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African Water Resource Database

GIS-based tools for inland aquatic resource management

1. Concepts and application case studies

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1. Concepts and application case studies

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Preparation of this document

This study is an update of an earlier project led by the Aquatic Resource Management for Local Community Development Programme (ALCOM) entitled the "Southern African Development Community Water Resource Database" (SADC-WRD).

Compared with the earlier study, made for SADC, this one is considerably more refined and sophisticated. Perhaps the most significant advances are the vast amount of spatial data and the provision of simplified and advanced custom-made data management and analytical tool-sets that have been integrated within a single geographic information system (GIS) interface.

The publication is presented in two parts in order better to inform readers of various levels of familiarity with the benefits of spatial analyses for aquatic resources management.

Part 1 is divided into two main sections:

- The first section is aimed at administrators and managers with only a passing knowledge of spatial analyses but who would be interested to know the capabilities of the African Water Resource Database (AWRD) to assist with their decision-making. They may be department or division heads in government, non-governmental organizations (NGOs) and international organizations. Thus, a few examples of decision-making at this level based on spatial analyses from AWRD are described.
- The second section is addressed to professionals in technical fields who may actually or potentially employ the results of spatial analyses in their work. They may be in international organizations, government, universities or in the commercial sector. The case studies best serve to inform them of AWRD capabilities.

Part 2 is also divided into two main sections:

- The first section is written for spatial analysts in government, international organizations or the private sector.
- The second is for university teachers and students who may wish to use AWRD for educational purposes. This section includes a workbook with exercises, offering educational possibilities of AWRD.

Publication of this document has been supported by FishCode, the Programme of Global Partnerships for Responsible Fisheries of the FAO Fisheries and Aquaculture Department, through contributions provided by the Government of Norway to the FishCode Trust (MTF/GLO/125/MUL).

Foreword

The "Status and Development of the African Water Resources Database (AWRD)" was presented at the twelfth session of the Committee for Inland Fisheries of Africa (CIFA) held in Yaoundé, Cameroon, from 2 to 5 December 2002. The Committee acknowledged that such GIS-based products are "powerful tools for fishery and aquaculture management, planning and development." The Committee also noted that there were still outstanding issues to be resolved before such tools could practically and effectively be used by Member countries. The present report represents the follow-up activities based on CIFA's recommendations.

Inland aquatic resources in developing regions around the world are immensely significant for food security as well as economic growth and poverty alleviation. However, the rational and sustainable use of essential resources is critical. The multi-purpose nature of inland water use patterns creates distinct sets of challenges for implementation of responsible development and management measures, and hence to the promotion of water, food and environmental security.

Geospatial information is increasingly being used for better understanding development issues and improving decision-making. The Millennium Development Goals (MDG) and their 2015 targets for halving the proportion of people living with hunger and poverty, and improving living conditions in the sector of education, gender, health and sanitation have heightened this awareness.

This report is one of a series of GIS-based publications under production by FAO's Aquaculture Management and Conservation Service (FIMA) to update an earlier project led by the Aquatic Resource Management for Local Community Development Programme (ALCOM) entitled the "Southern African Development Community Water Resource Database" (SADC-WRD). The body of work presented represents both an expansion to the data and an enhancement of the original SADC-WRD analytic interface. Extended to cover the entire African continent, the new WRD has been entitled the "African Water Resources Database" and it is aimed at facilitating responsible inland aquatic resource management. It thus provides a valuable instrument to promote food security.

The AWRD allows for the integration of different types of information, e.g. fishery statistics, into a cohesive program that, because of its visual nature, is easy to understand and interpret. Systems such as the AWRD are excellent means to attract and direct investments in aquaculture and fisheries development.

I am confident that further explorations and applications of the AWRD data will deepen our understanding of inland aquatic resource management and will demonstrate the usefulness of the AWRD tool, whilst being immediately applicable to assist in a wide variety of recent issues addressed at CIFA such as: improving the reporting on status and trends in inland fisheries and aquaculture; co-management of shared inland fisheries resources; transboundary movements of aquatic species; and increased participation of stakeholders in the decision-making process about watershed area uses.

Alfred Yeboa Tetebo
CIFA Chairman
Director of Fisheries
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Abstract

This report represents a follow-up activity based on the recommendations by the Committee for Inland Fisheries of Africa (CIFA). The report is an update of an earlier project led by the Aquatic Resource Management for Local Community Development Programme (ALCOM) entitled the "Southern African Development Community Water Resource Database" (SADC-WRD). The body of work presented in this publication represents both an expansion to the earlier data and an enhancement of the original SADC-WRD analytic interface. Extended to cover the entire African continent, the new set of data and tools has been entitled the "African Water Resource Database" (AWRD). The overall aim of the AWRD is to facilitate responsible inland aquatic resource management. It thus provides a valuable instrument to promote food security.

The AWRD data archive includes 28 thematic data layers drawn from over 25 data sources, resulting in 156 unique datasets. The core data layers include: various depictions of surface waterbodies; multiple watershed models; aquatic species; rivers; political boundaries; population density; soils; satellite imagery; and many other physiographic and climatological data types. The AWRD archival data have been specifically formatted to allow their direct utilization within any geographic information system (GIS) software package conforming to Open-GIS standards. To display and analyse the AWRD archive, the AWRD also contains a large assortment of new custom applications and tools programmed to run under version 3 of the ArcView GIS software environment (ArcView 3.x). There are six analytical modules within the AWRD interface: 1) the Data and Metadata Module; 2) the Surface Waterbodies Module; 3) the Watershed Module; 4); the Aquatic Species Module; 5) the Statistical Analysis Module; and lastly, 6) the Additional Tools and Customization Module. Many of these tools come with simple and advanced options and allow the user to perform analyses on their own data.

The case studies presented in this publication illustrate how the AWRD archive and tools can be used to address key inland aquatic resource management issues such as the status of fishery resources and transboundary movements of aquatic species. This publication by no means cover all the issues that could be resolved using the AWRD, but they do provide a solid reference base for inland aquatic resource management in Africa. Based on a review and recommendations by CIFA, a number of opportunities to implement the AWRD tools and data in Africa have already been identified. Likewise, a number of future developments for the AWRD have been proposed, including AWRD-like frameworks for Latin America and Asia.

This publication is organized in two parts to inform readers who may be at varying levels of familiarity with GIS and with the benefits of the AWRD. The first part describes the AWRD and is divided into two main sections. The first presents a general overview and is addressed to administrators and managers while the second is written for professionals in technical fields. The second part is a "how to" supplement and includes a technical manual for spatial analysts and a workbook for university students and teachers.

The primary AWRD interface, tool-sets and data integral to the function of the AWRD are distributed in two DVD's accompanying part 2 of this publication and are also available for download on the Internet in FAO's GeoNetwork and GISFish GIS portals. A more limited distribution of the above primary database/interface, but divided among ten separate CD-ROM disks, is available upon request to FAO's Aquaculture Management and Conservation Service. Also, high resolution elevation datasets and images amounting to 38 gigabytes are available upon request for those who need them.

Jenness, J.; Dooley, J.; Aguilar-Manjarrez, J.; Riva, C.
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Patrizia Monteduro prepared the AWRD archive datasets for their publication on the Internet in FAO’s GeoNetwork GIS portal, and Roberto Giaccio wrote the script to convert the metadata documentation from the AWRD archive into an XML format for display in GeoNetwork.

Emily Garding made a final quality check on the AWRD tools and tested the exercises presented in the workbook of part 2 of this publication.

The authors benefited from the data provided by Jippe Hoogeveen on the “Atlas of Water Resources and Irrigation in Africa” and by John Latham on “Africover” databases.

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Some of the locational referencing tools for the AWRD were adapted from original tools developed for the McLennan Co. 9-1-1 Emergency Assistance District in Waco, Texas, the United States of America, and are presented here with their permission. Several general purpose tools, including the Select by Theme tool, the Query Builder tool, the Summarize tool and the statistics Histogram window, are adapted from original tools developed for the Saguaro project (University of Arizona; Tucson, Arizona, the United States of America, and are also presented here with their permission. We gratefully acknowledge the generosity of both organizations for sharing these resources with us.

We thank all the organizations which created the datasets and made them available for our use.

Chrissi Smith, Françoise Schatto-Terrible and Tina Farmer proofed the document and supervised its publication. The document layout specialist was Nadia Pellicciotta.

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Acronyms and abbreviations

ADM	Administrative data layer
AFDS	African Data Sampler
AGLW	Agriculture, Land and Water Division
AIMG	Ancillary Image and Map Graphic
ALCOM	Aquatic Resource Management for Local Community Development Programme
ANNO	Annotation
ANOVA	Analysis of Variance
AOI	Area Of Interest
AQSP	Aquatic Species
ARAS	Ancillary Raster
ASCII	American Standard Code for Information Interchange
AVEC	Ancillary Vector
AWRD	African Water Resources Database
AWRIA	FAO-AGLW's African Water Resources and Irrigation in Africa
BADC	Belgian Administration for Development Cooperation
BIL	Band Interleaved by Line raster data format
BIP	Band Interleaved by Pixels image file format
BMP	Bitmap
BNA	Early ASCII mapping format for Atlas-Graphics thematic mapping package
BSQ	Band Sequential image file
CCRF	FAO Code of Conduct for Responsible Fisheries
CD	Compact Disk
CGM	Computer Graphics Metafile
CIA	US Central Intelligence Agency
CIFA	Committee for Inland Fisheries of Africa
CRES	Centre for Resource and Environmental Studies
CRU	Climate Research Unit
DAF	Digital Atlas of Africa
dBASE	Database
DBC	Database Component
DCW	Digital Chart of the World
DD	Decimal Degrees
DEM	Digital Elevation Model
DMA	The former U.S. Defense Mapping Agency, which is now entitled the U.S. National Imagery and Mapping Agency (NIMA)
DN/DNNET	DCW Drainage Network layer
DPI	Dots-Per-Inch
DTED	NIMA's Digital Terrain Elevation Data at various raster postings
EC	European Commission
ECW	Earth Resource Mapping's "Enhanced Compression Wavelet" format for raster imagery
EDC	United States Geological Survey Earth Resources Observation Systems (EROS) Data Center

EMF	Enhanced Metafile Format
EPS	Encapsulated Postscript (file extension)
EROS	Earth Resources Observation Systems
ESAD	NASA's Earth Science Applications Directorate
ESRI	Environmental Systems Research Institute, Redlands, California
ETM+	Landsat Enhanced Thematic Mapper Data
ETOPO2	A 2 minute Elevation Topographic DEM including bathymetry
ETOPO5	An early global 5 minute DEM
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FIMA	Aquaculture Management and Conservation Service
GARP	Genetic Algorithm for Rule-Set Production
GeoCover-LC	Land Cover based on Ortho-Rectified LandSat Imagery
GeoNet	Gazetteer Name Server
GeoNetwork	FAO's Spatial Data and Information Portal
GIEWS	FAO's Global Information and Early Warning System
GIF	Graphic Interchange Format (file extension)
GIS	Geographic Information Systems and software platforms
GIWA	Global International Water Assessment
GLOBE	NOAA distributed release of GTopo30
GNS/GeoNet	NIMA's Geographic Names Server Gazetteer of Named Locations
GSDI	Global Spatial Data Infrastructure clearing-house for SDI
GSM	Golden Software Map, a proprietary GIS format
GT30/GTopo30	Global Topographic 30 arc second DEM database, nominal 1km postings
GT30BATH	Combined GTopo30 and Scripps/Smith and Sandwell Bathymetry
GUI	Graphical User Interface
GZTR	Gazetteer/Named Location
H1k/HYDRO1k	Global Hydrological 1 kilometre database
HTML	Hyper Text Markup Language
HYD	Hydrological feature subset of the LC/LCPOLY (DCW Land Cover layer)
ID	Identifier, usually denoting a unique numerical or alphanumeric code
IEBM	Image Export and Base Mapping tool-set of the AWRD
IHO	Standards for Maritime Waterbodies based on the International Hydrographic Bureau of the International Hydrographic Organization
ISCGM	International Steering Committee for Global Mapping
ISO	International Organization for Standardization
IW	VMap0 Inland Water layer
JPG/JPEG	Graphics file type/extension (lossy compressed 24 bit color image storage format developed by the Joint Photographic Experts Group)
JPL	NASA's Jet Propulsion Laboratory
JRC	Joint Research Centre of the European Commission
LAEA	Lambert Azimuthal Equal Area projection system
LC/LCPOLY	DCW Land Cover layer
LCL	Lower Confidence Limit
LME	Large Marine Ecosystems

LO	Layout
LOE	Level of Effort
LWDD	FAO's Land and Water Development Division
MADE	Multipurpose land cover databases
MGLD	MSSL Global Lakes Database
MM	The secondary maritime encoding parameter pertaining to the proposed FAO hydrological encoding standard
MODIS	Moderate resolution imaging spectroradiometer sensor on Terra satellite
MrSID	LizardTech's commercial compression format for spatial imagery
MSSL	Mullard Space Science Laboratory
NASA	U.S. National Aeronautical and Space Administration
NGA	National Geospatial-Intelligence Agency (new name for NIMA)
NGDC	NOAA's National Geo-Physical Data Center
NGO	Non-Governmental Organization
NIMA	U.S. National Imagery and Mapping Agency, formerly the U.S. Defense Mapping Agency (DMA)
NOAA	U.S. National Oceanographic and Atmospheric Administration
ODB	Object Database
ONC	Operational Navigation Charts
ORNL	U.S. Oak Ridge National Laboratory
Ortho/ORTH	Orthographically-rectified, i.e. flattened or adjusted for elevation changes
OrthoTM	Ortho-rectified or flattened imagery
OS	Operating System
OVRVW	A virtual Overview map
PAIA	FAO's Priority Areas for Interdisciplinary Action
PDF	Portable Document Format (Adobe Acrobat)
PNG	Portable Network Graphics (graphic file standard/extension)
PS	PostScript (file name extension)
PTES or Pfaf	Pfafstetter Topological Encoding Scheme, a 5 to potentially 22 long numeric digit or encoding string for encoding spatially based continental hydrographic data.
PY	Potential Yield
PYPUA	Potential Yield per Unit of Area
RAID	Redundant Array of Inexpensive Disks
RDBMS	Relational Database Management Systems
RGB	3 band spatial imagery forced into the Red:Green:Blue spectrum
RIV	Rivers and Drainage/Flow
RRSU	The SADC Regional Remote Sensing Unit located in Harare Zimbabwe
SADC	The Southern African Development Community
SAIAB	South African Institute for Aquatic Biodiversity (formerly known as JLB Institute of Ichthyology)
SARPO	The Southern African Regional Programme Office of WWF located in Harare Zimbabwe
SDE	see Manual (subsect. Excel Import and Export Tools)
SDI	Spatial Data Infrastructure
SHD	Shaded Relief

SIFRA	Source Book for the Inland Fisheries Resources of Africa
SRTM	Shuttle Radar Topography Mission
SSN-TF	FAO's Spatial Standards and Norm Task Force
SWB	Surface Waterbody
TIF/TIFF	Tagged Image File Format (graphics/image file format)
TM	Landsat Thematic Mapper.
TOC	Table Of Contents
TOR	Terms of Reference
U.S.	The United States
UCL	Upper Confidence Limit
UFI	Unique/Universal Feature Identifier
UN	United Nations
UN-CS	United Nations Cartographic Section
UNEP	United Nations Environment Programme
UN-GD	The UN-CS 1:10-1:5 million Global GIS Database
UNGIWG	United Nations Geographic Information Services Working Group
UNL	University of Nebraska at Lincoln, USA
URI	University of Rhode Islands, USA
URL	Universal Resource Locator for the identification of specific locations or web-sites on the WWW
USAID	The U.S. Agency for International Development
USFS	The U.S. Forestry Service
USGS	The United States Geological Survey
UTM	Universal Transverse Mercator
VMAP	NIMA's Vector Smart Map standard for various scales of vector data
VMAP0	Vector Map for Level 0
VPF	NIMA's Vector Product Format for the encoding of VMAP data libraries
VRTL	A seamless 1:750 000 Virtual basemap
WC	Water Course layer of VMAP0
WCMC	World Conservation Monitoring Centre
WDBII	CIA's 1:3 - 1:5m scale World Database II
WGS	World Geodetic Standard, 1984 standard datum and spheroid
WMF	Windows Metafile (file name extension)
WRD	The original SADC Water Resource Database produced by ALCOM
WRI	World Resources Institute
WS	Watersheds
WTLND	Wetlands
WVS	World Vector Shoreline
WWF	World Wide Fund for Nature (known as World Wildlife Fund in the U.S.)
WWW	World Wide Web

1. Spatial analysis for inland aquatic resources management

1.1 INTRODUCTION

Overview and objectives

Overview

Inland aquatic resources in developing regions around the world are of immense significance in terms of food security as well as economic growth and the alleviation of poverty. Aquaculture plays an increasingly important role in the global economy and fisheries contribute significantly to poverty alleviation, food security and recreation. However, ever-increasing demand for fish products makes it difficult to maintain the balance between supply and sustainable production. In addition to pressure resulting from the need to increase the exploitation of aquatic resources, the sustainable use of inland water resources is often put at risk from other human activities such as deforestation, dam-building, navigation, urbanization, water extraction, pollution and waste disposal, and the related loss of wetland habitat to arable land. Therefore, the multi-purpose nature of inland water use creates a very distinct set of challenges for responsible development and management, and hence the promotion of water, food and environmental security.

Water, the uses to which it is put and the impacts of those uses and other activities upon it, is central to the world development agenda. It is directly or indirectly relevant to all the Millennium Development Goals (MDG) and central to the implementation plan of the World Summit on Sustainable Development (UN, 2005). Testament to this is the ever-growing number of major international conferences, forums and summits on food security, environment and development that have dealt with water (e.g. 1992 UN Agenda 21 (UN, 1992), Chapter 18; 1996 World Food Summit (FAO, 1996); 2002 World Food Summit five years later (FAO, 2002a); 2002 Johannesburg World Summit on Sustainable Development; 2000 UN Millennium Declaration; World Water Forums (1997, 2002, 2003, 2006); World Water Day (1994–2006); 2006 World Water Week (Stockholm International Water Institute, 2006); 2003 International Year of Freshwater; 2005 General Assembly of the United Nations resolution A/RES/58/217; 2005 Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005); Global International Waters Assessment (UNEP, 2006a).

Specific to Africa, there exist wide disparities in water availability and general poor access to safe drinking water and sanitation. Overall, people across the continent suffer from the lowest water supply coverage in the world, a situation that has led to a dangerous health situation in many regions where hunger and water-related diseases are regular threats (UNESCO, 2003; FAO, 2005; UNEP 2006b; Comprehensive Assessment of Water Management in Agriculture, 2007). Africa is also an area of the world in which chronic hunger continues to be widespread (FAO, 1996; UNICEF, 2005; UNDP, 2005).

The total number of chronically undernourished people in the world is estimated by FAO at 854 million for the period 2001–03, of whom 820 million live in developing countries, 25 million in countries in transition and 9 million in developed market economies. As in previous years, more than half of the total number of undernourished, 61 percent, live in Asia and the Pacific, while sub-Saharan Africa accounts for 24 percent of the total. The highest prevalence of undernourishment is found in sub-Saharan Africa, where FAO estimates that 32 percent of the population is undernourished (FAO, 2006a). According to an FAO study on "World agriculture: towards 2015/30" (FAO, 2003) in sub-Saharan Africa, 12.4 percent of the population or 140 million people will still be undernourished by 2030. This will be by far the highest total for any region. Recent estimates by FAO for undernourishment predict for 2050 a reduction of the population undernourished to 5.8 percent equivalent to 88 million people (FAO Global Perspective Studies Unit, 2006). However, the fate of sub-Saharan Africa is still cause for serious concern.

The World Summit on Sustainable Development (WSSD) held in Johannesburg in 2002 provided the fundamental principles for the implementation of a sustainable development plan in response to a growing signs of over-exploitation and loss of biodiversity, modification of ecosystems and significant economic losses, and where international conflict on management of fish trade threatening the long-term sustainability of fisheries and the contribution of fisheries to food security.

As recognized in the FAO Code of Conduct for Responsible Fisheries, sustainability is a fundamental management and development requirement for both inland fisheries and aquaculture.

Many of the issues important for sustainability are entirely spatial, or they have important spatial elements. Participants at the WSSD summit found that issues of sustainability were comprised of a number of interrelated spatial elements. Section 132 of the WSSD Report advocates promotion of, "the development and wider use of earth observation technologies, including satellite remote sensing, global mapping and geographic information systems, to collect quality data on environmental impacts, land use and land-use changes… (UN, 2002)."

In order to respond at least in part to the above principles and objectives, the following sets of issues in sustainable inland fisheries and aquaculture practices have been identified by Kapetsky and Aguilar (2004) as having a spatial component:

Inland fisheries spatial issues addressed most frequently include: Status of fishery resources (habitat quality and quantity linked to fish abundance and distribution), fisheries (planning and potential), environment (impacts on fishes and habitats), multisectoral planning and management that includes fisheries.

Aquaculture spatial issues addressed most frequently include: Development (siting and zoning, strategic planning), practice and management (inventory and monitoring of aquaculture and the environment, as well as environmental impacts), and integration of aquaculture into other uses of lands and waters (management of aquaculture together with fisheries, multisectoral planning including aquaculture).

This publication addresses some of the issues cited above via the introduction of the African Water Resource Database (AWRD), a GIS-based analytical framework supporting aquatic resource management. Although the AWRD represents a wholly new development initiative, the original basis of the AWRD began in 1995 with an earlier project led by the Aquatic Resource Management for Local Community Development Programme (ALCOM) and the Southern African Development Community (SADC) Water Resource Database (Verheust and Johnson, 1998a, b; Johnson and Verheust, 1998). Therefore, the AWRD publication represents both the continuation and enhancement of the body of work resulting from ALCOM's earlier efforts.

Objectives

The overall aim of this report is to facilitate responsible inland aquatic resource management; thus providing a valuable instrument to promote food security. Specific objectives are aimed at stimulating and/or supporting the development of two important planning schemes:

- The development of regional, national and local level studies by providing: (a) a medium whereby fisheries, water and terrestrial resource managers can share and evaluate information; and (b) data and tools to analyse the sustained utilization of inland aquatic resources; and
- The development of comprehensive plans for technical assistance by FAO and other national and international organizations, as well as national governments and financing institutions for aquatic resource management.

Stakeholders

Fisheries are significantly impacted by many alternative uses of river and lake basin resources including: power generation, flood control, navigation, domestic use, agriculture, forestry, industry, mining, water transfers and wildlife conservation (Welcomme, 2001). Given this multitude of uses, it should be recognized that inland aquatic ecosystems and the organisms they support are among the most vulnerable natural systems on the planet. This factor is of particular importance when it is further recognized that almost all natural and human activities taking place within a basin affect the quality and quantity of the water and of the overall hydrological system (UNESCO-WWAP, 2003). Some of the main issues associated with water use amongst stakeholders are summarized in Box 1.

BOX 1

Multistakeholder issues in water use

Water quality, quantity and temperature are essential elements for all living aquatic resources and thus for fisheries and the development of aquaculture.

All human development targets relating to food require significant amounts of water. The growing demand for water for industries, agriculture, generation of hydropower, urban supply and navigation increases competition for this limited resource and often results in declining fisheries and limits to the expansion of aquaculture.

Agriculture requires the greatest proportion of water and increased demand for food potentially requires increasing amounts of water, even if realistic advances in water conservation are made. For example, water for use in irrigated agriculture is often extracted from natural river ecosystems. In doing so benefits may accrue to crop producers, but the extraction of water causes reductions in ecosystem services elsewhere (e.g., fisheries downstream). The irrigated area is part of the inland water ecosystem because (a) it derives direct benefits from it, and (b) has direct and indirect influences upon it. For example, rice paddies are widely acknowledged to be parts of inland water ecosystems. They have important biodiversity values themselves and are an accepted wetland type. However, there are intricate interrelationships between the natural components of inland water ecosystems and any agricultural system.

In addition, water also has significant value as drinking water supply and for human sanitation. For example, Millennium Development Goal (MDG) target 10 refers directly to this (by 2015, reduce by 50 percent the proportion of people without sustainable access to safe drinking water and basic sanitation). Superficially this may be regarded as an “ex-situ” use of water. However, the recycling of human wastes by in-situ inland water biodiversity (wetlands) worldwide is a major ecosystem service related to sanitation. Likewise healthy inland water ecosystems provide safe clean drinking water.

Another key linkage is that biodiversity rich, or healthy, systems stabilise water quality and reduce water-borne parasites and enable lower cost water treatment and supply. Links to human health are therefore also significant, in addition to the benefits of direct use of biological components for food and nutrition.

Livelihoods/poverty relationships therefore clearly transgress the water-land interface and go well beyond the simple direct exploitation of biological resources.

There is a wide range of potential users of the AWRD in the domains of environmental sustainability; continental, regional, national and local development planning; and research and education. Given the scalability and interrelated nature of applications possible using the AWRD, the following itemizes an overlapping list of potential stakeholders:

Continental: At the continental level hydrological modellers, development planners and researchers interested in: global change; diversity mapping; or, the convergence of anthro-environmental constraints and opportunities represent perhaps the largest and most immediate potential stakeholder base of the AWRD. This is due to two factors. First, there is both a wide acceptance and level of GIS training already existing within this user base. Second, it is generally easier to manipulate much of the publicly available data integrated into the AWRD to reflect continental conditions rather than those pertaining to a specific locality; i.e. it is easy to aggregate data into large spatial areas, but it can be difficult or impossible to extract local conditions based on aggregated datasets.

Regional: The AWRD could be used to support decision-making processes about transboundary issues by any regional organization or entity including international NGOs, multi-lateral donor entities and international commissions or authorities. For these stakeholders, the integrative and scalable capabilities of the AWRD allow the user to bridge the gap between data representative of local basin committees and national authorities and present a composite snap-shot of separate or multi-thematic data interactions.

National: At the national level, the AWRD is suitable for use by universities, departments or institutions working centrally within environment, hydrology, agriculture, and fisheries sectors. Specifically, the existing data and tool-sets provide an effective overview of human, hydrological and aquatic resource interactions. From such an overview, it becomes possible to build and map different scenarios on incidence or impact issues related to upstream and downstream concerns such as the building of a dam. For such stakeholders, the AWRD also provides an important medium for developing and communicating state of the environment reporting.

Local: In data poor countries, the AWRD tools and data archive provide a jump start for the local institutions, non-governmental organizations (NGOs) and water resource committees in terms of identifying areas either most at risk or in need of water and fisheries-related development interventions. The AWRD may be most suited in local areas for the identification of specific data gaps, and represents an important and easy-to-use resource that can be employed in community meetings, discussions with local leaders, and strategic planning sessions with subnational administrative authorities.

1.2 BENEFITS AND POTENTIAL APPLICATIONS

Benefits

The chief advantages of the AWRD are expected to lie in two areas. The first advantage is the extensive archive of data. The second focuses on the provision of easy-to-use and advanced data management and analytical tool-sets. Both aspects directly address some of the key issues in aquatic resource management.

Currently, there are 28 thematic data layers comprised of 156 unique datasets from over 25 data sources or libraries populating the AWRD data archive. An overview of the data contained in the AWRD archive can be described by the eight database components within which they reside. These eight components are: surface waterbodies; watersheds; rivers; aquatic species; gazetteer; ancillary vector; ancillary raster; and ancillary image and map background databases. Together, these database components contain representations of: surface hydrology, fresh water fish species, administrative boundaries; human population densities, elevation/bathymetry; soils; satellite imagery; air temperature and many other physiographic and climatological datasets. These data have been compiled from a full range and scale of publicly available data resources. Additionally, the data provided with the AWRD are not simple reproductions of existing databases downloaded from the Internet. Rather, each dataset has been rigorously compiled and processed based on the latest editions of the source materials. Due to these efforts, the AWRD likely represents the most comprehensive database of Africa ever developed with the goal of supporting aquatic and water resources management.

To display and analyse the archival data, the AWRD has been programmed to run under version 3 of the ArcView GIS software environment (ArcView 3.x). The ArcView GIS software is published by the Environmental Systems Research Institute, Inc. (ESRI). The base ArcView 3.x software is relatively inexpensive and is both widely used throughout Africa and within the international development community. In addition to the native GIS functions available within this base package, the AWRD provides an assortment of custom-designed applications and tools which previously could only be found in more advanced GIS environments via expensive add-on modules. In order to facilitate the utilization of the AWRD within African based institutions, ESRI has made a substantive donation of ArcView software licenses to FAO for distribution. Additionally, the AWRD archival data have been specifically formatted to promote their direct utilization within any GIS software package conforming to Open-GIS standards.

The spatial and data management tool-sets of the AWRD can be summarized based on the six analytical modules into which each tool has been organized. These modules are accessible via a single integrated interface and allow simple access to the following custom-designed applications: 1) the Data and Metadata Module; 2) the Surface Waterbodies Module; 3) the Watershed Module; 4); the Aquatic Species Module; 5) the Statistical Analysis Module; and lastly, 6) the Additional Tools and Customization Module.

Using the AWRD interface, users can access not only tabular and spatial data viewers for the creation of spatial distribution maps, but can also test and visualize complex spatial relationships; conduct robust statistical analyses concerning the spatial extent and distribution of such relationships; locate and reference similar areas identified during previous analyses; save analytical criteria; export and/or map results; and perhaps most important of all, integrate their own data for comparison or individual analysis. All of the tool sets of the AWRD are available throughout the interface and have been designed to facilitate a broad range of applications and user skill levels.

Perhaps the primary benefit of the AWRD is that all of the data and tools included are freely available for non-commercial use, improvement and distribution within the public-domain. Given this, users can employ the data and software modules of the AWRD and perform analyses of their own data free of copyright use or licensing fees. Lastly, the tools available via the AWRD interface are fully described in help menus and most come with simple and advanced options, significantly enhancing their usability and allowing them to be learned reasonably easily.

At present it is difficult to either itemize all of the potential applications of the AWRD or to weigh the expected benefits. Nonetheless, drawing upon the best practices reported in relation to the original SADC-WRD, and based on the design parameters of both the interface and data, some of the expected benefits attributable to the use of the AWRD could be:

- **Improved inland fisheries and aquaculture management** through improved inland fisheries and aquaculture reporting practices, improved generation of statistics organized ecologically by waterbody, river and lake basins, and improved communication of results from inland fisheries and aquaculture planning;
- **Sustainable use of natural resources** through improved inland fisheries and aquaculture planning; integrated evaluation and management of water resources and the combined evaluation of anthropogenic, terrestrial and aquatic species data;
- **International/regional transboundary coordination** via advanced visualization, scenario building and data standardization/integration. Particularly, support for river basin and/or aquifer management authorities who are endeavouring to develop integrated and cooperative approaches for shared resources at river basin level. The Watershed Module and related analytical tools were developed with this use specifically in mind and represent one of the most comprehensive and intensive programming efforts undertaken for the AWRD; and
- **Improved decision-support** aimed at: assessing the state of the inland fishery environment (e.g. human induced changes, watershed vulnerability, and transboundary issues; reversing degradation of the environment and reducing loss of habitats; multi-purpose conservation, rehabilitation and restoration of aquatic systems and habitats, opportunities and constraints to inland fishery enhancements; conflict resolution of allocation of resources; and increasing community-level responsibility for the management of watersheds.

Potential applications

It is anticipated that the AWRD will find broad applications within both inland fisheries and integrated natural resources management by providing managers with tools and data to assess potential impacts of various management alternatives.

Some of the specific applications and benefits from the use of the AWRD are illustrated in this publication in the form of six case studies: (a) surface waterbodies inventory; (b) inventory of fisheries habitats and fisheries productivities; (c) predicting potential fish yield; (d) preliminary hydrological reporting; (e) invasive and introduced aquatic species; and (f) production of simple map graphical outputs and base mapping. The overall aim of these case studies is to set out some of the issues in inland aquatic resource management and demonstrate the benefits of using the AWRD data and tools to resolve them. Box 2 provides a summary of the issues derived from these case studies, with a more detailed description provided in section 2.4.

BOX 2
Summary of application case studies

1. Surface waterbodies inventory. The AWRD archive provides spatial data which can be used to develop more consistent baselines upon which analysis, base mapping, and monitoring and evaluation tasks could be conducted to more fully support fisheries and integrated water resources management.

2. Inventory of fisheries habitats and fisheries productivities. Surface waterbody area and count data derived from the surface waterbody database component can be used to inventory fishery habitats across Africa and to relate fishery habitats to fisheries productivities and environmental variables. The purpose of this case study is to demonstrate that fisheries can effectively be managed only when the characteristics of fishery habitats are known.

3. Predicting potential fish yield. Potential fish yield is a critical value for fisheries managers, and can be influenced by a large number of factors including the developmental stage of the fishery. When such data is not available, however, the AWRD provides tools to estimate this value based on the surface area of the waterbody and, possibly, the mean annual air temperature of the waterbody drainage basin.

4. Preliminary hydrological reporting. The tool-sets and data compiled for the AWRD allow users to define the extent of any hydrological analysis to encompass an area of interest based on a single watershed, a larger river system or basin, or a complete megabasin. These features also allow users to effectively summarize statistical information across a range of human, environmental, and climatological factors, and to then evaluate the resulting data via a host of robust statistical analyses.

5. Invasive and introduced aquatic species. Watersheds allow users to focus their analyses on specific river reaches, larger-scale river basins (e.g. the White Nile River) or, at the broadest scale, entire river systems or megabasins (e.g. the entire Nile). Therefore, the AWRD provides a robust approach to the analysis of aquatic taxa. Furthermore, this approach can be further refined to include the utilisation of the statistical and data classification tool-sets of the AWRD in conjunction with information related to environmental and human impact factors.

6. Production of simple map graphical outputs and base mapping. The tools, graphics and content developed to support this case study demonstrate that the AWRD can provide a wide range of options to users for the production of base or reference maps, which can be integrated and support more dynamic and realistic state of the environment reporting.

The issues addressed in these case studies deal mainly with those related to inland fisheries and more specifically the status of fishery resources (i.e. habitat quality and quantity linked to fish abundance and distribution). It should be noted, however, that although more broad fisheries and aquaculture analyses can be addressed via the AWRD, theses applications could not be presented as specific case studies given the limited resources on hand. Based on an internal FAO reviews of the AWRD, a number of additional analyses were identified which could be addressed via the AWRD. These applications are presented in Box 3, with a number of other potential uses being covered in the AWRD manual and help files.

BOX 3
Other applications of the AWRD for inland fisheries and aquaculture

Inland fisheries

- Status of fisheries resources: Enhanced prediction of the distribution and impacts of Invasive Species;
- Fisheries information and management: Waterbodies inventory for a country in terms of kinds, numbers, and surface areas and the implications in terms of catch potential;
- Environmental impacts: Potential effects of soil degradation and river sedimentation on fisheries; and
- Multisectoral planning and management: Multisectoral aquatic resources management needs in African lake basins.

Aquaculture

- Inventory and monitoring: Inventory of government and commercial aquaculture sites using information from FIMA's National Aquaculture Sector Overview's (NASO's);
- Suitability of site and zoning: Ingest aquaculture locations from NASO's;
- Strategic Planning: Polyculture, or where more than one species is likely to do well; climate change, aquaculture and inland fisheries;
- Anticipating consequences of aquaculture;
- Environmental impacts on aquaculture; and
- Aquaculture together with fisheries.

Modified from Kapetsky (2004)

The above discussion demonstrates that the scope of analyses possible via the AWRD is by no means restricted to fisheries reporting or planning. Indeed, due to the diverse range of spatially referenced data at multiple scales and the large number of robust data management and spatial manipulation tool-sets, land managers and analysts from many disciplines may use the AWRD to answer a wide variety of management questions or research problems. Discussion Box 4 provides a brief description of the applicability of the AWRD for more focused water resources management, and includes an overview of the general capabilities to support ecological and conservation issues, as well as more general development planning.

BOX 4
Multistakeholder applications of the AWRD

Development planning
- Supporting the implementation of an ecosystem approach to aquaculture;
- Use of large-scale landscape features to identify ecoregions for conservation planning purposes;
- Evaluation of physical, biogeochemical and human interactions influencing coastal change (e.g. contribute to the Land Ocean Interactions in the Costal Zone project of the International Geosphere Biosphere Project (Arthurton *et al.*, 2002);
- Assessment of potential effects of management alternatives;
- Long and medium term action plans;
- Monitoring, evaluation and reporting;
- Assimilation of poverty and inequality issues; and
- Inventory of waterbodies, aquaculture and agriculture.

Biodiversity and environment
- Hydrological and species-specific climatic zoning or suitability classification;
- State of the environment reporting;
- Identification of threats to protected areas and related conservation issues;
- Planning of aquatic species census and data collections;
- Management of water quality, species and habitat diversity monitoring data;
- Identification of potential habitat of endangered or threatened species;
- Analysis of relationships between environmental variables;
- Environmental impact assessment and analysis;
- Continental to national scale evaluation of protected area efficacy for freshwater biodiversity;
- Identification of areas important for conservation of freshwater biodiversity;
- Development of continental or nationwide freshwater biodiversity conservation plans;
- Development of species-specific occurrence or abundance models based on landscape-scale habitat conditions;
- Modeling of potential species dispersal pathways across the landscape; and
- Determination of habitat quantity and capacity when habitat needs are known (or modeled) for a species of interest.

Spatial visualization and base mapping
- Advanced spatial referencing and gazetteer functionality;
- Robust visualizations of hydrological relationships in and between river systems;
- Continental to national scale base mapping, including multi and cross-sectoral data; and
- Representation of sub-national hydrological or hierarchical enumeration units.

Downstream impact assessment
- Management of water in transboundary river basins;
- Support of cooperative management frameworks for river basins (e.g. management of lakes and their basins for sustainable use (ILEC, 2005));
- Analysis of areal extent and populations at risk; and
- Development of emergency response and mitigation plans.

J. Jorgensen, L. Maiorano, D. Soto and A. Steel, personal communication, 2006

Based on the potential applications of the AWRD, the following provides a description of the potential AWRD user base at the continental, regional, national and sub-national levels.

Continental applications
The AWRD can provide an analytical bridge between regional, national and local planning exercises, benefiting institutions concerned with managing water and inland aquatic resources over large regions.

A diverse set of organizations and users can benefit from these decision-support capabilities including: international development and aid agencies such as the United Nations Development Programme, the World Bank, the US Agency for International Development, the European Directorate for General Development, etc.; internationally focused environmental and non-governmental organizations such as the United Nations Environment Programme's Global Environmental Facility and World Conservation Monitoring Centre, the International Union for the Conservation of Nature, the World Wide Fund for Nature, the World Resources Institute and Conservation International, etc.; a variety of agricultural research centers, such as the centers of the Consultative Group on International Research, and universities with programs focusing on global or African data questions.

Regionally specific applications
A well designed aquaculture program cannot ignore cross-sectoral issues, given the propensity of river systems to cross national borders. Aquaculture programs should also consider regional or trans-country boundary issues. In order to accommodate these considerations, the AWRD has been programmed to allow potential users to conduct data retrieval queries and spatial analyses based not only on a range of surface hydrological relationships, but also such relationships in conjunction with hierarchical divisions such as country and sub-national boundaries.

One project which highlights the suitability of the AWRD for bridging the gap between the local and national levels is its planned adoption under the Ghana National Aquaculture Strategic Framework (NASF). The NASF provides a synergistic and cross-sectoral framework and guidelines for revising the roles of the public and private sectors, privatising support services and input delivery, and focusing on high potential zones for aquaculture development (Moehl, 2006).

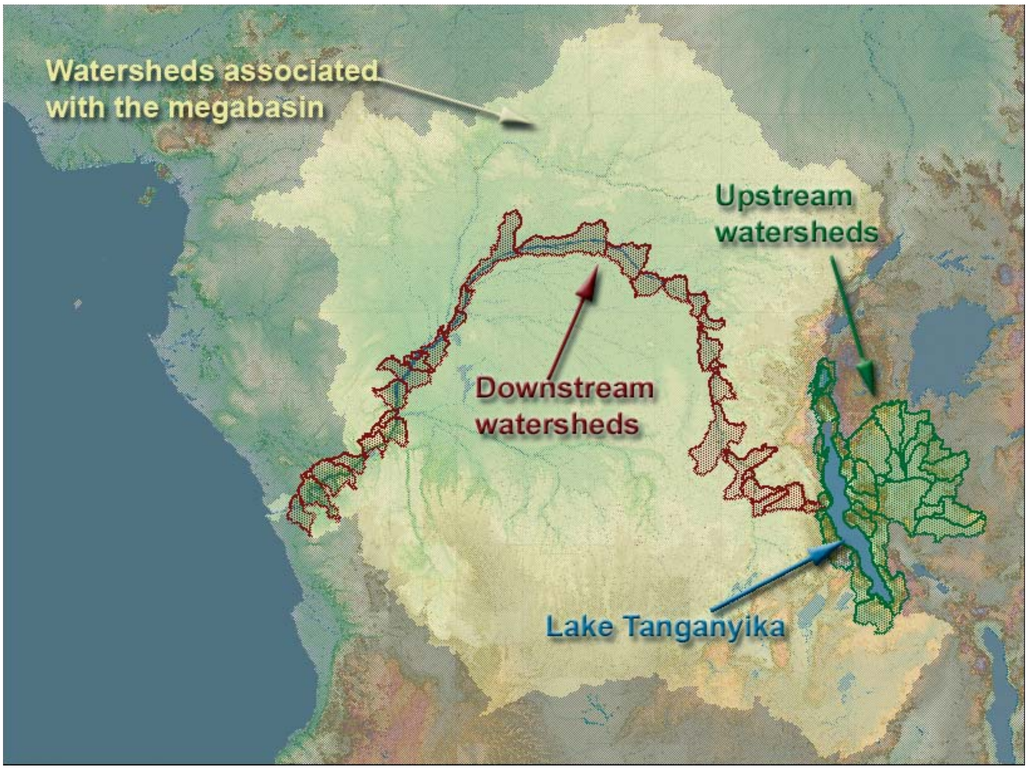
Specific to trans-boundary considerations and the Ghana NASF, the much larger Volta River System was chosen as a test case for further revising the AWRD data archive to include higher resolution topographic and satellite image data for this river system as a whole. Although the NASF is at this stage focused on Ghana, modifications were made to include the complete river system in anticipation that the framework will be extended to become a trans-national effort. However, until this eventuality can be institutionalized, the NASF is presented as an example of a national application of the AWRD which can be bridged to the local level.

