCCS introduced a radically new approach to land cover classification, which enhanced its compatibility with the information requirements by global environmental initiatives and multi-user applications. It was developed in the framework of the FAO Africover project and provided the basis for development of the advanced land cover mapping methodology and GLCN.

- Computer-aided interpretation of land cover polygons from remote sensing imagery is based primarily on *GeoVIS interactive image interpretation system*, which is linked with *LCCS* and the *Advanced Interactive Database (AID)* that guides and homogenizes the interpretation process. The *GeoVIS*, which is vector-based, is also linked with pixel-based *Advanced Interpretation and Mapping System (AIMs).* Its use is being phased out since the new version of *GeoVIS* software also includes the pixel-based image analysis capacity but its operation is simpler;

- The heart of GLCN land cover mapping methodology is the *Multipurpose Advanced Database for Environmental information (MADE).* It contains a complete set of interpreted, geo-referenced and validated land cover polygons with their associated LCCS classifiers providing a systematic description of land cover characteristics. It also contains standard cartographic datasets, such as coordinate grid, cultural and hydrographic features, coastlines and shorelines, political boundaries, geographic names, etc. The *MADE* is linked with the *Advanced Database Gateway (ADG),* which allows the end-users to selectively recombine land cover polygons and create customized land cover products. It is also linked with *meta-database*, which provides description of land cover and other datasets stored in *MADE*.

9.2.1 GLCN Land Cover Classification System (LCCS)

Detailed technical description of LCCS is in Chapter 10. The LCCS has adopted an innovative approach to land cover classification: instead of top-down approach starting with land cover classes, it describes their characteristics, the classifiers, which uniquely identify the classes. This novel approach facilitates the multipurpose land cover classification: while the class names are application-related, the classifiers are application-neutral, supporting any application. One of the main benefits of LCCS is that end-users can form themselves the land cover classes best suited to their respective applications. The LCCS is compatible with all types of land cover classes, regardless of their application, geographic location or ecological zone.

The LCCS has not only significantly increased the effectiveness and efficiency of land cover mapping, it also provides the basis for its standardization. Despite the large number of land cover classification systems in use, none has been internationally accepted as a standard because they do not fulfill the above requirements needed for multipurpose worldwide applicability. The LCCS is the only universally applicable system in operational use at present. It enables a comparison of land cover classes regardless of data source, economic sector or country. It also allows a translation of land cover classes from other classification systems into the LCCS classes. These features are important for reliable assessment of land cover changes and for modeling of future trends.

The second version of LCCS, the LCCS 2, was recently released (end 2004). It has a number of improvements, which have further strengthened its power, effectiveness, consistency and user-friendliness. They include a change of the programming language, strengthened integration with other GLCN software modules, enhancement of software functionality and modification of the glossary (section 10.6).

9.2.2 GeoVIS Interactive Image Interpretation System

GeoVIS is a vector-based GIS module for on-screen interactive visual interpretation of remote sensing images displayed on computer monitor. Its functionality includes raster data management, vector drawing and editing including topological functions, the LCCS and AID links and specification of the minimum mappable area (MMA) for each of the eight major dichotomous land cover classes.

Raster data management provides the flexibility of importing either the multispectral image data of the full remote sensing scene (e.g. the Landsat scene 170 km x 185 km) or only of its part corresponding to the area specified by the user. Image color composites of the ground area are formed and displayed on-the-fly from the multispectral image data imported by spectral bands. GeoVIS also employs a data compression technique that allows rapid display of large images at varying scales.

GeoVIS online link with LCCS module facilitates and speeds up the classification process and its integration with delineation of land cover polygons. The link with the Advanced Interactive Database (AID) facilitates harmonization of interpretation by different interpreters and increases its consistency through display of standardized examples corresponding to interpreted land cover classes and their features.

GeoVIS has greatly contributed to simplification of image interpretation process while raising its accuracy and consistency.

9.2.3 Advanced Interactive Database (AID)

AID is an interactive software module developed to guide interpreters and homogenize land cover interpretation. Ground photographs of land cover classes and associated brief description of their characteristics are organized in a logical and systematic way and displayed on computer screen together with remote sensing image that is being interpreted. They provide a ready reference and assist the interpreters during delineation and identification of land cover classes and their characteristics. There is a link to other ancillary data that may be needed for land cover interpretation. The possibility of interactive comparison of spectral and spatial image signatures of selected land cover polygons with reference examples of corresponding land cover types and their characteristics stored in AID has contributed to significant improvement of image interpretation results. It has increased their consistency because of reduction of discrepancies among different interpreters.

The main benefits of the AID module are realized through its integration with the GeoVIS module. These two integrated modules represent a new advanced approach to computer-aided interpretation of land cover from remote sensing images.

9.2.4 Advanced Interpretation and Mapping System (AIMS)

AIMS is the extension of a pixel-based digital image analysis system. Although it has been upgraded with some vector functionality it still remains principally a raster-based system. It enables an interactive use of ancillary data through their display, together with satellite image, in geographically linked windows. The main advantage of AIMS is that it enables fast analysis of optical (visible and near-infrared spectral bands) and microwave (synthetic aperture radar - SAR) satellite images. Drawing of polygons and lines are done in a seamless way.

The AIMS is particularly useful when the vector-based land cover data layer is being merged with other geospatial data in raster format or for joint analysis of optical and SAR remote sensing image data. The latter case often arises in humid tropics areas because the SAR systems record clear images of the Earth's surface even through heavy clouds while it may take a year or more before a good quality optical image is acquired.

The major limitation of AIMS is its limited GIS vector-based functionality. Since the GeoVIS vector-based on-screen delineation and interpretation of land cover polygons is simpler, better integrated with GIS processing and GLCN database, the use of AIMS is being phased out. Its future tasks will be limited to specialized image analysis tasks, particularly those involving the SAR images, as mentioned above.

9.2.5 Multipurpose Advanced Database for Environmental Information (MADE)

MADE is the core of GLCN decision support system. It allows the integration of land cover data with other related data, their joint processing according to users' specifications and production of land cover maps, assessment of land cover changes and forecasting of trends. (Figure 2). MADE consists of two interlinked components: datasets and database management system (DBMS). The DBMS provides rules for storage, organization and retrieval of data. It also controls the security and integrity of the database. The security function prevents unauthorized users from viewing or manipulating the database layers.

The ESRI shapefiles were selected as GIS format for MADE datasets. It is an international GIS format, which can be viewed directly in most GIS software packages. The shapefiles are also used by GeoVIS as its data format. The semi-standardized structured query language (SQL) is used for MADE management.

Five types of datasets (database layers) are stored with the same structure, format and geo-reference framework in MADE:

- Basemap layer;
- Land cover layer;
- Satellite imagery layer;
- Field validation data layer;
- Collateral data layer.

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The base map layer consists of the cultural (man-made) features including the settlements, roads, dams, etc.; political and administrative boundaries; coastlines and shorelines; hydrographic features; dominant topographic features; and geographic names, are compiled from the existing topographic maps. All information selected for inclusion in the basemap layer is edited, digitized, geometrically corrected and transformed into UTM cartographic projection.

The land cover layer is compiled from GeoVIS-based interpretation of the most recent satellite multispectral digital images that meet the quality and cloud cover requirements. It contains the output of GeoVIS final (the second round) interpretation (Figure 2). Required ground resolution of remote sensing multispectral imagery compatible with land cover mapping at a scales of 1:200 000/1:250 000 is 50 m, which corresponds to 0.20mm/0.25mm at image scale. The size of digital image pixel footprint corresponding to ground resolution of 50 m is about 35m. Spatial resolution of multispectral image products from several EO satellites (Landsat TM & ETM, SPOT and IRS) fulfills this requirement. The Africover-EA project selected the Landsat-TM&ETM multispectral digital image products, with 30m pixel size and 185x170km scene size, as the primary source of optical remote sensing data for land cover mapping. The selection was based on their availability and cost. There is some uncertainty about their availability until 2009/2010 when the next satellite with Landsat-type sensors is launched by NASA. The RADARSAT-1 SAR standard or wide mode microwave image products (30m pixel size, 100x100km or 150x150km scene sizes) are suitable for areas with persistent cloud cover. However, the interpretation of land cover from SAR microwave images requires different interpretation skills.

The satellite imagery layer contains the set of remote sensing image data used for interpretation of land cover and associated data file identifying the type of satellite (in most cases Landsat TM or ETM), date of image acquisition, UTM coordinates zone, Worldwide Reference System (WRS) location of satellite scenes (their path and row numbers), format of satellite scenes (Tif for Landsat scenes)) and selected spectral bands (4, 3 & 2 for Landsat TM and ETM imagery) used for creation of color composites.

The field validation data layer contains the coordinates and description of field validation sites, information from field validation forms and digitized ground photographs of land cover in validation sites. This layer is composed of four types of files: digitized ground photographs, general information, land cover information and other relevant observations. The general information files identify the observer, site location and its size, date and time of observation, and sites and orientation of ground photographs. They also contain description of landforms in validation sites. The land cover files contain detailed description of land cover characteristics and its seasonal aspects in format compatible with LCCS classifiers. Example of completed field verification form is in Annex 2.

Collateral data layer contains all other available information related to land cover interpretation, such as population density and other demographic data, climate data, environmental indices data (e.g. normalized difference vegetation index), etc.

9.2.6 GLCN Meta-Database

The GLCN meta-database provides the link between MADE and general public. While the access to MADE is restricted to qualified users, the meta-database is included in GLCN Internet web site. It contains a description of datasets stored in MADE and

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information about their geodetic and cartographic referencing, formats, dates of acquisition, quality and the terms of their availability. (Figure 2).

Another important role of GLCN meta-database is to provide information on other major land cover mapping projects undertaken by international or national organizations at global, regional or country-wide scales. The GLCN-TC is becoming an international clearinghouse for information on major land cover initiatives and its meta-database provides a platform for storage, translation when applicable and dissemination of such information. (Figure 1).

9.2.7 Advanced Database Gateway (ADG)

The ADG is advanced browsing and interrogation software through which the database can be addressed according to end users requirements. Its main function is to allow an easy and fast recombination of land cover polygons, not only by class name as it is usually done in GIS, but also by classifiers. The end users will thus be able to create their own land cover classes using the selected classifiers and produce land cover maps tailored to their applications.

The ADG basic software functions include “Display”, “Classifiers recombination” and “Setting threshold”:

(a) Display

- Display land cover classes;
- Display land cover classifiers;
- Display land cover classes and classifiers;
- Display coordinates;
- Display number of selected land cover polygons.

(b) Classifiers recombination using arithmetic and logical operators

- Add (+);
- Exclude (-);
- Only if (=);
- Contiguity (>>).

(c) Setting thresholds based either on accuracy or area size

- % threshold for accuracy (for example, 75%);
- Hectares threshold for area size (for example, 10 hectares).

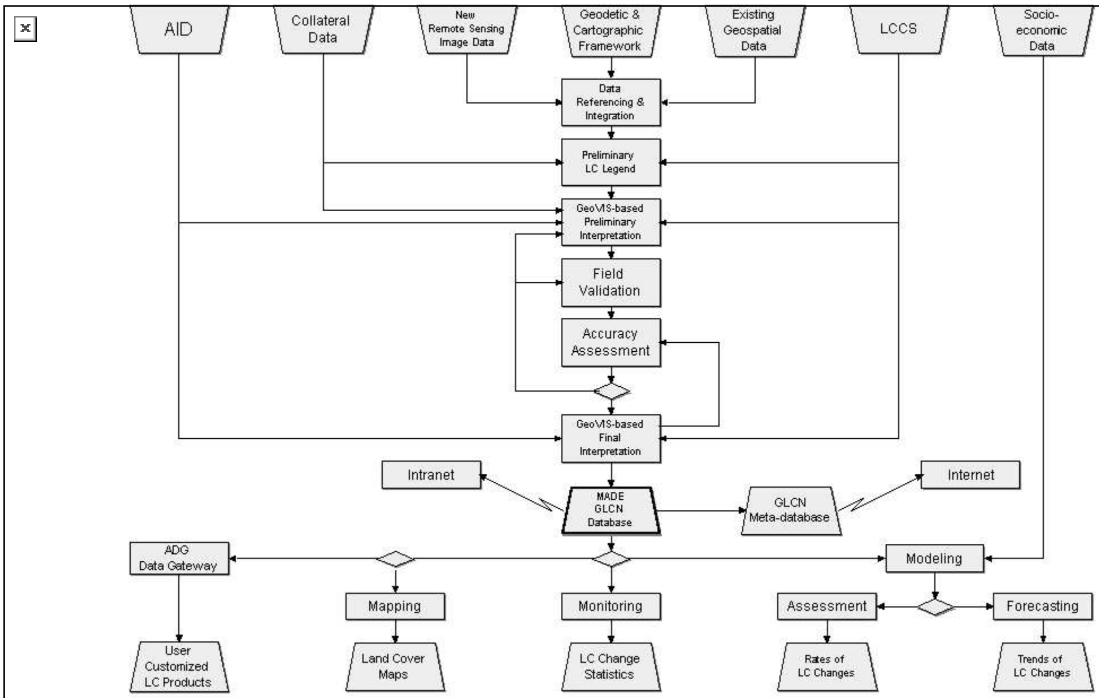

Figure 2: Schematic flowchart of GLCN methodology for land cover mapping.

9.3 Geodetic and Cartographic Framework for Land Cover Mapping

Uniform geodetic and cartographic framework applicable at the regional and global levels is of particular importance to GLCN because it provides a uniform geographic reference for land cover information anywhere in the world. Without a possibility to link the information on land cover and its changes to a specific area, which location is defined by coordinates, such information would have little relevance. Obviously, it is not good enough to know that large scale deforestation is occurring in the Amazonian forest, which covers over 4 million km^2, or that land erosion and accretion are changing the coastline in Bangladesh, if the geographic location of these and other land cover changes are in dispute. The lack of proper geo-referencing would delay effective assessment and monitoring of land cover changes and mitigation of their impacts.

Equally important is a requirement for harmonization of land cover databases and maps that were referenced to different geodetic and cartographic frameworks. They have to be transformed onto a common cartographic reference before their inclusion in a seamless, uniform and location-specific global land cover database. The availability of such a harmonized database, which provides a baseline reference for study of environmental changes, is an essential requirement by international environmental conventions related to climate change, protection of biodiversity and combat with desertification.

Geodetic and cartographic framework for land cover mapping is based on geodetic datum, which is defined by the dimensions of reference ellipsoid and the origin and orientation of the coordinate system. At present, the land cover mapping projects are referenced to a large variety of geodetic datums. Sometimes, different datums are used by mapping projects in the same country. This lack of compatibility in geographic referencing of data from different projects affects their comparisons and integration. For example, in Africa, there are over twenty geodetic datums currently in use. The situation is even more complex in Asia. As a result, there is little correspondence among coordinate systems used by land cover projects in different countries, making a compilation of uniform geo-referenced land cover database, covering several countries or the whole continents, difficult. For these reasons, a selection of uniform geodetic datum, suitable for land cover mapping at country, regional and global levels, was one of the earliest priorities of the Africover project.

The true shape of the Earth is represented by geoid, which is a hypothetical body defined by the Earth's gravity. Its surface corresponds to the surface of oceans covering the whole Earth. However, the geoid is not suitable as a reference surface for geodetic datum because its surface is too irregular, responding to variations in gravity forces. It was therefore replaced by ellipsoid, which can be mathematically defined. Over the years, as the knowledge of the Earth's dimensions was improving, number of different ellipsoids was defined to approximate the geoid. In 1979, the International Union for Geodesy and Geophysics (IUGG) approved the ellipsoid named the Geodetic Reference System 1980 (GRS 80) for international use.

Transformation of data coordinates from ellipsoid to plane surface is achieved by cartographic projection. The Universal Transverse Mercator (UTM) projection is used by the majority of large land cover mapping projects at scales 1:100 000 – 1:250 000 and has been adopted by many countries as the cartographic projection for their national topographic mapping at these scales. It is a cylindrical projection in which the meridians and parallels are first projected from the ellipsoid to a cylinder, which is then transformed into a plane. The transformation is realized in a series of UTM zones, each of 6^o width in longitude. For mapping at larger scales the 3^o UTM zones are usually used. Hence, there are sixty 6^o zones oriented in the North-South direction covering the Earth's ellipsoid. In order to minimize the scale distortions that the UTM projection introduces at the zones margins where they overlap, the scale is designed slightly smaller along the central meridian in each zone and slightly larger at their margins. The resulting maximum scale distortion is 0.1% in the equatorial region of each zone and decreasing in higher latitudes. Even the maximum UTM scale distortion value is compatible with the geometric accuracy of geocoded Landsat images as well as with the recommended planimetric accuracy of land cover polygons at GLCN mapping scales 1:100 000 – 1:250 000 (see below).

The Africover International Working Group for Geodesy and Cartography recognized the need to assure the compatibility among land cover mapping in different countries and recommended to reference the land cover and basemap data layers to a unified geodetic and cartographic framework for the whole African continent.

The following parameters of geodetic and cartographic framework for the Africa-wide land cover mapping recommended by the Africover International Working Group for Geodesy and Cartography was also adopted by GLCN:

- *Geodetic datum*: World Geodetic System 1984 (WGS 84);
- *Reference ellipsoid*: Geodetic Reference System 1980 (GRS 80);
- *Cartographic projection*: Universal Transverse Mercator (UTM) with 6^o zones;
- *Planimetric accuracy*: ±50m (dominant base map features) to ±100m (land cover polygons);
- *Map sheet layout*: based on the International Chart of the World (ICW).

Some environmental and land use planning applications require integration of land cover data with digital terrain model (DTM) data. Examples of such thematic applications are land use zoning, delineation and study of watersheds, assessment of water erosion risk, etc. DTM data are also required for geometric correction (orthorectification) of satellite images if geocoded images are not available. The Africover International Working Group for Geodesy and Cartography recommended the following elevation accuracy for DTM:

- *Thematic applications:* 50 m – 100 m;
- *Geometric correction:* 100 m – 150 m.

9.4 Design Concept and Production Steps of GLCN Land Cover Mapping Methodology.

Design concept of GLCN land cover mapping methodology consists of the following three phases:

1. Preliminary phase;
2. Land cover interpretation and database development;
3. End users mapping and modeling phase.

This concept differs from the usual land cover mapping procedures in three ways:

a) GLCN land cover mapping is based on the assessment of diagnostic attributes of land cover rather than on land cover classes;
b) Its main output is digital database rather than a hard copy map;
c) End users are closely involved in implementation of the third land cover mapping phase: generation of mapping and modeling products from land cover database.

These three signature features of GLCN land cover mapping methodology represent radical departure from established land cover mapping practices. Schematic flowchart outlining the GLCN land cover mapping methodology, the central roles of database and meta-database, and including the end users phase consisting of mapping and modeling products, is in Figure 2. It includes the main categories of inputs; land cover interpretation steps and their linkages; land cover database with associated meta-database as the main GLCN output; and the end users mapping and modeling output options.

9.4.1 Preliminary Phase of GLCN Land Cover Mapping Methodology.

Important part of GLCN land cover mapping methodology is its preliminary phase. Indeed, the success of land cover mapping in any country is significantly affected by successful completion of its preliminary phase. It consists of the following activities:

- Strengthening the land cover mapping capacities of organization responsible for country-wide land cover mapping programs. It includes advising on GLCN land cover mapping methodology; procuring the suite of GLCN software programs for land cover mapping; upgrading the computer hardware as required; selecting personnel for image interpretation, land cover classification, field validation survey, GIS processing and database management; training the selected staff in the effective use of GLCN suite of software programs for implementation of these tasks; and organizing an appraisal workshop on GLCN land cover mapping concept and products for their potential users.

- Establishment of Stakeholders Consultative Committee (SCC) for land cover mapping. Active cooperation with SCC is an essential prerequisite to specification and effective use of land cover mapping and modeling products. The SSC members should include the representatives of government agencies that will be the end users of land cover mapping products in the fields such as rural land use planning and sustainable development, food security assessment, natural disasters early warning system and assessment, environmental protection including monitoring of large inland water bodies and coastlines, climate change impact assessment, forest cover assessment, land degradation assessment, etc. Representatives of non-governmental agencies active in environmental protection and food security issues should be also invited to participate.

- Selecting and ordering the satellite images. Land cover mapping compatible with scales 1:100 000 – 1:250 000 requires multispectral images from high resolution satellite remote sensing systems with ground resolution in the range 10 m to 50 m. Once the baseline land cover dataset has been obtained and database established, the monitoring of land cover changes can be done by multispectral medium resolution satellite remote sensing systems with ground resolution in the range 200 m to 300 m. The overview of satellite optical and microwave (SAR) remote sensing systems producing the high and medium resolution images of the Earth's surface is in the Annex 3.