The AWRD has also been identified as a test-bed for the integration of higher resolution spatial data within the specific context of a trans-national effort. This FAO technical cooperation project is entitled the Regional Programme for the Integrated Management of Lake Tanganyika, and will cover the Lake Tanganyika basin (FAO, 2006b). The national stakeholders for this effort include the fisheries ministries of the four countries that border Lake Tanganyika: the Republic of Burundi, the Democratic Republic of Congo, the United Republic of Tanzania and the Republic of Zambia. In addition to these national stakeholders, a wide range of African and international donor committees and NGOs will participate as stakeholders in the effort. These stakeholders include the African Development Bank, the United Nations Development Programme/Global Environmental Facility, the FAO, the Committee for Inland

Fisheries of Africa (CIFA), the International Union for the Conservation of Nature (IUCN), the Nordic Development Fund, European Union, the Common Market for Eastern and Southern Africa, the Finnish Department for International Development Cooperation and others. As of the first quarter of 2007, the effort is in the first year of a five year programme.

As a major part of the programmed activities are related to the responsible management of fishery resources in the Lake Tanganyika basin (LTB), the fisheries related departments of FAO will maintain a technical assistance role in the effort. Specific to the application of the AWRD, given the relatively small area comprising the LTB, this effort will provide an excellent opportunity to showcase the spatial tool-sets of the interface and the multi-scale/multi-thematic coverage of the data archive during spatial definition and scenario building exercises amongst stakeholders. For example, Figure 1.1 illustrates the flow regime associated with Lake Tanganyika. In addition to this general application, the AWRD will also be used to jumpstart activities related to fisheries monitoring and the use of the technology for planning and data management.

FIGURE 1.1
Visualization of the flow regime associated with Lake Tanganyika

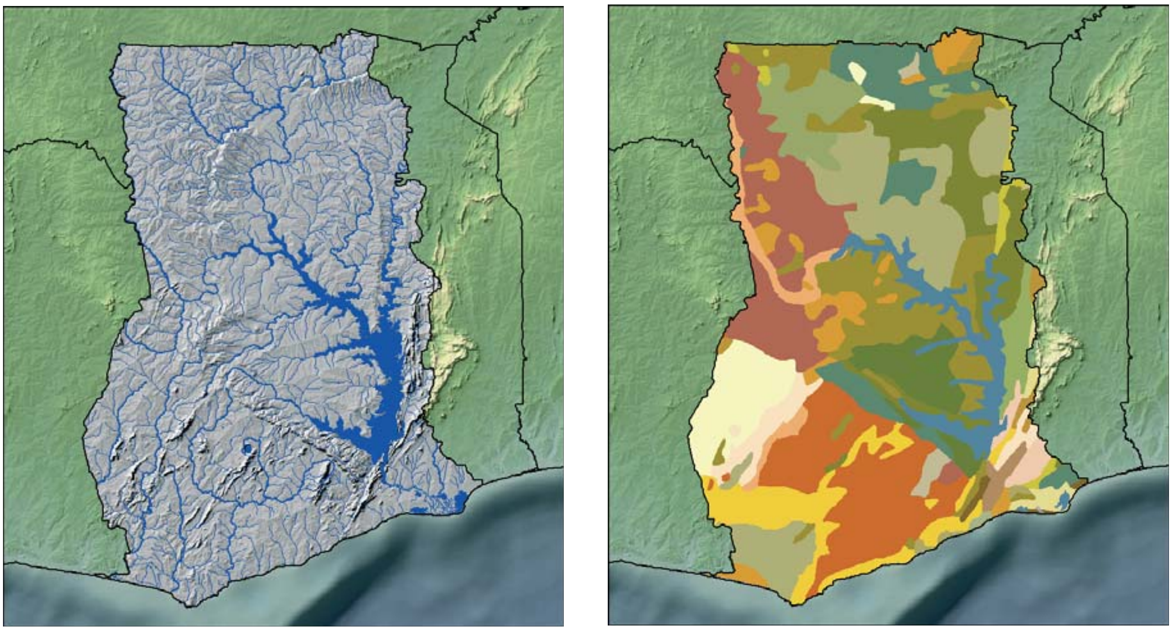


National applications
The AWRD was designed with both ease of use and scalability in mind. To this end, the data framework is very flexible and is relatively open to the types of data which can be easily integrated for spatial reference, map display, and analysis (e.g. satellite images, aerial photos, etc). Given these design attributes, in terms of data integration, mapping and analysis, the AWRD can effectively bridge gaps between the local, national and international levels. One project which highlights the suitability of the AWRD for bridging the gap between the local and national levels is its planned adoption under the Ghana NASF.

Within the NASF, it is proposed that the data of the AWRD be institutionalized, i.e. updated with local and nationally specific data, and the tool-sets of the interface then applied during the implementation of framework by the primary Ghanaian stakeholders. In this case the stakeholders include a diverse range of organizations that also highlight the general user base for which the AWRD is applicable at the national level. In addition to the FAO sponsoring project, the proposed Ghanaian stakeholders scheduled to adopt the AWRD under the NASF include: The Government of Ghana (GoG) Ministry of Fisheries; the GoG Water Research Institute; the University of Legon faculty of remote sensing, GIS and aquaculture; and the Natural Resources College of the United Nations University-Ghana.

The AWRD was not designed as an aquaculture decision support system *per se*. However, it does provide a large number of datasets that are important to aquaculture planning and management (e.g. lakes, rivers, precipitation, potential evapotranspiration, water temperature, soils, slope, population density, major cities, and roads) and all the AWRD tool-sets are relevant to aquaculture. Additionally, the AWRD archive contains many of the key datasets and results produced by Kapetsky (1994) and Aguilar-Manjarrez and Nath (1998) for a strategic assessment of fish farming potential in Africa. Thus, the NASF could first review the results already obtained for the Republic of Ghana, re-run the models produced by Aguilar-Manjarrez and Nath (1998) with the new data contained in the AWRD archive and then proceed to conduct more detailed studies with data at a higher resolution in areas that have been identified as having a high potential for aquaculture. Figure 1.2 illustrates some of the AWRD datasets of relevance to aquaculture in the Republic of Ghana.

FIGURE 1.2
Republic of Ghana illustrating elevation, lakes and rivers (left) and soils (right)



Local applications

One way of achieving better localized use and management of water resources is through community-based participation in land use planning exercises. Common in such exercises is a step in which local groups and/or individuals draw freehand maps representing their interpretation of local constraints and opportunities. GIS technology allows such interpretive maps to be referenced to real world locations and features, with the results then being presented back to the community as a check of underlying perceptions. As stated earlier, the AWRD can be used to help jumpstart fisheries and water resources management at the local level by providing a spatial map baseline for such exercises. Although the relatively small scale[1] of most of the data within the AWRD data archive may limit its use in such exercises, it does contain a relatively high resolution dataset of surface waterbodies covering Africa. This dataset is compatible with large scale 1:100 000 mapping and further data efforts have been instituted within the AWRD to establish methodologies allowing for the integration of higher resolution topographic and satellite image baselines. From these baselines, it will become possible to increase the currently supported 1:750 000 maximum scale, to a range of either 1:250 000 or possibly 1:100 000.

Indeed, while it is also anticipated that at the local level the AWRD will likely be better suited to the identification of data gaps, the data and interface do provide a baseline and framework which can be updated using locally coordinated data collection or institutional efforts. Such efforts could include: data collection via outreach programs to secondary school science departments, whereby key water quality baseline parameters are established for local surface waterbodies; or other methods which could include the integration of larger scale spatial data from countries that have completed the digitalization of 1:50 000 and or 1:250 000 scale topographic base maps, often based on post World War II stereo aerial photography. Examples of countries in Africa where these data have already been captured include the Kingdom of Morocco, the Republic of Namibia, the Republic of South Africa and the Republic of Uganda.

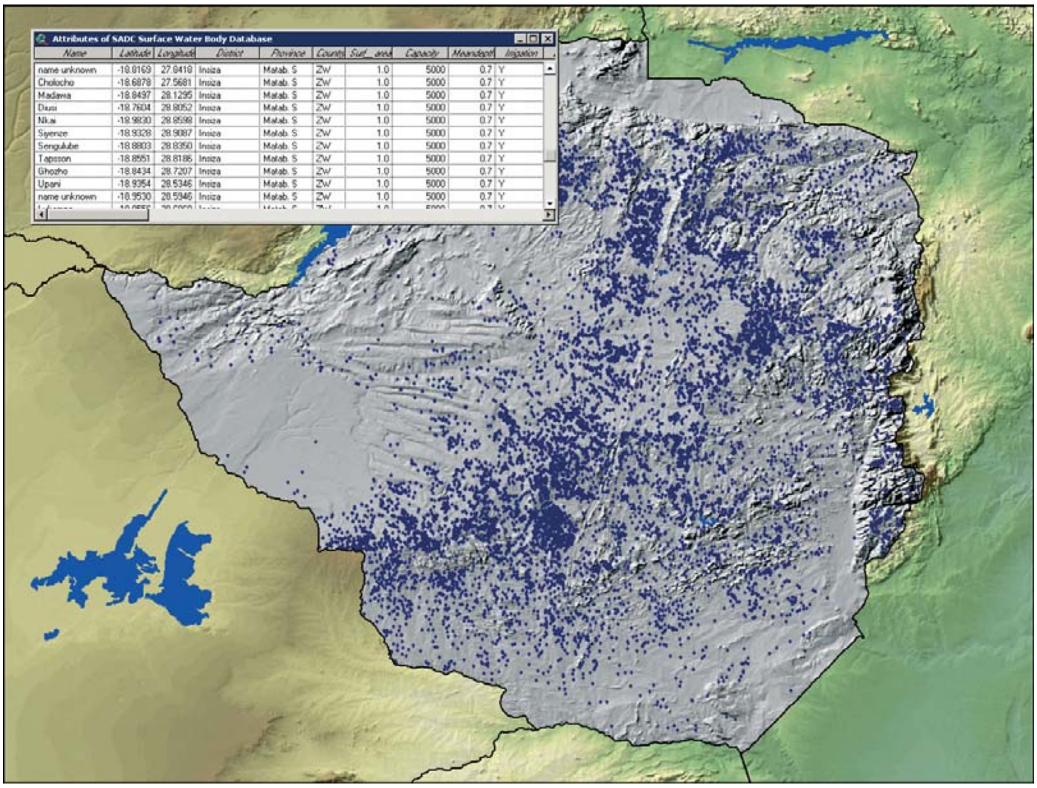
Based on these countries or perhaps other countries with an existing spatial data infrastructure such as the Republic of Zimbabwe, the following represents an list of potential local level AWRD stakeholders: Departments of Water Affairs, Fisheries, Extension Services in ministries such as Agriculture, Water, Forestry, Environment/ Tourism; government-owned companies such as water and power utilities; communal and commercial farmer unions; subnational authorities such as local councils and river basin committees; universities, polytechnic and agricultural colleges; and national trusts and NGOs.

There is an urgent need for better data on inland fisheries that could be interpreted in both economic and ecological terms. Reporting should be by individual or clusters of waterbodies, and should enable analysis in terms of river and lake basins. Although the cost of improving inland fishery data collection is high, failure to do so is also costly in terms of lessened or lost opportunities to increase food security and other social and economic benefits from inland fishery resources (FAO Inland Water Resources and Aquaculture Service, Fishery Resources Division, 1999). Nevertheless, the fundamental problem for the sustainability of inland fisheries today remains the lack of quantitative information about them. Part of this problem stems from an even more basic lack of information on the locations and expanses of waters that support inland fisheries. Without such basic information, estimates of production and the socio-economic aspects of fishing will always be incomplete. By the same token, without such basic information, comprehensive estimates of inland fishery potential cannot be made and impacts of environmental changes on fishery resources cannot be gauged. A framework in which to organize information about inland water systems exploited for fisheries is embodied in the AWRD.

From a fisheries viewpoint it is important to note that the various waterbody maps are linked to data that characterize them in terms of their physical and administrative characteristics as well as the landscapes around them (Figure 1.3). Historical production and limnological data, available for most of the larger waterbodies, and many of the smaller ones, can also be linked for analysis.

[1] In this publication the term ***small scale*** is used to denote the mapping of a large land area, e.g. the ratio 1:1 000 000 is a relatively small map scale and is commonly used to represent a whole country. In comparison, the term ***large scale*** represents the ratio used to map a relatively small land area, i.e. a 1:250 000 topographic map.

FIGURE 1.3
Small waterbodies in the Republic of Zimbabwe including tabular attribute information



In sum, the AWRD provides a solid framework for inland fisheries and environmental information in Africa. One of the next steps should be to find ways to assist countries to facilitate the organization of national level fisheries and environmental data collection, storage, and the manipulation and analysis of data within a version of AWRD specifically modified for that purpose.

Ultimately, inland aquatic resources will be sustained only by improvements in two directions: (1) better identification and spatial quantification of water quality and water quantity needs; and (2) increasing co-operation and co-ordination with other sectors who share concerns for the quantity and quality of water (Kapetsky, 2001). GIS and thus the AWRD, provides a tool to help achieve both goals, by estimating the importance of each sector's share in ecological, economic and, eventually, political terms, and more importantly by identifying areas of overlapping concern and mutual benefit.

Several activities at FIMA are relevant to this publication and that are highly recommended to the readers to complement the contents found in the present publication are: (1) an FAO on-line manual for self-training on GIS and remote sensing applications (Meaden and Kapetsky, 1991); (2) a technical manual on GIS in fisheries management and planning (de Graaf *et al*., 2003); and (3) a Global Gateway to GIS, Remote Sensing and Mapping for Aquaculture and Inland Fisheries. The Gateway (named GISFish) is available at http://www.fao.org/fi/gisfish.

2. Concepts and application case studies

2.1 INTRODUCTION

SADC Water Resource Database

Based initially in Harare, the Republic of Zimbabwe during 1992, ALCOM began conducting pilot activities in the member states of the Southern African Development Community (SADC). In addition to an overall goal defined as enhancing the standards of living for rural populations, the purpose of these activities was the demonstration of new techniques, technologies and methodologies for improved water resources management. Developed in conjunction with SADC host country institutions and other local collaborators, the milestone output of the ALCOM-SADC activity was the publication of the SADC Water Resources Database (SADC-WRD) in 1999.

The SADC-WRD met the above purpose comprising the innovative development and use of four primary databases: surface waterbodies, watersheds, rivers, and fresh water fish species. Controlling the integration of these databases, ALCOM used macros and other relational database[2] programming routines with the aim of providing fisheries and water resource managers with a means of producing and manipulating digital aquatic species distribution maps covering the SADC region. The production of such maps provided local managers with the ability to assess which fish species were likely to be present within a certain reach of river.

African Water Resource Database

Given the overall success of the SADC-WRD, in the third quarter of 2001 FAO-FIMA set out to expand the SADC-WRD continentally under an effort entitled the African Water Resource Database or AWRD. As an integral part of this new effort, FIMA determined that the depth of data within the archive, as well as the data management and analytical capabilities of the interface should be dramatically improved. Further, based on lessons learned during the SADC-WRD, increased benefits could also accrue to stakeholders if the expanded data and more refined tool-sets of the AWRD were not strictly limited to those purposes specifically envisioned in its design. With this rationale in mind, ESRI's ArcView 3.x GIS software was identified as the most commonly used GIS amongst stakeholders, and ESRI's open Shapefile format was adopted as the standard format for vector data within the expanded AWRD archive. All toolsets and user interfaces were developed within ArcView 3.x and therefore can be used for a wide range of tasks outside of the core AWRD functions.

Concepts and terminology used in the AWRD

Although a Glossary of Terminology and a discussion of the specific data resident within the AWRD archive are contained within other sections of this publication, it is useful to specifically introduce three key terms as they are employed within the AWRD. These three terms are: watershed, megabasin and flow regime.

[2] A relational database system (RDBMS) is a type of database management system that stores data in the form of related tables. Relational databases are powerful because they require few assumptions on how data are related or how specific records will be extracted from the database. As a result, the same database can be viewed in many different ways.

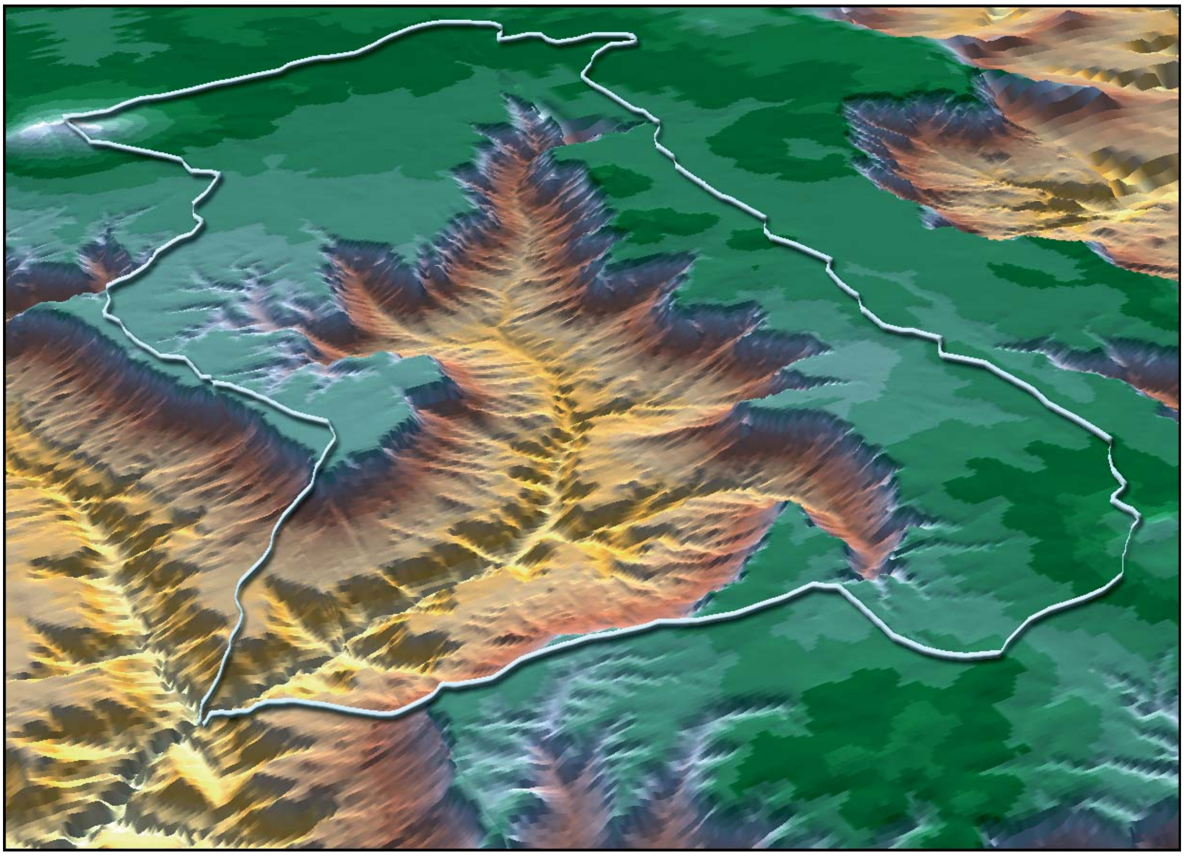
Watershed

In regards to the analysis and visualization of hydrological relationships via the AWRD the unit of choice is the watershed. Within the AWRD, the terms ***watershed***, ***catchment*** and ***drainage basin*** are synonymous with each other and are used to denote the area drained to a particular reach of river or a specific point of discharge. According to Dunne and Leopold (1978):

> A drainage basin is the area of land that drains water, sediment, and dissolved materials to a common outlet at some point along a stream channel. The term is synonymous with watershed in American usage and with catchment in most other countries. The boundary of a drainage basin is known as the drainage divide in the United States and as the watershed in other countries. Thus the term watershed can mean an area or a line. The drainage basin can vary in size from that of the Amazon River to one of a few square meters draining into the head of a gully. Any number of drainage basins can be defined in a landscape depending on the location of the drainage outlet on some watercourse.

Figure 2.1 portrays a generalized depiction of a watershed as it is used in the AWRD synonymously with the terms catchment and drainage basin.

FIGURE 2.1
Demarcation of a watershed, basin or catchment on a landscape



For most analyses dependant on physiographic or landscape factors, watersheds provide an ecologically defensible approach to the analysis of river systems at various scales and simplify the process of incorporating human and environmental impact data into any analysis. Due to this, and depending on scale, watershed units allow users to focus their analyses on specific river reaches, larger-scale river basins and at the broadest scale, entire river systems. Within the AWRD archive, three watershed models of differing resolutions have been consolidated to facilitate the scalable analysis of individual catchments, larger basins and broader river systems.

River basins, systems and megabasins

In general usage, the term ***river basin*** is commonly used to identify the total upstream contributing area associated with a point of discharge. This point of discharge can be at the confluence of another river basin or a surface waterbody, or at either a terminal inland sink, such as a pan, or marine outflow via a lagoon, estuary or delta. In comparison, the term ***river system*** can be defined more broadly, and topologically is comprised of both the total upstream and downstream flow regime associated with a specific watershed, confluence or terminal point of discharge. In order to distinguish larger river systems at the continental scale and avoid confusion with common or local naming conventions, the term ***megabasin*** was adopted during the development of SADC-WRD to denote larger and more complex river systems.

The Nile River is an example of a megabasin and reference to this river as the Nile megabasin is often useful for continental comparisons or when it proves necessary to distinguish it from major component river systems or basins. An example of this would be a discussion requiring the separate identification of the White and Blue Nile river basins and then their differentiation of as components of the broader Nile. The following text provides an example of when a greater level of specificity would be helpful during a discussion of specific catchment areas within the context of the broader Nile.

> *The Lake George watershed lies at the uppermost reaches of the Nile river and contains the highest point in the megabasin, 4 657 meters. This watershed also represents the largest catchment area for Lake Edward and hence produces some of the largest contributing flows into Lake Albert before it joins with the Victoria Nile basin to form what is locally known as the Albert Nile. The White Nile River System is defined further downstream at the confluence of the Bahr al Ghazal and Albert Nile basins, and when joined with the Blue Nile River System further downstream at Khartoum, comes to be termed the Nile River proper as referenced in literature. In terms of the hydrological network comprising the Nile megabasin, the White and Blue Nile river systems provide the largest contributing flows.*

Flow regimes

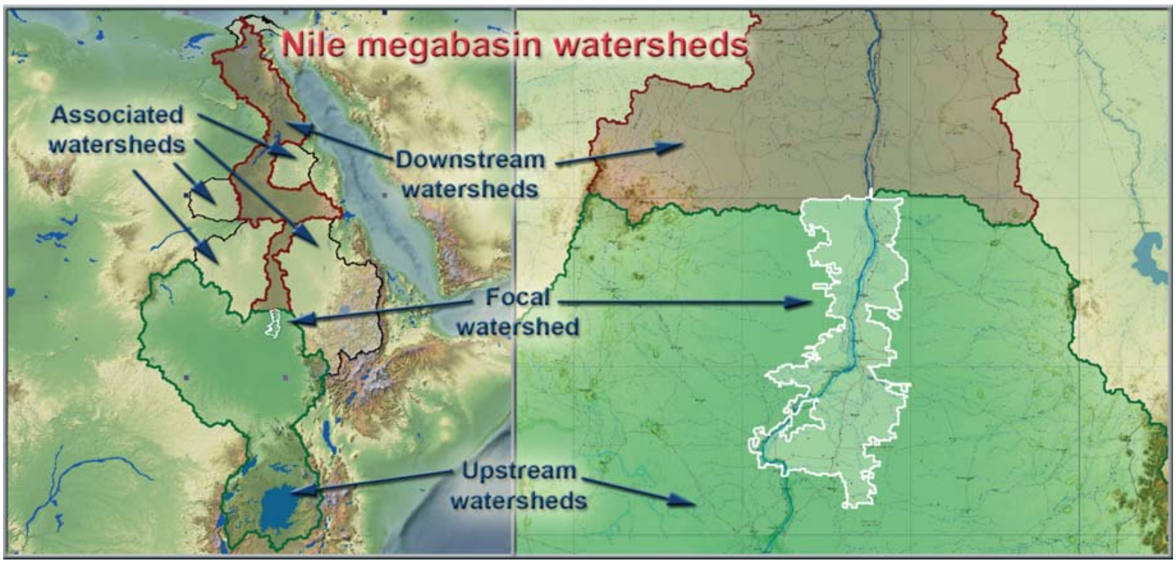
The term megabasin is used extensively within the AWRD to represent the broadest possible hierarchical unit that completely contains a network of surface hydrology. Therefore, a megabasin encompasses all tributaries, watersheds, basins and contributing river systems in such a network. In the AWRD, the term ***flow regime*** has been adopted to describe the complete network of surface hydrology within a megabasin. As used in the AWRD, a flow regime[3] represents an attempt to generalize the relationships comprising an overall network of surface hydrological into five components. For this generalization a watershed model is used as a spatial baseline from which the following collection sets are automatically created: Set 1) the focal watershed; Set 2) the upstream watersheds; Set 3) the downstream watersheds; Set

[3] The term *flow regime* as used for the AWRD is different but conceptually related to the term as used in both environmental planning and hydrology for describing stream morphology. In environmental planning, a flow regime can comprise either the whole river ecosystem or only a focal watershed, and usually concerns the influence of the: magnitude, frequency, duration, timing, and rate of change for flows in determining and maintaining habitats. For stream morphology, the term is used in association with bed formation and sediment loading based on fluid dynamics.

4) watersheds associated with a megabasin, but which are not directly influenced by flows through the focal watershed; and Set 5) watersheds not associated with or lying outside of the megabasin.

Figure 2.2, presents a visual depiction of the first four collection sets outlined above in white, green, red and grey respectively based on the selection of a focal watershed at the mouth of the White Nile River basin. At the left in the figure, the whole of the Nile River megabasin has been subset from a watershed model of Africa and its flow regime generalized based on the focal watershed highlighted at the right again in white.

FIGURE 2.2
Nile megabasin and flow regime associated with the watershed at the mouth of the White Nile River



Because the focal watershed lies just upstream of the confluence of the White and Blue Nile rivers, flows occurring below this watershed, i.e. from the east and the Blue Nile, have been classified as *associated*. With the exception of certain internally closed basins or sinks, watersheds classified as associated represent those areas of a river system that contribute base flow to the larger megabasin[4], but are not influenced by dynamics originating or passing through the focal watershed.

[4] Currently, the dependence of the AWRD on watershed models for the determination of a flow regime limits the use of the interface to surface hydrology based on polygonal watershed units.

2.2 SPATIAL DATA

The primary purpose for which the AWRD data archive was developed was to assist less advanced GIS users in Africa—who may not have the training, resources or access to the Internet necessary to download and process raw data themselves—with as comprehensive a set of data as possible consistent with the analytical and visualization requirements defined for the AWRD. A secondary goal was to compile the archive in as rigorous a manner as possible so that the data would be useful to both advanced users of the AWRD as well as scientists within the FAO and the broader international development community. A final goal was to compile certain datasets in such a way that users without access to ESRI's commercial add-on Spatial Analyst and 3D Analyst modules could both analyze and visualize that data easily using the AWRD analytical tools.

Similar to the SADC-WRD, the data contained within the AWRD archive have been organized to facilitate their retrieval via Database Components (DBCs). The original SADC-WRD contained four database components: the Surface Waterbody DBC, the Watershed DBC, River DBC and Aquatic Species DBC. However, with the exception of the Aquatic Species DBC which has been only slightly modified from this original baseline, both the spatial extent and depth of archival data compiled for the AWRD have been significantly expanded. Further, in direct comparison to the original SADC-WRD, the AWRD currently provides seamless coverage of continental Africa and related African island states, and in some case the world, while the original SADC-WRD was limited to only a portion of southern Africa. Table 2.1 presents a comparison of the data within these two editions of the WRD.

Efforts were made to reduce the use of technical terms in this section but in many cases this was not possible. Users are recommended to consult the glossary section presented in this publication whenever necessary.

In addition to the relative increase in the number of datasets which allow for the continental expansion of analyses via the AWRD interface, significant in Table 2.1 is the increased number of thematic data layers made available by DBC for this edition of the archive. These layers include not only topographic, physiographical and climatological data – providing the analytic baselines for the AWRD – but also extensive compilations of multi-scale vector data, digital elevation data and satellite imagey to support landscape visualization and base mapping. Combined, these refinements developed for the AWRD comprise what is likely the most comprehensive archive of water management and base resource mapping data ever compiled for Africa.

As currently structured, the AWRD archive is comprised of resource material from some twenty-eight spatial data sources or institutions. Table 2.2 contains an index of the twenty-eight general categories into which data from the AWRD archive can be classified.

From Table 2.2 it can be seen that an extensive archive of data has been provided for analysis and visualization within the AWRD. Because the scales and resolutions of the original source data listed in Table 2.2 are reported in a variety of measures, where possible a comparative scale value based on the nautical mile[5] has been estimated for the raster data listed in the table.

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5 A nautical mile, i.e. a sea or geographic mile, has been standardized at 1.852 km representing the average length of one minute of arc of latitude. Because: (a) the pixel size of non-metric raster data is often reported as arc seconds, minutes or portions of a degree; and (b) the size of projected rasters will vary when transformed into a decimal degrees based on their global location, the nautical mile provides a simple norm for comparison. For example: the measures 30 arc seconds, nominal 1 Km or 0.00833° have been used to describe the size of the GTopo30 DEM data; and the measures 3 arc seconds, 0.000833° and nominal 90 metre are used to describe the more refined publicly available SRTM data. In nautical miles, these data measure 0.5 NM and 0.05 NM respectively.

TABLE 2.1
Comparison of SADC-WRD and AWRD

Topic	SADC Water Resources Database	African Water Resources Database
Spatial Coverage	Southern African Development Community	Continental Africa, Madagascar and Island States
Database Components (DBCs)	Four Database Components: Surface Waterbody, Watershed, Rivers and Aquatic Species	Eight Database Components: Surface Waterbody, Watershed, Rivers, Aquatic Species, Gazetteer, Ancillary Raster, Ancillary Vector, and Ancillary Image.
Vector Data Format(s) and scale	Proprietary, BNA, and flat ASCII	ESRI Shapefile, nominally an Open-GIS format.
	1:250 000 for some point data and 1:1 000 000 for polygonal and linear features	1:65 000 to 1:5 000 000 for a range of point, line and polygon features
Grid Data Format(s) and resolution	WinDisp-IML and IDRISI {OpenGIS}	ESRI Grid and JPEG 2000, including full resolution point and polygon vector derivatives for climate and rainfall data.
	1 kilometer	1 to 5 kilometers, with some 15 to 30 meter localized or 500 meter continental imagery
Tabular Data Format(s)	Lotus Approach, dBase3, ASCII text	dBaseIV
Relative number of data layers	4 thematic data layers comprised of 10 datasets from four data sources	28 thematic data layers comprised of 156 totally unique datasets from over 28 data sources or libraries.
Surface Waterbody Database Component	2 data layers	19 data layers
Watershed Database Component	1 watershed model	3 complex watershed (WS) models, 1 basic WS delineation, and 1 integrated maritime/terrestrial WS reference
Rivers Database Component	1 data layer	6 data layers
	1 data layer	1 data layer, and 2 web based resource "layers"
Aquatic species		

Terminology: SADC (Southern African Development Community); WRD (Water Resources Database); ESRI (Environmental Systems Resource Institute); GIS (Geographic Information System); ASCII (American Standard Code for Information Interchange); BNA (a generic ASCII based vector data format).

TABLE 2.2
Topical listing of source data comprising the AWRD archive

Data Type or Category	Source Institution	AWRD Extent	Source Data Type	[1]Source scale - resolution	[2]Comparative analytical / map scale	Description
Air Temperature	CRES	Africa	Raster	0.05°	3-NM / 1:20 000 000	Cumulative and monthly summaries of temperature
Aquatic Species	FishBase	Global	Text Point	n.a	n.a / 1:2 000 000	Internet based resource of terrestrial and marine species
	SAIAB	SADC	Point	n.a	n.a / 1:1 000 000	Capture records for 700+ fresh water fish species
Bathymetry	ETOPO2	Global	Raster	0.03333°	2-NM / 1:12 500 000	Nominal 3.7 Km bathymetry and terrestrial elevation values
Climate	CRU	Africa	Raster	0.16667°	10-NM / 1:70 000 000	30 year cumulative/monthly summary for 8 climate types
Coastline – Administrative	WVS+	Africa	Vector	1:250 000	n.a / 1:250 000	Linear and polygonal coastal, country and bathymetry
Digital Elevation Model	SRTM-GTopo30	Africa	Raster	0.00833°	0.5-NM / 1:3 500 000	DEM building on GTopo30, with ETopo2 bathymetry
	SRTM	Volta Africa	Raster	0.000833°	0.05-NM / 1:350 000	Seamless nominal 90 metre DEM of Volta megabasin
	SRTM	Tanganyika Africa	Raster	0.000833°	0.05-NM / 1:350 000	Seamless DEM covering Lake Tanganyika basin-Watershed
Framework Library	VMap0 5th Edition	Africa	Vector	1:1 000 000	n.a / 1:1 000 000	20 plus topical data layers
	RWDBII	Global	Vector	1:3 000 000	n.a / 1:3 000 000	14 plus topical data layers
Gazetteer	GEOnet	Africa	Point	1:250 000	n.a / 1:250 000	1.2 million named locations under 6 major topical classes
Gazetteer and Annotation	DCW	Global Africa	Point	1:1 000 000	n.a / 1:1 000 000	Over 20 000 named locations and map annotation labels
Human Population	ORNL	Africa	Raster	0.00833°	0.5-NM / 1:3 500 000	Weighted human population density, available by WS
Hydrologically Filled DEM	HYDRO1k	Africa	Raster	1 kilometer	0.5-NM / 1:3 500 000	Modified GTopo30 DEM for flow routing networks
	WRIA	Africa	Raster	1 kilometer	0.5-NM / 1:3 500 000	Modified GTopo30 DEM for irrigation run-off networks
Land Cover - AfriCover	FAO	Eastern Africa	Vector	~1:250 000	0.015-NM / 1:250 000	Standardized regional land cover classification baseline
Land Cover - GLC2000	JRC	Africa	Raster	0.00833°	0.5-NM / 1:3 500 000	Standardized year 2000 land cover classification baseline
Large Marine Ecosystems and Terrestrial Basins	GIWA	Global	Vector	~100 000 cell	n.a / 1:20 000 000	A basin delineation of land and related marine environments
Limnological, World Lakes and Rivers	FAO	Global	Tabular Point	n.a	n.a /1:5 000 000	A series of inter-linked tables based on literature research
Major River Basins	WRI	Global	Vector	~250 000 cell	n.a / 1:65 000 000	Broad delineation of major basins, State of Environment

Data Type or Category	Source Institution	AWRD Extent	Source Data Type	[1]Source scale - resolution	[2]Comparative analytical / map scale	Description
Physiography, Hypsography	DCW	Africa	Vector	1:1 000 000	n.a /1:1 000 000	Harmonized bathymetry, coastline and terrestrial elevation
Pseudo 3D Backgrounds	FAO	Africa	Image	Varied	all scales	Enhanced 2.5d satellite and elevation background images
Rainfall	EDC	Africa	Raster	8 kilometers	4.3-NM /1:30 000 000	12 year time series with monthly and annual summaries
Satellite Based Imagery	ETM+ Browse	Africa	Image	465 metre	0.25-NM / 1:1 750 000	Seamless medium resolution African satellite image mosaic
	TM	Volta	Image	28 metre	0.015-NM / 1:125 000	Beta test case for seamless mosaicing of TM imagery
	ETM+	Tanganyika	Image	15 metre	0.008-NM / 1:65 000	Beta test case for seamless mosaicing of ETM+ imagery
	MODIS	Africa	Image	0.00833°	0.5-NM / 1:3 500 000	2.5d enhanced version of NASA Blue-Marble mosaic
Soils	FAO	Africa	Vector	1:5 000 000	n.a / 1:5 000 000	Major soil great groups and characteristics for continent
Surface Waterbodies	SRTM	Africa	Vector	~1:100 000	0.015-NM / 1:125 000	Highest resolution waterbody and coastal mask of Africa
	DCW	Africa	Vector	1:1 000 000	n.a / 1:1 000 000	Consolidation of SWB features, DNNET-LCPOLY
	VMap0 - DCW	Africa	Vector	1:1 000 000	n.a / 1:1 000 000	Harmonized DCW and VMap0 "named" SWB features
Virtual Base Maps	FAO	Africa	Image	1:750 000	0.15-NM / 1:1 000 000	Seamless virtual maps for use either in or outside of GIS
Water Temperature	FAO	Africa	Raster	0.05°	3-NM / 1:20 000 000	Cumulative and monthly summaries of temperature
Watershed Model	WWF ALCOM	Africa	Vector	5 000 cell	n.a /1:2 500 000	A three level named watershed model of continental Africa
Watershed - River – Irrigation	FAO	Africa	Vector	10 000 cell	n.a / 1:5 000 000	Rivers, surface waterbodies and 2 level watershed model
Watershed and Flow Network	HYDRO1k	Africa	Raster	4 000 cell	n.a / 1:2 000 000	A six level watershed model and derivative flow routes
Wetlands	WCMC	Africa	Vector	1:1 000 000	n.a / 1:1 000 000	Seamless recompilation of country based separates

Terminology: ALCOM (Aquatic Resource Management for Local Community Development Programme); CRES (Centre for Resource and Environmental Studies); CRU (Climate Research Unit, East Anglia University); DCW (Digital Chart of the World); DEM (Digital Elevation Model); DNNET (DCW drainage network layer); EDC (United States Geological Survey Earth Resources Observation System (EROS) Data Center); ETM+ (LandSat Enhanced Thematic Mapper); ETopo2 (2-minute elevation terrain DEM); FAO (Food and Agriculture Organization of the United Nations); GEOnet (Gazetteer Name Server); GIWA (Global International Waters Assessment; GTopo30 (Global 30 arc second topography database); HYDRO1k (Global 1 kilometre hydrological database); JRC (Joint Research Centre of the European Commission); LCPOLY (DCW land cover polygon layer); MODIS (Moderate resolution imaging spectroradiometer sensor aboard the Terra satellite); NIMA (U.S. National Imagery and Mapping Agency); ORNL (U.S. Oak Ridge National Laboratory); RWDBII (Revised/Relational World Databank II); SADC (Southern African Development Community); SAIAB (South African Institute for Aquatic Bio-diversity); SRTM (Space Shuttle Radar Topography Mission); SWB (Surface Waterbodies); TM (LandSat Thematic Mapper); VMap0 (Vector Map Level 0); WCMC (World Conservation Monitoring Centre); WWF (World Wide Fund for Nature; WRI (World Resources Institute); WVS+ (World Vector Shoreline).

[1]Source scale – resolution: The resolution or pixel size of the original source data of each AWRD dataset. The source scale values are reported in either metric or decimal degree units; please see Note[2] below.

[2]Comparative analytical / map scale: The term nautical mile (NM) is used for the comparison of raster data and the determination of their relative scalar representation based on the assumption that a minimum of 100 pixels per inch would be available at any analytical or printed map scale.

Structural organization and composition of AWRD archive

As noted earlier, the structure of the AWRD archive is based on the concept of Database Components (DBCs). There are currently eight DBCs in the AWRD archive and with the exception of data layers derived from framework libraries or data sources containing multiple themes, the topical index provided in Table 2.2 illustrates how each data source is classified by DBC. For example: rivers data, including linear outlines derived from any related surface waterbody polygonal features have been placed in the River DBC; watershed data in the Watershed DBC; and surface waterbody or wetlands-related data in the Surface Waterbody DBC. Because many of the data sources used for the AWRD thematically contain a variety of data layers, individual source layers may have been placed in multiple DBCs. This is particularly true for vector data from so-called "framework libraries" such as the VMap0, which contain river, SWB, gazetteer, roads and a host of other layers.

In all cases, the latest editions of data from only the original source institutions were used as the baseline for any data processed for inclusion in the archive. Table 2.3 provides a summary of the number of unique data layers available by DBC.

To provide consistency with the organization of the original SADC-WRD, additional data which could not be placed into an existing SADC-WRD DBC have been placed into one of three ancillary [i.e. supplementary, auxiliary or additional] DBCs (the Ancillary Raster, Ancillary Vector and Ancillary Image DBCs) or a separate Gazetteer DBC. This was done for a number of reasons: (i) conceptually it was determined that these data were not required to directly facilitate the analytical functions of the AWRD interface; (ii) statistical or other methods were already in place to summarize or encapsulate the layers in question for general use within the AWRD, in particular for users who did not have access to the Spatial Analyst add-on module to ArcView; (iii) the data processed were derived for the purposes of research related to either the future expansion of the AWRD globally or the enhancing the native analytical functions of the interface; and (iv), to facilitate the potential distribution of the AWRD interface and archive via CD-ROM, i.e. to users without access to a DVD device/reader or with only limited hard-disk space.

In short, the DBC structure was maintained and the use of additional ancillary database components added to facilitate both a general and more limited distribution of the AWRD archive via either multiple DVD or CD-ROM based media, while maintaining native access to all of the data via the GIS interface and AWRD tool-sets. Table 2.4 provides a summary of the primary and optional data distributions available for the AWRD.

As shown in Table 2.4 the full AWRD data archive is comprised of 42.2 gigabytes of unique data[6]. However, only approximately 8 GB of data, comprised of approximately 156 unique thematic layers, are essential for the operation of the various AWRD modules and toolsets, and therefore only these data are distributed with the AWRD documentation. The remaining data (mainly high-resolution elevation datasets and images) are available by request to FAO-FIMA for those users who need them.

[6] If uncompressed satellite imagery and derivative RGB images were to be included in this sum, even excluding baseline data, the size of the AWRD lies well in excess of 100 gigabytes of processed data.

TABLE 2.3
Summary of AWRD Database Components

	Name of Database Component	Acronym	Feature types and unique spatial layers in AWRD[1]						
			Tabular/ Catalog	Image	Line	Point	Polygon	Raster	Total
1	Surface Waterbody	SWB-DBC	3	-	2	9	9	-	23
2	Watersheds	WS-DBC	-	-	-	-	5	-	5
3	Rivers	RIV-DBC	-	-	4	2	-	-	6
4	Aquatic Species	AQSP-DBC	-	-	-	2	3	-	5
5	Gazetteer	GZTR-DBC	-	-	-	2	-	-	2
6	Ancillary Vector	AVEC-DBC	5	-	20	14	25	-	64
7	Ancillary Raster	ARAS-DBC	-	-	-	-	-	26	26
8	Ancillary Image	AIMG-DBC	3	22	-	-	-	-	25
	Total		11	22	26	29	42	26	156

Summary is representative only as it includes the listing of each unique AWRD data layer and not: (i) the number of source data layers which were processed to create a unique layer; (ii) the actual number of tiles or sub-grids comprising an individual raster dataset or any vectorized derivatives if relevant; or (iii) the actual number of unique datasets in the archive. Even though thematically-grouped features from a single dataset such as a gazetteer may be used to inform multiple DBCs, the dataset is listed only once in the table. In addition to classifying the AWRD data by DBC as in Table 2.3, the archive can also be described as containing:

a) 177 broader topical data classifications, based on both the feature data type and scope, from which it is possible to load;
b) 665 unique data or map layers for access into the AWRD Interface, based on;
c) 16 926 individual datasets having some spatial reference.

Note: 16 264 of the individual datasets listed under c) are tiled components of higher resolution data layers, and are set for only limited distribution due to either the total disk space required and/or their limited spatial extent.

Table 2.3 presents the numbers of unique datasets. An individual dataset may be listed in multiple DBC sub-tables if that dataset is a member of more than one database component (see sections below).

Terminology: Database Component (DBC) library, Surface Waterbody (SWB), Watershed (WS), Rivers and Drainage/Flow (RIV), Aquatic Species Component (AQSP), Gazetteer/Named Location (GZTR), Ancillary Vector (AVEC), Ancillary Raster (ARAS), Ancillary Image and Map Graphic (AIMG.

TABLE 2.4
Summary of AWRD distribution media options

Distribution	Distribution Extent and Size	Description
Primary AWRD interface, tool-sets and data integral to the function of the AWRD based on DBCs	(2) DVD 8.5 Gb	Primary distribution of the full AWRD publication, including: interface/tool-sets, all eight archival DBCs and all related documentation in one DVD.
Primary AWRD interface, tool-sets and data integral to the function of the AWRD, as well as more limited distribution data available on request.	Internet 42.2 Gb	Full AWRD data archive will be stored in FAO's GeoNetwork http://www.fao.org/geonetwork/srv/en/main.home AWRD Interface and tool-sets will be stored in "GISFish" A Global Gateway to Geographic Information Systems (GIS), remote sensing and mapping for aquaculture and inland fisheries to be released at the end of 2006.
Limited CD-ROM distribution based directly on the above AWRD primary publication	(10) CD-ROM Limited/on request	A more limited distribution of the above primary publication but divided on to ten separate CD-ROM disks. Data cannot be directly accessed by the AWRD tool-sets, and user must copy data from separate CD-ROMs on to a hard-disk.
Limited DVD based distribution of raster DEM and satellite image data for Volta and Lake Tanganyika basins	(1) DVD 4.4 Gb Limited/on request	Beta test data comprising: Arc-Grid based DEM and hillshade data, and either LandSat TM or ETM+ satellite image data compressed into the Jpeg2000 format. Purpose of these data are to establish the most suitable structure for the combined distribution of higher resolution raster, satellite image and derivative data to users of the AWRD
Limited DVD based distribution of continental SRTM 3-arc second DEM baseline and derivative DEM data	(4) DVDs 5.3 to 4.3 Gb Limited/on request	Beta test comprised of nominal 90 metre SRTM DEM data providing seamless and full continental coverage of Africa and related Island States. Four different sets of data are available for use, testing or review 3 204 overlapping 1°x1° Arc-Grid formatted tiles: the Baseline data, with oceans set to 0 and terrestrial void areas maintained at the original -32,000 value; the Null dataset, with oceans and terrestrial void areas set explicitly to no-data based on a nominal 1-arc seconds mask derived from the AWRD SRTM-SWBD data; the Filled dataset, with terrestrial no-data areas back-filled with data from the SRTM-GTopo30 DEM; and the Hillshade dataset, derived from the Null dataset based on a combination of slope and aspect designed to minimize shadows. Seamless and pseudo RGB based representations of each dataset are available for as separate image catalogs on each DVD.
Limited DVD based distribution of 2.5d color-classified DEM and hillshaded SRTM 3-arc seconds data derivatives	(1) DVD 2.1 Gb Limited/on request	A 2.5d enhanced RGB image base combining the above Null and Hillshade datasets to highlight topographical changes and relief. These data are again comprised of 3 204 overlapping 1°x1° tiles and provided a seamless image background suitable for visual interpretation and base mapping at the scale of 1:250 000. The data are provided in the Jpeg2000 format accessible via an image catalog.

Accessing the AWRD archival data by source or theme

In order to improve access to archival data by source, analytical or mapping requirement, a number of mechanisms have been built into the AWRD interface for the retrieval of data. For the most common analytical and visualization demands programmed into the AWRD, access to the relevant available data is transparent to the user. For example: SWB data are referenced when the SWB Module is started from within a map view and watershed, aquatic species and gazetteer data are all available on demand when the relevant analytical module or tool-set is initialized. Similarly, the majority of the raster data have been integrated into the Watershed Module and are available seamlessly on demand where appropriate via the other modules of the AWRD.

Examples of data available on a module-by-module basis are summarized in Section 2.3 with more detailed information made available in the Technical Manual in part 2 of this publication.

In addition to automated access of data via the AWRD analytical interface, four further mechanisms are also available to assist users with the retrieval of data based on (i) A tool to search for and load specific datasets, (ii) precompiled ArcView projects, (iii) the Image Export and Base Mapping extension, or (iv) standard manual method. The first method allows you to search for any dataset by name, or to select from lists of datasets organized by DBC. The second of these methods is based on a set of precompiled ArcView projects, i.e. APR project files, which can be used as seed files for many anticipated types of analyses. The third method provides access to composite sets of data via the Image Export and Base Mapping extension of the AWRD. In addition to these methods, the standard manual method for loading data into ArcView is of course still available to users of the AWRD. All of these methods for accessing and retrieving data are discussed in the AWRD Technical Manual or in part 2 of this publication under metadata, and are detailed in the on-line Help functions of the interface.

Detailed listing of individual data layers by database component

Due to the number of data sources and the resulting number of individual data layers that have been compiled for the AWRD, the following sections provide an overview of the actual AWRD archive datasets on a DBC-by-DBC basis. Tables summarizing the characteristics of each dataset are included in each section. In these tables, data with limited distribution, i.e. some image or raster data rows listed in Tables 2.11 and 2.12, are highlighted in grey. Further, because (i) an individual AWRD archival layer may be used in more than one DBC, (ii) certain image or raster data layers may be comprised of individual 1 by 1 tiles providing continental coverage of Africa, and (iii) some raster data layers may be comprised of multiple grid datasets representing annual, monthly or decadal values in either summary or time-series, a greater number of data layers may be discussed or represented in the tables below than were listed in Table 2.3.

In the following tables, the “Extent/Purpose” summarizes both the spatial coverage provided by each thematic layer and the native ability for this layer to be currently analyzed using the AWRD Interface. For this latter summary, “Analysis” means that the layer can be processed by the AWRD, while “Reference” means that the layer provides either contextual or visual spatial reference information to the user. Although reference data layers cannot currently be analysed via the AWRD, such data have been added to inform future analytical revision of the interface and to provide robust base mapping capabilities from within the AWRD.

In addition to the discussions and tables which follow, in order to conform to international and FAO spatial data standards for the development and exchange of data, metadata[7] conforming to the ISO-19115 standard are available for each data layer archived within the AWRD. The metadata associated with each dataset contained within the AWRD archive are available via the AWRD "Data and Metadata Module" using either the "Data Inventory" tool (also presented in part 2 of this publication) or the Metadata Viewer for any of the AWRD datasets selected for display.

Surface Waterbodies Database Component

The Surface Waterbodies Database Component of the AWRD currently contains nineteen unique data layers pertaining to lakes, dams, reservoirs, impoundments, and other types of waterbodies and wetlands, including an extensively processed and seamless version of the 1:100 000 scale surface waterbody database recently made available by NIMA, NASA and EarthSat. This is the highest resolution SWB dataset that will likely be available for the remainder of this decade. The SWB layers of the AWRD are summarised in Table 2.5 and include cross-tabular comparisons/indicators of the polygonal SWB data listed at the sub-national, national and continental levels.

Unlike the original SADC-WRD database component, which was limited to one point feature data layer and one polygonal feature data layer, the AWRD is designed to allow users to access any one of the above layers, or to customise the interface by adding their own SWB data layers. Additionally, in comparison to the SADC-WRD, the AWRD no longer maintains separate tabular attribute databases providing national subsets or pre-classified climatological and aquatic species information for each SWB based on pre-processed GIS overlays. Instead, for the SWB-DBC, the results of either queries or any specific analyses are produced on-the-fly and are only maintained in the temporary workspaces of the AWRD.

[7] Metadata can be defined as the information about the data, and for geophysical data may include: the source of the data; its creation date and format; its projection, scale, resolution, and accuracy; and its reliability with regards to some standard (ESRI, 2001).

TABLE 2.5
Overview of Surface Waterbodies Database Component

Dataset Name	Data Class	Source	Count of Features	Source Scale	Comparative analytical / map scale	Extent Purpose	Description
AfriCover Surface Water Body Features	Surface Water Features	FAO	11 296	1:250 000	0.015-NM / 1:125 000	East Africa Analysis	SWB and related hydrological features subset of the AfriCover country separates and compiled into a seamless baseline
Consolidated VMap0 Surface Water-Hydro Features	Surface Water Features	VMap0 I DCW	25 128	1:1 000 000	n.a / 1:1 000 000	Africa Analysis	Seamless and topologically robust derivative of source VMap0 SWB and related hydrological features, i.e. swamps, etc. data layers maintaining the inter-layer topological consistency established for the 5th Edition
Consolidated WCMC Wetlands	Wetlands	WCMC	4 404	1:1 000 000	n.a / 1:1 000 000	Africa Analysis	Various SWB and wetland feature types re-encoded from country separates of WRI-AFDS into a seamless continental derivative
FAO-AquaStat 1:1m Major African SWBs	Large Dams	FAO	837	1:1 000 000	n.a / 1:1 000 000	Africa Analysis	Dams from FAO African Water resources in Africa database
FAO-AquaStat Large African Dam Database	Dams and Reservoirs	FAO	1 192	10 000 cell	n.a / 1:5 000 000	Africa Analysis	Large dams and reservoirs projected from a LAEA original used for the FAO African Water Resources and Irrigation database
FAO-MRAG Lake-River Fisheries Tabular cross-table references	Limnological: Lakes-Rivers	FAO	Various based on tables	n.a	n.a / 1:5 000 000	Global Reference	Cross tables: Main Reference; Chemistry/Biology; Demography; Catch Data; Fisheries Data; Hydrology/Climate; Morphology; Waterbodies; Summary; and Bibliographic References
FAO-MRAG Spatially Referenced Water Bodies	Limnological: Lakes-Rivers	FAO	499	n.a	n.a / 1:5 000 000	Africa Analysis	A subset of the World Lake tabular references from the dataset below which could be cross-referenced to VMap0 SWB features
FAO-MRAG World Lakes and Rivers Point Reference	Limnological: Lakes-Rivers	FAO	1 887	n.a	n.a / 1:5 000 000	Global Reference	Spatially referenced point locations of World Lake features
Harmonized DCW-VMap0 Surface Water Bodies	Surface Water Features	DCW I VMap0	25 673	1:1 000 000	n.a / 1:1 000 000	Africa Analysis	Seamless and topologically robust derivative of source DCW and VMap0 perennial/non-perennial SWBs from VMAP0-IW, DCW-DNNET and DCW-LCPOLY sources, harmonized to the original DCW SWB shorelines
Linear representation of above VMap0 SWBs	SWB Shorelines	VMap0 I DCW	30 413	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Robust separately encoded depiction of the SWB-Hydro polygonal outlines
Original Tabular edition of the SADC-WRD Surface Water Bodies Database	Dams and Reservoirs	ALCOM	18 098	1:250 000	n.a / 1:250 000	SADC Analysis	Similar to the above dataset but tabular and containing the full set of SADC-WRD attributes, many of which contain only null data
Point representation of above VMap0 SWBs	SWBs as Points	VMap0 I DCW	25 128	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Robust centre-point derivative of SWB-Hydro polygonal features
RWDB2 Surface Waterbodies	Surface Waterbodies	RWDBII	831	1:3 000 000	n.a / 1:3 000 000	Africa Analysis	Enhanced SWB polygonal derivative based on 4 separate RWDB2 Library layers
SADC Surface Water Body Database	Dams and Reservoirs	ALCOM	18 098	1:250 000	n.a / 1:250 000	SADC Analysis	Enhanced derivative based on the original SADC-WRD data of lakes and impoundments

Dataset Name	Data Class	Source	Count of Features	Source Scale	Comparative analytical / map scale	Extent Purpose	Description
SRTM Double-lined Rivers and Surface Water Bodies	Surface Waterbodies	SRTM	38 840	1:100 000	0.015-NM / 1:125 000	Africa Analysis	Nominal 30 metre derivative of SWB, Double-Lined River, and Inshore Island features robustly compiled and harmonized seamlessly from over 3 225 separate SRTM-SWBD data tiles
SRTM Surface Water Body Linear Outlines	SWB Shorelines	SRTM	54 741	1:100 000	0.015-NM / 1:125 000	Africa Reference	Linear representation of SWB, Double-Lined River, and Inshore Island Features
SRTM Surface Water Body Point Reference	SWBs as Points	SRTM	38 840	1:100 000	0.015-NM / 1:125 000	Africa Reference	Centroid point locations of SWB, Double-Lined River and inshore island features
Surface Water Body Features from GEOnet Gazetteer	Surface Water Features	GEOnet	46 591	1:250 000	n.a / 1:250 000	Africa Reference	Surface water features based on named locations GNS/ GEOnet Gazetteer, i.e. lakes, dams, reservoirs, pools, pans and wetland features
SWB-by-Admin cross-tabular references	SWB-by-Admin	FAO	Various based on tables	1:3m – 1:1m	n.a / 1:1 000 000	Africa Reference	Cross-tables comparing the various SWBs types available in the RWDB2, WCMC Wetlands, DCW hydro-related, VMap0 and SWBD data layers at the continental, national and subnational levels; link to SWB-By-Admin
VMap0 based Ad1 and Ad2 SWB-by-Admin polygon references	Admin-Bnds	VMap0	0.015-NM 1:125 000	1:1 000 000	n.a / 1:1 000 000	Africa Reference	One-to-one uniquely dissolved national and subnational polygonal administrative boundaries encoded for linkage and mapping of both WS-by-Admin statistics via WS Module and SWB-by-Admin summary statistics
VMap0 Surface Water Feature Point Reference	Surface Water Features	VMap0 I DCW	19230	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Robust derivative of VMap0-Ed5 data layers harmonized with DCW dams, lakes, waterholes, wells and other SWBs based on VMAP0-MP and DCW-DN/DSPNT sources

Watersheds Database Component

Similar to the SWB-DBC, the Watershed Database Component has been greatly expanded in regards to the extent and number of watershed (WS) models available for analysis within the AWRD. As in the SADC-WRD, although a user can still only interact with one WS model at a time, they can now choose between one of five WS data layers to work with. Table 2.6 summarises each of the available WS data layers and categorises them based on whether they are a simple WS delineation or a more complex WS model suitable for analysis.

As can be seen in Table 2.6, two WS delineations and three WS models are currently available within the AWRD. In general, a WS model can be distinguished from a simple WS delineation by the presence of attribute encoding which allows the differentiation between areas that are either upstream or downstream from any specific WS in the model. A WS model must also contain levels, whereby the attribute encoding for a watershed would also allow the determination of broader river systems or megabasins. Using a three-level model as an example, and a watershed surrounding Lake Victoria as a base, a user should be able to determine that the Lake Victoria watershed is part of the broader White Nile River basin, which is in turn part of the Nile megabasin. Although at a certain point nomenclature may become a problem, ideally a six level WS model would allow a user to determine that: the Lake Victoria watershed is part of the Lake Victoria drainage; which is in turn part of the Victoria Nile basin; which is itself a sub-basin of the larger Albert Nile drainage basin; which is again in turn part of the White Nile River basin; and ultimately that the lake is part of the Nile megabasin.

In the AWRD, much of the functionality available to a user is dependant on which WS data layer is chosen by the user, and whether this layer is a properly encoded WS model. The user has the ability to customise the AWRD by the addition of custom WS delineations or models, and a basic tool is provided to check the connectivity of the flow regimes for any models added.

Rivers Database Component

As with the previous two database components, the extent and number of available data layers in the Rivers Database Component has been increased in comparison to the SADC-WRD. The Rivers Database Component of the AWRD currently contains six data layers (Table 2.7). The four linear data layers use arc vectors (i.e. lines) to represent either the pattern of drainage or the relative flow accumulation of surface water across a landscape, continentally, at differing scales. In the case of river datasets derived from VMap0 and RWDB2, the outlines of relevant SWB features have been added to fill in gaps between certain features. The remaining two non-linear feature layers are based on either gazetteer locations of river confluences extracted from 1:250 000 scale topographic maps, or locations of annotation features representing map label names for river reaches on the base ONC Charts originally used to create the DCW/VMap0.

In addition to the numerical difference in data layers between the AWRD River DBC and the original SADC-WRD, another difference is that river features are no longer broken at country boundaries and the various soil, elevation, and watershed attributes, which were previously hard-coded to the linear features, are no longer maintained specifically within the archive.

TABLE 2.6
Overview of Watersheds Database Component

Dataset Name	Data Class	Source	Count of Features	Source Scale	Comparative analytical / map scale	Extent Purpose	Description
ALCOM-WWF Watershed Model	Watershed Model	WWF I ALCOM	5 456	5 000 cell	n.a / 1:32 0500 000	Africa Analysis	A 3-level watershed model of Africa developed by ALCOM-WWF/ SARPO from DCW hypsographic and GTopo30 based DEMs and edited manually to conform with the VMAP0/DCW Rivers
FAO-AquaStat Major Basins Watershed Model	Watershed - River - SWB - Irrigation	FAO	608	10 000 cell	n.a / 1:5 000 000	Africa Analysis	A 2-level watershed model of Africa, projected and encoded from original FAO-AGLW LAEA based WS model for irrigation and water resources
GIWA Large Marine Ecosystem/ Basin Delineation	Large Marine and Terrestrial basins	GIWA – URI	2 936	~100 000 cell	n.a / 1:20 000 000	Global Reference	Global International Waters Assessment's Terrestrial WSs and Large Marine Ecosystems, A medium resolution WS delineation based on terrestrial modifications to the NOAA-URI Large Marine Ecosystems
HYDRO-1 Kilometer Watershed Model	Watershed and Flow Network	HYDRO1k	7 133	4 000 cell	n.a / 1:2 5000 000	Africa Analysis	A 6-level watershed model based on the EDC-UNEP HYDRO1k effort, that was projected, verified and downstream encoded from the original Pfafstetter encoded watershed model in LAEA
WRI Major Watersheds of the World Delineation	Major River basins	WRI-Rutgers	254	~250 000 cell	n.a / 1:65 000 000	Global Reference	Watersheds of the World published by the World Resources Institute, A cleaned version of this watershed delineation enhanced to include WRI's original publication attributes

TABLE 2.7
Overview of Rivers Database Component

Dataset Name	Data Class	Source	Count of Features	Source Scale	Comparative analytical / map scale	Extent Purpose	Description
Consolidated VMap0 River-Surface Water body Network	Rivers and SWBs	VMap0 I DCW	173 504	1:1 000 000	n.a / 1:1 000 000	Africa Analysis	Seamless and topologically robust derivative of source VMap0 SWB linear outlines integrated with WC, dam, canal and other feature data layers
Drainage network River annotation map labels as point features	Map Labels	DCW	~3 900	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Enhanced derivative based on annotation layers of DCW-DNNET data source
FAO-AquaStat 1:5m African Rivers	Rivers	FAO	32 636	1:5 000 000	n.a / 1:5 000 000	Africa Analysis	Rivers from the FAO Atlas of Water Resources and Irrigation in Africa, A robustly encoded rivers data layer with fair connectivity. Scale listed as 1: 5 m, but more detailed than layers of similar scale.
HYDRO-1 Kilometer Flow Drainage Network	Watershed and Flow Network	HYDRO1k	15 478	4 000 cell	n.a / 1:2 5000 000	Africa Analysis	Hydro1k based river flow accumulation network for Africa, projected to decimal degrees from Lambert Azimuthal Equal Area base, the only confirmed network river layer in AWRD
River Features from GEOnet Gazetteer	River Discharge	GEOnet	138 700	1:250 000	n.a / 1:250 000	Africa Reference	GNS/GEOnet named river confluence and outflow locations Value-added derivative of source w/non-diacritical names of river confluence's
RWDB2 Rivers and Surface Water Body Outlines	Rivers and SWBs	RWDB2	4 376	1:3 000 000	n.a / 1:3 000 000	Africa Analysis	Enhanced Rivers linear derivative based on 4 separate RWDB2 Library layers, with outlines of surface waterbodies topologically intersected and integrated

Aquatic Species Database Component

Unlike the previous three database components discussed, the Aquatic Species Database Component is the one component of the archive that could not be expanded significantly to provide Africa-wide coverage for the AWRD. However, the aquatic species data covering the SADC region has been recently updated, as well as expanded and rigorously re-encoded to account for both verified and unverified species reference locations within the AWRD. The core revisions to the AQSP-DBC were carried out in large part by the South African Institute for Aquatic Bio-diversity (SAIAB). The SAIAB was formerly known as the JLB Smith Institute of Ichthyology and in regards to aquatic species data, the AWRD contains an FAO specific revision of the data in the SAIAB's "GIS Atlas of Southern African Freshwater Fish", (SAIAB, 2003). The data layers contained in the Aquatic Species DBC are summarized in Table 2.8.

In addition to the revised aquatic species data, the AQSP-DBC also includes a tool to link to FishBase (http://www.fishbase.org/home.htm), an Internet-based global information system of fish species data. FishBase and other pending linkages to sites maintained by organisations such as the SAIAB are also being evaluated as potential test beds for increasing the spatial extent of data coverage and as data maintenance hubs which can be used to ensure the long term viability of aquatic species monitoring via the AWRD.

Gazetteer Database Component

Gazetteers are tabular listings of named locations which allow the spatial referencing of each place name. The AWRD currently contains two fully featured gazetteer baselines, each of which is summarised in Table 2.9. In addition to hydrographic features, each of the gazetteers described below also provide named locations for: other natural and physiographic features, populated places, and various types of related social and physical infrastructure.

TABLE 2.8
Overview of Aquatic Species Database Component

Dataset Name	Data Class	Source	Count of Features	Source Scale	Comparative analytical / map scale	Extent Purpose	Description
Aquatic Species Political Boundary Reference	Aquatic Species l Political	Varied	5 690	varied	n.a	Africa Analysis	Aquatic Species Political Boundaries processing data layer
Aquatic Species Watershed Modeling Reference	Aquatic Species l Watershed	Varied	608	varied	n.a	Africa Analysis	Aquatic Species Watershed Boundaries processing data layer
Restricted version of main SAIAB Aquatic Species Locations	Aquatic Species	SAIAB	798	n.a	n.a / 1:1 000 000	SADC Analysis	A compressed version of the main SAIAB aquatic species data layer, including endangered-threatened species locations. A password is required to unzip these data, which would then be used to replace the existing dataset.
SAIAB Aquatic Species Locations	Aquatic Species	SAIAB	766	n.a	n.a / 1:1 000 000	SADC Analysis	Main aquatic species data layer containing point and ancillary tabular attributes of capture data, Verified: 35 292 location references comprising 247 unique aquatic specie l Unverified: 1 080 location references covering 517 unique aquatic specie
SAIAB Threatened and Endanger Species Boundaries	Aquatic Species	FAO	92	n.a	n.a / 1:2 000 000	SADC Analysis	Threatened to endangered species watershed boundaries based SAIAB and HYDRO1k

TABLE 2.9
Overview of Gazetteer Database Component

Dataset Name	Data Class	Source	Number Features	Source Scale	Comparative analytical / map scale	Extent Purpose	Description
DCW Gazetteer	Gazetteer	DCW	151 739	1:1 000 000	n.a / 1:1 000 000	Global l Africa Reference	Full Digital Chart of the world Gazetteer database
GEOnet Gazetteer Database	Gazetteer	GEOnet	1 083 354	1:250 000	n.a / 1:250 000	Africa Analysis	Full value-added derivative of ASCII GEOnet January 2006 gazetteer baseline, including non-diacritical names

Ancillary Vector Database Component

The Ancillary Vector Database Component (AVEC-DBC) contains the greatest number of unique data layers within the AWRD. The AVEC-DBC can be considered as a repository for all vector data which could not be placed or accounted for in the other DBCs of the AWRD. Hence, the AVEC-DBC was developed primarily to support various scales and types of either base mapping or analyses.

The Ancillary Vector Database Component contains robust and enhanced versions of the source data layers residing in four framework data libraries: the 2005 SRTM Surface Waterbody Database; the 2004 3rd Edition of the World Vector Shoreline; the 2000 5th Edition of the Vector Smart Map Level 0; and Version 1.1 of the Relational World Databank II released in 1997. In addition to data from these four sources, this DBC also contains data layers compiled from the original 1992 DCW which were dropped during the transition from the DCW to the VMap0 and other data. A framework data library can be considered as differing from other sources of data in that it generally contains multiple thematic layers, (e.g. coastlines, political boundaries, roads, rivers and/or populated places), and is generally maintained and released as various editions. As is the case for all the data processed for the AWRD, these data are derived directly from the original data source and are generally reprocessed from the ground up in order to provide robust derivatives[8]. The data layers contained in the AVEC-DBC are summarised in Table 2.10.

As can be seen on Table 2.10, the AWRD contains almost complete compilations of data from the specified framework libraries, including: contours and spot elevations; cities and populated places; roads, rail, and air transport infrastructure; generalised and detailed political boundaries; physiography; marine waterbodies; etc. In addition to these framework based compilations, the AVEC-DBC also contains FAO third-order administrative boundaries and seamless translations of all land surface features contained in the original DCW which were dropped during the transition to the VMap standard. The AVEC-DBC also contains an annotation layer, using ESRI's Arc-Info coverage format in order to provide users with the seventeen layers of map labels captured from the source ONC Charts for the original DCW.

[8] The processing of robust derivatives from a source library is a somewhat complex task requiring a number of basic steps and cross-checks. In general, the process starts with: (i) building coastlines from linear source features, followed by (ii) building polygons which reflect oceanic islands and landmasses, (iii) checking for gaps or other topological errors and (iv) cross-checking results against any polygonal baseline that may also reside in the source library. After processing offshore islands and landmasses, additional polygonal features such as surface waterbodies, political boundaries, etc. are added. Next, linear features such rivers and roads are added, and finally any point feature types from the source library. In this way, both linear and polygonal attributes can be maintained separately, while at the same time ensuring any spatial accuracy is maintained. Coincident feature error checks are performed and where possible, or necessary, encoding harmonization is performed to minimize the number of output derivative layers. Once completed, the resulting derivatives are generally compared against previously published editions of the source library to ensure that no features were dropped by the maintenance organization or contractor, and further feature consolidation is performed where necessary. The specific processing details associated with data processed from all source data are provided in the metadata accompanying each dataset.

TABLE 2.10
Overview of Ancillary Vector Database Component

Dataset Name	Data Class	Source	Count of Features	Source Scale	Comparative analytical / map scale	Extent Purpose	Description
Consolidated table of air temperature	Air Temperature	CRES l FAO	1 004 351	0.05°	3-NM / 1:20 000 000	Africa Analysis	Consolidated table of monthly air temperature
Consolidated table of CRU Evapotranspiration	Evapo-transpiration	CRU	92 717	0.16667°	10-NM / 1:70 000 000	Africa Analysis	Consolidated Table of CRU Evapotranspiration
Consolidated table of CRU Precipitation	Precipitation	CRU	92 715	0.16667°	10-NM / 1:70 000 000	Africa Analysis	Consolidated Table of CRU Precipitation
Consolidated table of water temperature	Water Temperature	CRES l FAO	1 004 351	0.05°	3-NM / 1:20 000 000	Africa Analysis	Consolidated table of water temperature
Consolidated tables of 8 km average 10 day cumulative Meteosat-GTS interpolated daily rainfall	Precipitation	EDC	471 688	8 kilometers	4.3-NM / 1:30 000 000	Africa Analysis	Consolidated set of 14 cross tables representing the vectorized values consolidated by year, long and short-term average rainfall values: 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, long-term and short-term tables
Consolidated VMap0 Bathymetric-Coast-Contour Lines	Bathymetry and Land Contours	VMap0 l 3rd Edition	108 715	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Seamless and topologically robust derivative of all linear VMap0-Ed3 bathymetric, coastline, and terrain contour data layers
DCW Annotation or original ONC-Chart Map Labels	Annotation Map Labels	DCW	26 278	1:1 000 000	n.a / 1:1 000 000	Global l Africa Reference	A robust compilation annotation from all 17 of the original DCW layers containing annotation features, including: Ocean\ Underwater; Physiographic; Transportation; Drainage; Land Cover and Populated Places as separate annotation layers in a single Arc-Info coverage
DCW Drainage Network Point Features	Surface Waterbodies	DCW	4 808	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Enhanced derivative based on annotation layers from DCW-DNNET source layer translated into point features for reference in the SWB-DBC
DCW Drainage Point Features	Surface Waterbodies	DCW	1 635	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Enhanced derivative based on annotation layers from DCW-DNPNT source layer translated into point features for reference in the SWB-DBC
DCW Elevation Class Polygons	Elevation Range	DCW	21 456	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Elevation class range class for vehicular suitability
DCW Land Cover (Hydrological Features)	Surface Water Features	DCW	7 067	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Wetlands and other SWB features dropped during the DCW standard change to VMAP0Wet/Inundated land and other hydrological features from the DCW DNNET and LCPOLY sources, updated w/VMAP0 IW
DCW Land Cover (Land Surface Features)	Land Surface	DCW	7 682	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Seamless dataset containing all other DCW land feature types not subset into the above dataset for use via the SWB-DBC

Dataset Name	Data Class	Source	Count of Features	Source Scale	Comparative analytical / map scale	Extent Purpose	Description
FAO 1:5 Million Scale Soils	Soils	FAO	4 909	1:5 000 000	n.a / 1:5 000 000	Africa Reference	Compilation of FAO Soil great group and major attribute characteristics with country boundaries removed
FAO National-Ad1 Boundaries	Admin.	FAO	58	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Ad1-Polygonal representation of countries based on VMap0 and perhaps DCW
FAO Subnational-Ad2 Boundaries	Admin.	FAO	674	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Ad2-Polygonal representation of 1st-order subnational boundaries from country sources integrated with VMap0/DCW Ad1 boundaries
FAO Subnational-Ad3 Boundaries	Admin.	FAO	5 690	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Ad3-Polygonal representation of 2nd-order subnational boundaries from country sources integrated with VMap0/DCW Ad1 boundaries
RWDB2 Airports	Airports	RWDBII	15 044	1:3 000 000	n.a / 1:3 000 000	Global Reference	Point based representation of Airports
RWDB2 Coastal-Surface Water Body Linear Boundaries	Coastline Shoreline	RWDBII	25 319	1:3 000 000	n.a / 1:3 000 000	Global Reference	Linear output of coastlines and SWB features, derived from integration of 7 RWDB2 library layers
RWDB2 Coastal-Surface Water Body Polygon Boundary	Landmass and SWBs	RWDBII	20 874	1:3 000 000	n.a / 1:3 000 000	Global Reference	Topologically corrected polygonal derivative of 7 RWDB2 library layers to create continental baselines
RWDB2 Gazetteer	Gazetteer	RWDBII	3 031	1:3 000 000	n.a / 1:3 000 000	Global Reference	Point based gazetteer of named locations
RWDB2 National-Ad1 Linear Boundaries	Admin.	RWDBII	18 870	1:3 000 000	n.a / 1:3 000 000	Global Reference	Ad1-Linear coastlines, national and other areas of sovereignty boundaries compiled from multiple RWDB2 source layers; circa 1997
RWDB2 National-Ad1 Polygonal Boundaries	Admin.	RWDBII	12 905	1:3 000 000	n.a / 1:3 000 000	Global Reference	Ad1-Polygonal representation of national and other areas of sovereignty boundaries compiled from multiple RWDB2 source layers; circa 1997
RWDB2 National-Ad2 Linear Boundaries	Admin.	RWDBII	26 648	1:3 000 000	n.a / 1:3 000 000	Global Reference	Ad2-Linear coastlines, national, 1st order subnational and other areas of sovereignty boundaries compiled from multiple RWDB2 source layers; circa 1997
RWDB2 National-Ad2 Polygonal Boundaries	Admin.	RWDBII	16 035	1:3 000 000	n.a / 1:3 000 000	Global Reference	Ad2-Polygonal representation of national, 1st-order subnational and other areas of sovereignty boundaries compiled from multiple RWDB2 source layers; circa 1997
RWDB2 Populated Places	Admin-Business Centres	RWDBII	55 038	1:3 000 000	n.a / 1:3 000 000	Global Reference	Point based representation of Populated place with encoding differentiating national and subnational capitals and other related administrative centres
RWDB2 Ports	Ports	RWDBII	4 792	1:3 000 000	n.a / 1:3 000 000	Global Reference	Point based representation of major port and harbours

Dataset Name	Data Class	Source	Count of Features	Source Scale	Comparative analytical / map scale	Extent Purpose	Description
RWDB2 Railway Lines	Railroad	RWDBII	25 407	1:3 000 000	n.a / 1:3 000 000	Global Reference	Linear railway layer consolidated from 2 separate source data layers
RWDB2 River-Surface Water Body Network	Rivers and SWBs	RWDBII	29 177	1:3 000 000	n.a / 1:3 000 000	Global Reference	Linear outlines of SWB features integrated with Rivers and other linear surface hydrological features
RWDB2 Roads	Roads	RWDBII	72 099	1:3 000 000	n.a / 1:3 000 000	Global Reference	Linear roads layer consolidated from 3 separate source data layers
RWDB2 Surface Waterbodies	Surface Waterbodies	RWDBII	8 750	1:3 000 000	n.a / 1:3 000 000	Global Reference	Enhanced SWB polygonal derivative based on 4 separate RWDB2 Library layers
SRTM 1-by-1 Degree Reference Polygons	Reference Tiles	SRTM	64 800	1:100 000	0.015-NM / 1:125 000	Africa Reference	SRTM 1x1 degree tile reference layer with various encoding attributes such as SRTM tile names, availability, extent and UTM 1:250 000 map reference
SRTM Coastlines	Coastline	SRTM	11 070	1:100 000	0.015-NM / 1:125 000	Africa Reference	Linear representation of the nominal 30 metre coastlines; this is the highest resolution determinate currently available and was compiled and harmonized seamlessly from over 3 225 separate SRTM-SWBD data tiles
SRTM Data Source Reference Polygons	DEM Source	SRTM	7 536	1:100 000	0.015-NM / 1:125 000	Africa Reference	Polygonal representation of the original grid data specifying the source data used to compile the SRTM 3 and 30 arc-second DEM data
SRTM Landmass and Ocean Island Polygons	Island-Landmass	SRTM	4 333	1:100 000	0.015-NM / 1:125 000	Africa Reference	Seamless polygonal continental landmass and oceanic island mask data layer derived from SRTM-SWBD tiled database
Vectorized 10-by-10 minute Grid (Point)	Climate	CRU	92 718	0.16667°	10-NM / 1:70 000 000	Africa Analysis	Vectorized 10-by-10 minute Grid (Point)
Vectorized 10-by-10 minute Grid (Polygon)	Climate	CRU	92 718	0.16667°	10-NM / 1:70 000 000	Africa Analysis	Vectorized 10-by-10 minute Grid (Polygon)
Vectorized 8-by-8 Kilometer Rainfall Point Reference	Precipitation	EDC	471 688	8 kilometers	4.3-NM / 1:3 500 000	Africa Analysis	Vectorized 8-by-8 Kilometer Grid Reference
Vectorized 8-by-8 Kilometer Rainfall Polygonal Reference	Precipitation	EDC	471 688	8 kilometers	4.3-NM / 1:3 500 000	Africa Analysis	Vectorized 8-by-8 Kilometer Grid Reference
Vectorized CRES Half Degree Point Reference	Water Temperature	CRES | FAO	1 004 351	0.05°	3-NM / 1:20 000 000	Africa Analysis	Vectorized CRU 10-by-10 Minute Point Reference
Vectorized CRES Half Degree Polygon Reference	Climate	CRES | FAO	1 004 351	0.05°	3-NM / 1:20 000 000	Africa Analysis	Vectorized CRU 10-by-10 Minute Polygon Reference

Dataset Name	Data Class	Source	Count of Features	Source Scale	Comparative analytical / map scale	Extent Purpose	Description
VMap0 Airports	Airports	VMap0 l 5th Edition	762	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Robust derivative of VMap0-Ed5 data layers with harmonized encoding
VMap0 Canals	Canals	VMap0 l 5th Edition	194	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Seamless and topologically robust derivative of all linear Transport/Rail VMap0-Ed5 data layers
VMap0 Capital Cities	Capitals	VMap0 l 3rd Edition	55	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Derivative of current African capital cities from other VMap0-Ed3 data layers
VMap0 General Point Feature Reference	Reference	VMap0 l 5th Edition	17 136	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Consolidation of all VMap0 point features, robust derivative of VMap0-Ed5 data layers with harmonized encoding
VMap0 Generalized Coastline-National Reference	Reference	VMap0 l 5th Edition	5 978	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Seamless and topologically robust derivative of VMap0-Ed5 data layers
VMap0 Industrial Pipeline Reference	Pipelines	VMap0 l 5th Edition	186	1:1 000 000	n.a /1:1 000 000	Africa Reference	Seamless and topologically robust derivative of VMap0-Ed5 data layers
VMap0 Industrial Processing Polygons	Processing Zones	VMap0 l 5th Edition	92	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Seamless and topologically robust derivative of VMap0-Ed5 data layers
VMap0 International Date Line	Reference	VMap0 l 5th Edition	82	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Seamless and topologically robust derivative of linear VMap0-Ed5 Industry and related data layers
VMap0 Land Surface and Physiographic Reference	Land Type	VMap0 l 5th Edition	7 047	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Seamless and topologically robust derivative of VMap0-Ed5 data layers
VMap0 Landmass and Oceanic Island Polygons	Mask	VMap0 l 5th Edition	2	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Seamless and topologically robust derivative of source VMap0 data layers for landmass and oceanic island data layers
VMap0 Major Road Library Reference	Reference	VMap0 l 3rd Edition	10 113	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Major roads as contained in the VMap0-Ed3 Library Reference, but dropped in VMap0-5th Edition
VMap0 National-Ad1 Linear Boundaries	Coastline – Admin.	VMap0 l 5th Edition	1 826	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Ad1-Seamless and topologically robust derivative of all linear VMap0-Ed5 coastline and national/sovereign boundary data layers cross-checked against related polygonal vectors
VMap0 National-Ad1 Polygonal Boundaries	Admin.	VMap0 l 5th Edition	1 122	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Ad1-Seamless and topologically robust derivative of all polygonal VMap0-Ed5 coastline and national/sovereign boundary data layers cross-checked against related linear vectors
VMap0 National-Ad2 Linear Boundaries	Coastline – Admin.	VMap0 l 5th Edition	3 656	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Ad2-Seamless and topologically robust derivative of all linear VMap0-Ed5 coastal, national, subnational and sovereign boundary data layers cross-checked against related polygonal vectors
VMap0 National-Ad2 Polygonal Boundaries	Admin.	VMap0 l 5th Edition	1 753	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Ad2-Seamless and topologically robust derivative of all polygonal VMap0-Ed5 coastal, national, subnational and sovereign boundary data layers cross-checked against related linear vectors

Dataset Name	Data Class	Source	Count of Features	Source Scale	Comparative analytical / map scale	Extent Purpose	Description
VMap0 Ocean and Sea Polygon Reference	Oceans	VMap0 l 5th Edition	25	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Seamless and topologically robust derivative of VMap0-Ed5 polygonal Ocean/Sea data layers
VMap0 Oceanic Island Point Reference	Offshore Islands	VMap0 l 5th Edition	1 474	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Oceanic point feature derivative of VMap0-Ed5 Political Point data layer
VMap0 ONC and Data Quality Reference	Data Class	VMap0 l 5th Edition	284	1:1 000 000	n.a /1:1 000 000	Africa Reference	Seamless and topologically robust derivative of VMap0-Ed5 data layers
VMap0 Populated Place Point Reference	Reference	VMap0 l 5th Edition	39 172	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Robust derivative of VMap0-Ed5 Populated Place data layer
VMap0 Populated Place Polygons	Populated Place	VMap0 l 5th Edition	1 505	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Seamless and topologically robust derivative of VMap0-Ed5 data layers
VMap0 Railway Line Reference	Railroad	VMap0 l 5th Edition	2 492	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Seamless and topologically robust derivative of all linear Transport/Rail VMap0-Ed5 data layers
VMap0 Roads Reference	Roads	VMap0 l 5th Edition	84 205	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Seamless and topologically robust derivative of all linear Transport/Roads VMap0-Ed5 data layers
VMap0 Spot Elevation Points	Spot Elevations	VMap0 l 3rd Edition	80 449	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Robust derivative of VMap0-3rd spot elevation layers spatially crossed checked against DCW coincident spot features to establish small closed contour features attributed improperly as points
VMap0 Utilities Line Reference	Utility	VMap0 l 5th Edition	2 476	1:1 000 000	n.a / 1:1 000 000	Africa Reference	Seamless and topologically robust derivative of linear VMap0-Ed5 Utility and related data layers
WVS+ Coastline-Political Boundary Linear Reference	Coastline – Admin.	WVS+	6 065	1:250 000	n.a / 1:250 000	Africa Reference	Linear and polygonal coastal, country and bathymetry
WVS+ Landmass-Island-National Boundary Reference	Coastline – Admin.	WVS+	5 409	1:250 000	n.a / 1:250 000	Africa Reference	WVS+ Landmass-Island-National Boundary Reference
WVS+ Landmass-Island-National Point Reference	Coastline – Admin.	WVS+	5 409	1:250 000	n.a / 1:250 000	Africa Reference	Linear and polygonal coastal, country and bathymetry

Ancillary Raster Database Component

The Ancillary Raster Database Component (ARAS-DBC) contains a large number of datasets formatted as ESRI grids. Table 2.11 provides an overview of the raster data layers in this component database. Because these datasets are in grid format, they can be viewed in ArcView but they cannot be analyzed unless the ArcView Spatial Analyst extension is installed. Users will find that these datasets are much more useful if Spatial Analyst is available. As discussed previously, data layers highlighted in grey within this table are set for only limited distribution or on-line access for this edition of the AWRD.