  Selection of suitable satellite images is based on their image quality, percentage of cloud cover and date of recording. Interpretation of land cover based on images recorded at two dates yields higher accuracy. When preparing a schedule of mapping tasks, at least three months lead time should be reserved for delivery of satellite images.

- Compilation of collateral data includes information related to land cover that is available at various government organizations and, in some cases, abroad. Collateral data include existing maps (land cover & land use, topographic, forestry, soils, etc.) and other geospatial data (climatic, demographic, etc.) as well as relevant statistical data, information on land use and environmental protection policies, etc. Useful information can be usually obtained from the topographic survey organization, ministry of agriculture, forest inventory institute, soils institute, and statistics institute. Considerable knowledge about land cover and its changes is sometimes available from the government district offices. The extent of familiarity with land cover should be considered when recruiting staff for image interpretation.

9.4.2 Land Cover Interpretation and Database Development.

Implementation of the second phase of GLCN land cover mapping methodology, the land cover interpretation and database development, consists of the following main tasks (Figure 2):

a) *Integration and referencing of input geospatial data* to GLCN geodetic and cartographic framework (Section 9.3). Input satellite images should be ordered in geocoded format, referenced to GLCN geodetic and cartographic specifications. They provide the baseline dataset for referencing other geospatial data. The quality of input data to be included in the interpretation and mapping processes should be assessed and the data labeled to prevent degradation of results to the level of the lowest quality dataset. Effective links with relevant non-spatial datasets should be established during this processing step.

Existing aerial and ground photographs that provide useful information on land cover types should be referenced to input satellite images to facilitate their interpretation. In most countries aerial photographs that were used for topographic or thematic mapping, land reform, resettlement planning, etc., are available.

b) *Development of a "virtual" preliminary land cover legend.* Its development is based on experience of project officers, survey of literature and interviews with specialists in related fields with local knowledge of the area. It may also include brief field visits to selected areas. This task is implemented for each country participating in land cover mapping project. Hence, there will be a different initial list of preliminary land cover classes for each country. Class names follow the LCCS nomenclature but common names used in the country are included as well in order to prevent possible misunderstanding by local interpreters. The preliminary land cover legend contains significantly more classes than its final version because of aggregation of classes during the interpretation process.

c) *Preliminary interpretation* of land cover from Landsat TM/ETM multispectral images (Annex 3) displayed on computer monitor. Delineation of preliminary land cover classes is based on image color, contrast, pattern and texture differences (photomorphic image signatures), but there are no field validation data available at this stage. The GeoVIS Interactive Image Interpretation System (section 9.2.2) is used to support this task. Since it is a vector-based system, stratification of the image scene into polygons corresponding to distinct interpretation units is a straightforward task. It is facilitated by computer enhancement of digital imagery, which can be zoomed, contrast-stretched and displayed in variations of false colors. Consistency during delineation of interpretation units is an important requirement. Since the task involves subjective decisions, it requires good experience and is best done by the same person. When there are more interpreters, the harmonization of their interpretation skills should be included in their training.

After the delineation of interpretation units is completed, they are linked to preliminary legend (paragraph b) and labeled. In the course of this task execution, the preliminary legend is continually modified; its classes may be aggregated or split to reflect the reality as recorded in the satellite image. The interpretation units of the same appearance have the same label, but they may be further revised during the final interpretation stage (paragraph e).

The outcomes of this stage consist of delineated land cover interpretation units linked to revised preliminary land cover legend. However, both these outcomes will be further modified based on results of intermediate accuracy assessment after the field validation has been completed and before the final interpretation takes place.

d) *Field validation* of a representative sample of delineated interpretation units. This task consists of field assessment of pre-defined diagnostic attributes for land cover classification, the classifiers, which are the key LCCS components.

The objective of field validation is to evaluate the classifiers needed for unique identification of land cover class in each validation site. The field validation sampling rate depends on the complexity of interpretation units. Obviously, the well-defined, homogeneous interpretation units require a lower rate of field validation than those with fragmented land cover pattern. Results of field validation are recorded in the field validation forms. One form is required for each validation site (Annex 2).

Itinerary of field validation survey should follow (never precede) preliminary delineation of interpretation units (paragraph c) and be carefully planned. Practical considerations, such as the security and accessibility of the area will top the list of criteria for selecting the field validation sites. After elimination of some areas based on these practical considerations, a plan for field validation of preliminary land cover classes is prepared. Planning of field validation missions should also include a selection of alternative validation sites. This will reduce an improvisation in changing the selected sites during field missions.

The field validation forms include the topomap coordinates of planned validation sites as well as GPS coordinates of sites in which the field validation actually took place (section 8.3). Care should be taken to assure that both sets of coordinates are well within the same interpretation unit that was selected for field validation. Photographs, taken at four directions when it is practical, are an important part of field validation. They provide an objective record of land cover in the validation site at the time when the mission took place.

Field validation data are used for intermediate accuracy assessment of preliminary land cover legend, resulting in revision of corresponding interpretation units (paragraph c). Only the classes with the minimum accuracy threshold of 60% - 70% are retained and included in the final interpretation stage. The results of field validation consist of a final land cover legend and associated sets of evaluated classifiers for each revised preliminary land cover class. The number of land cover classes will be further reduced and their accuracy increased during the final interpretation stage.

e) *Final interpretation of land cover classes* and finalization of mapping units (land cover polygons) is based on LCCS (section 10) and supported by GeoVIS and AID software modules (sections 9.2.2 and 9.2.3). It consists of the following tasks:

- Review of final land cover legend and classifiers resulting from field validation;
- Final delineation of mapping units (land cover polygons) based on LCCS;
- Accuracy assessment of land cover classification based on field validation data;
- Final editing of data and polygons;

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- GIS processing and integration of land cover; base map; collateral and validation data layers in GLCN land cover database (MADE);
- Updating of meta-database.

Execution of this task starts with finalized land cover legend, associated interpretation units and land cover diagnostic attributes that were evaluated for each land cover class during field validation stage. This task usually involves further reduction of land cover classes. Such a decision often results from the requirement that the mapping units must be identified with at least 70% accuracy. Areas with fragmented land cover will have higher number of mixed mapping units that can be delineated with adequate accuracy. Topography, soils, hydrography, density of population and the type of land use in the mapped area influence the level of homogeneity or fragmentation of land cover within the mapping unit. The predominant land cover type and the estimated percentage of up to two more land cover types within the mapping unit define the mixed mapping units.

Each final land cover class is identified by unique names, codes and string of classifiers. This identification consists of a total of six elements:

- Identification of major dichotomous land cover class (out of eight classes);
- Class user name that is commonly used in the country;
- LCCS class name that is derived from classifiers of this class;
- Map code, which is a synthetic alphanumeric code used during interpretation;
- LCCS GIS code, which is linked with the LCCS classifiers of this class;
- LCCS classifiers that define the class.

Since some of these elements are redundant for class identification, it is expected that their list will be reduced in the next revision of LCCS software.

The results of final interpretation consist of a dataset of final land cover classes with associated classifiers, accuracy assessments (of class and classifiers) and coordinates of land cover polygons. This dataset is reviewed and certified for its compliance with GLCN specifications. Then it is transferred to Multipurpose Advanced Database for Environmental information (MADE). Description of land cover dataset characteristics is transferred to meta-database. (Sections 9.2.5 and 9.2.6; Figure 2).

The MADE is continually updated as new or revised data become available. Its main and unique features are the neutral and unambiguous definitions of classes stored in its land cover data layer and inclusion of their classifiers. These features distinguish MADE from other land cover databases and strengthen its applicability.

9.4.3 End Users–Defined GLCN Land Cover Mapping and Modeling Products

The unique characteristic of LCCS is the flexibility of legend formation. It is the only land cover classification system that allows the users to select the classes for the legends best suited to their respective applications. Furthermore, since the GLCN database stores all classifiers that were used during classification process, the users can reformulate the classes by modifying the number of classifiers used for their definition.

The range of users'-defined land cover products, which can be developed from data stored in MADE, is outlined in Figure 2. They include the following products:

- *User customized land cover products*. Their development is supported by Advanced Data Gateway (ADG), which provides users with flexibility to change land cover classes through recombination of classifiers and to set their own thresholds for accuracy and minimum mappable area (section 9.2.7). Map legends of these products will be tailored to users specifications;
- *Land cover map* based on MADE "ready-made" land cover classes, GLCN accuracy specifications and minimum mappable area. Users can select the classes best suited for their applications;
- *Tabulation of land cover statistics*. This product is particularly suitable for statistical monitoring of significant land cover changes in specified regions. Change monitoring requires the availability of multidate land cover datasets;
- *Mathematical modeling* of land cover change rates and future trends. Knowledge of land cover change rates and trends is particularly important for planning of sustainable development and environmental protection. This type of models requires the socio-economic data inputs and their integration with land cover and other geospatial data (topographic, soils, climatic, etc.) in MADE.

9.5 Content and Accuracy Criteria of Land Cover Databases

Increased use of digital cartography and databases in land cover mapping has required modification of traditional cartographic criteria for the assessment of map content and its accuracy. The GLCN approach to this task has been pragmatic, based on experience with implementation of the Africover project.

The following map content and accuracy criteria are used by GLCN:

- Minimum Mappable Area (MMA), including
- Mixed Mapping Units (MMU);
- Scale Adequacy Index (SAI);
- Accuracy of land cover classes.

9.5.1 The Minimum Mappable Area (MMA)

The minimum mappable area corresponds to the smallest size of mapping unit that is stored in database or displayed on a map as a discrete land cover polygon. Its determination depends on ground resolution of input data, type of data processing (e.g. resampling or aggregation of original data), analysis/interpretation procedure (digital, manual, interactive), land cover mapping scale, applications and practical/budgetary considerations. The size of minimum mapping area influences the cost of land cover dataset as well as the range of its applications.

The MMA is a cartographic criterion that is traditionally linked to the map scale because it has to comply with cartographic requirements for presentation of the map content and its readability. It is obvious that the smaller the map scale is, the bigger the map generalization is, resulting in larger MMA. In digital databases, the MMA still fulfills an important function because it defines the level of detail of land cover classes. The Advanced Database Gateway (section 9.2.7) automatically recombines the land cover polygons according to MMA threshold.