From Table 2.11 it can be seen that the AWRD contains raster data at a number of different pixel sizes or resolutions. These raster datasets are integral to the functionality of certain tool-sets within the AWRD. For users without the Spatial Analyst module, statistical summary tables have been prepared on a watershed-by-watershed, and in some cases administrative boundary, basis for each of the datasets listed. As a further aid to users without Spatial Analyst, vectorized versions of the climatologically-related data listed above have also been prepared. These data are available from within the AVEC-DBC (see Table 2.10) and their use is documented in the case studies section of the publication. Similarly, a number of pre-classified pseudo 3D image backgrounds have been prepared to facilitate the visualization and map output of the DEM data listed in Table 2.11. These data are described in the Ancillary Image DBC section of this document.

Lastly, due to copyright distribution issues, human population data previously slated for integration into this DBC could not be included and users must download LandScan or GPW data directly from ORNL or CIESIN respectively. Statistical summaries of the LandScan data have however been included in the AWRD on a watershed-by-watershed basis and are therefore available for analysis.

Ancillary Image Database Component

The eighth and final database component of the AWRD archive is the Ancillary Image DBC. The data layers in the AIMG-DBC were developed to provide pre-classified elevation backgrounds; contextual base map graphics, and satellite image backdrops against which the core functionality of the AWRD interface could be displayed and highlighted. The layers are geo-referenced and provide users with a number of ways to visualise landscapes and differentiate hydrographically related features.

Table 2.12 provides an overview of the data layers which were developed, enhanced, or compiled for inclusion in the AIMG-DBC. These images and maps enable users to view and print high-quality graphical backgrounds at map scales ranging from approximately 1:750 000 to over 1:100 000 000 from within the AWRD. Higher-resolution imagery, up to 1:65 000, are available in the larger optional distribution of the AWRD archive.

All of the graphics listed in Table 2.12 are in highly compressed image formats and their use within the AWRD is dependant on the automated loading of standard viewer extensions to ArcView. The use of these compression formats allow each of the layers in the AIMG-DBC to be displayed at, and in some cases below, the minimum viewing scales listed in Table 2.12; albeit with some potential loss in interpretive and/or output quality. Pseudo RGB representations of all the raster data listed in Table 2.12 are also available to users of the AWRD, regardless of whether the Spatial Analyst module is available. Therefore, these data also represent an important resource for landscape visualization and base mapping.

TABLE 2.11
Overview of Ancillary Raster Database Component

Dataset Name	Data Class	Source	Number of Cells	Source Pixel Size	Comparative analytical / map scale	Extent Purpose	Description
**Annual Total Air Temperature	Air Temperature	CRES l FAO	15 grids 1 450 x 1 380	0.05°	3-NM / 1:20 000 000	Africa Analysis	Air Temperature. 3-arc minute, 15 grids of monthly and summary annual statistics. A vectorized version of these data is contained in AVEC_DBC for users without Spatial Analyst.
Consolidated 30 as SRTM-ETopo2 Hillshade	Hillshade	SRTM-GTopo30	10 800 x 11 400	0.00833°	0.5-NM / 1:3 500 000	Africa Analysis	Grid based hillshade of consolidated 30 as SRTM-ETopo2 DEM
Consolidated SRTM 30 as DEM and ETopo2 Bathymetry	DEM	SRTM-GTopo30	10 800 x 11 400	0.00833°	0.5-NM / 1:3 500 000	Africa Analysis	Consolidated SRTM-GTopo30 DEM with masked ocean values backfilled based on ETopo2 Bathymetry
ETOPO2 2 arc-minute Hill-Bathymetric Shading	Hillshade Bathymetry	ETOPO2	5 400 x 10 800	0.03333°	2-NM / 1:12 500 000	Global Analysis	ETOPO2 2 arc-minute Hill-Bathymetric Shading
ETOPO2 2 arc-minute Terrain-Bathymetry DEM	Bathymetry	ETOPO2	5 400 x 10 800	0.03333°	2-NM / 1:12 500 000	Global Analysis	ETOPO2 2 arc-minute Terrain and Bathymetric DEM
FAO-AquaStat 1 km Hydrologically Filled DEM	Hydro- Filled DEM	FAO	9 194 x 8 736	1 kilometer	0.5-NM / 1:3 500 000	Africa Analysis	Hydrologically filled GTopo30 DEM with the main stems of cartographic rivers "burned-in" for irrigation analysis for the AWRIA
GLC-2000 Based 1 km Global Land Cover	Land Cover GLC2000	JRC - FAO	8 457 x 9 745	0.00833°	0.5-NM / 1:3 500 000	Africa Analysis	1 Km Global Land Cover processed from the SPOT Vegetation sensor
HYDRO1 Kilometer Hydrologically Filled DEM	Hydro-Filled DEM	HYDRO1k	9 194 x 8 736	1 kilometer	0.5-NM / 1:3 500 000	Africa Analysis	An hydrologically filled version of the GTopo30 DEM employing a Afro-centric Lambert Azimuthal Equal Area Projection
Lake Tanganyika SRTM 3 as DEM Mosaic	DEM	SRTM	14 401 x 16 801	0.000833°	0.05-NM / 1:250 000	Tanganyika Analysis	Lake Tanganyika SRTM 3 as DEM Mosaic
Lake Tanganyika SRTM 3 as Hillshade Mosaic	Hillshade	SRTM	14 401 x 16 801	0.000833°	0.05-NM / 1:250 000	Tanganyika Analysis	Lake Tanganyika SRTM 3 as Hillshade Mosaic
Land/Island 30 as Mask based on WVS+	Mask	WVS+	10 800 x 11 400	0.00833°	0.5-NM /1:3 500 000	Africa Analysis	WVS+ 1:250 000 based landmass and oceanic mask derived for processing SRTM-GTopo30 DEMs
Land-Ocean Processing Mask	Climate	CRU	1 080 x 2 160	0.16667°	10-NM / 1:70 000 000	Africa Analysis	Land-Ocean Processing Mask, 10-arc minutes
**Monthly Evapo-transpiration	Evapo-transpiration	CRU	13 grids 1 080 x 2 160	0.16667°	10-NM / 1:70 000 000	Africa Analysis	Evapotranspiration, 10-arc minute, 13 grids of monthly and summary annual total. A vectorized version of these data is contained in AVEC_DBC for users without Spatial Analyst.
**Monthly Precipitation	Precipitation	CRU	13 grids 1 080 x 2 160	0.16667°	10-NM / 1:70 000 000	Africa Analysis	Precipitation, 10-arc minute, 13 grids of monthly and summary annual total. A vectorized version of these data is contained in AVEC_DBC for users without Spatial Analyst.
**Monthly Water Temperature for April	Water Temperature	CRES l FAO	19 grids 1 450 x 1 380	0.05°	3-NM / 1:20 000 000	Africa Analysis	Water Temperature. 3-arc minute, 19 grids of monthly and summary annual statistics. A vectorized version of these data is contained in AVEC_DBC for users without Spatial Analyst.

Dataset Name	Data Class	Source	Number of Cells	Source Pixel Size	Comparative analytical / map scale	Extent Purpose	Description
**Rainfall, 8 Kilometer, Long Average	Precipitation	EDC	36 grids 1 152 x 1 152	8 kilometers	4.3-NM / 1:35 000 000	Africa Analysis	Interpolated rainfall data based on gauge data for the period 1920 to 1980, 36 grids. A vectorized version of these data is contained in AVEC_DBC for users without Spatial Analyst.
**Rainfall, 8 Kilometer, Short Average	Precipitation	EDC	36 grids 1 152 x 1 152	8 kilometers	4.3-NM / 1:35 000 000	Africa Analysis	Meteosat-GTS 10 day cumulative daily satellite estimated rainfall average, 1995 to 1999, 36 grids. A vectorized version of these data is contained in AVEC_DBC for users without Spatial Analyst.
**Rainfall, 8 Kilometer, Decadal 1995-2004	Precipitation	EDC	342 grids 1 152 x 1 152	8 kilometers	4.3-NM / 1:35 000 000	Africa Analysis	Set of 342 monthly grids of Meteosat-GTS 10 day cumulative rainfall estimates from April of 1995 to December of 2004. A vectorized version of these data is contained in AVEC_DBC for users without Spatial Analyst.
SRTM 30 as DEM w/Oceans Masked	DEM	SRTM-GTopo30	10 800 x 11 400	0.00833°	0.5-NM / 1:3 500 000	Africa Analysis	Enhanced SRTM-GTopo30 DEM with ocean values masked and set to null
*SRTM 3-arc second DEM-Baseline 1°-by-1° Grid Tiles	DEM	NASA I SRTM	3 204 grid tiles 1 201 x 1 201	0.000833°	0.05-NM / 1:250 000	Africa Analysis	"Seamless" set of 3 304 Arc-Grid based DEM tiles derived from the Version 2 of the SRTM 3-arc second data library covering Africa; nominal 90 metre
*SRTM 3-arc second DEM-Filled 1°-by-1° Grid Tiles	DEM	FAO	3 204 grid tiles 1 201 x 1 201	0.000833°	0.05-NM / 1:250 000	Africa Analysis	Derivative of the above "Null" SRTM 3-arc second dataset with terrestrial void areas backfilled with SRTM-GTopo30 DEM, 3 204 Arc-Grid tiles
*SRTM 3-arc second DEM-Hillshade 1°-by-1° Grid Tiles	Hillshade	FAO	3 204 grid tiles 1 201 x 1 201	0.000833°	0.05-NM / 1:250 000	Africa Analysis	Arc-Grid "2.5d Hillshade" based derivative of SRTM 3-arc second "Null" set covering Africa, 3 204 tiles
*SRTM 3-arc second DEM-Null 1°-by-1° Grid Tiles	DEM	FAO	3 204 grid tiles 1 201 x 1 201	0.000833°	0.05-NM / 1:250 000	Africa Analysis	Derivative of the above "Baseline" SRTM 3-arc second dataset with ocean and terrestrial void areas set to null using a SRTM-SWBD 1-arc second mask, 3 204 Arc-Grid based tiles
SRTM-SWBD Based 30 Arc-Second Land/Ocean Mask	DEM	SRTM-GTopo30	10 800 x 11 400	0.00833°	0.5-NM / 1:3 500 000	Africa Analysis	A 30 arc-second land/ocean mask derived from the SRTM-SWBD nominal 30 metre coastline data
Volta Basin SRTM 3 as Based DEM Mosaic	DEM	SRTM	13 201 x 14 401	0.000833°	0.05-NM / 1:250 000	Volta Analysis	Volta basin SRTM 3 as Based DEM Mosaic
Volta Basin SRTM 3 as Based Hillshade Mosaic	Hillshade	SRTM	13 201 x 14 401	0.000833°	0.05-NM / 1:250 000	Volta Analysis	Volta basin SRTM 3 as Based Hillshade Mosaic

*Data layer is comprised of multiple source 1x1 degree tiled raster grids for the Extent area listed

**Data layer is comprised of multiple raster grid datasets of the same cell dimensions which represent annual, monthly or decadal value summaries for some time period in years and/or the same values over a time-series

TABLE 2.12
Overview of Ancillary Image Database Component

Dataset Name	Data Class	Source	Count of Features	Source Scale	Comparative analytical / map scale	Extent Purpose	Description
2.5d DEM Sharpened 2nd Generation MODIS Blue Marble mosaic	Satellite based Imagery	SRTM MODIS	37 221 x 45 583	0.002083°	0.125-NM / 1:850 000	Africa Reference	MODIS image mosaic, see below, overlaid atop 7.5as Hillshade of derived from SRTM 3as base. As with image above, only provides greater detail in areas of high relief
2.5d DEM Sharpened ETM+ Image Mosaic	Satellite based Imagery	SRTM ETM+	37 221 x 45 583	0.002083°	0.125-NM / 1:850 000	Africa Reference	ETM+ image mosaic, see below, overlaid atop 7.5as Hillshade of derived from SRTM 3as base
2.5d Enhanced 1st Generation NASA Blue Marble 30as Mosaic	Satellite based Imagery	MODIS	9 600 x 9 600	0.00833°	0.5-NM / 1:3 500 000	Africa Reference	2.5d enhanced version of circa year 2000, NASA Blue-Marble mosaic
2.5d Enhanced 30 as ETM+ Shaded Mosaic	Satellite based Imagery	ETM+ Browse	19 509 x 18 899	465 metre	0.25-NM / 1:2 500 000	Africa Reference	Derivative of the above ETM+ mosaic base, 2.5d enhanced based on the SRTM 30as DEM for ≥ 1:2.5m scale mapping
2.5d Enhanced ETopo2 Terrain and Bathymetry color classified	Elevation Bathymetry	ETOPO2	10 800 x 5 400	0.03333°	2-NM / 1:12 500 000	Global Reference	2.5d enhanced color classified, nominal 3.7 Km, bathymetry and terrestrial elevation enhanced with hillshade
2nd Generation MODIS Blue Marble mosaic	Satellite based Imagery	MODIS	18 612 x 22 793	0.004167°	0.25-NM / 1:1 750 000	Africa Reference	NASA Blue Marble, nominal 460 metre MODIS August 2004 based RGB Satellite Image Mosaic
7.5as Hillshade based on SRTM3as and ETopo2 Bathymetry	Hillshade	SRTM	37 221 x 45 583	0.002083°	0.125-NM / 1:850 000	Africa Reference	Nominal 230 metre hillshaded DEM building on v.2 SRTM 3as base with ETopo2 bathymetry added
Africa Background, ETopo5	Elevation Bathymetry	ETOPO5	985 x 973	0.083333°	5-NM / 1:45 000 000	Africa Reference	2.5d enhanced color classified, 5-arc minute nominal 9.25 Km, bathymetry and terrestrial elevation enhanced with hillshade used for rapid production graphics in part 2 of this publication.
African Virtual Base Map	Virtual Base Map	FAO	51 784 x 51 084	1:750 000	0.15-NM / 1:1 000 000	Africa Reference	1:750 000 scale seamless base map of continental Africa based on VMap0-Ed3, DCW, and Classified GTopo30 DEM
Baseline 15as ETM+ Image Mosaic	Satellite based Imagery	ETM+ Browse	18 910 x 23 158	465 metre	0.25-NM / 1:1 750 000	Africa Reference	Seamless medium resolution LandSat ETM+ satellite image mosaic, circa year 2000 baseline, modified for natural color
Color Shade of SRTM30as w/ ETOPO2 Bathymetry	Hillshade	SRTM-GTopo30	9 600 x 9 600	0.00833°	0.5-NM / 1:3 500 000	Africa Reference	DEM building on GTopo30, with ETopo2 bathymetry
ETopo2 Color Classified Terrain and Bathymetric Elevations	Elevation Bathymetry	ETOPO2	10 800 x 5 400	0.03333°	2-NM / 1:12 500 000	Global Reference	Nominal 3.7 Km bathymetry and terrestrial elevation color classified based on elevation range values
Flattened SRTM 30 as Based Elevation/Relief	DEM	SRTM-GTopo30	9 600 x 9 600	0.00833°	0.5-NM / 1:3 500 000	Africa Reference	DEM building on GTopo30, with ETopo2 bathymetry
Grayscale 15as ETM+ Image Mosaic	Image Hillshade	ETM+ Browse	19 509 x 18 899	465 metre	0.25-NM / 1:1 750 000	Africa Reference	Derivative grayscale version of the above medium resolution ETM+ satellite mosaic baseline, 2.5d enhanced based on the SRTM 30as DEM data
Grayscale Hillshade of ETopo2 Terrain and Bathymetry	Hillshade Bathymetry	ETOPO2	10 800 x 5 400	0.03333°	2-NM / 1:12 500 000	Global Reference	Nominal 3.7 Km Grayscale image of bathymetry and terrestrial elevation

Dataset Name	Data Class	Source	Count of Features	Source Scale	Comparative analytical / map scale	Extent Purpose	Description
Grayscale Hillshade of SRTM30as w/ETOPO2 Bath.	Hillshade	SRTM-GTopo30	9 600 x 9 600	0.00833°	0.5-NM / 1:3 500 000	Africa Reference	DEM building on GTopo30, with ETopo2 bathymetry
*Lake Tanganyika LandSat ETM+ 2.5d Shaded Image Catalog	Seamless Image Catalog	FAO	Access to 120 tiled images	15 metre	0.008-NM / 1:65 000	Tanganyika Reference	Catalog based on the above baseline of 120 natural color ETM+ orthorectified images, 2.5d enhanced based on the SRTM 3as DEM data
*Lake Tanganyika LandSat ETM+ Baseline Image Catalog	Seamless Image Catalog	FAO	Access to 120 tiled images	15 metre	0.008-NM / 1:65 000	Tanganyika Reference	Catalog of 120 natural color enhanced LandSat-ETM+ orthorectified Lat/Long projected RGB images, 7 805 x 7 805 pixels, in JPEG2000 format, tiled to match the structure of the SRTM 3as DEM; circa year 2000
Lake Tanganyika SRTM ~90m Hillshade Mosaic	Hillshade	SRTM	16 801 x 14 401	0.000833°	0.05-NM / 1:250 000	Tanganyika Reference	Seamless DEM hillshade covering Lake Tanganyika basin-watershed
**SRTM 3as 2.5d Hillshade Grid Catalog	Seamless Image Catalog	FAO	3 204 grid tiles as images	0.000833°	0.05-NM / 1:250 000	Africa Reference	Catalog of Arc-Grid based hillshaded depiction of NASA 3as SRTM Version 2 for Africa, seamless compilation of 3 204 1°x1° overlapping tiles
**SRTM 3as 2.5d Null/Backfilled Grid Catalog	Seamless Image Catalog	FAO	3 204 grid tiles as images	0.000833°	0.05-NM / 1:250 000	Africa Reference	Catalog of Arc-Grid based derivative of SRTM 3-arc second Version 2 DEM for Africa, seamless tiled compilation with oceans set to null using SRTM-SWBD 1-arc second mask and terrestrial void areas backfilled with SRTM-GTopo30 DEM
**SRTM 3as 2.5d RGB Image Catalog	Seamless Image Catalog	FAO	Access to 3 204 tiled images	0.000833°	0.05-NM / 1:250 000	Africa Reference	Catalog of RGB image derivative of v.2 SRTM 3as hillshaded DEM for Africa, seamless tiled compilation of color classified DEM by elevation range and hillshade
**SRTM 3as Baseline Grid Catalog	Seamless Image Catalog	FAO	3 204 grid tiles as images	0.000833°	0.05-NM / 1:250 000	Africa Reference	Catalog of Arc-Grid based derivative of SRTM 3-arc second Version 2 DEM for Africa, seamless baseline of 3 204 1°x1° overlapping tiles
**SRTM 3as Null Value Grid Catalog	Seamless Image Catalog	FAO	3 204 grid tiles as images	0.000833°	0.05-NM / 1:250 000	Africa Reference	Catalog of Arc-Grid based derivative of SRTM 3-arc second Version 2 DEM for Africa, seamless tiled compilation with ocean and terrestrial void areas set to null SRTM-SWBD 1-arc second mask
Volta Basin LandSat TM 2.5d Shaded Image	Satellite based imagery	FAO	42 465 x 46 324	28 metre	0.015-NM / 1:125 000	Volta Reference	Above TM orthorectified image base 2.5d enhanced based on the SRTM 3as DEM data
Volta Basin LandSat TM Baseline Image	Satellite based imagery	FAO	42 465 x 46 324	28 metre	0.015 / 1:125 000	Volta Reference	Natural color enhanced LandSat-TM orthorectified Lat/Long reprojected RGB images in JPEG2000 format, circa 1995
Volta River Basin SRTM ~90m Hillshade Mosaic	Hillshade	SRTM	13 201 x 14 401	0.000833°	0.05-NM / 1:250 000	Volta Reference	Seamless nominal 90 metre DEM hillshade of Volta megabasin

*Data layer is comprised of multiple JPEG2000 images and provide seamless coverage for the Extent area listed in a rapid manner without the need for a user to load individual source tiles.

**Data layer is comprised of multiple source 1x1 degree tiled raster grids. For users either with or without the ArcView Spatial Analyst extension, such catalogs provide a rapid and seamless mechanism for portraying grid based data as an image.

Summary of data compiled for the AWRD data archive

Earlier in this section it was stated that, the AWRD archive likely represents the most comprehensive archive of water management and base resource mapping data ever compiled for Africa. The following list attempts to examine this assertion in light of the primary and secondary purposes for which the archive was developed based on the general applications anticipated for each of the diverse thematic layers presented previously in Table 2.2.

1. **In terms of water resources and fisheries management,** this assertion is supported in part by the integration of thematic layers from each of the baseline and/or pre-eminent databases which have been either developed or made publicly available between 1997 and November, 2006. Thematically these layers were presented in Table 2.2 and include: aquatic species data; hydrologically filled DEMs[9], related watershed models and linear flow networks; and surface waterbody and limnological data. With the exception of the DEM baselines, all of the above thematic layers included in the archive have undergone extensive spatial and attribute error checking, and include other significant forms of value-added processing. Summary statistical data have been generated and are available via the AWRD Interface for the DEM data to enable their integration in any watershed-based analysis undertaken via the AWRD Interface.
2. **In regards to base resource mapping data**, the above statement is supported by the inclusion of layers from each of the source baselines for: 1:3 000 000 and 1:1 000 000 scale cartographic framework data libraries; 1:3 000 000, 1 000 000 and 1:250 000 scale gazetteer data resources; and terrain and bathymetric DEM resource baselines at nominal scales ranging from 1:12 500 000 to 1:350 000 made publicly available between 1992 and June, 2006. It should be noted that within the AWRD archive, these resources have been integrated in as complete a manner as possible, and include highly refined derivatives which in some cases also represent further analytical inputs for both AWRD uses and/or the general international development community. Summary statistical data have been generated and are available via the AWRD Interface for the 30 arc-second DEM data referenced above, nominal 1:3 500 000 scale, for users without Spatial Analyst.
3. **Additional analytical resources:** In addition to these water, fisheries and base mapping resources, a variety of further analytical resource layers representing: decadal, monthly and annual rainfall and climatic data for time periods or series including 1920–1980, 1961–1990 and 1995–2005 at nominal scales of 1:220 000 000 through 1:30 000 000; year 2000 human population and land cover at a nominal scale of 1:3 500 000, and soils circa 1995 at a scale of 1:5 000 000 have also been integrated into either the AWRD archive directly or are available via the interface. For users without access to Spatial Analyst: rainfall and climatic data have been summarized for direct analysis via the various modules of the AWRD Interface, and vectorized versions of these data have also been prepared. Human population data have been summarized for direct analysis via the various modules of the AWRD Interface and land cover data are available as a simple visual reference. To facilitate regional and watershed-based analyses, the baseline Soils data were processed to remove national boundaries for coincident units based on attribute consolidation.

[9] DEM is an acronym for Digital Elevation Model. It represents a topographic surface using a continuous array of elevation values, referenced to a common datum. DEMs are typically used to represent terrain relief.

4. **Additional reference, base mapping and publication quality graphic** renditions of all reference DEMs listed under 2) above have been prepared to facilitate a variety of rapid pre-classified DEM and pseudo 3D landscape visualizations regardless of whether a user has access to either ESRI's Spatial Analyst or 3D Analyst commercial add-on modules. The renditions represent full-resolution geo-referenced versions of the source DEMs and can be viewed both within a GIS and outside via a browser or most image viewing software. Although the highest resolution DEM data are set for only limited release, a seamless continental mosaic was created from this baseline as a 2.5d image backdrop for users to support potential reference mapping down to a scale of 1:850 000. In addition to these DEM derivatives, for users without access to Leica's Image Analyst commercial add-on module to ArcView, a variety of satellite-based and 3D-enhanced imagery has been integrated into the AWRD archive. Continental wide circa year 2000 imagery at scales of 1:3 500 000 and 1:1 750 000 are available to all users of the AWRD; while circa 1995 1:125 000 scale imagery for the Volta megabasin and circa 2000 1:65 000 scale imagery for the Lake Tanganyika Watershed are set for limited distribution.

Overall, perhaps the chief value of the data contained within the AWRD archive is that, although the data are derived from some twenty-eight spatial data sources or institutions, the data were processed in a consistent manner by one organization. One of the benefits of this development method is that a considerable amount of expertise has been gained and to some degree institutionalized. Because the AWRD tool-sets and analytical modules are largely *not* African centric, the only reason the AWRD cannot be used directly outside of Africa at the time of publication are related to data. Hence, the level of expertise gained will become an important consideration towards making the global expansion of the AWRD more cost-effective and possible. Another benefit of the AWRD archive development is that both the ultimate source and the processing history of each input data layer, i.e. its lineage, is clear on a layer by layer basis for all AWRD derivatives. Because the lineage is clear, even though no known errors have been identified as having been introduced into the AWRD outputs, if at some point in the future errors are found they will likely be consistent[10] and more readily corrected.

In particular, with regards to vector based derivative data contained within the AWRD archive, a further general benefit of having outputs processed by one organization using a clear processing lineage is that a variety of checks were able to be performed between different editions of the source material. Such checks are most often confined to the realm of commercial data products. To the knowledge of the AWRD developers, the archive represents the first time such efforts have been undertaken for publicly available data. Related to this, a further benefit of the AWRD archival data is that their copyright is clear and is specifically unencumbered for use and onward distribution for any non-commercial purpose.

For both direct users of the AWRD and any institution requiring data for a river basin, country, region or continent-wide area of interest within Africa, the AWRD data archive will provide access to many high quality value-added data layers which were previously unavailable publicly. Table 2.13 provides a summary of what the AWRD development team consider to be some of the unique and/or essential data layers which have been compiled for the archive.

[10] Unless specifically stated in the metadata documentation, double-precision coordinate references were used for all processing of source vector and raster data. Due to this, it is highly probable that if errors are found at some future date, they will not have been degenerative. Rather, any such errors should be the result of introduced biases or improper shifts in either coordinate geometry or attribute values which can be easily rectified in a consistent manner.

TABLE 2.13
Summary of AWRD datasets

Dataset name	Source	Number of features	Source scale
Surface Waterbodies Database Component			
AfriCover Surface Water Body Features	FAO	11 296	1:250 000
Consolidated WCMC Wetlands	WCMC	4 404	1:1 000 000
FAO-MRAG Spatially Referenced Waterbodies	FAO	499	n.a
RWDB2 Surface Water Bodies	RWDBII	831	1:3 000 000
SRTM Surface Water Body Point, Line and Polygon Reference	SRTM	38 840	1:100 000
Surface Water Body Features from GEOnet Gazetteer	GEOnet	46 591	1:250 000
VMap and Harmonized DCW-VMap0 Surface Water Bodies	VMap0 l DCW	25 128	1:1 000 000
Watersheds Database Component			
ALCOM-WWF Watershed Model	WWF l ALCOM	5 456	5 000 cell
FAO-AquaStat Major Basins Watershed Model	FAO	608	10 000 cell
GIWA Large Marine Ecosystem/Basin Delineation	GIWA – URI	2 936	~100 000 cell
HYDRO-1 Kilometer Watershed Model	HYDRO1k	7 133	4 000 cell
WRI Major Watersheds of the World Delineation	WRI-Rutgers	254	~250 000 cell
Rivers Database Component			
Consolidated VMap0 River-Surface Water body Network	VMap0 l DCW	173 504	1:1 000 000
FAO-AquaStat 1:5m African Rivers	FAO	32 636	1:5 000 000
HYDRO-1 Kilometer Flow Drainage Network	HYDRO1k	15 478	4 000 cell
River Features from GEOnet Gazetteer	GEOnet	138 700	1:250 000
RWDB2 Rivers and Surface Water Body Outlines	RWDB2	4 376	1:3 000 000
Aquatic Species Database Component			
Aquatic Species Political Boundary Reference	Varied	5 690	varied
Aquatic Species Watershed Modeling Reference	Varied	608	varied
Restricted version of main SAIAB Aquatic Species Locations	SAIAB	n.a	1:1 000 000
SAIAB Aquatic Species Locations	SAIAB	798	1:1 000 000
SAIAB Threatened and Endanger Species Boundaries	FAO	92	1:2 000 000
Gazetteer Database Component			
DCW Gazetteer	DCW	151 739	1:1 000 000
GEOnet Gazetteer Database	GEOnet	1 083 354	1:250 000
Ancillary Vector Database Component			
DCW (Digital Chart of the World) Datasets	DCW	Various	1:1 000 000
FAO 1:5 Million Scale Soils	FAO	4 909	1:5 000 000
FAO National and Subnational Boundary Datasets	FAO	Various	1:1 000 000
RWDBII 2001 (Revised/Relational World Databank II) Datasets	RWDBII	Various	1:3 000 000
SRTM (Space Shuttle Radar Topography Mission) Landmass, Offshore Islands and Coastlines Datasets	SRTM	Various	1:100 000
VMap0 2000 5th Edition (Vector Map Level 0) Datasets	VMap0	Various	1:1 000 000
WVS+ (World Vector Shoreline) Datasets	WVS+	Various	1:250 000
Ancillary Raster Database Component			
Annual and Monthly Air Temperature	CRES l FAO	1 450 x 1 380	0.05°
Annual and Monthly Evapo-transpiration	CRU	1 080 x 2 160	0.16667°
Annual and Monthly Precipitation	CRU	1 080 x 2 160	0.16667°
Annual and Monthly Water Temperature	CRES l FAO	1 450 x 1 380	0.05°
ETOPO2 2 arc-minute Terrain-Bathymetry DEM	ETOPO2	5 400 x 10 800	0.03333°
FAO-AquaStat 1 km Hydrologically Filled DEM	FAO	9 194 x 8 736	1 kilometer
GLC-2000 Based 1 km Global Land Cover	JRC - FAO	8 457 x 9 745	0.00833°
HYDRO1 Kilometer Hydrologically Filled DEM	HYDRO1k	9 194 x 8 736	1 kilometer
Monthly, Decadal, Short- and Long-Term Rainfall	EDC	1 152 x 1 152	8 kilometers
SRTM 30as DEM and Hillshade for Africa	SRTM	Various	0.00833°
SRTM 3as DEMs and Hillshades for Africa	SRTM	Various	0.000833°
Ancillary Image Database Component			
2.5d Colored ETopo5 Terrain/Bathymetry	ETOPO5	985 x 973	0.083333°
2.5d Enhanced 30 as ETM+ Shaded Mosaic	ETM+ Browse	19 509 x 18 899	465 metre
2.5d Enhanced ETopo2 Colored Terrain/Bathymetry	ETOPO2	10 800 x 5 400	0.03333°
2.5d Enhanced NASA Blue Marble 30 as Mosaic	MODIS	9 600 x 9 600	0.00833°
African Virtual Base Map	FAO	51 784 x 51 084	1:750 000
Baseline 15 as ETM+ Image Mosaic	ETM+ Browse	25 473 x 18 921	465 metre
Classified ETopo2 Terrain/Bathymetry	ETOPO2	10 800 x 5 400	0.03333°
Color Shade of SRTM30as w/ETOPO2 Bathymetry	SRTM-GTopo30	9 600 x 9 600	0.00833°
Flattened SRTM 30 as Based Elevation/Relief	SRTM-GTopo30	9 600 x 9 600	0.00833°
Grayscale 15 as ETM+ Image Mosaic	ETM+ Browse	19 509 x 18 899	465 metre
Grayscale Hillshade of SRTM30as w/ETOPO2 Bath	SRTM-GTopo30	9 600 x 9 600	0.00833°
Greyscaled Hillshade of ETopo2 Terrain/Bathymetry	ETOPO2	10 800 x 5 400	0.03333°
SRTM 3as Color Classified Image Catalog for Africa	SRTM	Various	0.000833°

2.3 AFRICAN WATER RESOURCE DATABASE INTERFACE

ArcView 3.x comes with many additional tools written or licensed by ESRI (Environmental Systems Research Institute, Inc., the publishers of ArcView), and these are installed automatically when ArcView is installed. These tools are referred to as “Extensions”. The AWRD tool itself is an example of an extension, and they are generally written for very specific analytical, graphical or data-management purposes. The AWRD provides an assortment of new custom-designed applications and tools in addition to those provided by ArcView 3.x.

Through the AWRD interface, users maintain the older SADC-WRD functionalities but can now access through a single interface not only tabular and spatial data viewers for the creation of spatial distribution maps, but can for the first time: test and visualize complex spatial relationships; conduct robust statistical analyses concerning the spatial extent and distribution of such relationships; locate and reference similar areas identified during previous analyses; save analytical criteria; export and/or map results; and perhaps most important of all, integrate their own data for comparison or individual analysis.

Currently, there are six analytical modules which comprise the core of the AWRD interface and tool sets: (1) the data and Metadata Module; (2) the Surface Waterbodies Module; (3) the Watershed Module; (4); the Aquatic Species Module; (5) the Statistical Analysis Module; and lastly, (6) the Additional Tools and Customization Module. Most of the analytical modules and tools come with simple and advanced options and all of the modules and tool sets of the AWRD are available throughout the interface.

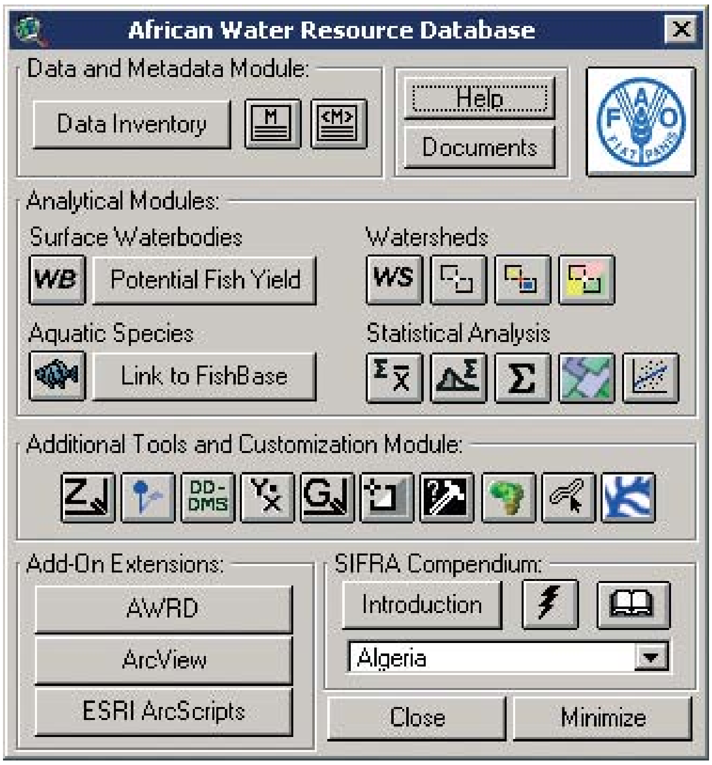
This section provides a brief overview of the general AWRD Interface and the various tool-sets available within each of the six modules. The main tools are described with examples along with a brief of their benefits and potential applications in inland aquatic resource management with a focus on inland fisheries and aquaculture.

A set of application case studies illustrating various decision support scenarios using the AWRD data and tools are available in Section 2.4 to users as aids and training examples; more detailed descriptions of all the modules and tools are available in the AWRD Technical Manual (part 2 of this publication), and educational materials and traning exercies are provided in a workbook (part 2 of this publication).

The full suite of tools provided with the AWRD are available through several buttons and menu options on the ArcView View, Table and Layout interfaces. These include a variety of statistical tools and general enhancements to the basic ArcView 3.x interface as well as several functions specifically designed to analyse surface waterbodies, watersheds and aquatic species. There are three main interfaces to access the different tools and modules developed for the AWRD: (1) AWRD Interface, (2) AWRD Modules menu and (3) AWRD Tools. For most users, the primary source for AWRD functions will be the AWRD Interface, accessible by clicking the  button in the ArcView View button bar. The “AWRD Modules” and “AWRD Tools” menus provide direct access to the four primary analytical modules and to many of the additional GIS-based tools respectively. Most of these functions are also available on the AWRD Interface, but some users may also find it convenient to access the functions directly from these menus.

These interfaces are illustrated in Figure 2.3 and are described in detail in the AWRD technical manual (part 2 of this publication).

FIGURE 2.3
GIS interface



Data and Metadata Module

Within GIS terminology, metadata are the descriptive data about both spatial data and any tabular data which can be used to classify or attribute the individual features of such spatial data. The Data and Metadata Module is comprised of a "Data Inventory" and metadata tools.

Data Inventory

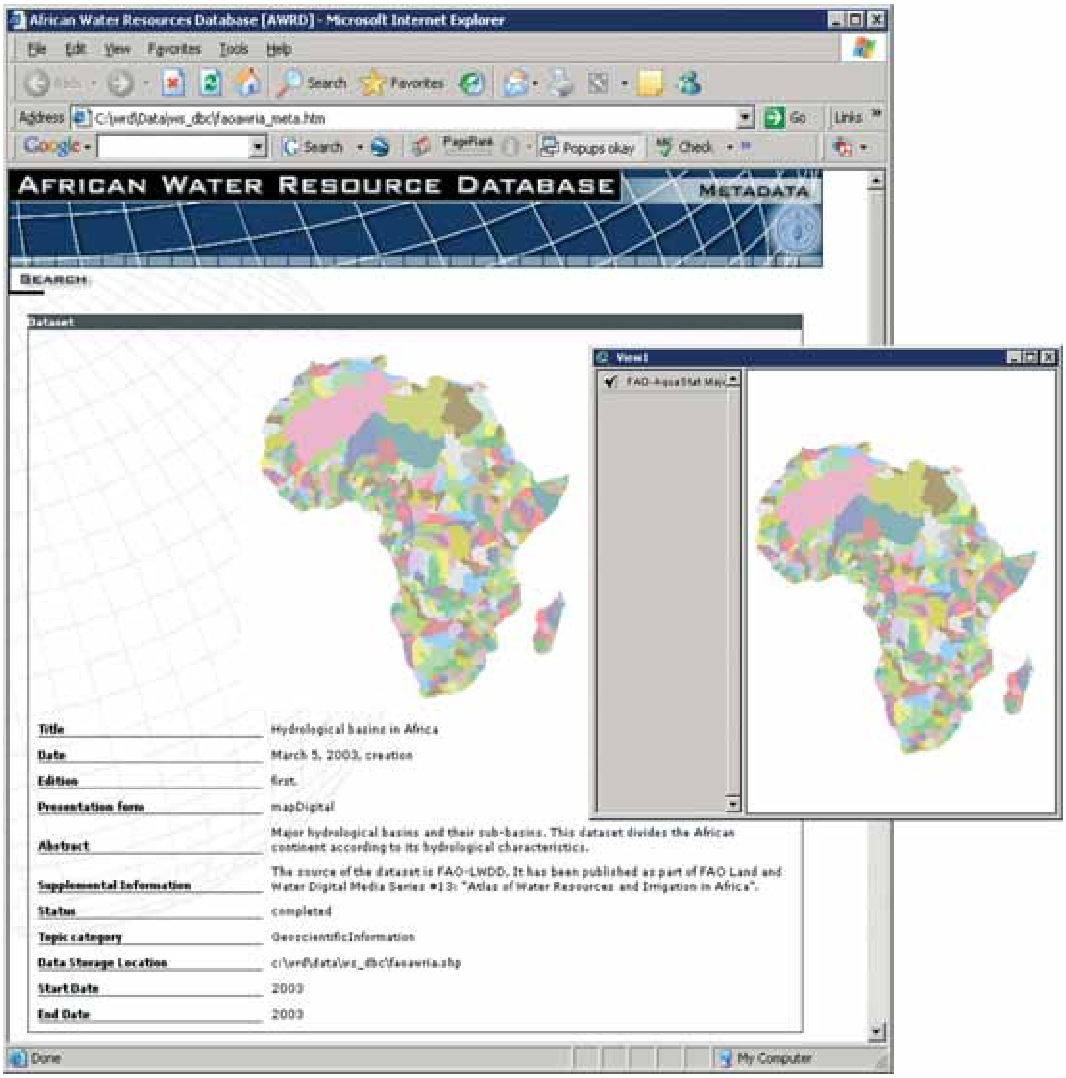
The "Data Inventory" button [Data Inventory] on the AWRD interface allows users to quickly search for and load all data from the AWRD data archive. This function also provides basic descriptive data for all datasets, and includes a button to open the dataset metadata.

Metadata Viewer

Using the AWRD interface a user can opt to review the metadata for any of the AWRD datasets selected for display by clicking the Metadata Viewer button [M] on the AWRD Interface.

Figure 2.4 presents a metadata report for one of the AWRD datasets modelled on the layout generated by FAO's Spatial Data and Information Portal, GeoNetwork (http://www.fao.org/geonetwork/srv/en/main.search). The inventory table also includes hyperlinks to the metadata reports of each data selected.

FIGURE 2.4
Metadata HyperText Markup Language (HTML) summary report

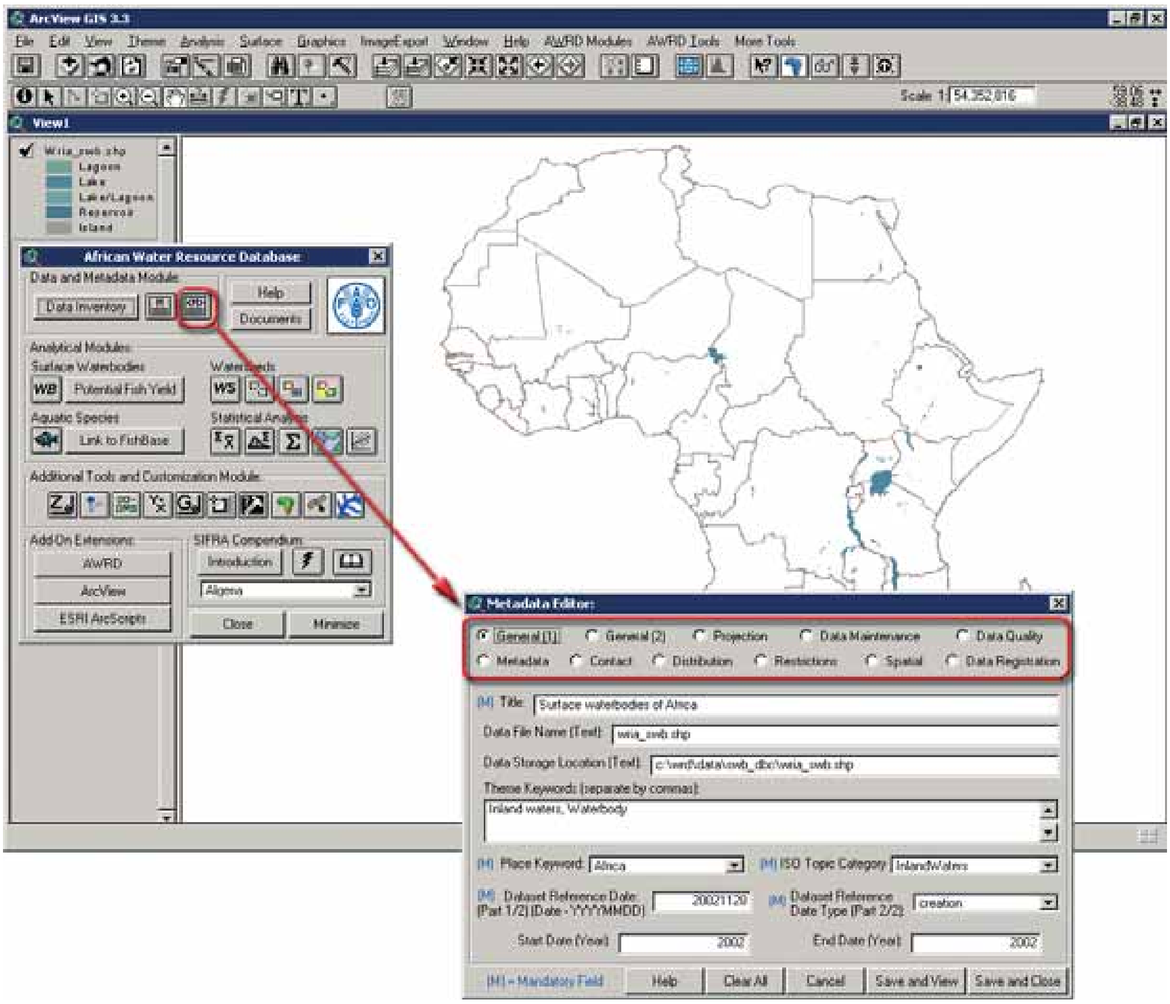


The Metadata tools provide users with the means to review the metadata concerning the 38 general topic divisions provided with the AWRD, as well as add metadata to their own data themes. In addition to providing users of the AWRD with a means of reviewing the metadata associated with the spatial data covered in Section 2.2, the Metadata tools allow users to capture, modify and distribute metadata. The module supports the review and production according to the ISO 19115 metadata standard and is fully compliant with the HyperText Markup Language (HTML) based reporting structure employed by FAO's GeoNetwork.

Metadata Editor

The user can use the Metadata Editor tool to quickly and easily generate a new metadata report for a new datasets or overwrite an existing version. The Metadata Editor tool can be opened by clicking the Metadata Editor button on the AWRD Interface. As can be seen at the top of Figure 2.5, the Metadata Editor tool allows users to review and edit a wide variety of metadata associated with a spatial data layer. The topical metadata which can be evaluated include: General (1), General (2), Projection, Data Maintenance, Data Quality, Metadata, Contact, Distribution, Restrictions, Spatial and Data Registration references. Each of these eleven topical references has its own unique viewing window such as the "General (1)" reference depicted in Figure 2.5. A complete description for each of the eleven metadata topical reference views are detailed in the AWRD Technical Manual (part 2 of this publication).

FIGURE 2.5
Metadata General (1) Reference Dialog



Benefits and applications
Metadata are extremely useful for analyzing and sharing data, providing such essential information as: the source and scale of the original data, the coordinate referencing system, and descriptive information on its quality, accuracy and attributes.

Surface Waterbodies Module

The Surface Waterbodies (SWB) Module is designed to give users of the AWRD quick and easy access to data on surface waterbodies in Africa. In addition, the SWB Module also provides users with a method to predict potential SWB fish yields based on two possible models. The module is designed to work with eleven surface waterbody datasets provided with the AWRD. The SWB Module can be opened by simply clicking on the **WB** button and then specifying which of the fifteen waterbody layers will be considered for analysis (Figure 2.6).

Statistical reporting

As with all of the viewers and tools of the AWRD, users of the SWB interface are provided with the means to "register" their own waterbody datasets for examination within the viewer. To "register" a dataset is to add that dataset to the AWRD GIS interface in such a way that the AWRD tools will be able to calculate statistics on those data. When a surface waterbody dataset is registered, then the Surface Waterbody viewer will allow you to select that dataset from a list and calculate statistics on it.

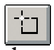
In Figure 2.6, Lake Tanganyika was selected from the surface waterbodies database component using the SWB selection tool available as a button  in the AWRD interface. Because the user has selected only this single waterbody, the viewer lists only a single record for review and by default will display the summary statistics concerning this SWB (Table 2.14).

FIGURE 2.6
Surface Waterbodies attribute and statistics report

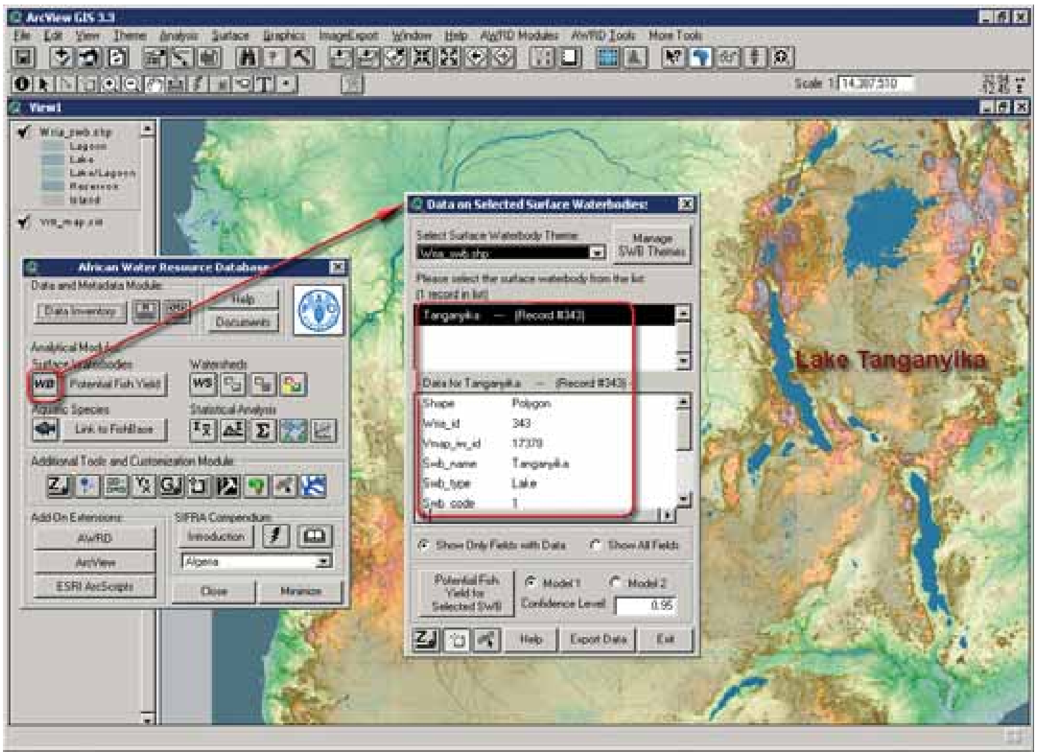


TABLE 2.14
Summary statistics for Lake Tanganyika

Description	Attribute field name	Value
ID	Field [Wria_id]	343
ID	Field [Vmap_iw_id]	17 378
Name	Field [Swb_name]	Tanganyika
Surface waterbody type	Field [Swb_type]	Lake
Surface waterbody code	Field [Swb_code]	1
Hydrological code	Field [Hyd_code]	1
Hectares	Field [Laea_ha]	3 284 471.8
Acres	Field [Laea_acres]	8 115 929.7
Perimeter	Field [Laea_prmtr]	1 878 035.7
Km^2	Field Area	32 844.7

Note: The fieldname "Laea", means that these values are based on the Lambert Equal Area Azimuthal projection.

Benefits and applications

From a fisheries viewpoint it is important to note that the various surface waterbodies are linked to data that characterize them in terms of their physical and administrative characteristics as well as the landscape around them. Historical production and limnological data, available for most of the larger waterbodies and many smaller ones, can also be linked for analysis. The Surface Waterbodies Statistics Viewer offers users the ability to display these key attributes concerning the waterbody selected and to generate a basic statistics report.

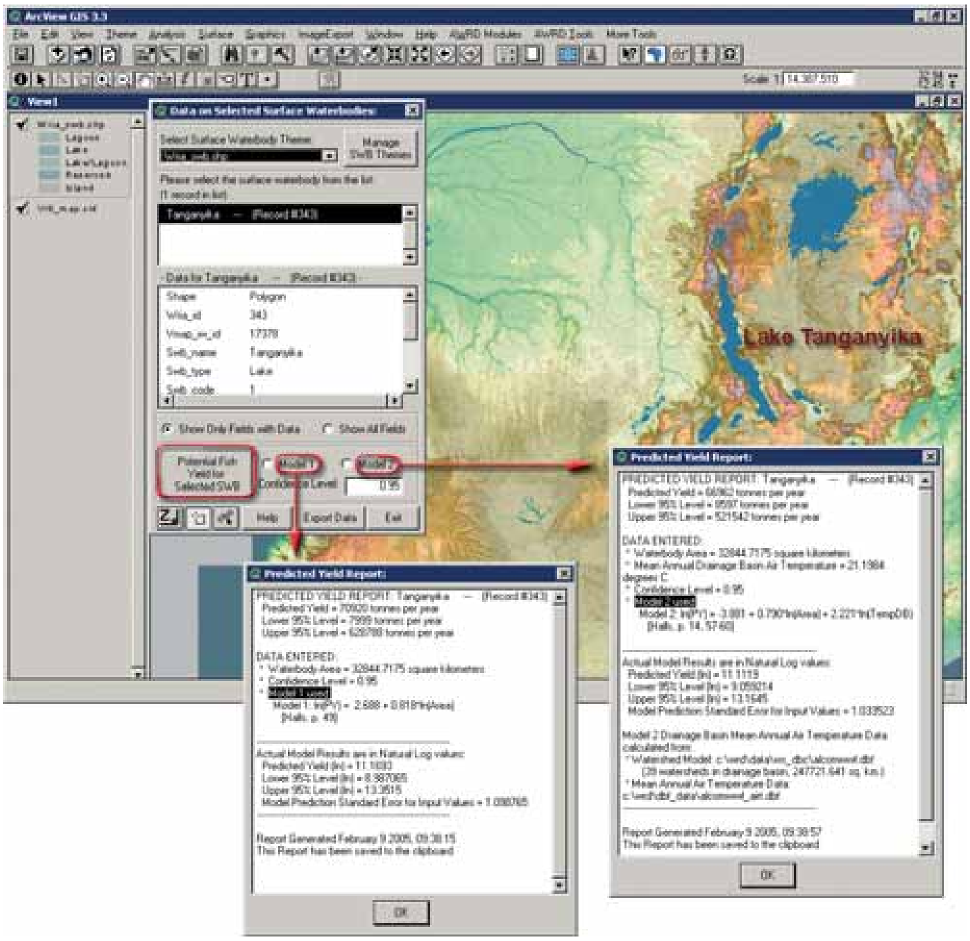
Predicting potential fish yield

One of the core analytical functions of the Surface Waterbodies Module is the ability to estimate potential fish yields of a SWB in metric tonnes based on one of two models developed by Halls (1999). Essentially Model 1 predicts potential yield based only on the surface area of a waterbody, while Model 2 uses both the surface area and the mean annual air temperature of the drainage basin of that waterbody. Please refer to "Predict Potential Fish Yield" in part 2 of this publication section 1.3 for a detailed explanation of Halls' models. If the waterbody surface area is not available for the selected waterbody, then the "Potential Fish Yield for Selected SWB" function will be disabled. Similarly, if there is no air temperature data available, then the Model 2 option will be disabled.

A Potential Fish Yield analysis is started by clicking on the "Potential Fish Yield for Selected SWB" 

button displayed on the SWB Module dialog as shown on Figure 2.6, and will output results similar to those displayed in the Figure 2.7. In this example, Model 1 predicted a potential yield of 70 920 tonnes per year from Lake Tanganyika, while Model 2 predicted a potential yield of 66 962 tonnes per year.

FIGURE 2.7
Example of potential fish yield predictions for Lake Tanganyika



The potential fish yield report provides users with detailed information on the model applied, the data and values used to generate the predicted yield output, and the predicted yields in the original natural log values. The data in the report is automatically saved to the clipboard and it can be pasted into any text-editing program. A discussion on the use of confidence intervals and the predictive accuracy of this analytical tool are contained in part 2 of this publication.

Benefits and applications
Potential yield is a critical value for fisheries managers. Historical data or current observed fish yield values should generally provide more accurate estimates of potential fish yield than the AWRD models, but these models provide a statistically-based guide when better data is unavailable.

Other functions of the SWB Module
In addition to the general statistical reports and predictive yield functions of the module, users are also given tools to: (a) Export selected sets of SWBs to a separate ArcView dBASE table, which can facilitate the ongoing analysis of subsets of data (e.g. in Excel); (b) Access extensive Zooming and Locational Reference tools and (c) Calculate general descriptive spatial statistics on the selected waterbodies.

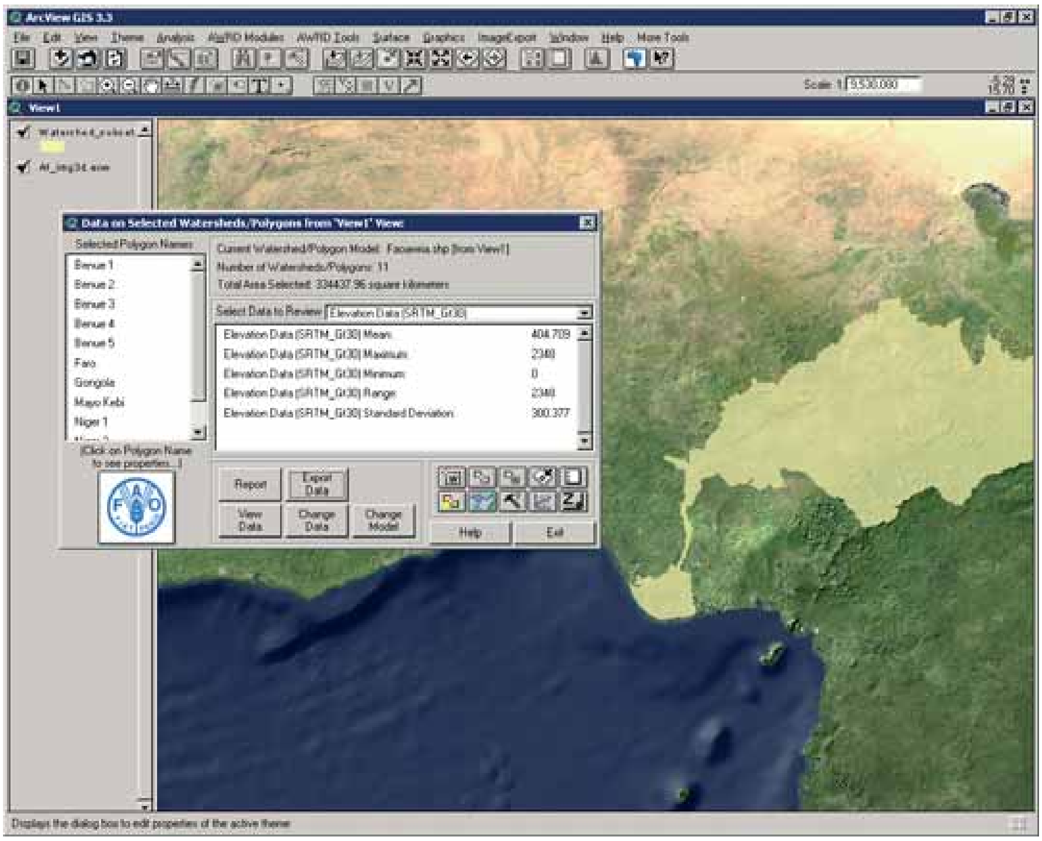
Watersheds Module
The Watersheds Module and related analytical tools represent perhaps the most comprehensive and intensive programming effort undertaken within the AWRD interface. This module offers a wide variety of tools specifically designed to analyse and visualize watersheds. These tools take advantage of the hydrological relationships between watersheds and use these relationships to identify which watersheds are upstream, which are downstream, and which make up the overall flow regime and/or megabasin.

Watershed data layers can be simple or complex. Some watershed data layers are basic watershed delineations composed only of polygons outlining the watershed boundaries. Other watershed data layers are more complex watershed models, in which each watershed is encoded so that the upstream and downstream watersheds can be easily determined. Watershed models also often include the hierarchical level of the watershed within the river system network.

Within the AWRD, to be considered a valid watershed model for analysis via the Watersheds Module, each of the watersheds within a theme must have both an ID field and a field indicating the ID value of the watershed immediately downstream, and these attribute fields must be "registered" within the module. The AWRD WS-DBC currently contains five watershed layers, and three of these layers represent validly encoded WS models which come pre-registered with the Watersheds Module.

At the top centre of the module, users are presented with basic information describing the current watershed model, the current view, the number of watersheds selected, and the total land area selected, while on the left side of the module is a list of all the currently selected watershed records (Figure 2.8). Users may examine the attribute data associated with any of these watersheds by simply clicking on the name or reference available in the record list. A representation of the tool using elevation data is illustrated in Figure 2.8.

FIGURE 2.8
Watersheds Module interface



In addition, at the bottom left of the dialog the Watersheds Module also contains the WS Maintenance tools, available as buttons to generate a text report describing the currently selected watersheds, export those watersheds to a new table (allowing users to analyse the data in some other analytical software), view the original background data used to generate the statistics, change the data to analyse, and change the watershed model.

Watershed Selection and Analysis tools

Many of the analytical functions within the AWRD are designed to work on only a subset of features out of the overall dataset. This allows users to identify an area of interest, and then restrict all analyses to only that region. Within the Watersheds Module, this means the user must select those watersheds of interest before conducting any analyses. The AWRD Watersheds Module provides several tools to select watersheds based on their location, their hydrological relationship with neighbouring watersheds, and their proximity to other features in other datasets.

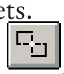
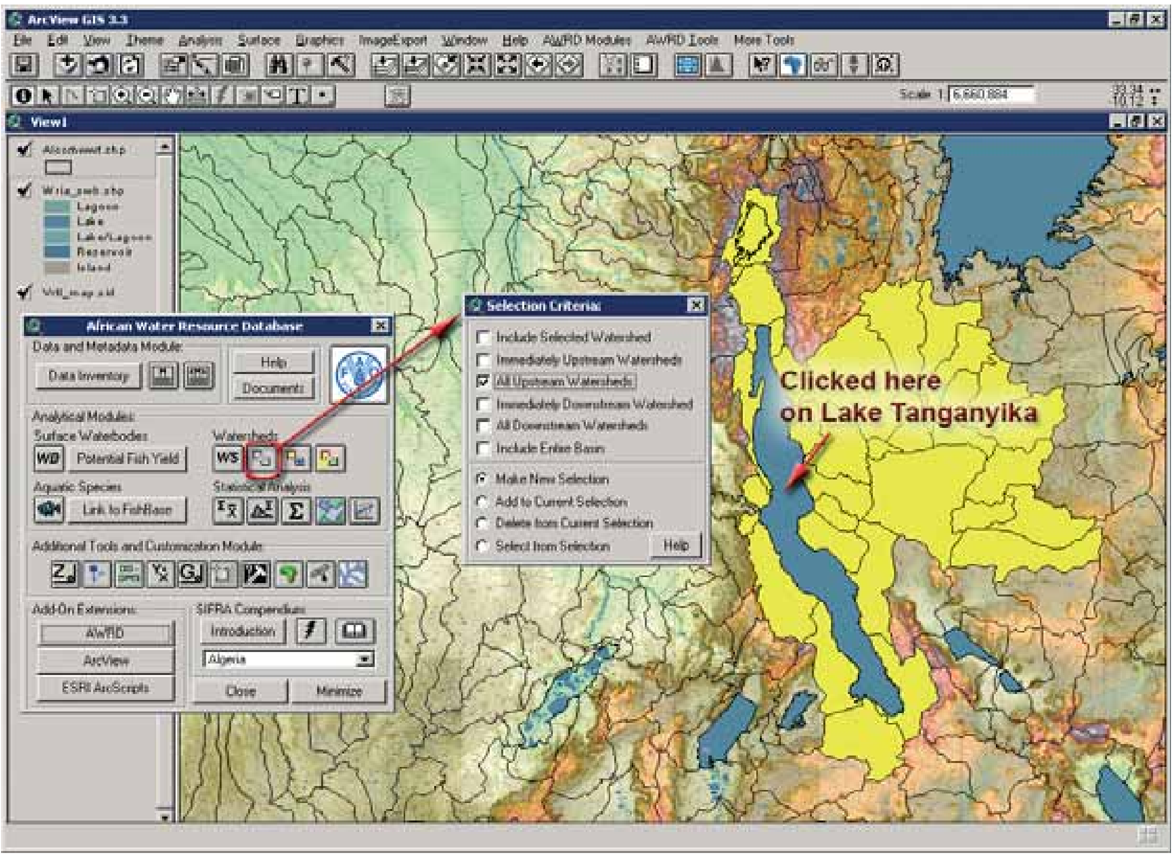
The Watershed Selection tool can be opened by clicking the  button on either the AWRD Interface or on the Watersheds Module dialog. Because this tool operates directly on a "registered" watershed model, the tool will only be enabled if such a model is present in the view and if valid hydrological relationships are defined for it. The "Selection Criteria:" dialog in Figure 2.9 opens when this button is clicked, and the tool is used by simply clicking on any watershed within the active view. The "Selection Criteria" dialog stays open as long as the tool is used.

FIGURE 2.9
Upstream drainage basins for Lake Tanganyika



In the example displayed in Figure 2.9 the user was interested in identifying all those areas that drained into Lake Tanganyika, so they first checked the "All Upstream Watersheds" option, and then chose "Make New Selection", and lastly clicked anywhere on Lake Tanganyika. The watersheds selected based on this query are highlighted in yellow on the display and illustrate the upstream areas representing the Lake Tanganyika drainage basin. Any further statistical calculations conducted by the user on the watershed model would now be limited to the selected set of watersheds.

Multiple selection options can also be considered, such that the user could add all the areas that drained into Lake Victoria to the selected set as well, or possibly choose to remove selected features from the set.

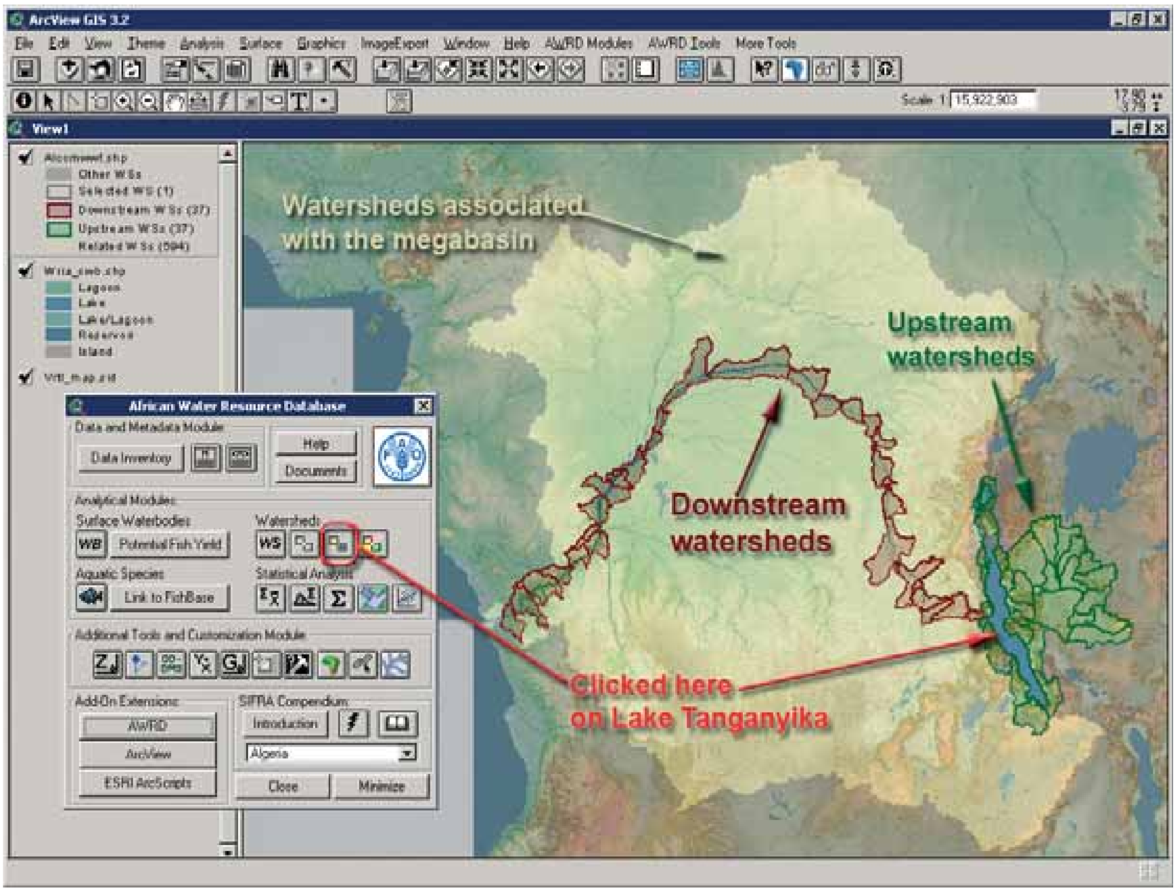
Benefits and applications
The identification of "upstream watersheds" enables the spatial delineation of factors that directly or indirectly affect fishery potential. Thus this tool can be used in conjunction with models to predict fishery potential under natural conditions for various kinds of waterbodies and in tropical and sub-tropical waters.

Identify Upstream and Downstream Watersheds

The primary tool for visualizing and exploring the hydrological network or flow regime associated with a watershed is the "Identify Upstream and Downstream Watersheds" tool. This tool allows users to identify all upstream, downstream and megabasin watersheds and shade them in such a way that they are easy to identify; the resulting legend applied to the theme contains counts of how many watersheds are upstream, downstream, associated, etc.

This tool works on the currently selected watershed model, and therefore is only enabled if this watershed model is present in the active view. Once the tool is open, any mouse click directed to the active view will result in the "preferred" WS model registered with the Watersheds Module by the user, being classified and displayed in a manner similar to Figure 2.10.

FIGURE 2.10
Visualization of the flow regime associated with Lake Tanganyika



As can be seen from the above figure, the "Identify Upstream and Downstream Watersheds" tool can be used to effectively classify on-the-fly any flow regime associated with an individual watershed or river basin. The tool produces a clear visual map of all the watersheds that are hydrologically related to any particular watershed based on classifying: those watersheds upstream; those downstream; those associated with the flow regime as part of the megabasin and lastly, those watersheds which are unassociated with the flow regime and outside of the megabasin.

This tool also automatically opens the Watersheds Visualization tools dialog, offering users twenty unique tool functions for zooming, panning, roaming and flashing the different aspects of a hydrological network as defined by the "Identify

Upstream and Downstream Watersheds" tool, modifying how those watersheds are displayed, and potentially exporting the results of any flow regime analysis to a new theme. The function of each of these tools are described in detailed part 2 of this publication.

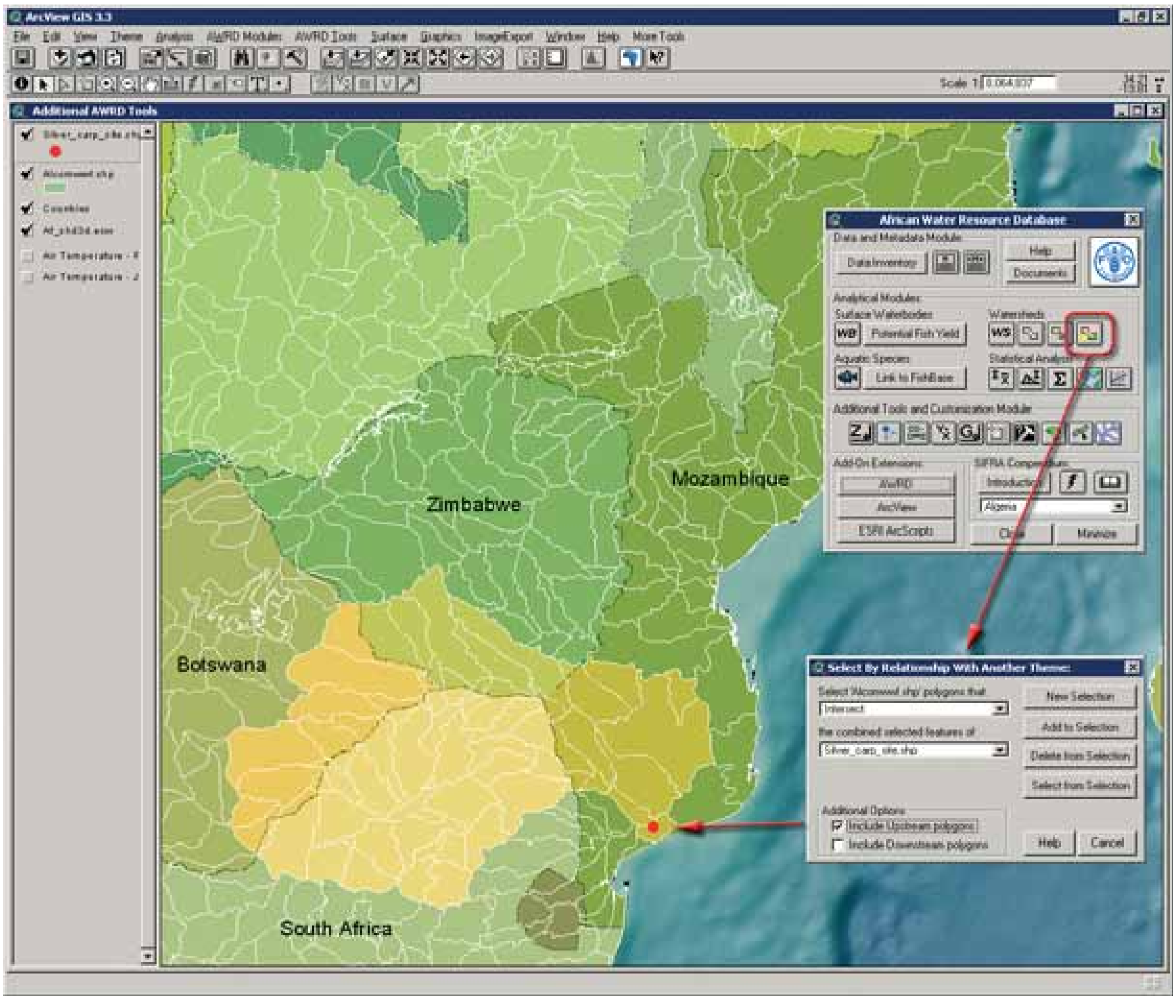
Benefits and applications
This tool can be of great value for assessing pollution from runoff of "upstream" watersheds into aquaculture ponds or residuals from aquaculture ponds into "downstream" watersheds.

Analysis of invasive and introduced aquatic species is another area were this tool has great value because such introductions can have impacts both upstream and downstream within a hydrological system.

Select by Relationship with Another Theme

The "Select by Relationship with Another Theme" tool facilitates complex and possibly iterative selection(s) of watersheds based on where they lie in relation to the selected features of other theme(s). This tool is opened by clicking on the button available directly on the AWRD Interface. In the example below (Figure 2.11), Silver carp are now in Limpopo drainage and the area in yellow (lower left) shows potential Distribution through 4 countries.

FIGURE 2.11
Distribution of Silver carp through four countries



Benefits and applications

This tool can assist in addressing transboundary issues, for example to help assess the risks and benefits from the use of alien species (i.e. introduced or exotic species) in fisheries and aquaculture.

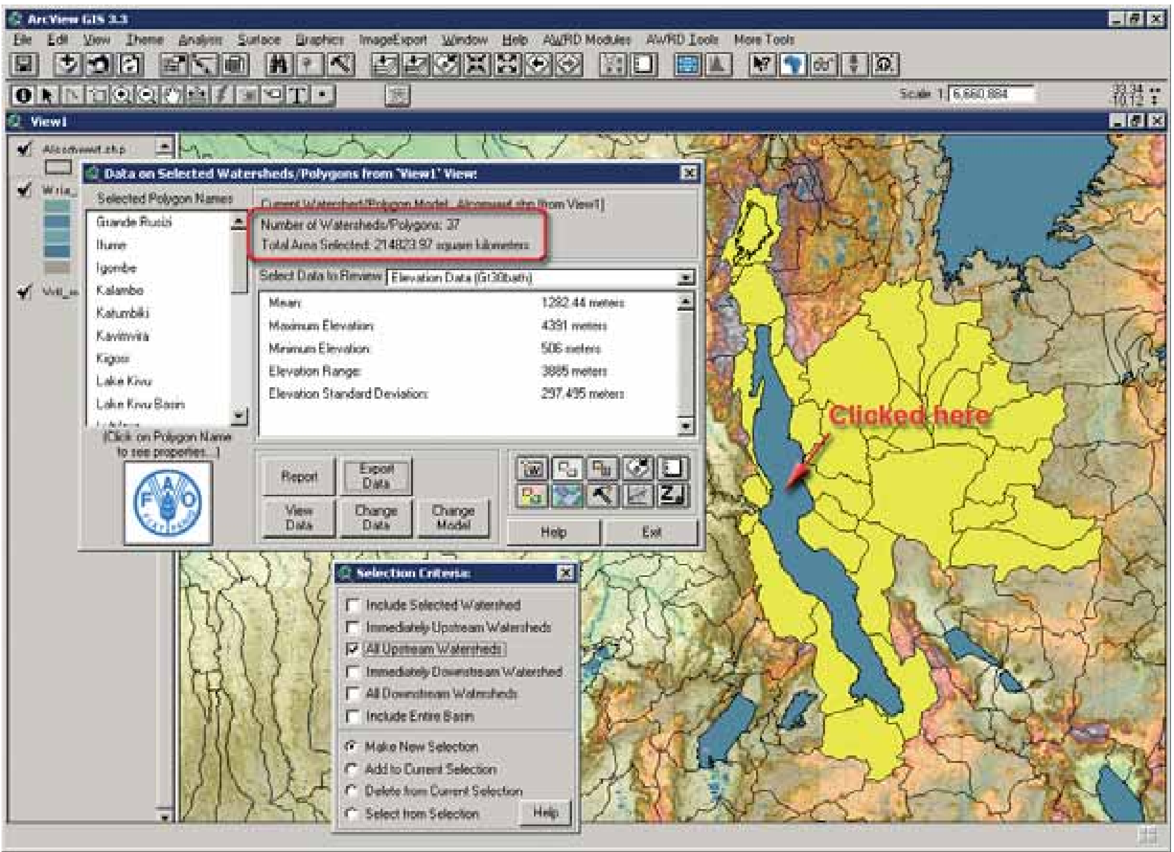
It is anticipated that the AWRD will provide an effective baseline for visualizing, measuring and reporting the parameters underlying the trans-boundary issues involved in the shared utilization of water resources and river basin planning.

Watershed Statistics Viewer

The Watershed Statistics Viewer offers users a wide variety of statistics based on the current set of selected watersheds. As was illustrated in Figure 2.10, a user could use the "Select Upstream and Downstream Watersheds" tool to select all the watersheds which drain into Lake Tanganyika. Given this or any other selection set, the user could now use the tools on the Watershed Statistics Viewer to generate sets of statistics across the entire selected area based on several possible datasets.

The Watershed Statistics Viewer can be opened by clicking on the WS button. Figure 2.12 highlights just such an example, where the cumulative elevation statistics for the thirty-seven watersheds in the Lake Tanganyika drainage basin results are presented.

FIGURE 2.12
Cumulative elevation statistics for upstream watersheds in Lake Tanganyika



Benefits and applications
In addition to the elevation data layer, the AWRD includes a number of useful data layers such as: population densities, mean air temperatures, precipitation and potential evapo-transpiration. By choosing another dataset listed under the "Select Data to Review" pull-down menu, users can customize this module to generate summary statistics for any or all of these data, or any other additional raster datasets a user "registers" within the Watersheds Module. Summary statistics can be generated for any "registered" polygonal data layer, and users are not limited to examining WS models alone with this module. They can, for example, generate summary statistics within administrative boundaries, and the watershed module includes an administrative boundary layer as one of the preregistered watershed models for exactly this purpose.

Aquatic Species Module

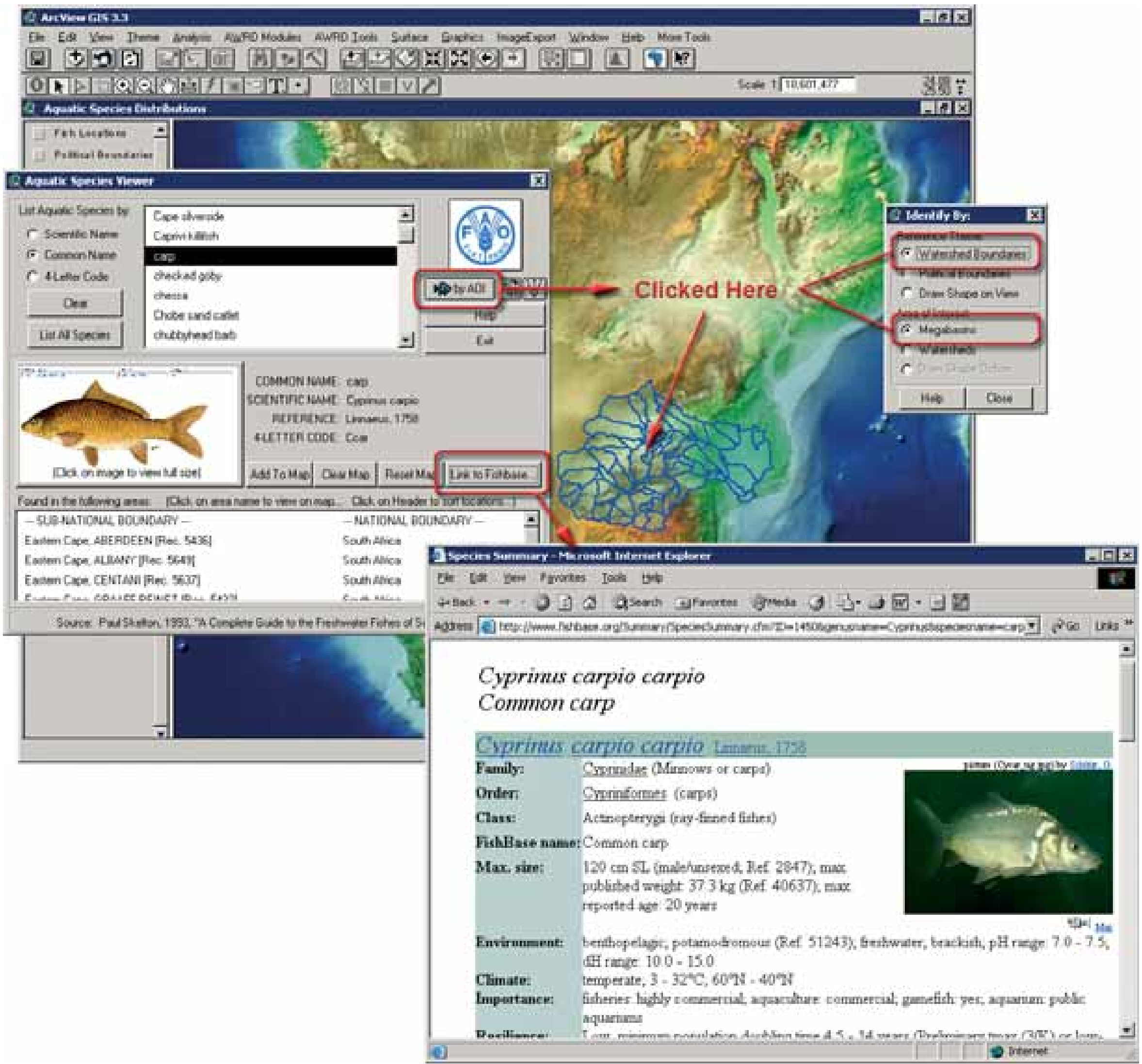
The Aquatic Species Module provides users with the ability to spatially represent and visualize the distributions of aquatic species, identify all species within a particular area, and to potentially access a large amount of descriptive information on those species via the "FishBase" Internet database. "FishBase" is a relational database with information to cater to different professionals such as research scientists, fisheries managers, zoologists and many more. FishBase on the web contains in-depth discussions and data on practically all fish species known to science.

The Aquatic Species Module interface is opened by clicking on the  button on the AWRD interface. Although the user can modify the base view associated with this module, the module defaults to providing the user with four themes. These themes include: the reference locations from the Aquatic Species database, a watershed model for mapping species distributions, an administrative data layer for creating thematic representations of the extents of species coverage, and a shaded relief graphic image of Africa.