In most land cover maps and databases, the minimum mappable area is of the same size for all classes. For example, the EC-CORINE land cover map of Europe at 1:100 000 scale uses a uniform MMA of 25 mm^2 at the map scale, which corresponds to 25 hectares on the ground. Disadvantage of uniform MMA is its inherent rigidity in representation of land cover classes regardless of their types.

The Africover project used variable sizes of MMA, depending on the type of land cover classes. The concept of variable MMA sizes improved efficiency of land cover mapping of 8.5 million km^2 in East Africa with hundreds of land cover classes including vast areas of deserts, grasslands, and forests. The use of uniform MMA sizes would have been entirely inappropriate and lead to increased cost of project implementation.

The GLCN has not specified the values of variable MMA sizes because their final determination rests with the end-users. Otherwise, the applicability of GLCN land cover database would be reduced. The end-users can select the MMA values, compatible with their applications, for each class. The land cover polygons will be then automatically recombined by ADG. However, the GLCN-TC may determine the upper levels of MMA sizes for selected land cover classes to assure that their generalization is compatible with the range of GLCN mapping scales 1:100 000 to 1:250 000.

9.5.2 Mixed Mapping Units (MMU)

The cartographic concept of mixed mapping units is related to the concept of minimum mappable areas. As it was discussed in the previous section (9.5.1), the size of MMA is related to the map scale. When the size of MMA is increased, the larger number of "pure" land cover mapping units ("pure" land cover polygons) has to be aggregated into mixed mapping units. Hence, there is a trade-off between the MMA sizes and number of MMU that is, between map readability and its information content. In order to reduce the number of mixed mapping units and yet to optimize the information content of land cover map according to the importance of land cover classes, the Africover project adopted variable MMA sizes. It also developed the Scale Adequacy Index (section 9.5.3) that evaluates the proportion between "pure" and mixed mapping units for each class.

An important feature of GLCN aggregation procedure is that the process is fully documented, which allows determination of the information content of mixed mapping units (aggregated polygons). The mixed mapping units are always composed of a maximum of three land cover classes. For example, when the areas of polygons corresponding to land cover classes A and B are below the MMA threshold, an aggregated polygon is created and coded as a mixed mapping unit. A specific syntax was developed for MMU labeling, in this case either A/B or B/A:

A/B: class A is dominant, covers over 50% of polygon area. Class B covers at least 20%.
B/A: class B is dominant, covers over 50% of polygon area. Class A covers at least 20%.

The only exception to the minimum of 20% coverage of the mixed polygon area is the class of isolated agricultural fields with the threshold of 10%.

9.5.3 Scale Adequacy Index (SAI)

Scale adequacy index, evaluates the proportion of "pure" and mixed mapping units for each land cover class stored in the database. It is an empiric formula for the assessment of how adequate is the MMA size in relation to the sizes of land cover mapping units (land cover polygons):

$$SAI\ of\ Class\ A = \frac{Sum\ of\ class\ A\ \text{“}pure\text{”}\ mapping\ units\ areas}{Total\ sum\ of\ class\ A\ \text{“}pure\text{”}\ and\ mixed\ mapping\ units\ areas}$$

Case 1: If the class A was not aggregated into any mixed mapping units, it would be only represented in "pure" mapping units and its Scale Adequacy Index would be 1.0. This would indicate that the size of Variable Minimum Mappable Area (VMMA) of this class was too small;

Case 2: If the class A was represented only in the mixed mapping units, its Scale Adequacy Index would be 0. Obviously, in this case the Minimum Mappable Area was not compatible with class A. It was too large in comparison to sizes of class A "pure" mapping units, which had to be aggregated with other land cover classes. The use of VMMA enables a tailoring of MMA sizes to sizes of polygons of important land cover classes;

Case 3: If a half of the total area of class A consists of polygons that are smaller than the minimum mappable area, they have to be aggregated into the mixed mapping units representing 50% of class A area. Its Scale Adequacy Index would then be 0.5.

Although SAI facilitates the tailoring of VMMA sizes to be compatible with the sizes of mapping units of land cover classes, the SAI values should be interpreted with a caution. For example, in areas with extensive subsistence agriculture, there are many small isolated cultivated fields. Knowledge about their existence is important for the assessment of food security in the area. Because of their sizes and scattered distribution, all of them will likely be included in the mixed mapping units. There is an exception for this land cover class that allows its inclusion in the mixed mapping units even if it occupies less than 20% of MMU area. The threshold for this class was lowered to 10% in order to allow its visibility. Even if the SAI for this class “small isolated cultivated fields” is 0, it would not be practical to select sufficiently small VMMA to allow its SAI to reach a value over 0.5. It would require input data with finer ground resolution and field validation at more detailed level. It thus would not be compatible with land cover mapping at scales 1:100 000 to 1:250 000.

9.5.4 Accuracy Assessment of Land Cover Classes

There is no consensus on accuracy measures for land cover mapping at regional and global scales. Although there is an agreement about the importance of accuracy evaluation, there are number of methods currently in use, which make a comparison of results from different projects difficult. The situation is not helped by inconsistency in definitions and field validation of land cover classes.

Accuracy standards used in topographic mapping are obviously not applicable. Most of the land cover classes are not clearly delineated in nature but separated with transitional areas in which the classes are mixed. For example, a decision where a class “closed trees” becomes a class “open trees”, “treed grassland”, “scattered shrubs”, etc. is highly subjective. Even if delineation of land cover classes is done by an image analysis system based on histograms of pixel values, it will still result in arbitrary delineation of classes disregarding their gradual transition that is characteristic for natural ecosystems.

In spite of these reservations, the accuracy of land cover classification and mapping is an essential requirement that should be included in all projects. If the accuracy of land cover classes, that is, the extent of their misclassification, is not known, they are practically useless. Since there is usually a considerable variation in the accuracy of different land cover classes, the classification accuracy has to be assessed for each class separately, in addition to the assessment of overall classification and mapping accuracies.

An accuracy evaluation method most often used in land cover mapping is based on confusion tables in which the commissions (plus errors) and omissions (minus errors) are compared and summarized for each land cover class. While the confusion tables express the classification accuracy of land cover classes, they are somewhat inadequate for the expression of their mapping accuracies that is the errors in their location. Such errors combine both the commissions and omissions, since they reflect the change in class pattern due to area gains from other classes (commissions) as well as area losses to other classes (omissions). Hence, the following four accuracy measures for land cover classification and mapping are described:

- *Classification accuracy of individual land cover classes;*
- *Overall classification accuracy;*
- *Mapping accuracy of individual land cover classes;*
- *Overall mapping accuracy.*

a) **Evaluation of classification accuracy** is usually based on error matrices (confusion tables), which are constructed for validation sample sites in which independent land cover "ground truth" data were collected. The location and size of validation sample sites should assure an adequate (statistically meaningful) representation of all land cover classes. The land cover classes interpreted from satellite imagery are then compared with validated land cover classes (ground truth data), their accuracy assessed in terms of omissions and commissions and expressed in percentage for each class.

   Classification accuracy of individual land cover classes is computed by dividing the correctly classified area of class X by the area assigned to class X during interpretation (total area that was correctly and erroneously classified as class X).

   Overall classification accuracy is computed by dividing the correctly classified area of validation sites by the total area of validation sites.

   The usual threshold of classification accuracy is 70% although exceptions can be made for small land cover classes. The classification accuracy is a sufficient accuracy measure when the final product is the land cover statistics of the area. However, when land cover map or other geo-referenced land cover products are required, the classification accuracy has to be complemented by another accuracy measure, the mapping accuracy.

b) **Evaluation of mapping accuracy** of land cover classes is needed for the assessment of errors in location of land cover classes, such as in their representation on a map. It is important to remember that the classification of a class may be 100% correct and yet its display on a map may be erroneous because of the combined effect of omissions and commissions to and from other classes respectively. Therefore, the formula for calculation of mapping accuracy must include both types of errors (omissions and commissions).

   Mapping accuracy of individual land cover classes is computed by dividing the correctly classified area of class X by the area assigned to class X during interpretation, which includes the areas from other classes that were erroneously interpreted as class X (commissions) plus the area of class X that was erroneously assigned to other classes (omissions). Hence, the correctly classified area is divided by a sum of correctly classified area plus the areas of commissions and omissions.

Overall mapping accuracy is then defined as the weighted arithmetic mean of mapping accuracies of all land cover classes. Class weights correspond to their proportional representation in the project area.

10. GLCN Land Cover Classification System (LCCS)

In the past and in many cases still at present, the land cover mapping is based on an ad hoc classification system with pre-defined land cover classes tailored to specific objectives and geographic area, without any links to other classification systems. Furthermore, the definitions of land cover classes and their validation procedures are often arbitrary, with no compatibility among different projects. This prevents meaningful comparison of land cover statistics derived from different land cover projects and partially explains discrepancies in the areas of land cover categories. These shortcomings of land cover classification systems with pre-defined classes were addressed during implementation of the FAO Africover project covering 8.5 million km^2 in East Africa.

The FAO Land Cover Classification System (LCCS) is an important spin-off development of the Africover-EA project. It is a multi-user oriented, systematic *a priori* classification system. In the *a priori* classification systems the land cover classes are defined before their interpretation starts. Their main advantage is that pre-defined classes allow their standardization, are independent of geographic area and data collection methodology. However, their disadvantage is the difficulty of fitting limited number of pre-defined classes to a large variety of "real life" land cover types. The land cover projects using the conventional *a priori* classification systems covering extensive areas would require a large number of pre-defined classes to represent all land cover types present in the project area.

10.1 LCCS Design Concept

The LCCS innovative design has overcome the difficulties of *a priori* classification systems. It has evolved from realization that an unwieldy number of pre-defined classes would be required to represent land cover of large heterogeneous area, such as that mapped by the Africover project, with an adequate detail corresponding to the ground resolution of the input satellite imagery data. It is based on the following unique concept: rather than using pre-defined classes, the LCCS uses universally valid pre-defined set of independent diagnostic attributes, the classifiers, which identify the land cover classes. This presumes that any land cover class, regardless of its type and geographic location, can be identified by a pre-defined set of classifiers. The number of classifiers used determines the level at which the land cover is classified. Thus, the larger number of classifiers is needed when a more detailed classification of land cover is required and *vice versa*. The LCCS output is a comprehensive land cover characterization, independent of mapping scale, data collection method, ecological zone, application and geographic location. Furthermore, the classifiers provide much better insight into the characteristics of land cover types than it would be possible if only their names were available. Thus the LCCS has retained the advantages of *a priori* classification systems, including their universality and compatibility with standardization, but shed off their disadvantages.