Analysis of aquatic species distributions

Some of the key functions available through this module include the ability to: spatially represent and visualize the distributions of aquatic species; identify and review species endemic to a specific sub-national or national area, potentially access a large amount of descriptive information on those species via the Internet; and lastly, to select a particular area on the map and generate a species distribution map based on a linkage to a watershed model or administrative units. In the example illustrated in Figure 2.13, the user has chosen to list the > 700 species in the database by their common name, and has selected the "Carp" species for analysis. In addition, the user has chosen to add a map of this species' distribution onto their view. Since an image of this species is available through the interface, a graphic of the species is also displayed. A list of sub-national and national regions in which this species has been observed displayed at the bottom of the module, and the user can sort this list by either sub-national or national attributes. Thematically, this module provides users with species locations from the reference database and produces either potential distribution maps based on a watershed model or broader containment maps from an administrative data layer. Finally, the user connected to FishBase and accessed a large body of additional data on the carp.

FIGURE 2.13
Summary of functions available from the Aquatic Species Module



Benefits and applications

The AWRD can support the analysis of species distributions using either watersheds, administrative boundaries, and environmental criteria. It is also possible to analyze distributions based on structural features and environmental conditions which may impede the movement of certain species.

A more detailed example illustrating some of the many potential uses of this tool is presented in section 2.4 where a case study on “Invasive and introduced Aquatic Species” is described using this tool.

Another potential application of this tool could be to assess the fish species potentially present within a certain catchment, and therefore those which can be recommended for the sustainable stocking of dams and rivers.

Statistical Analysis Module

With the exception of the WS Module, the Statistical Analysis Module represents the most concentrated programming effort instituted within the AWRD, and in combination with the suite of tools provided for finding locations, provides a wholly new analytical component that was not available in the original SADC-WRD.

Field Summary Statistics tool

The Field Summary Statistics tool provides users of the AWRD with the ability to calculate a much broader range of summary statistical data, with a higher level of precision than the standard summary statistics provided with ArcView. The tool is available in the AWRD Interface, on button bar of any table and from a variety of the tools throughout the AWRD by clicking on the button.

For example, the surface waterbodies database of the Southern African Development Community (SADC) contains more than 18 000 waterbodies with attribute fields including geographical, administrative, meteorological, socio-economic, physical and chemical data as well as data on the use of the waterbody, presence of plant and animal species and fishing activity. Although the database focuses on fish and fisheries, it has a very general scope and there are multiple applications in other disciplines: health (control of waterborne diseases), environmental issues (species distribution), development (water distribution), irrigation, etc. Figure 2.14 illustrates how this tool can use this SADC dataset to easily generate a wide variety of descriptive statistics on surface waterbodies.

Benefits and applications

Summary statistics are an essential part of any basic data analysis. The standard ArcView summary statistics do very well at reporting the minimum, maximum, mean, sum and standard deviation of a dataset. The AWRD summary statistics enhance this basic functionality by providing information on the shape of the distribution (skewness and kurtosis), the variation in the data (variance, average deviation and quartiles), and additional information on the dataset central tendencies (median, mode and standard error of the mean).

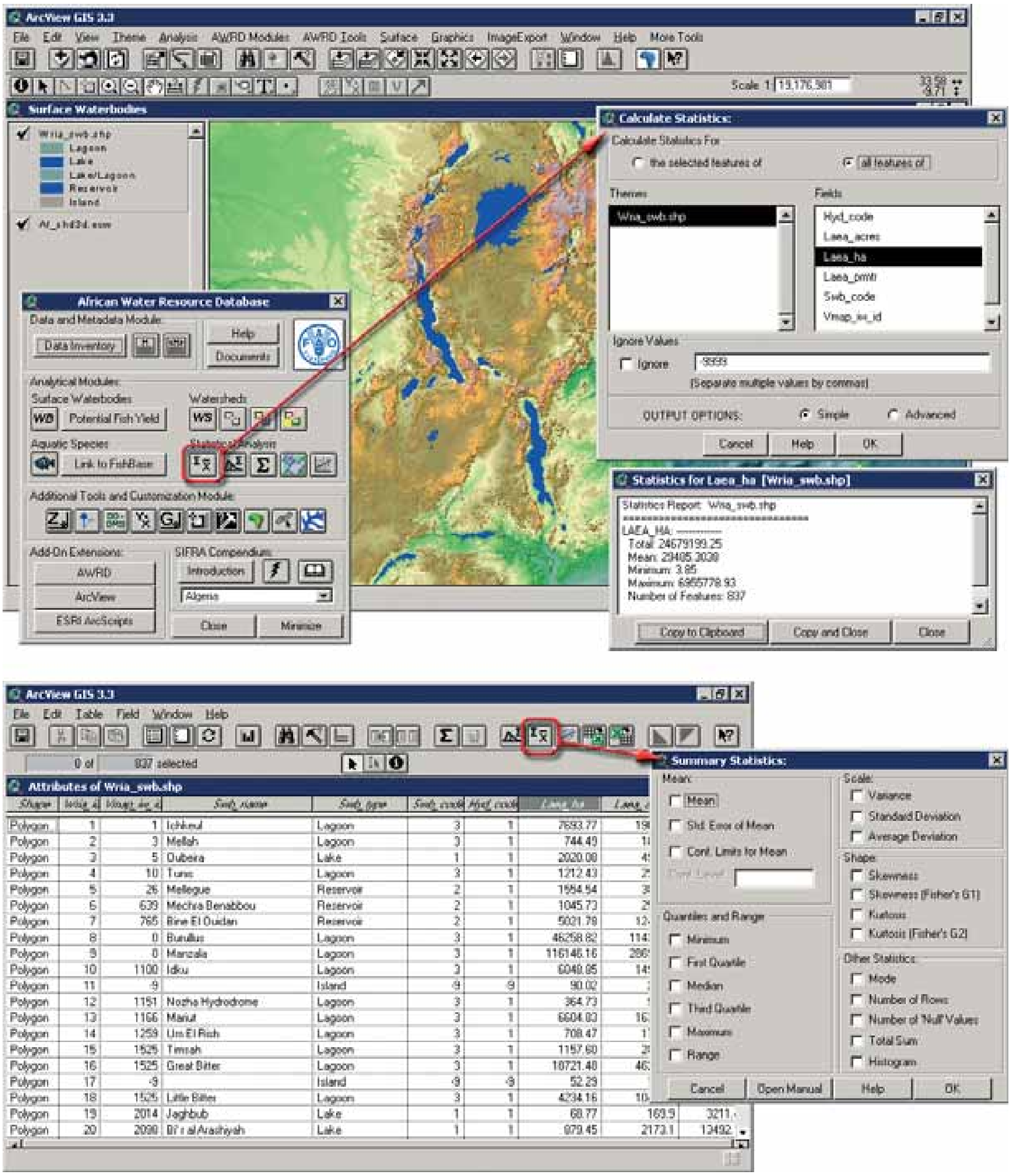
Probability Distribution Calculators

The AWRD includes two versions of a Probability Distribution Calculator. The first of these calculators, the "Probability Distribution Calculator" is designed to work from a view, while the second, the "Table Probability Distribution Calculator" is designed to be run from a feature attribute table or data table.

Both of these calculators are powerful and valuable tools for statistical analysis. The basic purpose of many statistical analyses is to determine whether some observed event is reasonable given some basic assumptions, or whether the odds against such an event are so great as to imply that the basic assumptions are wrong. These calculators provide a way to calculate the odds of an event happening based on those basic assumptions.

These tools are available on the Table button bar and in the AWRD Interface, by clicking on the button. The tool works on the selected set of data, if such a set has been defined. A representation of the tool using the SADC surface waterbodies database can be found in Figure 2.15.

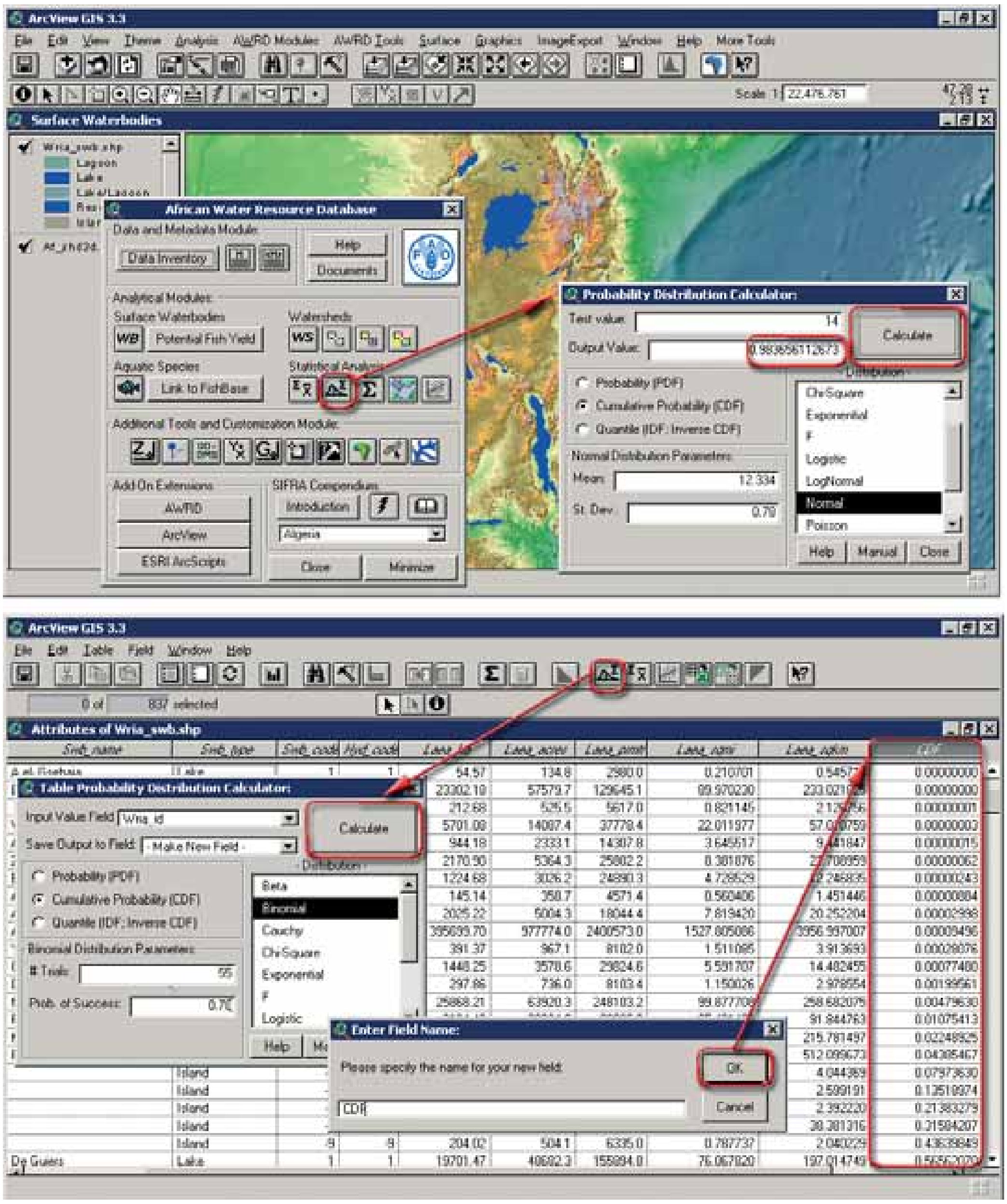
FIGURE 2.14
Summary statistics calculator accessed from View (on the top) and from Table mode (on the bottom)



The Distribution functions included with either the view based calculator or the tabular calculator may be grouped into three categories.

In general, the *Probability Density Functions* return the probability that the Test Value = X given that particular distribution.

FIGURE 2.15
Probability distribution calculators accessed from View (on the top) and from Table mode (on the bottom)



The *Cumulative Distribution Functions* return the probability that the Test Value <= X, given that particular distribution.

The *Quantile Functions* (sometimes referred to as *Inverse Density Functions* or *Percent Point Functions*) return the Value X at which $P(X)$ = [specified probability], given that particular distribution.

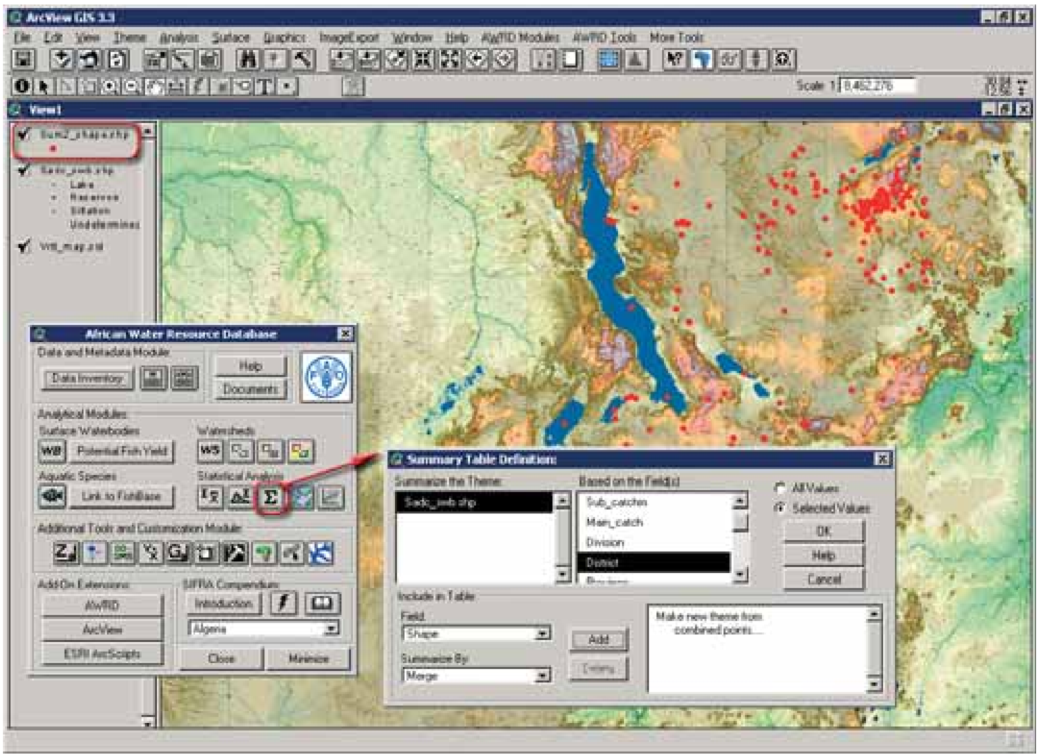
Benefits and applications

Very few software packages include tools to calculate statistical probabilities, and yet statistical probabilities form the basis of most sophisticated analysis. Typically uses must purchase expensive statistical software to gain access to these functions and even then these expensive packages are rarely capable of integrating into a GIS system. These AWRD tools therefore provide powerful and critical functionality that is unobtainable for most GIS users.

Summarize Theme tool

The Summarize Theme tool allows users to divide up a dataset into smaller datasets based on some attribute value and then to calculate statistics for each group. For example, if we had a theme of several aquatic species locations, and if this theme included the country name of each location, then we could use the Summarize Theme tool to count how many unique species were observed in each country. Another scenario might involve a rivers theme, where we could calculate the total length of rivers within a region. This tool can be accessed by clicking the Σ button in the AWRD Interface. A representation of this tool using the SADC surface waterbodies is illustrated in Figure 2.16.

FIGURE 2.16
Summarize Theme tool



Benefits and applications

This tool can assist in reporting on individual waterbodies. For example, a user could use this tool to calculate the total waterbody area in a region, or the number of waterbodies of various types in a region. Effectively, it can provide a method and means to provide robust aggregate fisheries reporting while maintaining the disaggregate level data.

Classification and ranking tool

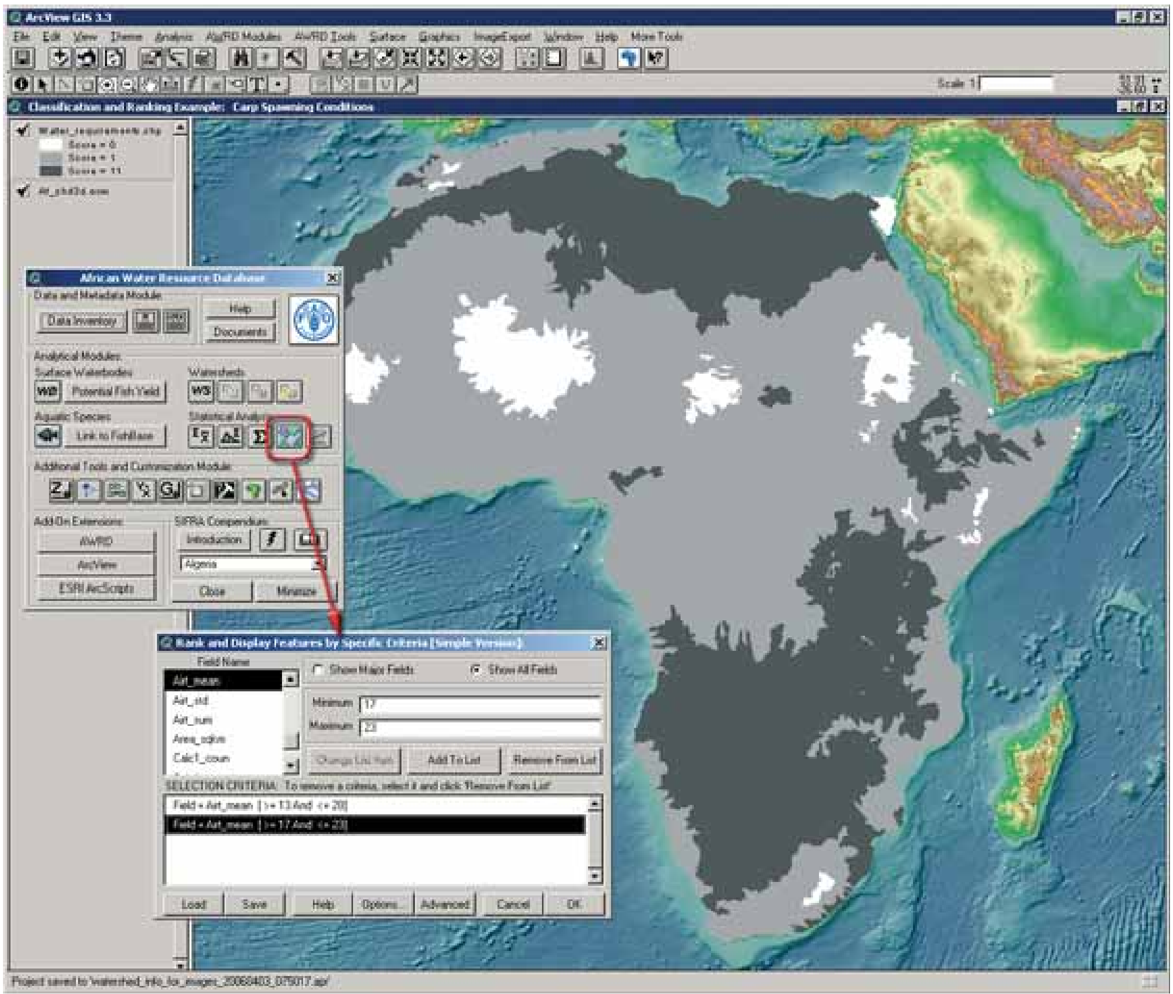
The Classification and Ranking tool provides users with the means to classify watersheds, or any vector theme, according to a wide variety of simple and complex functions. With these tools, users can rank features based on either single or multiple criteria, as well as identify features that do not meet any selection criteria at all. In addition, users can save specific sets of criteria so that a particular classification scheme can be replicated, modified and various scenarios matching different criteria tested.

This tool is intended to enable users of the AWRD to build up various selection sets based on a several criteria. For this reason, a certain amount of testing is implicit to the use of the tool. With the simple version of this tool, users can only choose to set a minimum and maximum range for the field(s) specified for testing, while with the advanced version, users can construct more sophisticated criteria sets which may then be used to rank different features. The advanced version offers greater power in terms of building cumulative scores, and the criteria can include attribute fields containing words, names or alphanumeric codes, as well as including weighting values, critical knock-out constraints and exclusion logic.

The Classification and Ranking tool is available by clicking on the  button in the AWRD Interface. Figure 2.17 highlights the application of the simple version of the Classification and Ranking tool. In this example, watersheds were classified according to the spawning temperatures for common carp. Two spawning temperatures were used for interest and for contrast. The two classes were (1) 13 =< t =< 28 representing the lowest and highest temperatures found for reproduction to take place in the wild, and (2) 17 =< t =< 23 representing the lowest and highest temperatures in the range of optimal temperatures for reproduction in the wild found in the literature.

FIGURE 2.17

Application of the simple classification and ranking tool to indicate spawning temperatures for common carp on a watershed-by-watershed basis



To illustrate the Advanced Classification and Ranking tool, we classified the landscape according to how suitable a watershed might be for pond construction, based on annual precipitation, potential evapotranspiration and an adjustment factor for ground seepage. An overall water requirement index was calculated as:

Water requirement = (Precip. [mm] x 1.1) - (Pot. Evap [mm] x 1.3) – Seepage ([80 mm/mo])

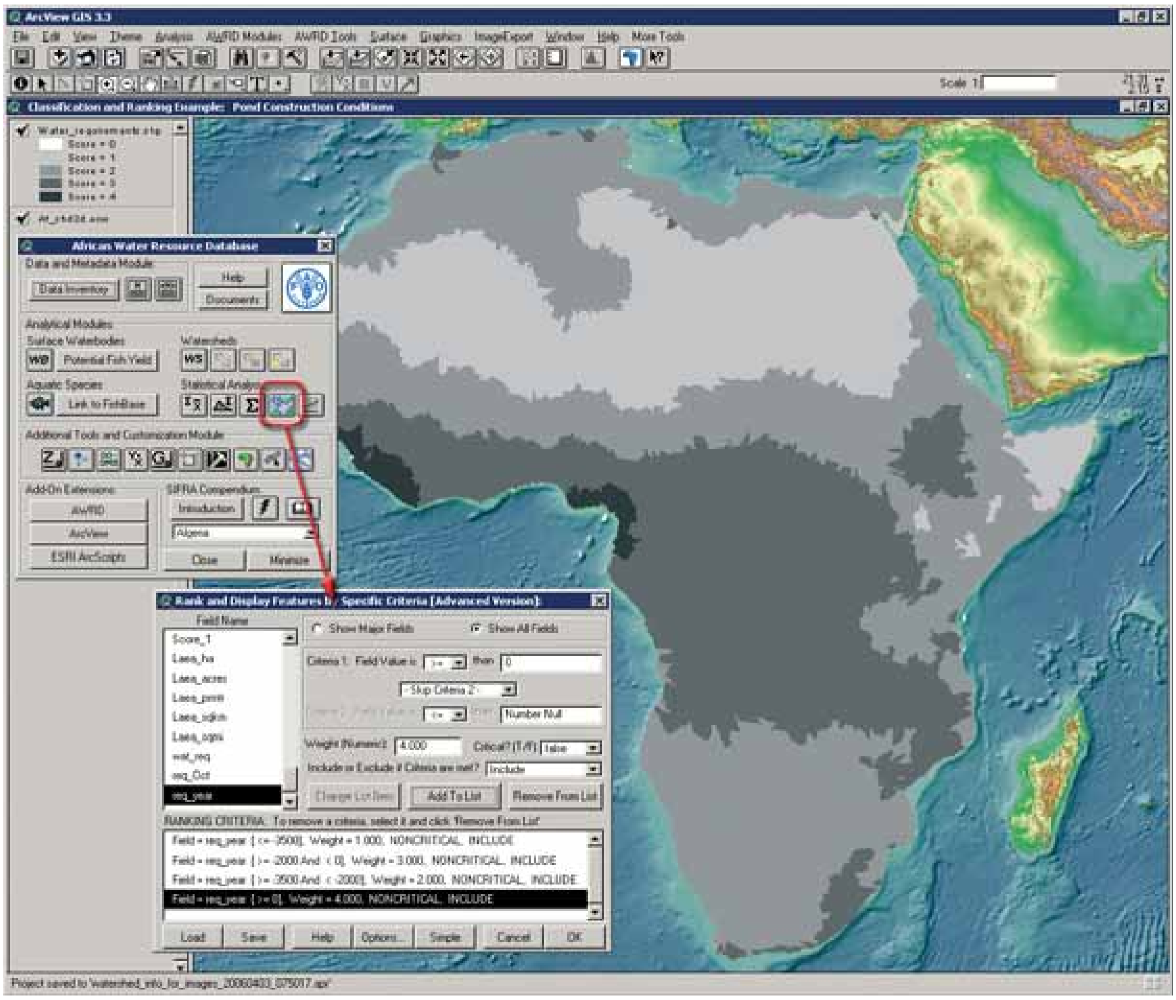
Based on criteria developed by FAO in *A Strategic Reassessment of Fish Farming Potential in Africa* (Aguilar-Manjarrez and Nath, 1998) we classified the landscape into 4 categories, where “4” was Very Suitable and “1” was Very Unsuitable. These categories are defined in Table 2.15 and illustrated in Figure 2.18.

TABLE 2.15
Water requirement submodel

Category value	Water requirement	Interpretation
1	< -3 500 mm	Unsuitable – Many problems
2	-3 500 to -2 000 mm	Very likely to encounter water availability problems.
3	-2 000 to 0 mm	Moderately suitable for ponds
4	> 0 mm	Very suitable as a water source for ponds.

Source: Adapted from Aguilar-Manjarrez and Nath (1998)

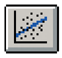
FIGURE 2.18
Application of the advanced classification and ranking tool to determine suitability of ponds for fish farming based on water availability



Benefits and applications

This classification and ranking tool can potentially be used to create an Index of Watershed Indicators (IWI) to characterize the condition and vulnerability of aquatic systems in each of the watersheds in Africa. The tool could also be used to help develop habitat suitability models, by identifying areas that meet sets of habitat criteria.

Simple Linear Regression tool

The Simple Linear Regression tool is opened by clicking on the  button on the AWRD Interface. This tool allows users to conduct simple linear regression analyses between two numeric fields in a table, and examine the values in these fields for any correlation. Similar to the other statistical tools available through the AWRD, the regression tool will either analyse all of the records in a table or only those records that lie within the currently selected set.

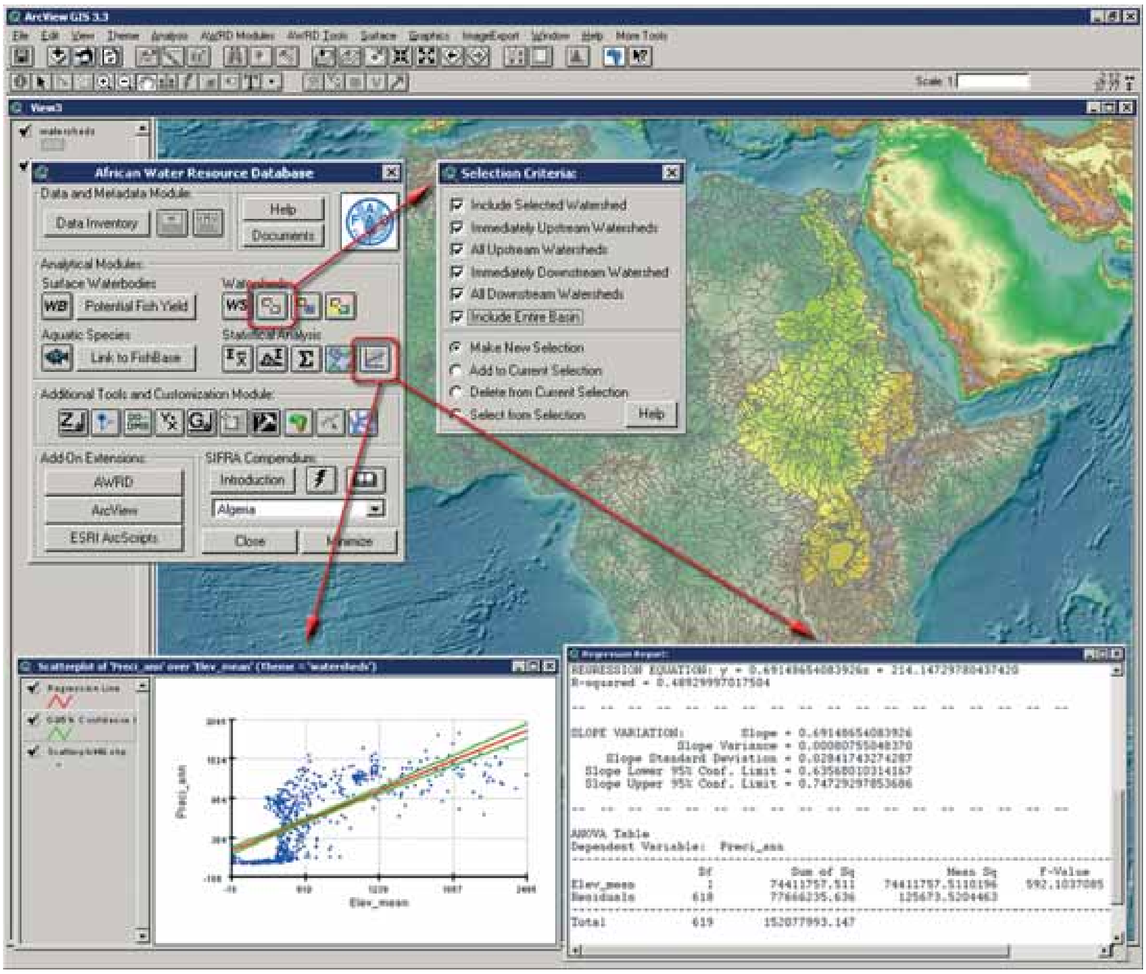
The Simple Linear Regression tool provides users with a robust method for analysing relationships between data. The tool can be used, for example, to tell a user whether fish stocks tend to rise or fall as nutrient levels in a particular surface waterbody rise and fall, and to provide the user with a probability that any relationship established is due solely to chance.

The results of the analysis do not, however, demonstrate any causative relationship, and because of this, a user could not for example, use the tool with any certainty to say that: an *X* rise in nutrient levels would cause fish stocks to increase to level *Y,* even if a strong correlation was established. Furthermore, regression analysis makes certain assumptions about the data, such as independence of samples and constant variance over the range of the sample data, which may be violated in some cases. When these assumptions are violated, the conclusions we draw from the analysis become weaker.

This said, linear regression is still one of the oldest and most commonly used statistical procedures available. This tool provides a wide range of statistical output options associated with the regression, as well as general descriptive statistics on the dependent and independent variables. A report is also automatically generated by the tool and is saved to the user's hard-drive and then opened in a text window for the user to review. Optionally, a user may also chose to generate a scatter-plot illustrating the regression relationship, and if the user elects to generate confidence bands, predicted values, residuals or standardized residuals, then the tool will also produce a new theme in the active view for review.

The optional list of summary statistics produced via the tool conform to those outlined in the "Field Summary Statistics" tool (Figure 2.14), and like that tool, the Simple Linear Regression tool can also restrict the analysis to a subset of features by selecting those features prior to analysis. Figure 2.19 highlights the use of the Simple Linear Regression tool in conjunction with the "Select Upstream and Downstream Watersheds" tool from the Watersheds Module, and is demonstrative of the tight integration between all the modules and tools of the AWRD. In this example, the Nile megabasin becomes the focus of the user's regression analysis, the result of which depicts a reasonably strong relationship between annual precipitation and elevation, with a *P-Value* of < 0.0000001 and an R^2-value of 0.49, suggesting that the variation in elevation accounts for approximately 49 percent of the variation in precipitation within the Nile megabasin.

FIGURE 2.19
Regression analysis of rainfall and elevation for the Nile River megabasin



Benefits and applications
Linear regression is one of the most widely used and easily understandable statistical techniques available for identifying a linear relationship between variables. It is simple to say that one variable rises or falls as another variable rises or falls, but it is much more useful to be able to say exactly how much the variable changes, and to give a precise estimate of the uncertainty of the relationship. Linear regression gives users the ability to describe relationships in a useful and powerful way.

Additional Tools and Customization Module

Because of the range of tasks performed by the AWRD additional tools, there is no interface or concise dialog associated with these tools. In fact, although the development of a single viewer consolidating these would be a relatively straightforward programming task, it was determined that greater utility could be provided to users of the AWRD if these tools were distributed throughout the interface and available at anytime by a simple click of a button.

Tools for Finding Locations
The three primary tools available to assist a user in finding a location are: the “Find Location by Theme” tool; the “Enter Coordinates and Zoom to Location”; and the “Zoom to Gazetteer Locations” tool. Each of these tools has been designed to fill a specific niche, complimenting the different analytic requirements of users.

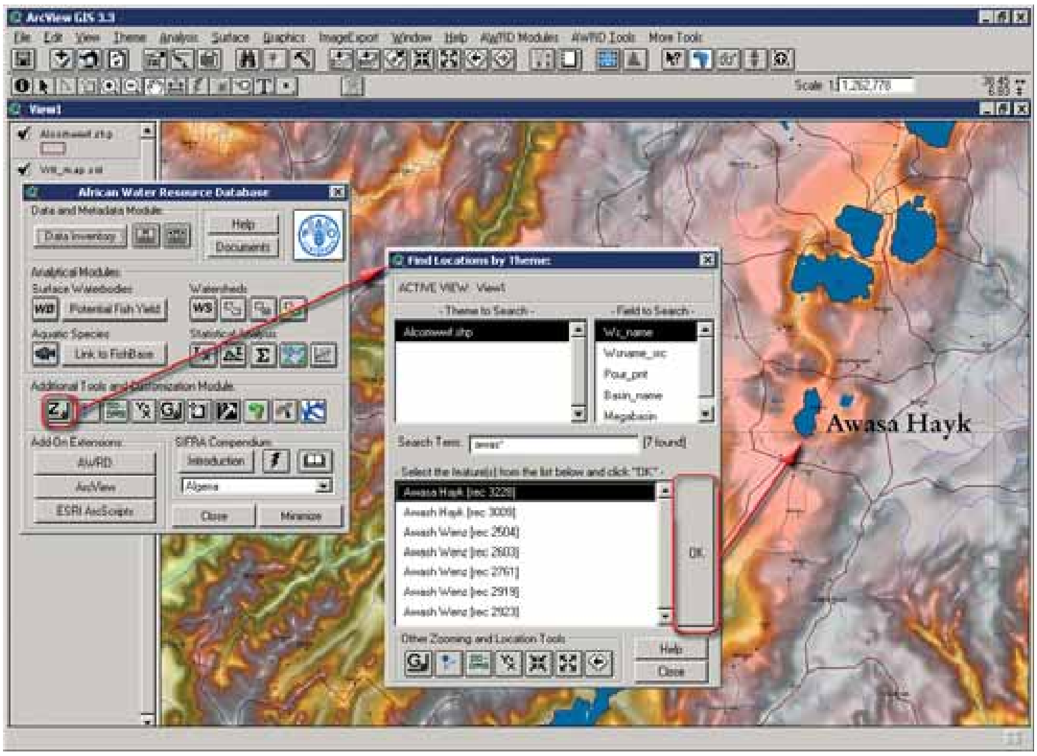
Find Location by Theme tool

The "Find Location by Theme" tool is designed to enable users to select features according by their attributes, and then zoom to the extent of those selected feature(s).

The tool is accessible through the  button in the AWRD Interface and on the Watersheds Module and Surface Waterbodies Module dialogs.

In Figure 2.20, the user was interested in locating the "Awasa Hayk" watershed within the "Alcomwwf.shp" theme layer, so they first selected the "Alcomwwf.shp" theme with the tool, and then entered the "awas*" search string. Based on the results returned, the user then selected "Awasa Hayk" from the list, and by clicking the "Ok" button, was zoomed to the extent of the feature.

FIGURE 2.20
Find Location by Theme tool



Coordinates Referencing tools

In cases where a user is required to find a location based on either latitude and longitude or some other coordinate reference, the AWRD provides the user with a suite of complimentary zooming and locational reference tools. These tools provide users with the capability of zooming to any Latitude/Longitude or projected coordinate reference at a specified scale, of converting between decimal degrees, degree/decimal minutes and degree/minute/decimal seconds; and of getting coordinates by clicking on screen.

The primary tool within this suite is the "Enter Coordinates and Zoom to Location" tool. This tool is designed to allow a user to enter coordinates via a variety of formats and to then zoom to the specified coordinate reference at a scale which is also determined by the user. The tool provides the user with the option of entering coordinates as: decimal degrees, degrees/decimal minutes, degrees/minutes/decimal seconds, or in any custom projection coordinates that can be interpreted by ArcView's projection engine.

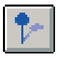
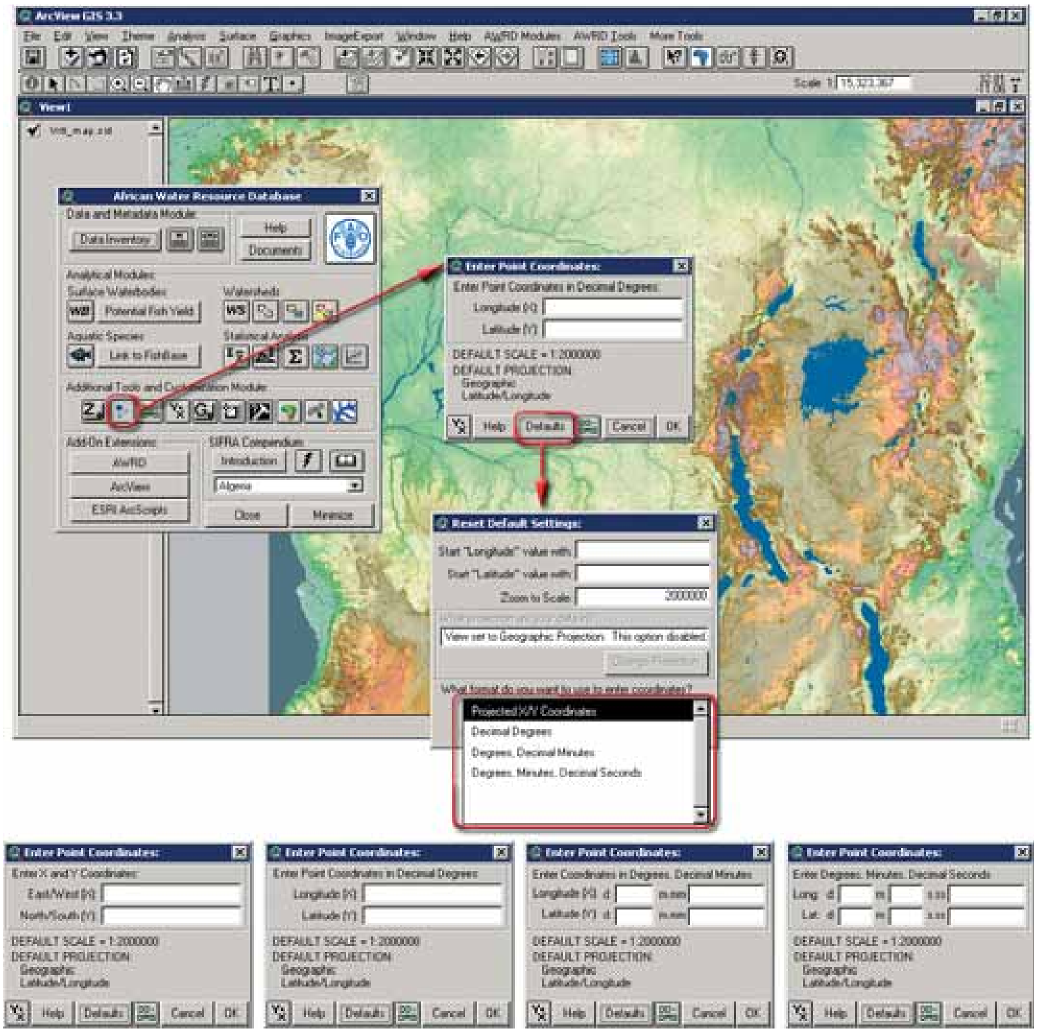
The tool can be opened by clicking on the  button on the AWRD Interface. Depending on whatever preferences the user has "registered" for this tool, one of the four dialogs displayed in Figure 2.21 will be opened when this button is clicked.

FIGURE 2.21
Enter Coordinates and Zoom to Location tool



Once the tool is opened, the user can begin entering coordinates in their "preferred" format, as shown in Figure 2.21. After a coordinate reference has been entered, the user needs only to click on the "OK" button to be zoomed to their desired location and scale specified in Figure 2.21.

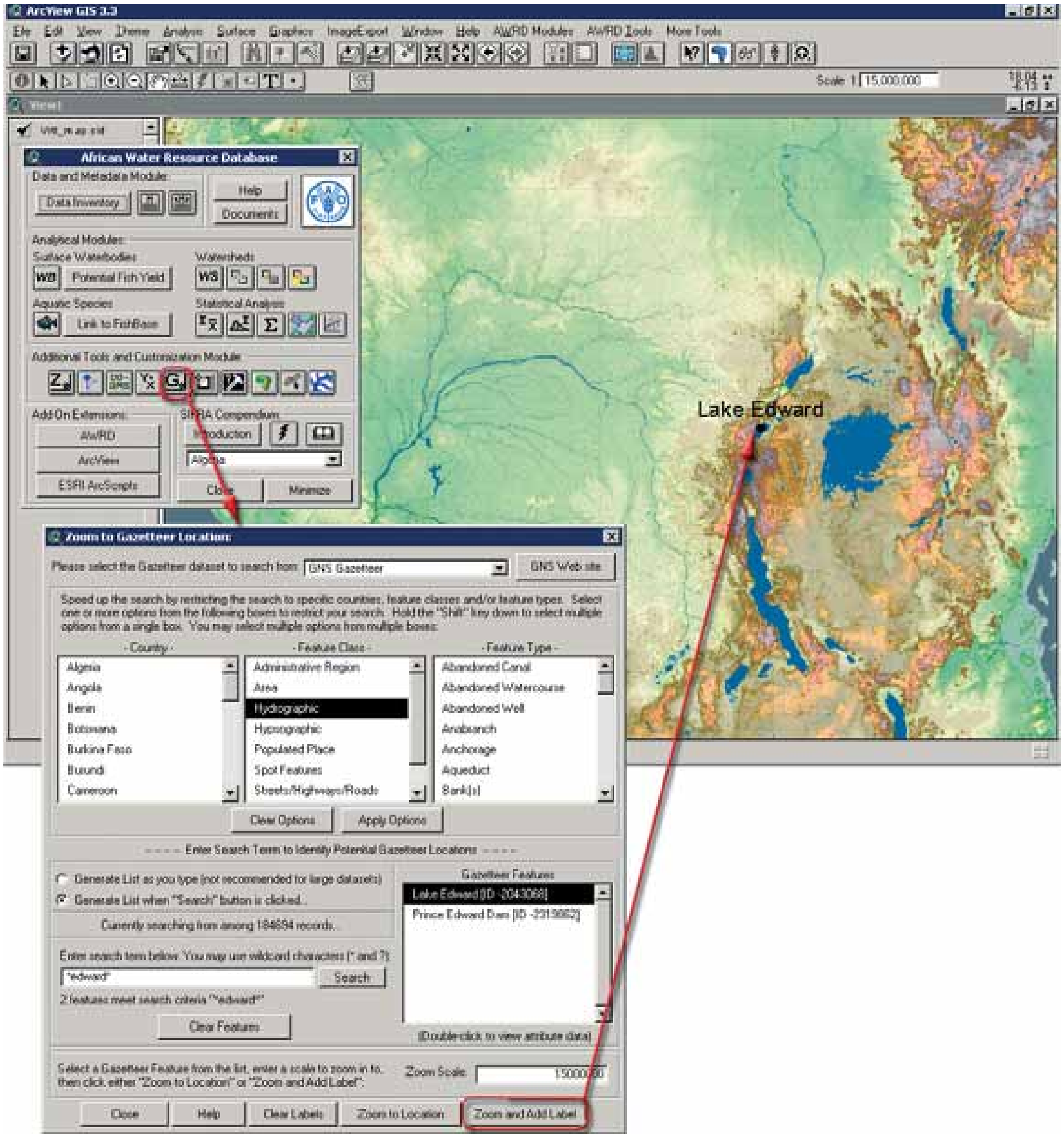
Benefits and applications
This tool allows the user to quickly "switch" between these formats and/or scales by simply clicking on the "Defaults" button and opening the "Reset Default Settings" dialog to change the coordinate preference. The "Reset Default Settings" dialog is also where the user "registers" the default scale for zooming, and can be used to set up any standard or custom projection parameters on-the-fly.

Zoom to Gazetteer Locations tool

There are two Gazetteer database component layers currently residing within the AWRD archive. This tool provides users with a method for locating and zooming to a named location based on a particular feature class and subtype, given that they "know" the name or even just a part of the name reference.

The "Zoom to Gazetteer Locations" tool is opened by clicking on the  button in the AWRD Interface. An illustrative example, using this tool to locate Lake Edward is displayed in Figure 2.22.

FIGURE 2.22
Find locations based on a gazetteer search



Benefits and applications

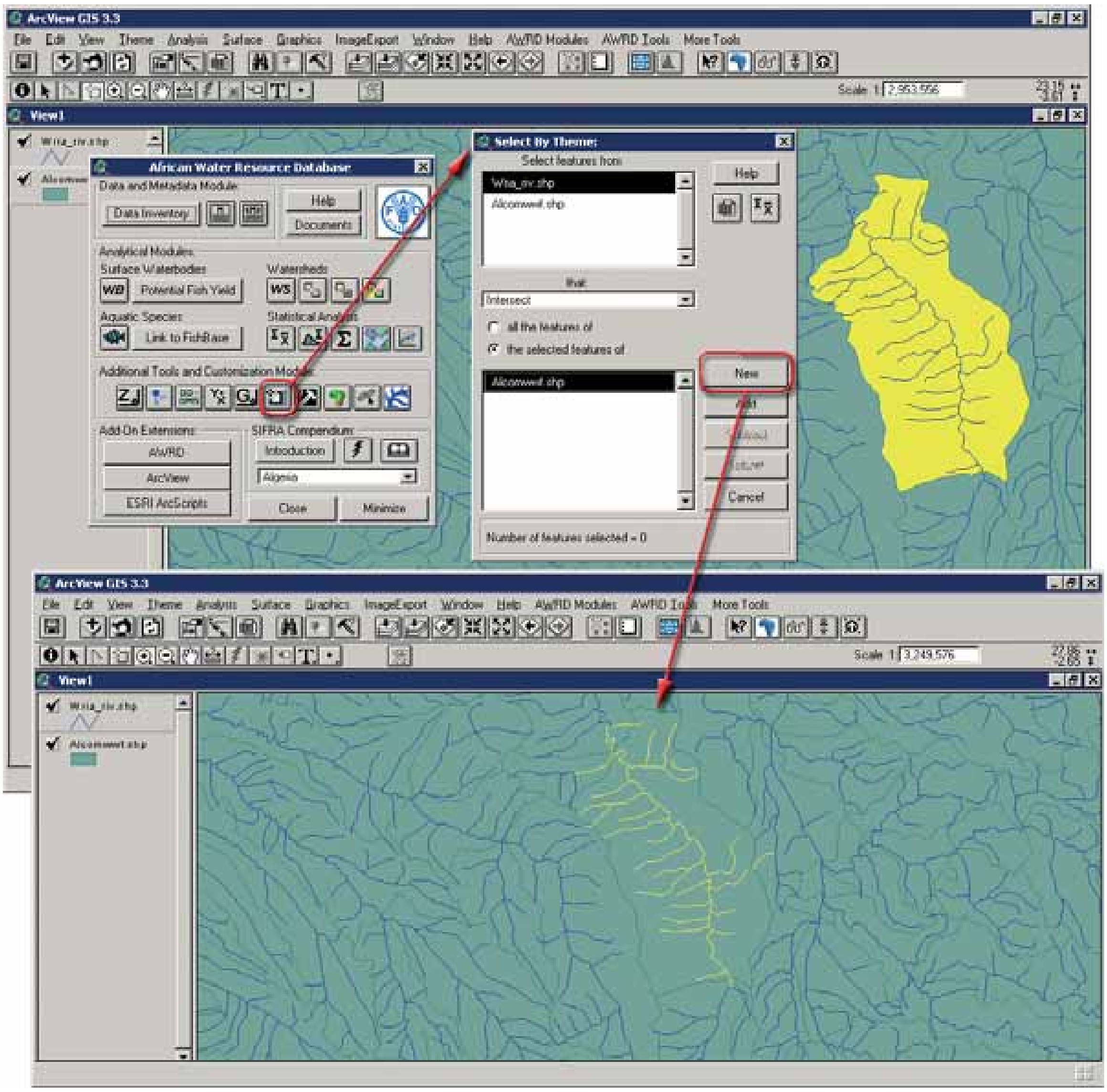
The "Zoom to Gazetteer Locations" tool enables users of the AWRD to effortlessly reference and spatially identify approximately 804 000 locations associated with over one million unique or alternate names.

Select by Theme tool

The Select by Theme tool is similar to the standard ArcView "*Select By Theme...*" function found in the View Theme menu, but with many added functions. It allows the user to select features from one theme based on their proximity to features from another theme.

For example, if the user was interested in selecting all the rivers that intersected a particular watershed, they would begin by selecting that watershed in the view and then either clicking the button on the AWRD Interface or selecting the menu option "*Select by Theme...*" in the AWRD Tools menu to open the Select by Theme tool dialog (Figure 2.23).

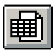
FIGURE 2.23
Selecting rivers that intersect a particular watershed



Benefits and applications
This tools facilitates the selection of features from other themes, which can then be used to calculate a wide variety of statistics.

Query Builder tool

The Query Builder tool is opened by clicking the  button on the AWRD Interface. This tool is similar to the standard ArcView Query Builder available in the View button bar, but with a variety of additional functions and features including the ability to apply complex queries to the data to either select features or to apply a theme definition.

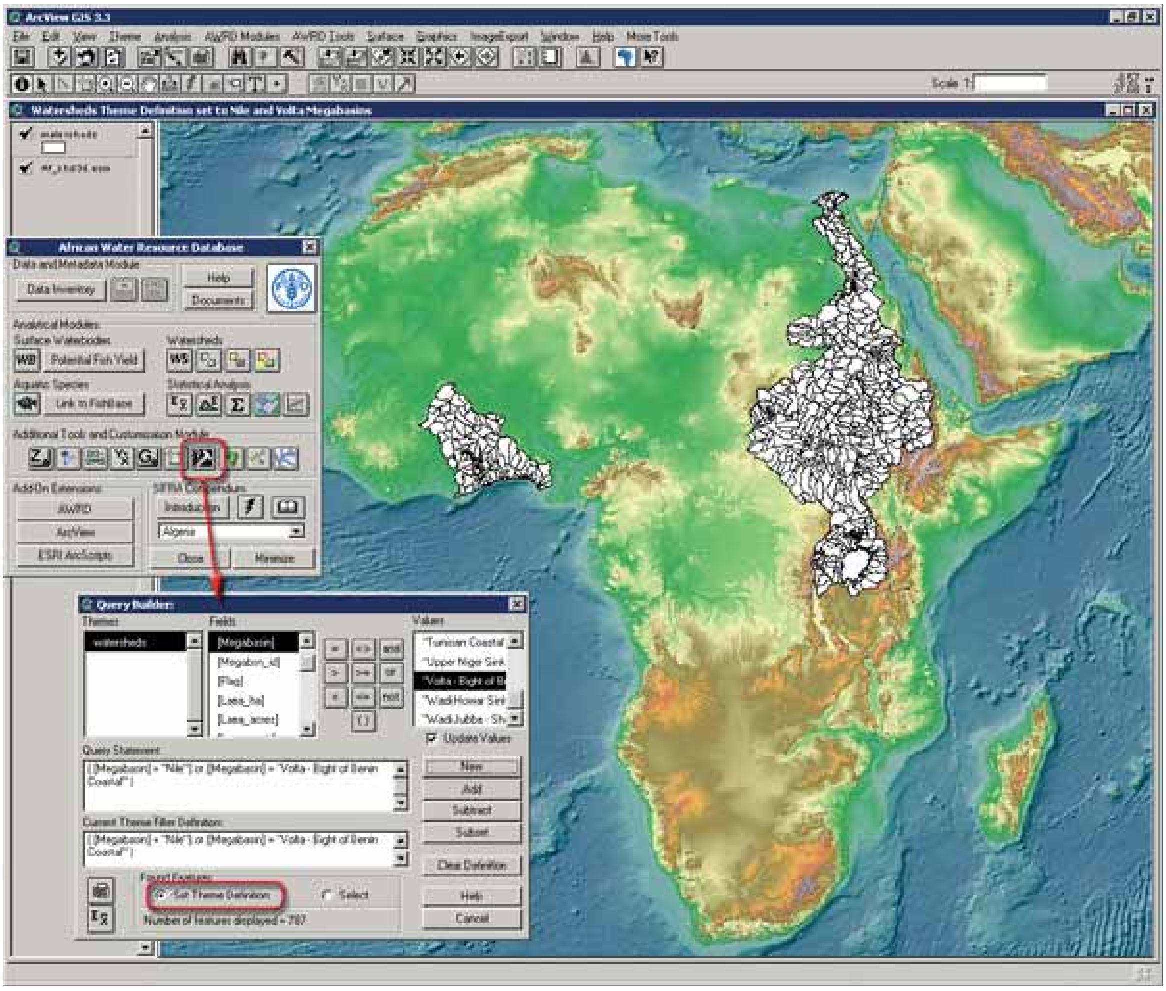
As with the "Select By Theme" tool above, the Query Builder dialog also offers two buttons that provide quick ways to view and analyse the attribute data for any of the themes in the view. The "Open Theme Table" button  will open the attribute table for the currently selected theme, and the "Field Summary Statistics" button  will open the Theme Summary Statistics dialog, from which you can calculate a wide variety of statistics on your theme.

Setting Theme Definitions

By setting a theme's definition, you tell ArcView to show you only the features that meet that definition. This is similar in concept to selecting features for analysis, except that in this case any features that do not meet the definition are simply not shown in the view.

For example, we could set the theme definition of our Watersheds theme so that it only shows the watersheds in the Volta and Nile megabasins. If we opened the table for this theme, the table would also show only the records for these two megabasins as illustrated in Figure 2.24.

FIGURE 2.24
Setting new theme definition with the Query Builder



Benefits and applications

Using this tool, users have the ability to both visualize and analyse complex hydrological, ecological, physiographic and species specific relationships, and to restrict analysis to a subset of the original data.

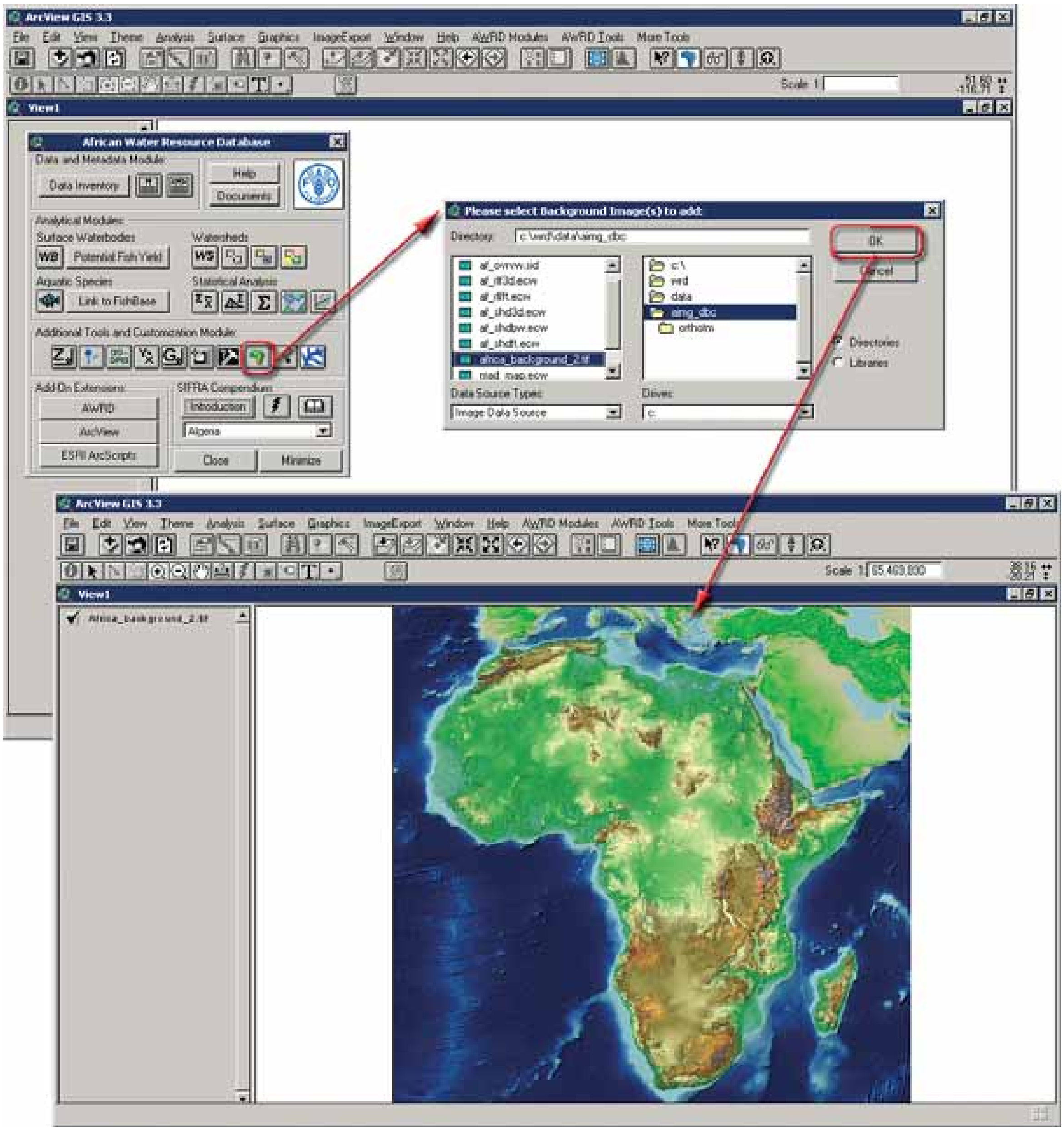
Add Background Base Map Image to View

The AWRD Image database component comes with a large number of base map images of Africa at several resolutions, which provide high-quality backgrounds for both on-screen viewing and for printing maps. This tool offers a simple way to add these base map images of Africa to the view.

By simply clicking the button on the AWRD Interface the user can choose the image or images to add (Figure 2.25).

FIGURE 2.25

The Add Basemap Image to View tool

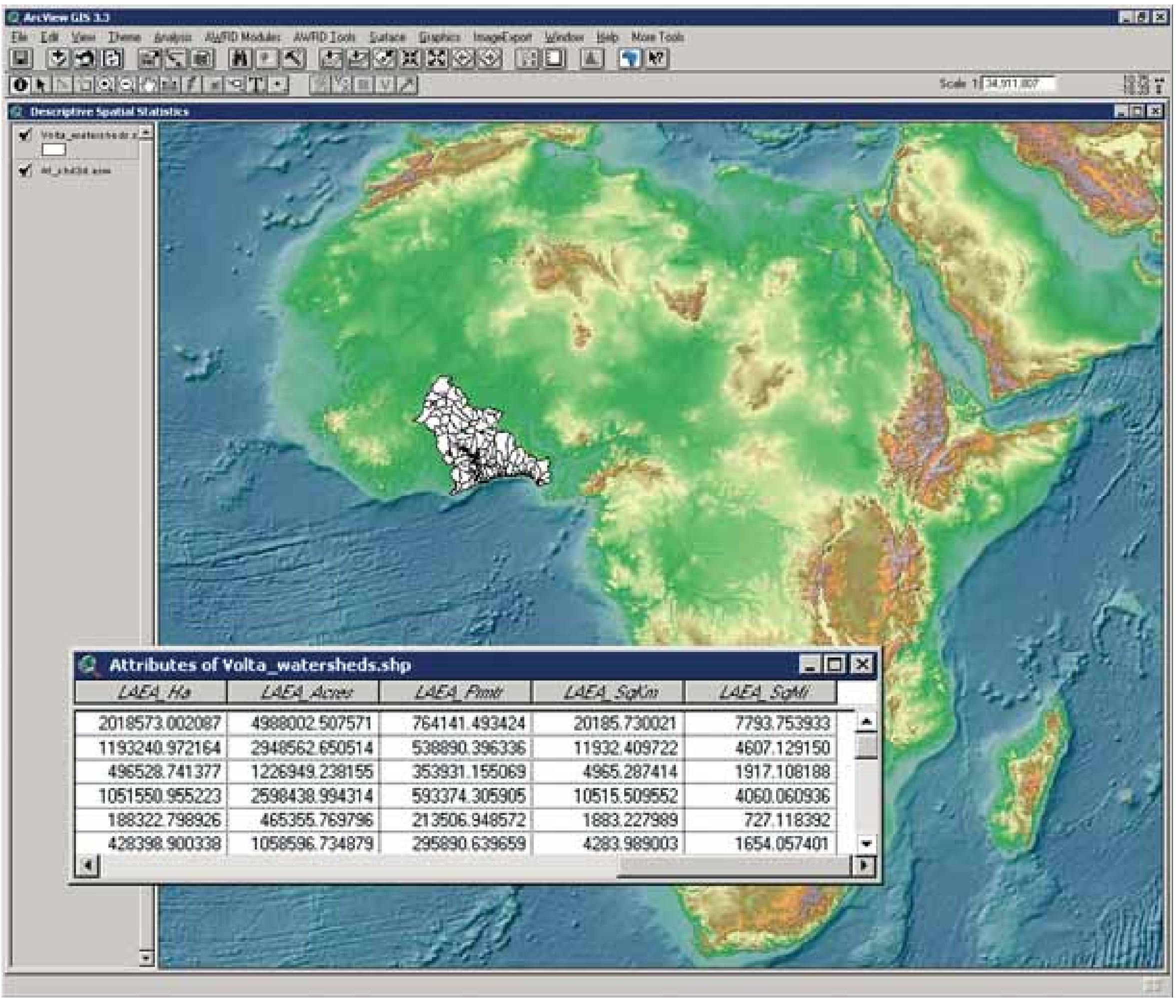


Benefits and applications
These backdrop images provide a spatial reference against which the core functionality of the AWRD interface can be displayed, and provide users with a number of ways to visualise landscapes and differentiate hydrographic features.

Tools for Calculating and Reporting Descriptive Spatial Statistics

The AWRD provides two methods for calculating area and perimeter lengths for polygons, and lengths of lines. The "Report GeoStats for Lines or Polygons" tool on the AWRD Interface allows you to click on polygons or lines and generate an immediate report, while the "*Calculate/Update Geostats in Polygon Theme Tables…*" menu item in the AWRD Tools menu allows you to calculate the values directly to the theme attribute table. A representation of this tool for Lake Volta can be found in Figure 2.26.

FIGURE 2.26
GeoStatistics tool



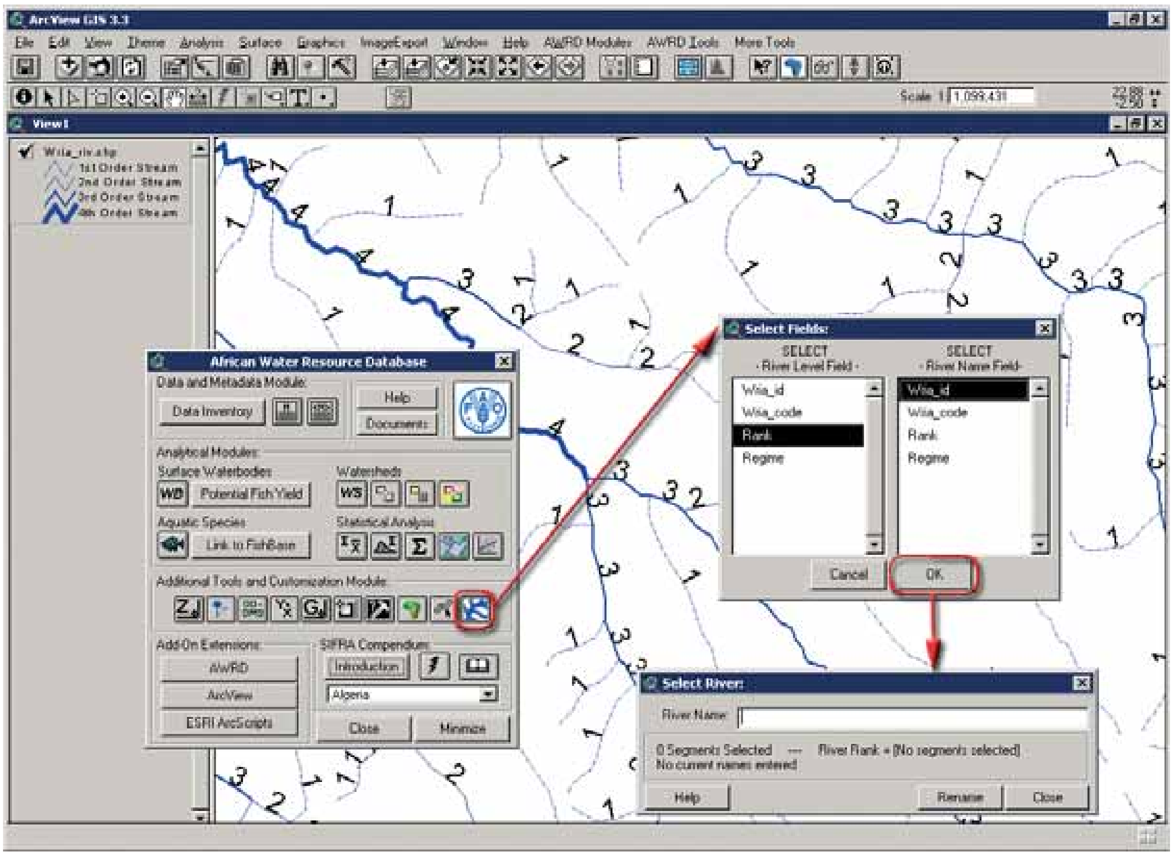
Benefits and applications
This is a useful tool to calculate areas and perimeter lengths for any polygon theme.

River Identification tool

The River Identification tool is designed to allow the user to identify continuous sections of river which are at the same order level. This assumes that the river theme being examined has river segments ranked according to the standard river order system, such that smaller tributaries have lower values than larger tributaries.

In this example (Figure 2.27), the smallest tributaries are identified with "1" values, and when two Level-1 tributaries come together they form a Level-2 river. Two Level-2 rivers merge to form a Level-3 river, etc.

FIGURE 2.27
River order values for rivers of FAO's Atlas of Water Resources and Irrigation in Africa



Benefits and applications

The River Identification tool provides a method of tracing river networks and for identifying errors in the dataset. It gives users an easy way to select, and potentially rename, all attached river segments of a particular order.

Image Export and Base Mapping tool

The Image Export and Base Mapping (IEBM) tool-set of the AWRD is comprised of a fairly complex set of geo-referenced image output, View, and Layout manipulation tools which are accessible through a menu driven interface. These tools are ideal for generating publication-quality images in a variety of formats, as well as for generating geo-referenced images that can be viewed alongside other GIS data.

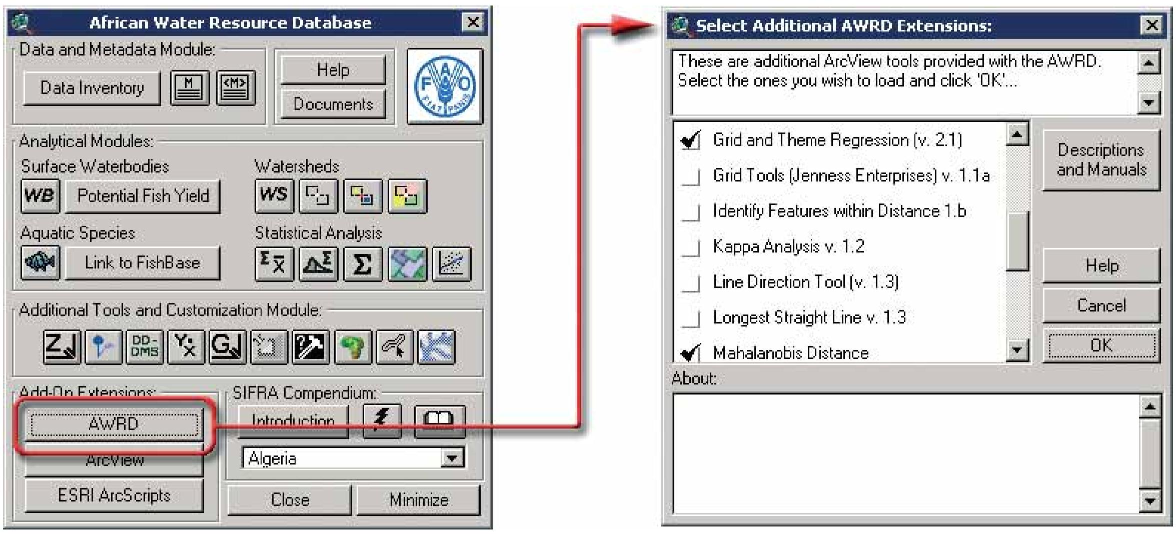
Benefits and applications
ArcView comes with certain standard functions to generate map images for use in presentation and publication. However, these standard functions often produce poor-quality output. The AWRD IEBM tools provides planners and managers with the ability to create high-quality maps for presentation and publication, for either digital presentations or hardcopy reporting, without requiring any additional software purchases.

Add-on extensions and adding additional AWRD Table and View functions

AWRD Add-on extensions
ArcView comes with many additional tools written or licensed by ESRI. These tools are referred to as "Extensions" and they are generally written for very specific purposes. The AWRD provides several additional extensions that are not directly related to the AWRD but which provide a number of useful tools. You can review and load any of these by clicking the "AWRD" button in the "Add-On Extensions" box (Figure 2.28) of the AWRD Interface.

Many of these additional extensions provide advanced analytical functions not available elsewhere in ArcView or the AWRD. These tools include more sophisticated regression functions, several specialized statistical tools, and several grid and vector data manipulation and analysis tools. The specialized statistics include the Kappa Statistic, which calculates the accuracy of predictive models, and the Mahalanobis Distances extension, which is an award-winning tool that identifies regions of the landscape that are most similar to some "ideal" set of conditions. Mahalanobis Distances are especially useful because they tell you exactly how similar any point on the landscape is to your ideal set of conditions, and they are sensitive to the relationships between different landscape variables. All tools come with complete manuals explaining how they work and what they can be used for.

FIGURE 2.28
Loading additional tools and extensions provided with the AWRD



ArcView Add-on extensions
To simplify the process of reviewing add-on extensions provided by ESRI, the AWRD includes a tool that shows you all these extensions. Click the "ArcView" button in the "Add-On Extensions" box.

ESRI ArcScripts

The ArcView User Community has produced a large number of ArcView tools which are freely available on the Internet. The largest compilation of these tools lies on the ESRI ArcScripts site and includes customized tools for ArcView and several other software packages produced by ESRI. The ArcScripts site provides links for over 2000 ArcView 3.x extensions and scripts. Because of the potential usefulness of this site, the AWRD offers this button to link you directly to the ArcScripts site: http://arcscripts.esri.com/. Click the "ESRI ArcScripts" button or select "*Additional ESRI Community Scripts and Extensions...*" in the AWRD Tools menu to link to the site (Figure 2.28).

Benefits and applications

The AWRD add-on extensions include a large number of powerful tools that enhance spatial analysis for a wide variety of different applications. This suite of tools provide simple solutions for many complex questions that typically arise in spatial analysis, such as nearest-neighbour analysis, grid projection and landscape management.

Additional ArcView Table and View functions

In addition to the standard AWRD tools available within the main dialog, the AWRD also includes several general tools to enhance the ArcView interface. These include functions to zoom forward and backward through a history of extents, tools to show and hide all legends in a view or to make all themes active or inactive, and several tools to edit or describe tables.

SIFRA Compendium

The Committee for Inland Fisheries for Africa Source Book for the Inland Fishery Resources of Africa (SIFRA) (Vanden Bossche and Bernacsek, 1990a; 1990b; 1991) is a compendium, waterbody-by-waterbody, country-by-country of information on inland fisheries and related topics. For an overview of the SIFRA Compendium, review the Introduction by clicking on the SIFRA Compendium "Introduction" button on the AWRD Interface or by selecting "*Open Introduction of SIFRA Compendium...*" in the AWRD Tools menu.

The AWRD includes two simple ways to review the SIFRA data for a particular country.

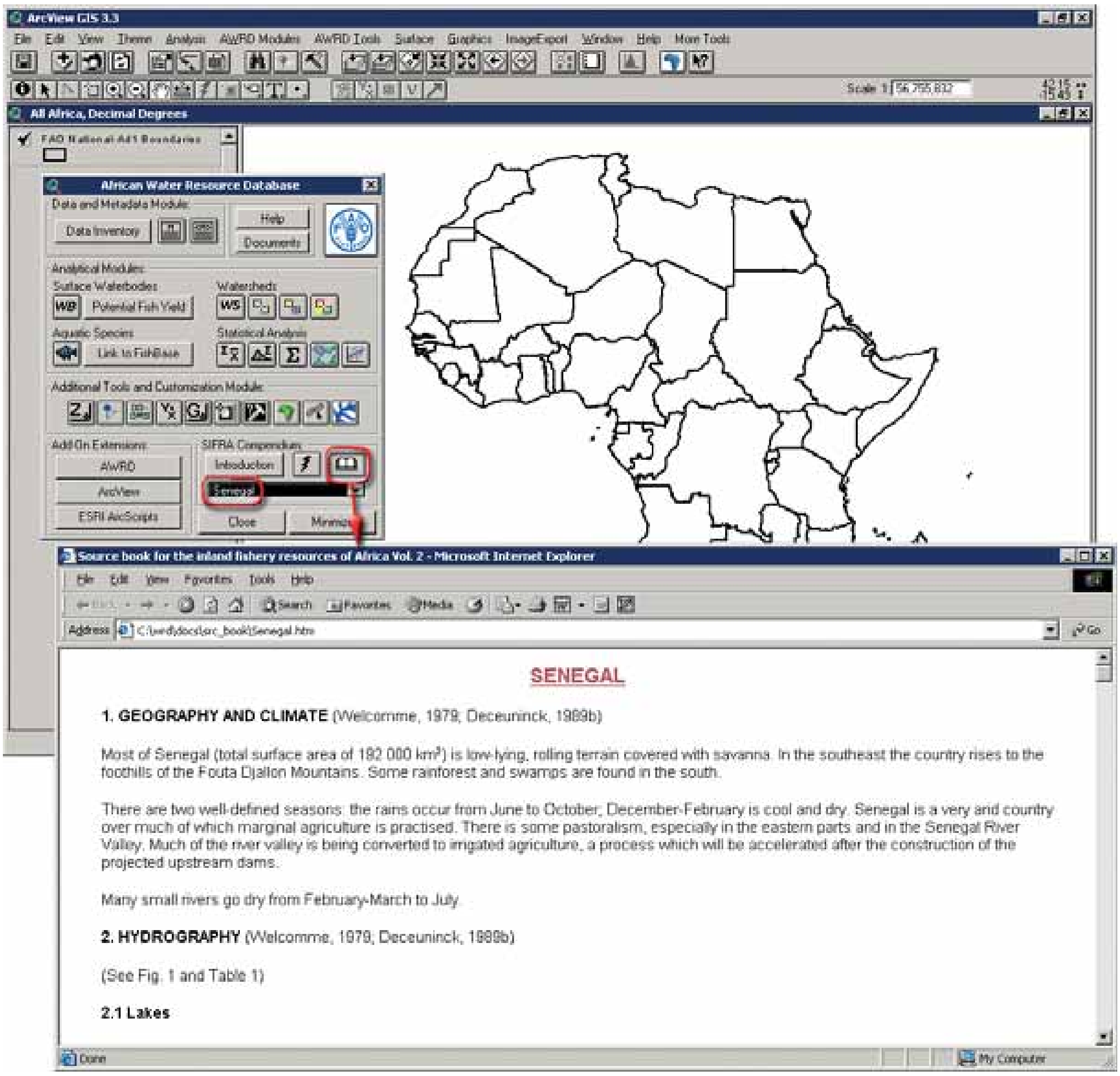
Review SIFRA Data Selecting from List

The drop-down list contains an alphabetized list of countries in Africa. Select a country from the list and then click the button to open the SIFRA file on that country (Figure 2.29). You can also access this function from the AWRD Tools menu where you select the option "*Open SIFRA File for Specific Country...*".

Review SIFRA Data by Clicking on Country

Alternatively, you can open the SIFRA file on a country by clicking on the button on the AWRD Interface to enable the SIFRA Compendium tool. When the tool is enabled, the button will look indented and your curser will change to a symbol. One can use the cursor to click on a country or region on the map. If you click on any of the countries in Africa, the SIFRA file for that country will open in your internet browser.

IGURE 2.29
Select SIFRA country data from list



Benefits and applications
SIFRA provides a vast amount of comprehensive information on Africa's inland fisheries in a uniform format, so this tool makes this information more readily accessible and of greater use in conjunction with AWRD datasets.

2.4. APPLICATION CASE STUDIES

Surface waterbodies inventory

Introduction and objectives

Introduction

Although the AWRD contains multiple surface waterbody (SWB) data layers, extensive work still needs to be undertaken before these data can be utilized to more fully support fisheries and integrated water resources management. With the exception of the point SWB database covering the SADC region of southern Africa (derived from the original WRD), most SWB data layers included with the AWRD lack many of the physical, limnological and environmental attributes that influence each individual waterbody.

Fortunately for Africa, a broadly inclusive baseline of useful attributes can be found within the Source Book for the Inland Fishery Resources of Africa (SIFRA). However, because the SIFRA reports (Vanden Bossche and Bernacsek, 1990a, b, 1991) are themselves based on compilations of data from a number of different sources, there is wide variability of data quality and quantity for SWB listings in each country. It is therefore difficult to summarize the data contained in these reports in a format that can be easily linked back to the original SWB data layers contained in the AWRD.

Objectives

The purpose of this case study is to determine the viability of creating a surface waterbody inventory by integrating the historic data records contained in the SIFRA reports with spatial data layers from within and outside of the AWRD data archive. The premise of the case study is that such integration would result in more harmonized and complete SWB data layers containing a composite of available attributes. This case study demonstrates two approaches to examine the potentials and limitations of integrating the SIFRA report data with spatial SWB feature data.

Approach 1: This approach uses spatial data from both within and outside the AWRD archive to create a consolidated inventory of SWB features for the United Republic of Tanzania. The purpose of this exercise is to determine the viability of creating hot-links from coincident or nearby spatial SWB features to the more detailed fisheries and limnological attributes contained in the SIFRA reports.

Approach 2: This approach looks for SWB features that are found in both the AWRD data layers and the SIFRA report for the Republic of Zimbabwe, in order to generate an attribute table which can be linked directly to spatial features in any standard GIS. This approach additionally estimates the amount of time and effort required to create such a table for other regions.

United Republic of Tanzania

Materials and methods

Data utilized

Detailed lake and reservoir data available from the FAO sponsored Africover Project, http://www.africover.org, are used to simulate a user specific spatial dataset from a hypothetical fisheries institution in the United Republic of Tanzania. The United Republic of Tanzania was chosen for this exercise in order to benefit from the availability of the completed Africover datasets, including a layer of waterbodies, covering the country. The Africover data were derived from 28.5 metres LandSat satellite imagery and are compatible with an approximate minimum spatial scale of 1:150 000. The United Republic of Tanzania is one of nine countries for which Africover datasets were available at the time this case study was prepared.

The attribute data used to simulate the historic reporting of limnological and fisheries statistics for this hypothetical Tanzanian institution are drawn from the SIFRA report for the United Republic of Tanzania.

In addition to the SIFRA data, subsets of data from several sources are used to provide source names for the Africover waterbodies and potential linkages back to the SIFRA information. These additional subsets are drawn from the SADC-SWB data layer and the NIMA GNS gazetteer data layer, and the subsets were extracted based on the Tanzanian boundary from the VMap0 political boundary layer Ad1_Py.shp.

The data utilized for the Tanzanian portion of this case study are presented in Figure 2.30 and Table 2.16.

FIGURE 2.30
Data employed for the Tanzanian analysis

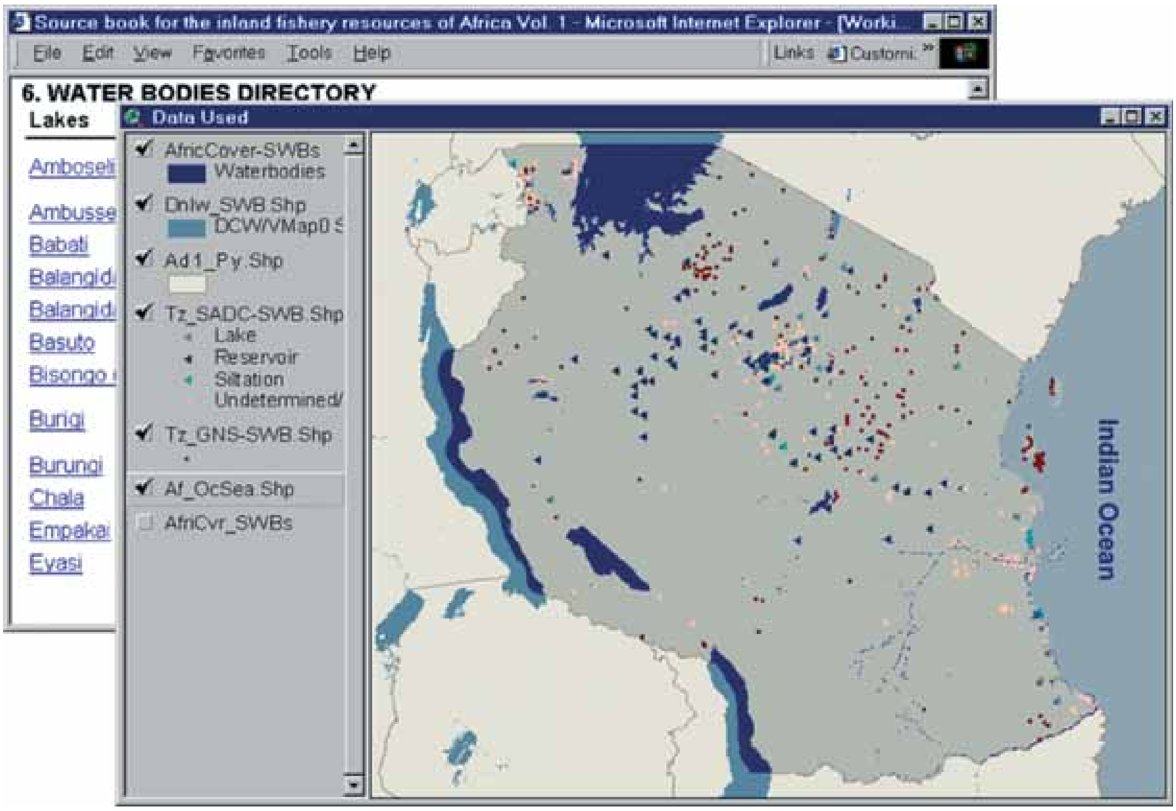


TABLE 2.16
Summary and purpose of data used for Tanzanian analysis

Data type	Data source	Data utilization or purpose
Africover polygonal data layer	AVEC-DBC: AfCvrSWB	The integration of a user specific SWB dataset into the AWRD for linkage to SIFRA data
SIFRA Compendium for Tanzania HTML based textual reference	AWRD SIFRA Document Archive: Tanzania	Limnological and fisheries data to be attributed to Africover waterbodies data for Tanzania
SADC-WRD SWB point data layer	SWB-DBC: SADC_SWB	Potential source of names for Africover SWBs for linkage to SIFRA waterbodies reporting data
NIMA GNS Gazetteer SWB specific subset point data layer	SWB-DBC: GNS_SWB	Alternate source of names for Africover SWBs for linkage to SIFRA waterbodies reporting data
VMap0 "Basic" political boundaries data layer	AVEC-DBC: Ad1_Py	Used to create buffered Tanzanian subsets of SADC-WRD and GNS SWB data layers

Methods

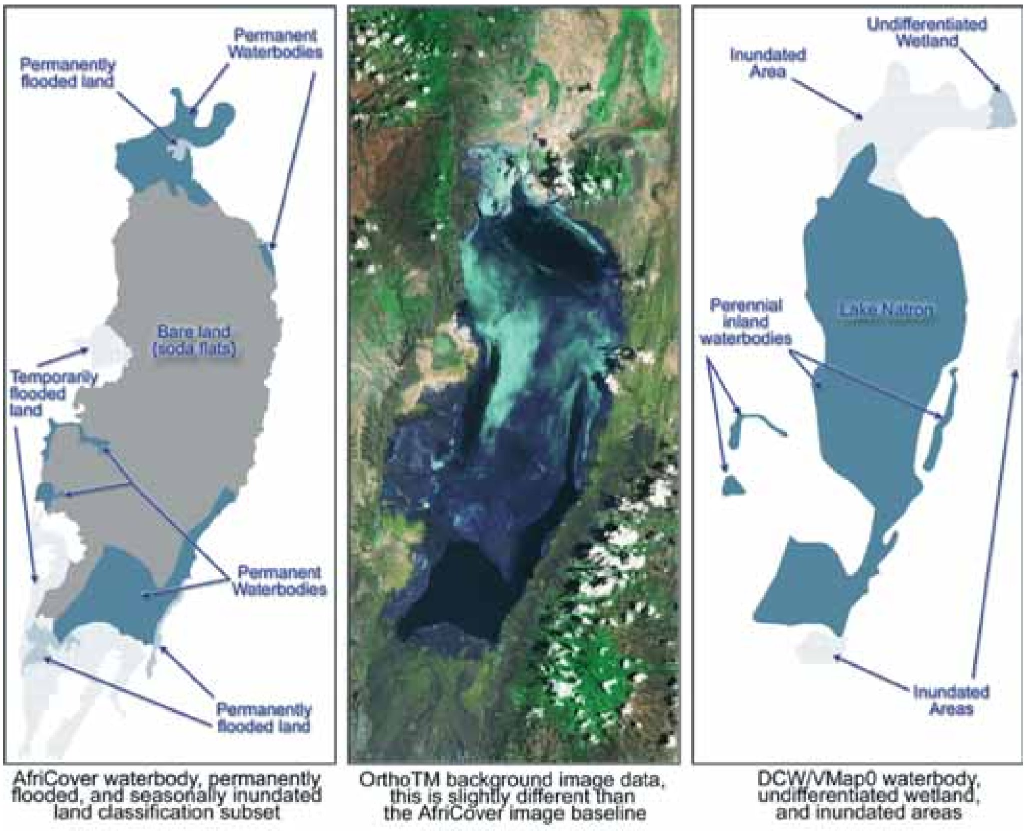
Data analysis

The Africover SWB data layer provides a comprehensive set of perennial or standing waterbodies, extracted from the larger Africover dataset of all wetland types. For the purposes of this case study the SWB layer was deemed appropriate.