The LCCS classifiers enable a clear definition of land cover class boundaries, without overlaps. The universality of LCCS is based on the following four characteristics:

- Independent of map scale;
- Independent of data source, that is data collection methodology;
- Independent of geographic location;
- Independent of application.

The above LCCS characteristics, combined with its capability to translate the existing land cover classifications into the LCCS-compatible land cover datasets, make the LCCS an optimal land cover classification standard for large projects. This is particularly important considering that an increasing number of regional and global land cover mapping and monitoring projects urgently needs a universally applicable land cover classification system for objective international comparisons of land cover state and its changes. Growing number of international projects are already using the LCCS as their classification standard.

Another unique approach to land cover classification adopted by LCCS was driven by pragmatic, operational considerations. Instead of attempting to use the same, large set of pre-selected classifiers compatible with land cover of large areas, such as the whole continents, it divided the classifiers into eight groups corresponding to eight major land cover classes representing the global land cover diversity. This has greatly reduced the number of classifiers needed for precise definition of any land cover class regardless of its location and thus significantly simplified the classification procedure. However, it required designing the LCCS implementation in two phases: the initial *Dichotomous Classification Phase* and the follow-up *Modular-Hierarchical Classification Phase*.

The *dichotomous phase* uses the following three classification criteria: presence of vegetation, edaphic condition and artificiality of land cover. It consists of three classification levels and results in eight major land cover classes in the third level. These classes are then further classified during the *modular-hierarchical phase*, based on eight sets of pre-defined classifiers. Each of the eight major land cover classes defined during the dichotomous phase has its own distinct set of classifiers, tailored to the type of land cover class. These *classifiers* are arranged in a fixed hierarchical structure, which has to be followed during classification procedure. Each set of *classifiers* also includes two types of additional, optional classification attributes, the *environmental attributes* and the *specific technical attributes*, which are used when further, more detailed description of characteristics of land cover classes is required.

The advantages of the FAO/UNEP Land Cover Classification System are manifold. It is a highly flexible system in which each land cover class is mutually exclusive and clearly defined, thus providing internal consistency. These characteristics are independent of the classification level. The classification can be stopped at any desired level and will result in clearly defined land cover class corresponding to that level. Any land cover type can be readily accommodated. The system is truly hierarchical and applicable at a variety of mapping scales and in any geographic location. It can be used as a reference standard system because it is based on diagnostic criteria that allow correlation with existing classifications and legends. The LCCS, which represents a paradigm shift in land cover classification, thus contributes towards harmonization and standardization of land cover classification and mapping.

10.2 LCCS Dichotomous Classification Phase

The LCCS dichotomous phase consists of three classification levels, which define eight major land cover classes in the third level, based on the following classification criteria (Table 1):

- *presence of vegetation,*
- *edaphic condition,*
- *artificiality of land cover.*

First level	Second level	Third level
PRIMARILY VEGETATED	TERRESTRIAL	MANAGED TERRESTRIAL AREAS
		NATURAL and SEMI-NATURAL TERRESTRIAL VEGETATION
	AQUATIC or REGULARLY FLOODED	CULTIVATED AQUATIC AREAS
		NATURAL and SEMI-NATURAL AQUATIC VEGETATION
PRIMARILY NON-VEGETATED	TERRESTRIAL	ARTIFICIAL SURFACES
		BARE LAND
	AQUATIC or REGULARLY FLOODED	ARTIFICIAL WATER BODIES
		NATURAL WATER BODIES, SNOW and ICE

Table 1. LCCS dichotomous classification phase.

10.3 LCCS Modular-Hierarchical Classification Phase

In the modular-hierarchical classification phase the selection of classifiers and their hierarchical arrangement are tailored to each of the eight major land cover classes corresponding to the third level of the dichotomous phase. Thus, eight different classifier sets are used in this phase. The user is not obliged to use all classifiers but has to respect their hierarchical arrangement. Depending on the required level of land cover information, the classification can be stopped at any time and the corresponding land cover class determined.

The defining characteristic of LCCS modular-hierarchical classification is that the definition of land cover classes is based on their respective sets of classifiers rather than on their names. This allows not only much better insight on the type of land cover classes but also facilitates their correlation with land cover classes from other classification systems. Therefore, the LCCS classifiers can be used for translation of existing land cover classifications. Since the eight sets of LCCS classifiers can accommodate all land cover types without thematic or geographic restrictions, the LCCS can be used as a reference land cover classification system worldwide.

The example in Tables 2 and 3, based on the (dichotomous) class "Natural and Semi-Natural Terrestrial Vegetation", demonstrates the concept of LCCS modular-hierarchical classification. The land cover class "Forest" is defined at increasingly detailed classification levels, depending on the number of classifiers used. The classification stops when the required level of class definition is reached. Note, that the modular-hierarchical classification phase starts with the classification level 4 because the broad land cover stratification at the first three levels was done during the dichotomous phase.

Each land cover class is described by three codes:

- Boolean formula, consisting of a string of classifiers used for the class definition (e.g. A3A10B2 in the example in Table 3);
- Common name of land cover class (e.g. "high closed forest");
- Numerical (GIS-friendly) code (e.g. 20006).

After the classification is completed and the land cover classes finalized, the map legend is automatically generated. The selection of classes and their aggregation depends on the type of map and its scale. One of the advantages of LCCS is that its classification is not a single-purpose one but can support map legends for a variety of applications.

<table>
<tr><th>Classification level</th><th colspan="6">Classifiers</th></tr>
<tr><td>4</td><td colspan="2">Life form of main layer
(e.g. woody, herbaceous)</td><td>Vegetation cover
of main layer</td><td colspan="2">Vegetation height</td><td>Spatial distribution
(macropattern)</td></tr>
<tr><td>5</td><td colspan="3">Leaf type
(e.g. broadleved, needleleaved, aphyllous)</td><td colspan="3">Leaf phenology
(e.g. evergreen, deciduous, mixed)</td></tr>
<tr><td>6</td><td colspan="2">Vertical stratification
second/third layer</td><td colspan="2">Vegetation cover
second/third layer</td><td colspan="2">Vegetation height
second/third layer</td></tr>
</table>

Table 2. Set of classifiers and their hierarchical arrangement corresponding to the dichotomous class Natural and Semi-Natural Terrestrial Vegetation.

Classifiers	Boolean formula	Class common name	Numerical (GIS) code
Life form (LF)	A3	Forest	20004
Vegetation cover (C)	A3A10	Closed forest	20005
Height (H)	A3A10B2	High closed forest	20006
Macropattern	A3A10B2C1	Continuous high closed forest	20007
Leaf type	A3A10B2C1D1	Broadleaved continuous high closed forest	20095
Leaf phenology	A3A10B2C1D1E2	Deciduous broadleaved continuous high closed forest	20097
2nd layer (LF,C,H)	A3A10B2C1D1E2 F2F5F7G2	Multilayered deciduous broadleaved continuous high closed forest	20628
3rd layer (LF,C,H)	A3A10B2C1D1E2 F2F5F7G2 F2F5F10G2	Multilayered deciduous broadleaved continuous high closed forest with emergents	20630

Table 3. Example of hierarchical classification of the class “Forest”, with increasing detail of its characterization, based on a set of classifiers listed in Table 2.

10.4 Optional Attributes of Land Cover Characterization

The LCCS modular-hierarchical land cover classification based on pre-defined and pre-arranged sets of classifiers can be complemented with additional characterization of land cover when its more detailed description is required. For this purpose, the LCCS includes, in addition to land cover classifiers, two kinds of optional land cover attributes, *the environmental attributes* and *the specific technical attributes*. However, it should be pointed out that the optional attributes provide an additional, complementary characterization of land cover rather than extending the classification by another level.

- *Environmental attributes*, which influenced the type and state of land cover and provide additional information about its characteristics but are not essential to its definition. Therefore, they should not be confused with land cover classifiers and used only when additional, more detailed land cover description is needed. These attributes, which include climate, landforms, altitude, soils, lithology and erosion, are not hierarchically arranged, can be selected as needed and combined in any user-defined order

- *Specific technical attributes,* which relate to specific applications. For example, the assessment of food security will require not only the areas of cropland but also the characteristics of crop types, their rotation and agronomic inputs. Thus, the specific technical attributes include the information on crop type yields and their rotation, types of irrigation and agronomic inputs in cultivated terrestrial areas, floristic aspects of natural and semi-natural terrestrial and aquatic vegetation, eutrophication and salinity of artificial and natural water bodies, etc.

10.5 LCCS Modules

The LCCS software package consists of four modules: classification, map legend, field data and translator (Figure 3):

a) ***Classification module*** performs the two-phase land cover classification in a comprehensive and systematic way. The LCCS land cover classification is comprehensive in the sense that any land cover can be readily accommodated. The pre-defined sets of classifiers and their hierarchical arrangement for each major dichotomous land cover class result in systematic classification regardless of the types of land cover classes and their geographic location. The more classifiers used, the greater the detail of land cover class definition. Hence, as the classification proceeds to higher levels, the detail of land cover mapping is increasing. The classes at any level are all unique and unambiguous. If the next classifier at any level could not be determined, the classification would stop and the definition of land cover class based on the last classifier used. A strict class boundary definition and internal class consistency are inherent to LCCS.

b) ***Legend module***. The unique characteristic of LCCS is the flexibility of legend formation. Since the GLCN database stores all classifiers that were used during classification process, users can select the classes and design the legend to suit best their requirements.

   Land cover legend usually contains only a subset of classification, consisting of classes applicable to project geographic area, its mapping scale and application. The land cover classes included in the legend have to comply with the following two related cartographic concepts: the minimal mappable area (MMA) and the mixed mapping units (MMU). While the MMA sets the limits for the size of the area of land cover classes to be included in the legend, the MMU allows inclusion of classes with smaller areas through their aggregation into larger units. The order of classes in a mixed mapping unit reflects the dominance of land cover types in the area with fragmented land cover.

c) ***Field data module*** allows structured storage of field observations recorded in the field validation forms, which provide description of land cover in the field validation sites. There is no LCCS expertise required for field data entry. The data are automatically translated into LCCS classifiers and attributes and exported to the *classification module*. This is an essential requirement for the conversion of preliminary land cover classes into the final ones. The *field data module* also contains the retrieval and edit functions that enable manual input of additional relevant information.

d) ***Translator module*** enables translation of existing land cover classifications and legends into the LCCS as a reference system. Its functions include the "*import*", which imports the land cover classes from an external legend, the "*display*", which displays the imported external classification and its translation into the LCCS, the "*similarity assessment"* between external and reference land cover classes, and the "*comparison*", which enables comparison of LCCS land cover classes with classes from external classification systems. The comparisons can be made at the land cover class or the classifier levels. This module thus enhances the LCCS role as the reference classification standard.

Flowchart modeling the inter-relationship among LCCS modules is in Figure 3:

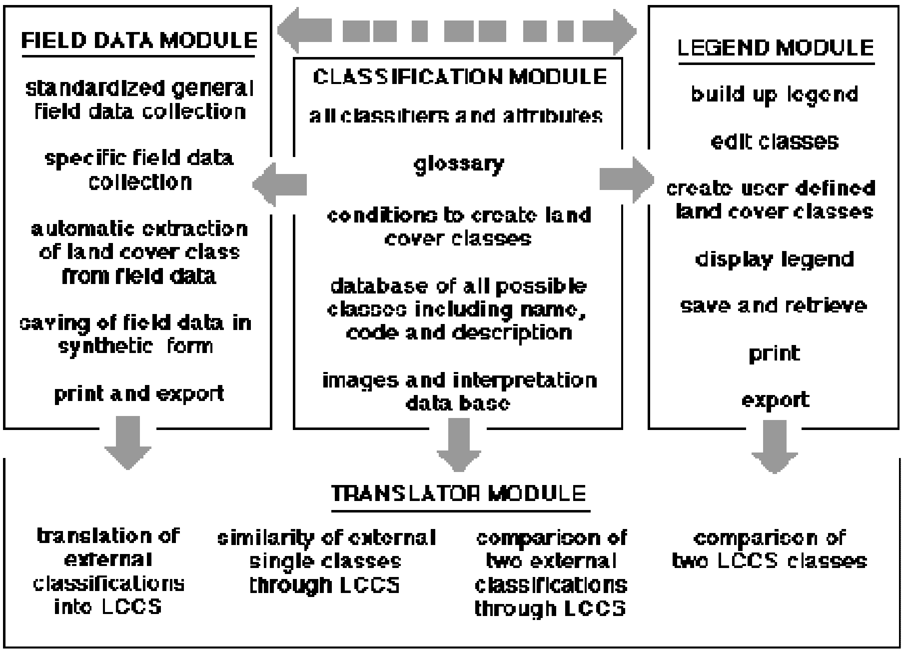

Figure 3. Overview of the LCCS modules, functions and linkages.

Naformátováno: Odrážky a číslování

10.6 New LCCS 2 Software Version

The LCCS 2 software version has enhanced the effectiveness and user-friendliness of the original version. The LCCS upgrade was based on five years of operational experience with LCCS use and feedback received from the users. The new version, available since the end of 2004, consists of the following changes:

- *Changed programming language*. The new LCCS version, the LCCS 2, is programmed in the Visual Basic C++. Its first version was programmed in the Microsoft Access 2.0;
- *Strengthened integration with GeoVIS, AID and ADG* facilitates the interpretation process and increases its accuracy and consistency of results from different interpreters;
- *Enhanced software functionality*. For example, the new version enables visualization of classifiers and corresponding land cover class at any classification level;
- *Increased options for combination of classifiers*. Additional combinations allow creation of more land cover classes and increased the LCCS compatibility with land cover mapping at very small scales;
- *Upgraded cartographic rules*. The upgrading increases the number of options for classification of mixed land cover units;
- *Installed new LCCS-LINK function*. It enables to link land cover classes with tabulated values of other environmental parameters, such as the normalized vegetation index, carbon dioxide exchange rate, etc.
- *Improved glossary*. Definitions of some land cover terms were changed. For example, the "closed forest" was changed to more neutral term "closed trees" and "woodland" to "open trees";
- *Implemented integration with software module for pixel-based image analysis*. This upgrading is expected to become operational during 2005.

11. Conclusions

The United Nations Secretary-General Kofi Annan's Millennium Report (2000), in which he addressed the challenges of the new century, identified the "three pillars" of the UN long-term goals:

- "Sustaining Our Future" by protecting the environment and its ecosystems;
- "Freedom from Want" through socio-economic development;
- "Freedom from Fear" by promoting peaceful co-existence among countries.

The degree to which these milestones are accomplished will determine the mankind's future. Their close relationship is being increasingly recognized. Sustainable economic development resulting in the reduction of poverty, increased food security, employment opportunities and rehabilitation of the environment will contribute to the improvement of the living standards, particularly in the least developed countries. The flowchart linking the sustainable economic development with the economic, social and political securities that lead to peaceful co-existence among countries is in Figure 4.

Industrialized countries have developed their economies without paying much regard to preservation of natural resources and protection of the environment. However, such a development model cannot be applied any longer for two reasons:

- Our common ship, the "mother Earth", is becoming overcrowded;
- Environmental degradation has reached dangerous level worldwide.

With the projected population growth of 40% in the next 50 years, practically all of it in developing countries, the carrying capacity of the Earth will have to increase by at least 60% to empower the elimination of abject poverty and improvement of the standard of living in developing countries. In order to reach such a substantial increase of the Earth's carrying capacity, the sustainable development and management of land and water resources have to become the cornerstones of economic development.

The sustainable development is a relatively new concept. It was defined in 1987 by the World Commission on Environment and Development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Bridging sustainability and productivity of land and water resources has become the greatest challenge. Successful realization of this task requires fulfillment of the following conditions:

- ✓ Political will of governments;
- ✓ Peoples awareness, commitment and participation;
- ✓ Availability of realistic information on current state of land and water resources.

The GLCN addresses the last condition through its activities focused on increasing the availability of and facilitating the access to reliable, timely and harmonized land cover information products worldwide.

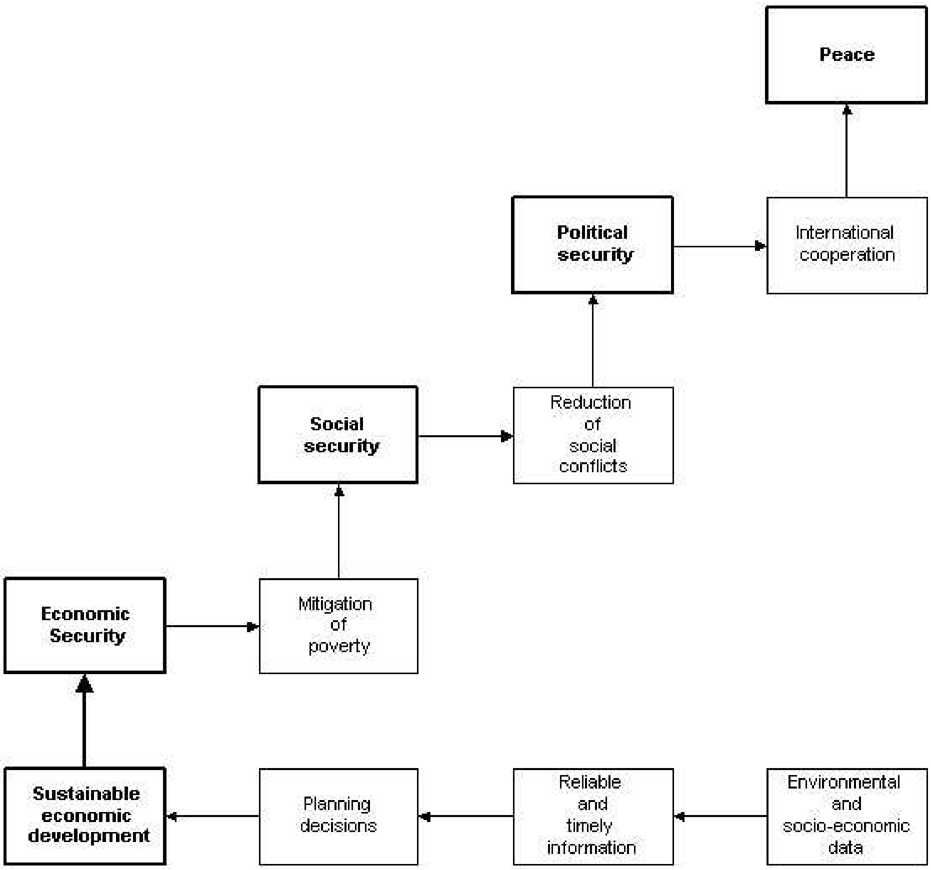

Figure 4. Schematic flowchart linking the sustainable economic development with the economic, social and political securities and peaceful co-existence among countries.

Land cover is the result of environmental conditions, including climate change, increasing scarcity of fresh water and land degradation; social factors, in particular population density and migration patterns; and economic development, reflected in the type and intensity of land use. It is, therefore, an objective indicator of the impact of changing natural and land use conditions. These characteristics of land cover, combined with advances of geo-information technologies that enable monitoring of land cover changes at country, regional and even global levels, make it one of the essential inputs to planning of sustainable development and management strategies for renewable natural resources.

The GLCN initiative embodies four major thrusts:

- Promoting and facilitating global harmonization of land cover mapping and monitoring technologies and data products;
- Increasing the awareness about existing land cover data and their accessibility through the establishment of global land cover meta-database and its linkages with major land cover databases;
- Continuing development of innovative software tools for more effective and efficient land cover mapping and monitoring;
- Strengthening the capacities for land cover mapping and monitoring in developing countries and countries with economies in transition.

Their realization will contribute to the achievement of GLCN objectives and thus to the fulfillment of one of the prerequisites of sustainable development planning: the availability of reliable information on land cover and its changes.

The incredible growth of satellite remote sensing, computer and communication technologies has provided the tools for continuous, systematic global Earth observation, mapping and monitoring. Digital cartographic databases are replacing the paper map archives, and on-screen interactive interpretation of virtual images of the Earth's surface displayed on computer monitor is replacing the manual interpretation of satellite images printed on paper. This migration from paper-based cartography to digital one has not only fundamentally changed the methodology of land cover mapping but significantly shortened its production cycle. It also facilitates integration of land cover data with other geospatial and socio-economic data and enables more effective tailoring of land cover information products to their end-users' specifications.

An essential requirement for effective application of geo-information technologies and their data products is the establishment of user-friendly geo-information networks, enhancing data availability at a country as well as worldwide levels. Such networks significantly contribute to benefits obtainable from international satellite-based mapping and monitoring initiatives because they increase the accessibility of their products, facilitate their multiple uses and reduce duplication of effort. GLCN fulfills this role in the fields of land cover mapping and monitoring. It promotes standardization of land cover mapping and monitoring methodologies and contributes to more effective dissemination of information on land cover databases and their products. Hence, it provides the needed link between advanced technology and its end-users.

The continuing high population increase in developing countries expected during the next 50 years demands mobilization of all our resources to be able to assure the adequate food and fresh water supplies while preserving the Earth's environment for future generations. The geo-information technologies are ready to provide the technical inputs needed by planners of sustainable development and management of renewable natural resources. The GLCN has been participating in this effort by facilitating an on-line access to harmonized global land cover information. Increased support for provision of technical assistance to developing countries, particularly to the least developed ones, is required to assure their active participation in the effective use of new technological tools and information products for sustainable development and management of the Earth's land and water resources.

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12.2 Websites

http://www.africover.org - FAO Africover project

http://www.fao.org/gtos - Global Terrestrial Observing System (GTOS).

http://www.igospartners.org - Integrated Global Observing Strategy (IGOS).

http://www.fao.org/gtos/igos/assets.asp - IGOS documentation, themes and links

http://www.globalcarbonproject.org - Integrated Global Carbon Observation (IGCO)

http://earthobservations.org/ - Ad hoc Group on Earth Observations (GEO)

http://www.esa.ssc.nasa.gov/geo - Ad hoc Group on Earth Observations (GEO).

http://eospso.gsfc.nasa.gov/eos_homepage/ - Earth Observing System (EOS).

http://eosdatainfo.gsfc.nasa.gov/ - Status of EOS satellite missions.

http://geo.arc.nasa.gov/sge/landsat/landsat.html. – Status of Landsat missions.

http://landsat7.usgs.gov/dataprod.php - Information on Landsat data products.

http://radarsat.space.gc.ca - Information on Radarsat status and products.

Annex 1.

The Artimino Declaration

We, the experts participating in the International Expert Consultation on Strategies for Land Cover Mapping and Monitoring, being jointly organized by FAO and UNEP in cooperation with the Italian Ministry of Foreign Affairs through the Istituto Agronomico per l'Oltremare, and with the support of the Regione Toscana, from 6 to 8 May 2002, at Artimino, Florence, Italy:

Realizing that the Earth ecosystems are increasingly experiencing anthropogenic pressures and that environmental degradation, poverty and food insecurity are strongly interlinked and continue to be the major factors threatening sustainable development in the new millennium;

Recognizing that baseline natural resource and environmental information, including in particular land cover and land cover change information, is key for addressing issues relating to poverty, food insecurity and environmental degradation and for developing operational solutions to sustainable development, and that consistent critical information components are lacking at the local, national and global levels;

Recognizing also that a number of initiatives on land cover mapping and monitoring are already in existence, but no single initiative at national, regional or international levels can effectively address the issues alone, and believing that an added value will be generated through synergy and harmonization of various initiatives among interested stakeholders;

Hereby fully support the establishment of a Global Land Cover Network in response to user needs and operational applications focusing on national perspectives and globally distributed responsibilities, with the objective of enabling the provision of information on land cover and its dynamics for better decision-making at all levels in support of sustainable development, through networking and harmonizing technical approaches at global, regional, national and local levels;

Invite FAO and UNEP to take the lead, in partnership with other UN agencies and international organizations and programmes, to provide technical and operational support for the development and the maintenance of the Network;

Call for building a coalition among governmental and inter-governmental agencies, academic institutions, the private sector and other interested stakeholders in the processes of institutional networking, strengthening national capacity, harmonizing land cover classification and mapping, and developing global land cover databases;

Request the donor community to financially support the development and successful operation of the Global Land Cover Network; and

Call further for all stakeholders concerned to integrate the recommendations of this Expert Consultation into their policy considerations and action plans.

Endorsed by consensus
8 May 2002

Annex 2 (page1)

An Example of Completed Field Verification Form.

Annex 2 (page 2)

Annex 2 (page 3)

Annex 2 (page 4)

Annex 3.

Overview of Satellite Remote Sensing Systems for Land Cover Mapping at Regional and Global Levels.

Number of Earth observation satellites and the capacities of sensors in their remote sensing payloads have been steadily growing. The United States, France, Russia, India, Japan, Canada, Brazil, China and the European Space Agency are operating the civilian satellite Earth observation programs. Several other countries are expected to join them.

Remote sensing data from EO satellites are the main source of information on land cover and its changes at global and regional levels. Satellite remote sensing is the only geospatial data source, which can provide the repetitive coverage of the Earth surface economically at these levels. The satellite optical and microwave remote sensing systems are usually categorized into four groups based on ground spatial resolution of their image data:

- Coarse resolution (about 1 km) remote sensing systems;
- Medium resolution (100 - 500 m) remote sensing systems;
- High resolution (10 - 100 m) remote sensing systems;
- Very high resolution (< 10 m) remote sensing systems.

The information content and level of detail in high resolution optical multispectral images are compatible with the requirements of land cover mapping at scales 1:100 000 to 1:250 000. The images from microwave (SAR) remote sensing systems are used in areas with persistent cloud cover, as in humid tropics. For example, it may take several years before a good quality satellite image is recorded by a satellite optical remote sensing system in some areas of central Africa or Indonesia.

Images recorded by medium resolution satellite remote sensing systems are suitable for monitoring land cover changes, compatible with mapping scales 1:100 000 to 1:250 000, once the baseline land cover dataset, based on interpretation of high resolution images, has been established.

Therefore, only the high and medium resolution satellite remote sensing systems were included in the overview.

Not all satellite missions reviewed in this Annex produce global image coverage or maintain a systematic archive of image data. Yet, depending on the location of the area where land cover mapping or monitoring is planned, information about these missions may enlarge the options for acquisition of input satellite images.

Based on cost of image data per 1 km^2, the Landsat TM and ETM images have been the most economic ones. However, there is a risk that there may be an interruption of

Landsat coverage if a bridging satellite with ETM system onboard is not launched before the National Polar-orbiting Operational Satellite System (NPOESS), which launch is scheduled in late 2009. The NPOESS will include the Landsat ETM+ remote sensing system in its sensors payload.

High Resolution (10 - 100 m) Satellite Remote Sensing Systems

a) Optical Remote Sensing Systems

- **Landsat 5-TM:** Image data from the Thematic Mapper (TM) remote sensing system has been widely used for land cover mapping and change monitoring. The Landsat series of Earth observation satellites, in operation since 1972, provides a long term remote sensing observatory that enables a reliable worldwide assessment of land cover changes over a 30-year period. The Thematic Mapper records image data in seven spectral bands (3 VIS, 1 near-IR, 2 mid-IR and 1 thermal IR). Their ground resolution is 30 m in the visible, near-IR, and mid-IR spectral bands and 120 m in thermal IR band. Image data are formatted into 170 km x 185 km scenes. They form the basis of Landsat's Worldwide Reference System (WRS), which is used for identification and ordering of Landsat image products.

  Landsat 5 was launched in March 1984. At this time (end 2004), it continues to provide high quality images on a regular basis worldwide. However, it has greatly exceeded its projected lifetime and its systems may fail and terminate its operations.

- **Landsat 7-ETM+:** It was the first satellite launched (April 1999) in the framework of the NASA's Mission to Planet Earth (MTPE) and its Earth Observing System (EOS), which is a long-term comprehensive global environmental monitoring program. The ETM+ remote sensing system records image data in eight spectral bands. The first seven bands are the same as the TM bands, the new, eighth band is panchromatic band (520 nm - 900 nm). Ground resolution is 15 m in the panchromatic band, 30 m in the visible and NIR bands and 60 m in the thermal IR band. Each ETM+ scene of 170 km x 185 km covers an area of 31,450 km^2 (the same size as TM scene). Total coverage of the Earth is accomplished every 16 days.

  In late May 2003, Landsat 7's ETM+ remote sensing system suffered a failure of its scan line corrector resulting in gaps in image coverage. The problem has been partially corrected by filling the gaps with data acquired at different dates, within weeks of each other.

  The US Government, in order to assure the Landsat data continuity, agreed to incorporate the Landsat-type remote sensing system on the **National Polar-orbiting Operational Satellite System (NPOESS)**. The first NPOESS spacecraft (C-1) is scheduled for launch in late 2009. In order to prevent a possible interruption of Landsat coverage, the US Government is considering a bridging satellite mission with Landsat-type remote sensing system before 2009.

- **SPOT 4-HRVIR.** New remote sensing system, the High Resolution Visible and Near Infrared (HRVIR) was introduced on SPOT 4, which was launched in March 1998. It consists of four spectral bands with 20 m ground resolution: green, red, NIR, and MIR. Although the HRVIR does not have a separate panchromatic band, the panchromatic images are recorded in the red band with ground resolution of 10 m. Image data are formatted into 60 km x 60 km scenes. An important feature of SPOT is its off-nadir viewing capability (27^{o} on either side of its track) that allows recording of stereo-images and production of digital elevation model (DEM). Total Earth coverage is accomplished every 26 days.
- **SPOT 5-HRVIR+** is the latest of the SPOT series of Earth observation satellites that started in 1986. It was launched in May 2002. Although its four spectral bands are the same as those on SPOT 4, their ground resolution is 10 m (instead of 20 m) in the three visible and NIR bands and remains 20 m in the MIR band. It also has a separate panchromatic band (510-730 nm) with very high ground resolution (5 m and 2.5 m). Precise geometric calibration of SPOT 5 is particularly important for mapping applications. The planimetric accuracy of its image data is 10 m (rms), elevation accuracy 5 m (rms). SPOT 5 images are useful for validation of global and regional land cover maps in sample areas.

- **IRS-1C & D-LISS-3.** The Indian remote sensing satellites (IRS 1C & 1D) were launched in December 1995 and September1997, respectively, and both are still in operation (2004). The identical Linear Imaging Self-Scanning remote sensing systems (LISS-3) used on these satellites record image data in one panchromatic and four spectral bands (green, red, NIR, and MIR). The ground resolution is 5 m (after resampling) in panchromatic band (500-750 nm) and 20 m (after resampling) in two VIS and one NIR spectral bands and 70 m in MIR band. Swath width is 140 km.

- **IRS-P6-RESOURCESAT-1.** The most advanced Indian remote sensing satellite, the RESOURCESAT-1 was launched in October 2003. Its sensor payload includes three remote sensing systems. One is a very high resolution system, two are high resolution systems. The high resolution systems include:
  - Upgraded LISS-3 high resolution remote sensing system yielding 20 m ground resolution (after resampling) in two VIS, one NIR and one MIR spectral bands. Swath width is 140 km;
  - Advanced Wide Field Sensor (AWiFS) yielding 50 m ground resolution (after resampling) in two VIS, one NIR and one MIR spectral bands. Swath width is 730 km.

- **ALOS AVNIR-2.** The Japanese Advanced Land Observing Satellite (ALOS) is scheduled for launch in late 2004. It will have three remote sensing systems, one very high resolution and two high resolution systems. The high resolution systems include:
  - The Advanced Visible and Near-IR Radiometer type 2 (AVNIR-2) for land cover observations. It will record images in four spectral bands (blue, green, red and NIR) with ground resolution of 10 m. Its swath width will be 70 km. It will have a cross-track pointing capability ($\pm 44^{o}$), which will enable stereo-imaging and frequent revisits of selected sites;
  - The Phased Array L-band SAR (PALSAR) for all weather, day-and-night observations, recording image data with 10 m (Fine Resolution mode) and 100 m (ScanSAR mode) ground resolution.

- **Resurs-01-3 & 4.** Russian remote sensing satellites are represented by the last two spacecrafts of Resurs-01 series: Resurs-01-3, launched in October 1994 to a mean orbit height of 678 km and Resurs-01-4, launched in July 1998 to a mean orbit height of 835 km. Each spacecraft has two remote sensing systems on board: the high resolution system MSU-E and the medium resolution system MSU-SK.

  The MSU-E system is multispectral optical radiometers with CCD line arrays, one for each of its three spectral bands (2 VIS and 1 NIR). The MSU-E system in Resurs-01-3 has ground resolution 35 m x 45 m and the swath width 45 km. In Resurs-01-4 the ground resolution is 33 m x 29 m and the swath width 58 km. The MSU-E system also has a cross-track pointing capability up to 30^{o}.

- **CBERS-1A & B.** The China – Brazil series of Earth Resources Satellites (CBERS) started with the launch of CBERS-1A in 1999. The CBERS-1B was launched in October 2003. Both satellites have an identical multisensor payload, which includes two high resolution and one medium resolution remote sensing systems. The high resolution systems are following:
  - CCD remote sensing system. It has five spectral bands (1 PAN, 3 VIS and 1 NIR), 20 m ground resolution and 120 km ground swath width. It has a cross-track pointing capability ($\pm 32^{o}$), which enables three days revisit capability.
  - IR-MSS remote sensing system. It has four spectral bands (1 PAN, 2 MIR and 1 TIR), 80 m ground resolution in the panchromatic and medium-IR bands and 160 m ground resolution in the thermal IR band. The ground swath width is 120 km.

(b) Synthetic Aperture Radar (SAR) Remote Sensing Systems

- **RADARSAT-1 SAR** was launched in November 1995. It is a Canadian commercial imaging SAR satellite, which operates in C-band (frequency 5.3 GHz) with horizontal polarization. The unique feature of RADARSAT SAR system is the wide choice of imaging modes. There are 25 possible choices, depending on the selection of incidence angle (10 to 59 degrees), ground resolution (6 choices, from 10 m to 100 m), and size of RADARSAT SAR scene (from 50 km x 50 km to 500 km x 500 km). Nominal ground resolution is 10 m in fine mode, 25 m in extended high mode, 30 m in standard and wide modes, 35 m in extended low mode, 50 m in ScanSAR-N mode, and 100 m in ScanSAR-W mode. **RADARSAT-2**, which is scheduled for launch in late 2005, will record image data also in C-band but with ground resolution from 3 m to 100 m and quad polarization (HH, VV, HV, VH) that will improve discrimination of land cover types and identification of agricultural crops.

- **ERS-2.** It was launched in 1995 by the European Space Agency. The ERS-2 has an identical imaging SAR system as the ERS-1 that was launched in 1991 and retired in 2000. Its SAR system operates in C-band with vertical polarization. Ground resolution of its imagery is 25-30 m, swath width 100 km. Incidence angle is fixed, 23° at mid-swath.

- **ENVISAT-ASAR.** It was launched by the European Space Agency in March 2002. Its remote sensing payload includes an Advanced SAR (ASAR) system with C-band (5.3 GHz frequency). The ASAR has three operating modes: global monitoring mode, wide swath mode, and image mode. The image mode (IM) yields imagery with 30 m ground resolution at dual polarization (HH or VV) over 100 km swath. The ASAR has a steerable imaging beam allowing image recording at different incidence angles.

- **ALOS-PALSAR.** Japanese Advanced Land Observing Satellite (ALOS) is scheduled for launch in late 2004. Its remote sensing payload will include the Phased Array L-band SAR (PALSAR) with two image recording modes: Fine Resolution mode and ScanSAR mode. In the fine resolution mode, the PALSAR will record images with ground resolution of 10 m in four spectral bands (blue, green, red and NIR) and quad polarization (HH, VV, HV, VH). Its swath width will be 70 km. It will have a cross-track pointing capability ($\pm 44^{\circ}$). Its L-band (1.27 frequency) will be of particular interest to forest mapping and monitoring.

Medium Resolution (100 - 500 m) Satellite Remote Sensing Systems

(a) Optical Remote Sensing Systems

- **TERRA-MODIS.** Moderate Resolution Imaging Spectroradiometer (MODIS) is an advanced remote sensing system that has been used on TERRA satellite since its launch in December 1999. It records the Earth's surface in 36 spectral bands. 29 of these bands are recorded with 1 km ground resolution (4.1-a), five bands (blue, green and 3 NIR bands) with 500 m resolution and two bands (red and NIR) with 250 m resolution at nadir. The bands with 250 m resolution enable production of NDVI. The swath width of 2,330 km provides global coverage every 1-2 days. TERRA-MODIS system is particularly suitable for global land cover mapping. About 50 receiving stations worldwide were recording MODIS direct broadcast data at the end of 2001.

- **AQUA-MODIS.** AQUA, which was launched in May 2002, is the second in a series of large EOS missions, following the launch of TERRA. Its sensor payload includes MODIS, with the same parameters as in TERRA (see above).

- **TERRA-MISR.** Multi-angle Imaging Spectro-Radiomater (MISR) is recording the multispectral images of the Earth surface simultaneously in fore, nadir and aft viewing angles, thus generating the stereo image sets. The images are recorded in four spectral bands, blue, green, red and NIR, with ground resolution of 275 m over 360 km wide swath. Global coverage is obtained every 9 days at the equator. MISR can also operate in Global Mode, yielding lower ground resolution, by averaging the adjacent pixels.

- **IRS 1C & D-WiFS**. The Wide Field Sensor system on the Indian Earth observation satellites IRS 1C & D has been operational since 1995 and 1997, respectively. It records image data with ground resolution 188 m at nadir in two spectral bands, red and NIR, which enable production of NDVI. Its swath width is 774 km, providing a global coverage every 5 days at equator.

- **ENVISAT-MERIS.** The Medium Resolution Imaging Spectrometer (MERIS), which records image data in 15 spectral bands (visible and NIR), can be operated at either full resolution (300 m at nadir) or reduced resolution (1.2 km at nadir). The 1.2 km image data are continuously recorded while the operation at full resolution is activated only upon users' request. Swath width of MERIS is 1,450 km. Its image products are similar to those generated by the TERRA-MODIS system.

- **Resurs-01-3 & 4.** Russian remote sensing satellites Resurs-01-3 and Resurs-01-4 were launched in October 1994 and July 1998 respectively. Each spacecraft has two remote sensing systems on board: the high resolution system MSU-E and the medium resolution system MSU-SK.

  The MSU-SK system has five spectral bands (2 VIS, 2 NIR and 1 TIR). Its ground resolution in VIS and NIR bands is 185 m x 140 m and the swath width 600 km for Resurs-01-3 spacecraft. In Resurs-01-4 the ground resolution is 130 m x 170 m and the swath width 710 km. The thermal IR band has ground resolution approximately four times poorer.

- **CBERS-1A & B.** The China – Brazil series of Earth Resources Satellites (CBERS) started with the launch of CBERS-1A in 1999. The CBERS-1B was launched in October 2003. Both satellites have an identical multisensor payload, which includes two high resolution and one medium resolution remote sensing systems. The medium resolution system is following:

- Wide-Field Imager (WFI). It has two spectral bands, 1 PAN (red) and 1 NIR, which enable generation of vegetation index data. It has 260 m ground resolution, 900 km ground swath width and 3 – 5 days revisit capability.

(b) Synthetic Aperture Radar (SAR) Remote Sensing Systems

- **RADARSAT-1 SAR.** The first Earth observation satellite with a SAR system designed for fully operational, commercial applications. It operates in C-band (frequency 5.3 GHz) with horizontal polarization. Since its launch in November 1995, it has been recording SAR imagery with selectable ground resolution from 10 m to 100 m and selectable SAR beam position (a choice of seven incidence angles). The ScanSAR-Wide mode yields 100 m ground resolution and the scene size 500 km x 500 km. The scale of ScanSAR-W map products is 1:250 000. **RADARSAT-2 SAR** is scheduled for launch in late 2005.

- **ENVISAT-ASAR.** The Envisat was launched in March 2002. It has onboard an Advanced SAR (ASAR) system with C-band (5.3 GHz frequency). The ASAR has three operating modes: global monitoring mode, wide swath mode, and image mode. The wide swath mode (WS) yields imagery with 150 m ground resolution at dual polarization (HH or VV) over 405 km swath. The ASAR has a steerable imaging beam allowing image recording at different incidence angles.

- **ALOS-PALSAR.** The Japanese Advanced Land Observing Satellite (ALOS) is scheduled for launch in late 2004. Its remote sensing payload will include the Phased Array L-band SAR (PALSAR) system. The PALSAR will have two operating modes: ScanSAR mode and Fine Resolution mode. In the ScanSAR mode the image data will be recorded with ground resolution of 100 m in four spectral bands (blue, green, red and NIR) and dual polarization (HH, VV). The swath width will be 250-350 km. The PALSAR will have a cross-track pointing capability ($\pm 44^{o}$). Its L-band (1.27 GHz frequency) will be of particular interest to forest mapping and monitoring.

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