Perhaps the major difference between the Africover SWB data layer and the lakes and other polygonal waterbody layers available from the AWRD SWB-DBC (based on the VMap0 data library), is the partitioning of waterbodies based on the seasonal fluctuation of the waterbody in question. This is demonstrated by the depiction of Lake Natron in Figure 2.31. In this figure, the Africover data for Lake Natron is actually partitioned into distinct "Standing" water polygons, separated by either other SWB features or land classified as "Bare". In comparison, the SWB features derived from the DCW/VMap0 data libraries depict Lake Natron as a much larger and more cohesive waterbody.

FIGURE 2. 31

Comparison of composite Africover surface waterbodies features with a satellite image base and similar features derived from the DCW/VMAP0



The Africover SWB data layer contains 394 standing waterbody features providing coverage for the United Republic of Tanzania. While this number does not include the extensive permanent and temporarily flooded land classes, mangroves, etc. of the full Africover land classification dataset, it does include those polygons representing rivers that are wide enough to be depicted as waterbodies. On maps, such rivers are commonly referred to as "double-lined" rivers because the boundaries of the polygons used to represent these features show both banks of the river.

In comparison to the Africover dataset, some 175 and 173 permanent SWB features, including double-lined river features, can be identified as intersecting with the United Republic of Tanzania based on either the seamlessly processed VMap0-Ed5 or the harmonized DCW/VMAP0 data layers of the AWRD.

Unfortunately, although a name has been added to the VMap0-Ed5 baseline of SWBs, only 70 of these 170 features were named; and as yet, a validated name for the SWBs represented in the Africover dataset has still to be developed. For this reason, SWBs must be assigned a name or unique numerical identifier before they can be cross-referenced with the SIFRA reports or other historical data.

Naming the Africover waterbodies

To simplify the naming process for this case study, only the Africover permanent waterbodies dataset was considered. The source name databases were limited to the SADC-WRD surface waterbody data layer and the SWB subset of the GNS gazetteer database. The "Nearest Feature" AWRD Add-on extension was used to assign a unique numeric identifier to the Africover waterbody dataset, based on the nearest waterbody in the SADC-WRD and GNS Gazetteer datasets. The tool also records the proximity for each point feature, with a value of zero representing actual containment in the Africover waterbody. After the nearest SADC-WRD and GNS Gazetteer SWBs have been identified, then the name of that SADC-WRD or GNS waterbody can be assigned to the Africover waterbody.

Results

Combined, approximately twenty minutes were required to set-up and to then run the add-on tool against both source name datasets. However, as multiple points can be assigned to each polygon, a further two hours were required to evaluate any duplicate matches. Finally, a further hour was required to join tables and assign names back to the polygonal Africover based on both point name sources. In total, 165 permanent waterbody polygons – or 42 percent – could be assigned names from one or both of the point data sources. Fifty-six of these waterbodies were named jointly by both the SADC-SWB and then GNS-SWB data layers.

Given the partitioning of certain larger SWB features in the Africover dataset, as illustrated for Lake Natron (Figure 2.31), and because the process did not consider double-lined rivers, the results of this semi-automated naming process were better than may first appear. In fact, since the simulated historic reporting data contain only 79 "records" for lakes and reservoirs, the results of the semi-automated process proved to be adequate for the purposes of this case study.

The SIFRA reports provide users of the AWRD with an important source of reference information on certain limnological factors and other physical characteristics of waterbodies including, in some cases, the historical reporting of both endemic fish species and catchment records. The SIFRA report for the United Republic of Tanzania documents 45 major lakes and 34 major reservoirs for the country. Table 2.17 provides a summary of the linkages between Africover and the SIFRA attribute information for these lakes and reservoirs.

TABLE 2.17
Summary of linkages between Africover and SIFRA

Number of Lakes	SIFRA lakes
36	Polygons from the Africover dataset which were linked to listings in the SIFRA report.
4	Additional lakes which were identified based on point features in either the SADC-SWB or GNS-SWB data layers, but could not be connected with an Africover polygon.
5	SIFRA lakes which could not be identified based on either of the name source point datasets.
45	TOTAL
Number of Reservoirs	**SIFRA reservoirs**
19	Africover SWB features which were directly linked to SIFRA listings.
9	Additional reservoirs which were identified based on point feature names from either the SADC-SWB or GNS-SWB data layers.
6	SIFRA reservoirs which could not be identified based on either of the name source point datasets. Three of these SIFRA listings contained possibly useful limnological or fisheries specific attributes.
34	TOTAL

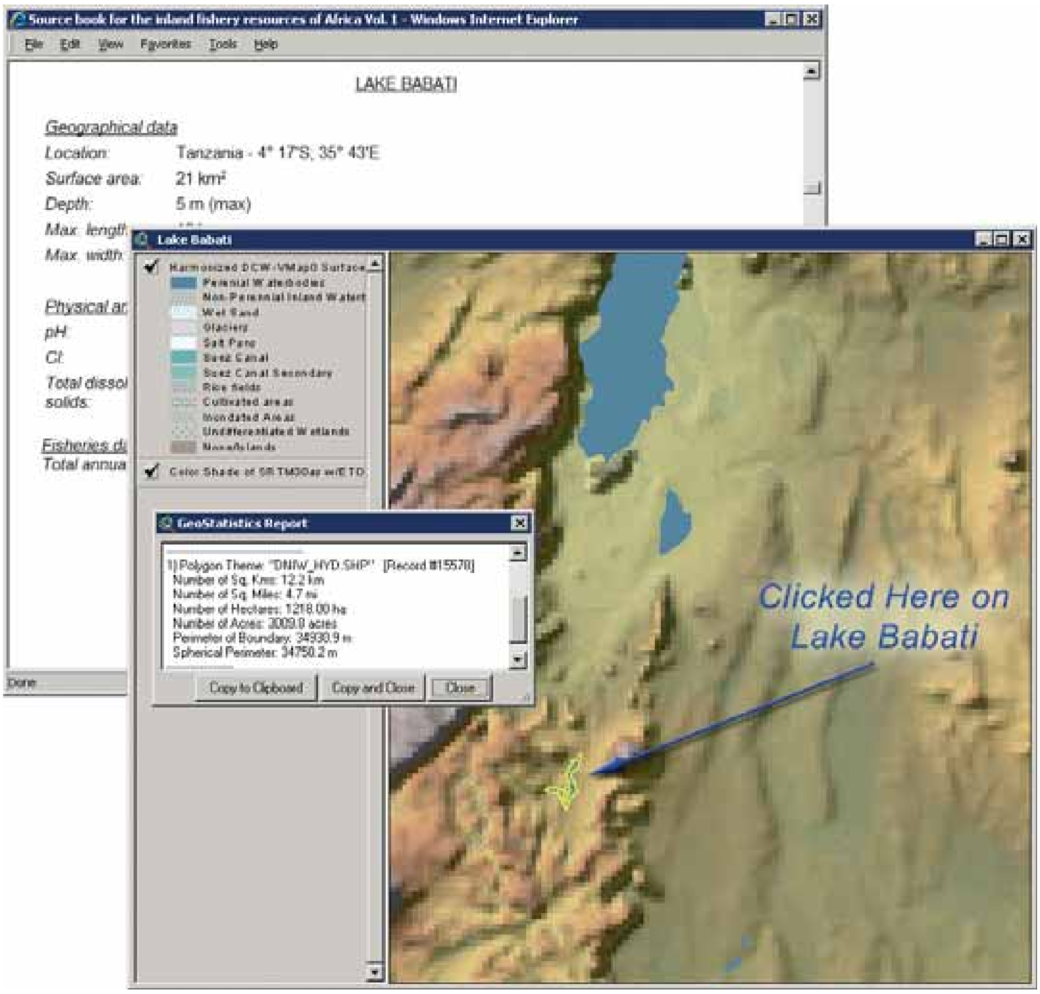
Within the United Republic of Tanzania, roughly half of the 79 lakes and reservoirs detailed in the SIFRA report contain limnological or fisheries attributes, while the majority contain only a basic reference to the SWB name and in some cases an approximate location and estimate of its size.

Further, as illustrated in Figure 2.32, the SIFRA data have not been reformatted from the historic textual reports into a tabular database format that would allow the direct linkage of attributes to features in spatial data layers. For this reason, only an HyperText Markup Language (HTML) based linkage between the Africover spatial data and the SWB listings in the SIFRA document for the United Republic of Tanzania is illustrated.

Figure 2.32 displays a partial report of the SIFRA data listing for Lake Babati at the centre of the United Republic of Tanzania against a map graphic from the main ArcView window. Lake Babati provides an example where the naming and harmonization of Africover features to SIFRA based listings for lakes and reservoirs was successful[11].

FIGURE 2.32

Example of the HyperText Markup Language based linkage of Africover spatial data to a surface waterbodies specific listing in the Tanzanian SIFRA report



[11] Due to an as yet unresolved issue with hot-links from ArcView to HTML pages containing internal anchor tags, clicking on a SWB will only link to the top of the *Section 6. Waterbodies Directory.* This may be resolved in the future by the use of basic Java scripts, however for the case study, a secondary click was required on the name of the SWB in this directory before the actual data listing could be accessed as shown above.

Discussion

The process of matching the named Africover SWB features to the SIFRA lakes and reservoirs was not as straight forward as was originally anticipated, and the harmonization of the two datasets required one additional day in order to account for differences in spelling, SWBs collocated in the AWRD and SIFRA source data but not represented by features in the Africover waterbody subset, and other inconsistencies or missing references between the datasets.

The levels of effort (LOE) required to complete the harmonization of the Africover waterbodies dataset and the SIFRA data can be summarized by the following tasks:

- Assignment of a name to the Africover waterbodies specific dataset using Tanzanian subsets of SADC-SWB and GNS-SWB data layers of the AWRD.
- Creation of a SIFRA sub-document of waterbody and wetlands, containing specific HTML anchor tags providing links to specific SWB listings.
- Modification of the existing AWRD tool providing access to the country based SIFRA reporting, to provide SWB specific HTML linkages.

In addition to the HTML hot-linking, the above tasks also result in an effective harmonization of the selected AWRD SWB features and the SIFRA data, and could therefore be used to create a more complete baseline of fisheries specific waterbodies.

All told, approximately one and a half days were required to complete the tasks described above linking the Africover SWB spatial features to the SIFRA report listings. However, because the processing methodology described for this exercise also represented a learning process, it is probable that this LOE would decrease with practice.

Based on the level of effort required for this method, it may be desirable to use a more streamlined process. For example, the order of the processing steps followed could be changed such that the linkage of SIFRA SWB listings would be undertaken across a core set of potential name source point datasets first. This would establish a SIFRA-specific spatial point data reference which could then be used to "inform" the linkage of attributes across polygonal data layers in a more cost effective manner. This more streamlined process was tested during the Zimbabwean exercise.

Republic of Zimbabwe

Materials and methods

Data utilized

The data employed during the Zimbabwean analysis were similar to those used in the Tanzanian exercise, including: the VMap0 Political boundary, the SADC-WRD SWB data layer, and the SWB subset of the GNS Gazetteer data layer. The Republic of Zimbabwe was chosen for this portion of the case study in order to benefit from the extensive listing of SWBs available for the country based on the original SADC-WRD SWB dataset. Africover datasets for the Republic of Zimbabwe were not available at the time this case study was prepared.

Figure 2.33, provides a pictorial view of the above baseline data layers.

FIGURE 2.33
Data utilized during the Zimbabwean analysis

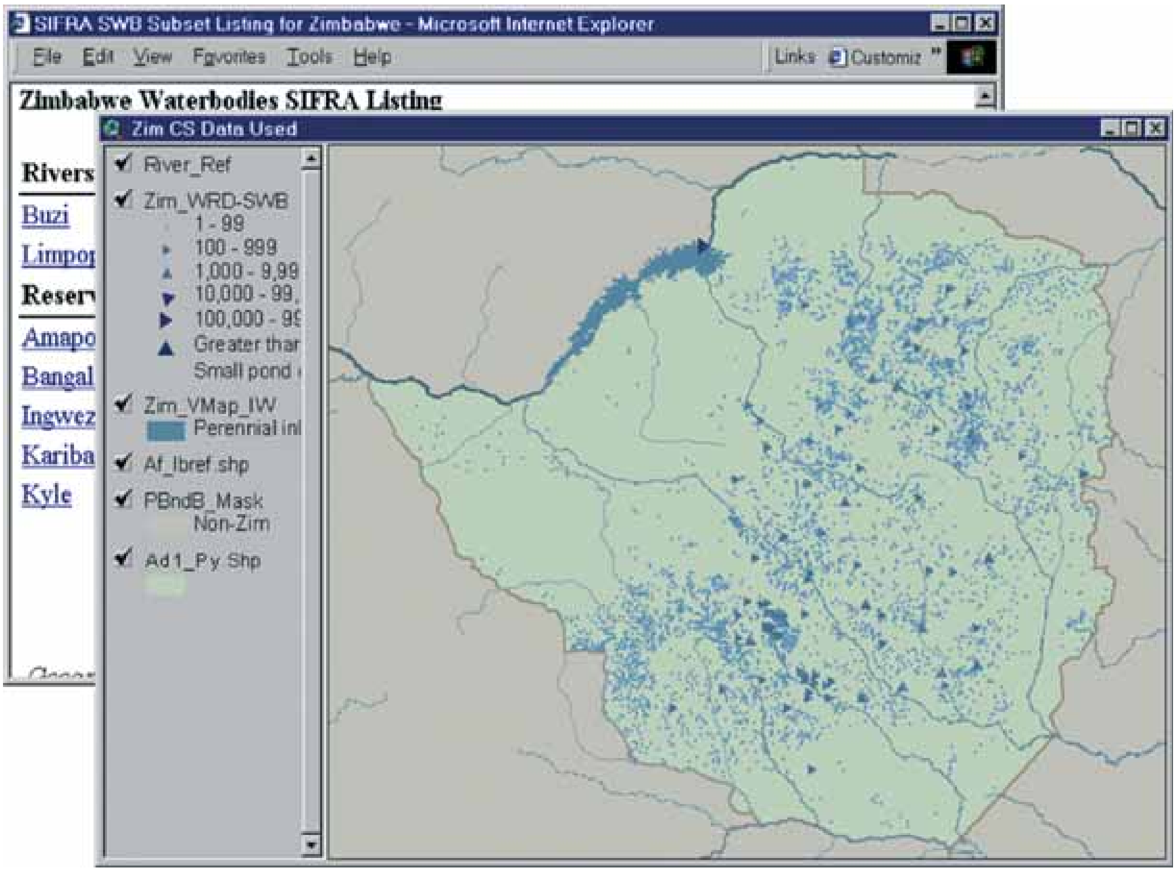


Table 2.18 provides a summary listing of the data utilized during the Zimbabwean portion of the case study.

TABLE 2.18
Summary and purpose of data used for Zimbabwean analysis

Data type	Data source	Data utilisation or purpose
Harmonized DCW-VMap0 Surface Waterbodies	SWB-DBC: dniw_hyd.shp	Primary baseline source for names and potential linkage to SIFRA Zimbabwean SWB reports
SIFRA Zimbabwe report	AWRD SIFRA Document Archive: Zimbabwe	Limnological and fisheries data to be attributed to Africover waterbodies data for Tanzania
SADC-WRD SWB point data layer	SWB-DBC: sadc_swb.shp	Secondary source of names for identifying SWBs for linkage to SIFRA waterbodies reporting data
VMap0 "Basic" political boundaries data layer	AVEC-DBC: Ad1_Py.shp	Used to create subsets of VMap0 and SADC-WRD SWB data layers for Zimbabwe

A subset of the Zimbabwean SIFRA report containing only the standard *Section 6. Waterbodies Directory* of the report was reformatted into a tabular database format for a direct linkage of attributes to the features in spatial data layers. The Inland Waterbody boundary data layer of the VMap0-5th Edition was used to provide a "named" polygonal baseline for the analysis.

Methods

Based on experience gained during the Tanzanian exercise, the analysis conducted for the Republic of Zimbabwe was more straight forward and required just over one day to complete. The majority of this time was spent: reformatting and applying HTML anchor tags to the baseline SIFRA Report; creating a tabular listing of summary attributes available between the VMap0 and SADC-WRD SWB spatial data layers and the SIFRA data listings; and attempting to harmonize historical and spelling differences in names used to identify similar SWBs between the three primary data bases.

A tabular report for the Republic of Zimbabwe was facilitated by the existence of a baseline table covering 34 SWBs in the SIFRA report. Surprisingly, this baseline did not include records for 19 of the dams or reservoirs discussed in the SIFRA report. In all, data were available in varying degrees for some 41 SWBs in the SIFRA report for the Republic of Zimbabwe. Further, due to either the comparatively small number of SWB listings in the Zimbabwean SIFRA report or the de-facto inclusion of the GNS Gazetteer SWB data in the "named" VMap0-Ed5 inland waterbody data layer – see Zimbabwean Discussion section below – it proved unnecessary to use the derivative GNS SWB layer of the AWRD archive for the Zimbabwean exercise. It is likely that this facilitated the analysis and reduced the time required to complete the exercise. One unexpected spin-off of the exercise was that it was possible to differentiate actual SWB features from polygons representing double-lined river features for the VMap0 Inland Waterbodies data layer.

Results

The results of the exercise are summarized for the three input databases in Table 2.19. This listing is followed by a map (Figure 2.34) depicting these results and a comparative table (Table 2.20) of the 45 SWB features found common between the three data sources.

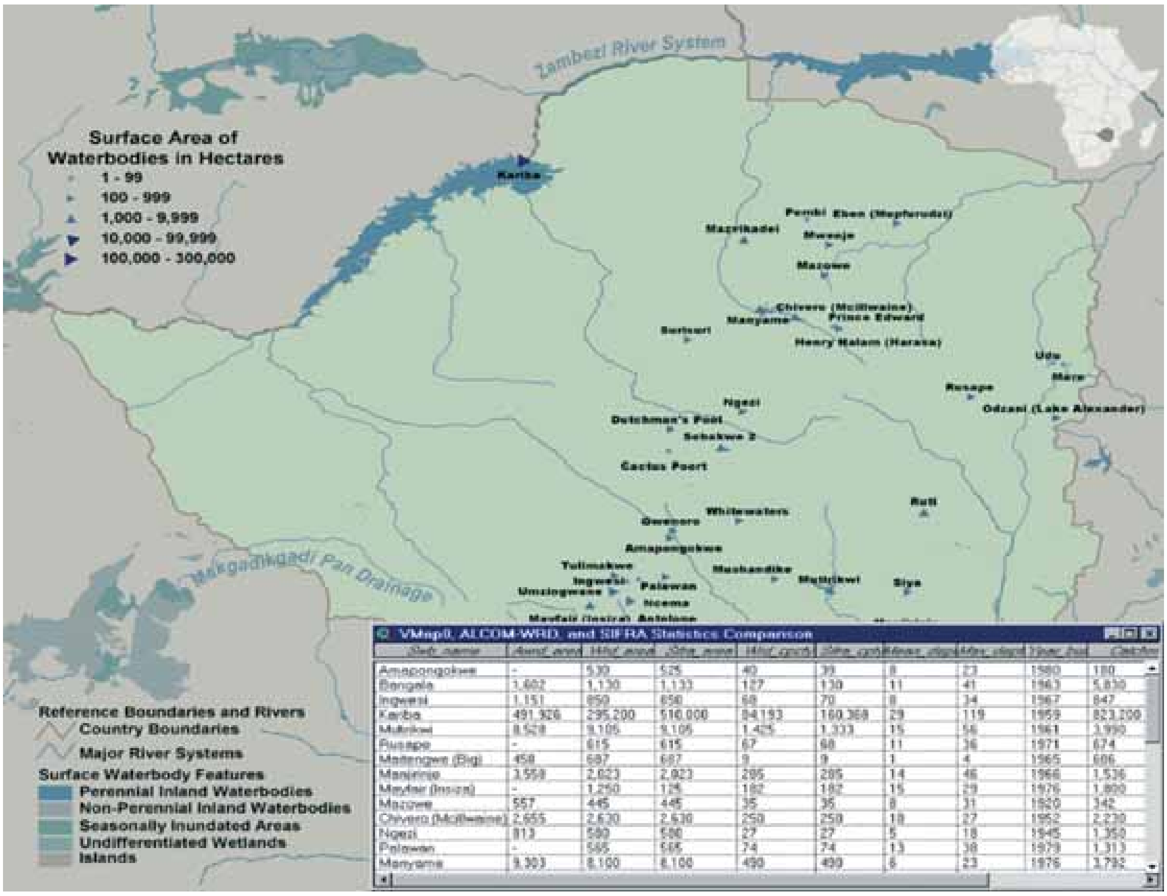
TABLE 2.19
Summary of Linkages between VMap0-Ed5, SADC-WRD and SIFRA

Number of SWBs	5th Edition of the VMap0 Inland Waterbody Layer
99	SWB features representing perennial and non-perennial waterbodies and seasonally inundated lands were either contained within or overlapped the borders of Zimbabwe.
60	Perennial SWB features containing a valid name attribute at the beginning of the exercise.
11	Additional VMap0-Ed5 Perennial SWB features that were named via the process.
31	Valid SWBs which could be differentiated from double-lined river polygons.
Of the 31 named and validated VMap0 SWB features identified, 26 features could be directly linked to SWBs in the SADC-WRD data layer and 13 features could be linked to the detailed SIFRA report listings for SWBs. Furthermore, 15 VMap0 SWB features could be linked directly to the original SIFRA summary table of Zimbabwean surface waterbodies.	

Number of SWBs	SADC-WRD (baseline of the three layers evaluated during the analysis)
6 230	SWB features represented in data layer for Zimbabwe
1 148	Features containing both a valid spatial reference and basic attributes valid for: a name, surface area, volume, capacity, and mean depth.
45	Features found to be common between the VMap0-Ed5 and SIFRA listing for Zimbabwean SWBs.
Only 4 of the SADC-WRD SWB Zimbabwean dam features > 1 000 hectares were found to be either not listed in the SIFRA document or not represented in the VMap0 data layer.	

Number of SWBs	SIFRA Compendium for Zimbabwe
19	SWB features for Zimbabwe containing detailed limnological and fisheries data in the SIFRA listing.
36	SWBs listed in the Zimbabwean SIFRA summary table containing both potentially useful data attributes and names. Surprisingly, this summary table did not contain a listing for the 19 SWBs for which more detailed data were available elsewhere in the report.
41	Unique SWB descriptions which were identified in total within the SIFRA report for Zimbabwe.
36	SWBs which could be geo-referenced based on either one or both of the VMap0-Ed5 polygonal or SADC-WRD point spatial data layers.

FIGURE 2.34
Surface waterbodies common between the VMap0, SADC-WRD, and SIFRA data including tabular attribute information



The complete table depicted as an inset graphic in Figure 2.34 is reformatted for clarity and presented in Table 2.20.

Discussion

The methods used during the Zimbabwean exercise employed the same AWRD toolsets utilized for the Tanzanian exercise. However, because the process used for naming SWBs in the original VMap0-Ed5 dataset was based primarily on the proximity of the polygonal features to map annotation labels derived from the same cartographic source; and secondarily comparing the polygons to waterbodies from the GNS Gazetteer, the VMap0-Ed5 named waterbodies represents a potential surrogate for two of the more comprehensive gazetteers providing near global coverage of waterbodies.

Due to this, the VMap0-Ed5 may now provide a rapid mechanism to streamline the spatial referencing of historical reports containing statistical or limnological characteristics of SWBs, but which have no usable coordinate reference other than a name. In fact, although the validated SWB features in the VMap0 Inland Waterbody data layer contained less than 3 percent of the features in the SADC-WRD SWB dataset for the Republic of Zimbabwe, the VMap0 alone accounted for almost 40 percent of the waterbodies listed in the SIFRA report for the country. In comparison, the SADC-WRD data set was able to account for a further 44 percent of the SWBs contained in the SIFRA report. Combined, the two spatial datasets were able to provide valid spatial referencing for just over 85 percent of the SWB listed in the Zimbabwean SIFRA report.

TABLE 2.20

Summary of common surface waterbodies data available for the Republic of Zimbabwe

Name of Surface Waterbody	VMap0	ALCOM SADC-WRD Waterbodies				SIFRA				
	Area (Ha)	Area (Ha)	Capacity (10^6 m^3)	Mean depth	Catchment area (km^2)	Year built	Area (Ha)	Volume[1]	Maximum depth	Use[3]
Amapongokwe	-	530	40	8	180	1980	525	39	23	-
Antelope	205	290	15	5	732	-	-	-	-	-
Bangala	1 602	1 130	127	11	5 830	1963	1 133	130	41	i
Bariee	39	8	0.14	2	-	-	-	-	-	-
Blanket	285	122	5	4	-	-	-	-	-	-
Cactus Poort	-	77	3	4	1 279	1944	77	3	16	c
Chivero (Mcillwaine)	2 655	2 630	250	10	2 230	1952	2 630	250	27	w,i,r,f
Dutchman's Pool	277	283	5	2	4 298	1954	283	5	13	c,i
Eben (Mupfurudzi)	-	205	13	6	290	1968	205	13	20	i
Gwenoro	618	466	32	-	-	1958	466	32	24	w
Henry Halam (Harava)	-	215	9	4	696	1973	215	9	18	w
Hulube	22	4	0.05	1	-	-	-	-	-	-
Ingwesi	1 151	850	68	8	847	1967	850	70	34	-
Kariba	491 926	295 200	84 193	29	823 200	1959	510 000	160 368	119	p,r,f
Little Connemara	-	44	-	-	-	1961	44	1	9	r
Maitengwe (Big)	458	687	9	1	686	1965	687	9	4	-
Manjirinje	3 558	2 023	285	14	1 536	1966	2 023	285	46	i
Manyame	9 303	8 100	490	6	3 792	1976	8 100	490	23	w,f
Mare	-	13	0.26	2	-	1955	9	1	7	r
Matopos	-	67	4	6	10	1901	67	4	18	i
Mayfair (Insiza)	-	1 250	182	15	1 800	1976	125	182	29	-
Mazowe	557	445	35	8	342	1920	445	35	31	i
Mazvikadei	-	2 707	350	13	1 127	1973	485	21	18	w
Mushandike	502	437	38	7	325	1938	437	38	33	i,r
Mutirikwi	8 528	9 105	1 425	15	3 990	1961	9 105	1 333	56	i,r,f
Mwenje	-	468	42	9	557	1969	202	13	20	c,i
Ncema	143	152	18	12	713	-	-	-	-	-
Ngezi	813	580	27	5	1 350	1945	580	27	18	i,r
Odzani (Alexander)	-	145	7	5	78	1965	74	7	24	w
Palawan	-	565	74	13	1 313	1979	565	74	38	-
Pembi	-	61	-	-	40	1961	61	2	11	w
Prince Edward	159	93	4	4	-	1929	105	4	8	w
Rusape	-	615	67	11	674	1971	615	68	36	i,w
Ruti	-	1 510	140	9	2 615	1976	150	140	31	-
Sabadzhimba	59	4	0.05	1	-	-	-	-	-	-
Sebakwe 2	1 515	2 374	266	11	2 705	1957	1 518	155	32	w,i,r
Sheet	120	13	0.25	2	-	-	-	-	-	-
Siya	-	810	106	13	518	1977	810	106	47	-
Surisuri	-	192	10	5	260	1968	213	9	14	c,i
Tulimakwe	186	170	8	5	773	-	-	-	-	-
Udu	-	26	1	3	-	1973	15	1	14	r
Umzingwane	572	456	57	13	407	1958	456	45	32	w
Upper Ncema	439	769	45	6	643	1973	769	46	32	w
Upper Umgusa	-	77	3	4	405	1947	77	3	13	i
Whitewaters	262	152	5	-	250	-	-	-	-	-

Terminology; c-commercial/industrial, f-major fishery (over 100 tonnes/year), I-irrigation, p-power generation, r-recreation, w-water supply

Conclusions

The AWRD archive provides spatial data which can be used to develop more consistent baselines upon which both analytical, base mapping, and monitoring and evaluation tasks could be built to more fully support fisheries and integrated water resources management. The results of the two exercises conducted for this case study show that waterbody features can be named and attributed using multiple data sources, and can then be linked with a multitude of other data sources including textual reports. Further, such value-added databases present the opportunity to potentially create the most robustly attributed spatial database of SWBs covering Africa.

The simplest and most cost-effective solution for the development of such a database would be the harmonization of available spatial SWB feature datasets and then individual hot-linking of the point features to the relevant SWB listing in the SIFRA waterbodies directory. An average level of effort of one day per country could be anticipated for the production of such a database covering Africa.

The development of a database more suited to direct analysis of SWB features including both a hot-link as well as a direct tabular link to a set of common data attributes from the SIFRA reports would average approximately 2.5 days per country [the level of effort will vary slightly depending on the hardware used]. Since this later effort would result in tabular data containing both limnological and fisheries specific statistical data which could be directly linked to spatial data features, such an undertaking could provide a valuable tool to more directly support fisheries and integrated water resources management extension efforts.

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Inventory of fisheries habitats and fisheries productivities

By J.M. Kapetsky with contributions from AWRD authors.

Introduction and objectives

Introduction

African inland fisheries represent an important contribution towards food security, income and employment in many African countries.

A major problem is the lack of information about many fisheries, resulting in fisheries that are not well managed. At the same time many fisheries may be threatened by degradation of the environment, loss of habitat and by overexploitation of fishery resources.

African inland fisheries are diverse in terms of species exploited, kinds of gears used, seasonality of fishing and variety of waterbodies exploited. Ultimately, in order to obtain the maximum benefits from the fishery resources, the fisheries have to be managed waterbody by waterbody, or by natural groups of waterbodies with similar ecological and use characteristics. Because of the threats to fisheries environments, fishery resources and fisheries have to be studied in an ecological context that uses watersheds as its framework. Thus, the first step in management is to inventory and characterize the waterbodies that support the fisheries. The second step is to characterize the watersheds in which the waterbodies reside in terms of natural features and human interventions.

This case study provides a broad inventory of African inland fishery habitats in terms of kinds, quantities and aggregate surface areas on a continental basis. Inland fisheries productivities by country are compared. Although this study is conducted from a continental perspective, the same approach could be used in developing an inland fisheries geographic information system at the country level, or even for sub-national areas.

Objectives

- Make an inventory of the kinds and quantities of fisheries habitats of African inland waters;
- Compare the fisheries productivities of African inland waters among countries.

Materials and methods

Data utilized

Africa-wide waterbody counts and surface areas are from a large number of sources in the Surface Waterbodies Database Component (SWB-DBC), described in detail in Section 2.2. Four primary sources are: World Conservation Monitoring Centre (WCMC); DCW VMap0Ed3; Vector Map Level 0 5th Edition (VMap0); and Geographic Name Server (GNS). Of these, the first three provide area estimates and counts of waterbodies while the last provides counts only.

The fish production data are from FAO FishStat Plus and are the average inland capture production by country for the period 2000–2004 (FAO, 2006).

This case study made use of tools available in the AWRD's Surface Waterbodies Module, Additional Tools and Customization Module, and the Statistical Analysis Module.

Results

a. Inventory of fisheries habitats

The goal is to identify the data sources that account for the most surface waterbody (SWB) area and SWB numbers in the greatest variety of habitats that are important for fisheries.

Another important aspect for inland fisheries is the inventory of waterbodies that can be identified by name and to which important fishery information can be attributed (e.g. limnology, fishery yield); however, this is the subject of the previous case study (i.e. surface waterbodies inventory).

Total fishery habitat area

The term "fishery habitat" is used loosely herein to include the kinds of waterbodies that can support fisheries, or that are otherwise important for growth, reproduction and movements of fishes.

Fisheries area and count compilations in three broad categories from each of the three data sources are summarized in Table 2.21.

TABLE 2.21
Counts and surface areas of surface waterbodies from three sources with non-fisheries habitats removed

Data set	WCMC		DCW		VMap0	
Type	Area (ha)	Number	Area (ha)	Number	Area (ha)	Number
Perennial Waterbodies	24 438 894	369	30 215 995	4 901	29 949 754	5 123
Non-Perennial Waterbodies	19 384 505	61	27 795 242	11 185	28 262 230	11 427
Flood-Plain/ Wetlands	71 672 934	2 166	66 551 760	5 004	37 595 310	3 747
Pans	6 875 563	260	316 466	130	153 278	79
Totals	122 371 896	2 856	124 879 463	21 220	95 960 572	20 376

Note: AWRD authors have interpreted a pan as "a natural basin or depression in land" in which case they could be at least seasonal fish habitats. The great salt pan of N Africa in Egyptian territory has been stocked with mullets, so they can be fish habitats in that sense too.

Looking at total areas, the WCMC and DCW data sets are in fairly close agreement whereas the VMap0 compilation has considerably less. In total numbers of waterbodies, the DCW and VMap0 data sets account for many more than the WCMC set. Looking at areas by habitat type, the WCMC set has considerably more wetlands and less non-perennial waterbodies that the DCW set.

Based on this summary, the DCW data set appears to have the clear advantage. It accounts for the largest total area and it includes the largest number of waterbodies among the three sets.

Area of fishery habitats by habitat type

The SWB data sets have been designed to provide an inventory of each kind of fishery and non-fishery habitat, by surface area and by count, on a country-by-country basis or by sub-national administrative boundaries.

Which data set is most useful from a fisheries viewpoint? The WCMC set includes 15 classes of which six classes of non-fishery habitats and unidentified areas can be removed (Seasonal Salt Pan, Salt Pan, Alkaline/Saline Lake, Islands, MF Unknown, Unknown). In contrast, The DCW data set includes nine classes, but only four of them can be identified as potential fishery habitats. Thus, this data set is less useful from a fisheries habitat perspective (Table 2.22).

TABLE 2.22
Surface areas of WCMC inland fisheries habitats of Africa

Fisheries habitats	Surface area (Ha)
Fresh Water Marsh	71 672 934
Impoundment	3 264 723
Lagoon	659 741
Lake	21 164 588
Mangrove	5 971 310
Pools	9 583
Semi-Permanent Lake	61 081
Swamp Forest	19 323 424
Tidal Wetland/Estuary/Coastal	632 459
Grand Total	122 759 843

The nine remaining WCMC classes of fishery habitats total nearly 123 million ha Africa-wide of which the greatest bulk are fresh water marshes at nearly 72 million ha. In total, inland fisheries habitats account for about 4 percent of the surface of the African continent.

The WCMC data were used to estimate each kind of habitat at the national level as shown in Table 2.23, but disaggregation to the same habitat types at sub-national levels also is possible.

Although the collection of information on inland fisheries has to be based on an ecological-habitat approach, management authority is based on administrative boundaries that often do not correspond to fishery habitats. Thus, it is a handy feature that the AWRD Add-On tools include functions that allow users to identify the administrative units that intersect with datasets such as the WCMC data and the other three data sets. This makes possible an inventory that can characterize any fishery habitat, or group of habitats, according to its ecological setting (watershed) as well as its administrative authority.

Counts of fishery habitats

The GNS data set identifies waterbody types and locations only as points, so there are no corresponding data on surface areas. Nevertheless, it is useful to have counts on waterbodies that are also fishery habitats for all of Africa that can be compared to the surface areas from the WCMC, DCW and VMap data sets.

There are 65 types of hydrological features, with a total of 150 221 separate locations for all of Africa. Many of these hydrological features might serve as fishery habitats (Table 2.23).

TABLE 2.23
Counts of fishery habitats for the African continent from the GNS data set

Fisheries habitat	Count	Fisheries habitat	Count
stream	117 254	crater lake	83
lake	7 891	sea	83
water tank	3 483	anabranch	78
bay	2 744	ponds	74
pond	1 638	bight(s)	68
ravine(s)	1 533	lake channel(s)	54
tidal creek(s)	1 364	roadstead	51
wetland	1 265	section of wadi	46
reservoir(s)	1 122	lakes	41
pool(s)	1 095	navigation canal(s)	39
marsh(es)	1 064	tidal flat(s)	38
canal	1 061	navigation channel	32

reef(s)	959	irrigation canal	30
cove(s)	914	canalized stream	18
swamp	679	docking basin	17
shoal(s)	655	mangrove swamp	14
inlet	546	seaplane landing area	14
waterfall(s)	522	streams	13
distributary(-ies)	417	abandoned watercourse	11
rapids	407	irrigation system	10
drainage canal	405	stream bend	7
lagoon	397	fishing area	6
marine channel	384	salt marsh	6
channel	325	headwaters	5
gulf	200	reach	5
strait	163	section of waterfall(s)	5
section of stream	153	whirlpool	5
lake bed(s)	148	section of lagoon	3
mud flat(s)	131	confluence	2
section of lake	121	lagoons	2
harbor(s)	117	crater lakes	1
estuary	111	watercourse	1
stream mouth(s)	91	Grand Total	150 221

As with the WCMC, DCW and VMap0 data set, the GNS data can be disaggregated in order to provide country level counts by type.

b. Fisheries productivity of African inland waters

Comparative knowledge about fisheries productivities of inland waters is useful for management purposes. The perennial question for managers is "How much fish can be removed without jeopardizing the future productive capacity of the resources?", and often the only indication that is available is based on the observed fishery performances of similar waterbodies elsewhere. From such data, models have been built to predict fishery yields for those waterbodies for which there are no catch data. One example of the use of such a model constitutes another AWRD case study (i.e. Predicting Potential Fish Yield).

The objective here is to compare fisheries productivities across African inland waters on a country basis.

The data are of two kinds: surface area and fish production. The surface area data are the fishery habitat data that have been derived from the WCMC data set as explained above. An assumption going along with the use of these data is that all of the fishery habitats in each country are exploited. In fact, there are five countries (i.e. the People's Democratic Republic of Algeria, the Republic of Djibouti, Eritrea, the Socialist People's Libyan Arab Jamahiriya, and Western Sahara), that have substantial areas of fishery habitats; however, these countries did not report inland capture production in the period 2000–2004.

The fish production data are from FAO FishStat Plus and are the average inland capture production by country for the period 2000–2004. One of the handicaps of using these data is that the production is not actually monitored for all of the countries, but is estimated from various data sources. Oftentimes, even in countries where the catch is monitored, not all of the production is accounted for because of logistical difficulties. It can be assumed that, for most countries, the production reported to FAO underestimates the actual production.

There were 44 countries for which there were production data for the period 2000–20004. The production data were compared with the fishery habitat surface area data (perennial and non-perennial waterbodies and wetlands). The results, fisheries productivities (kg/ha) by country, ranged from 0.1 kg/ha to 136.9 kg/ha, covering five orders of magnitude (Table 2.24).

TABLE 2.24
Inland fisheries productivities of African countries

Country	Fisheries habitat (ha)	Mean production 2000-2004 (tonnes)	Productivity kg/ha
Egypt	2 098 866	287 387	136.9
Liberia	34 235	4 000	116.8
Benin	295 786	28 919	97.8
Lesotho	584	37	62.7
Ghana	1 367 103	74 700	54.6
Burundi	255 938	13 081	51.1
Uganda	5 007 776	255 116	50.9
Kenya	3 057 628	147 442	48.2
Equatorial Guinea	22 161	1 015	45.8
Burkina Faso	190 082	8 700	45.8
Senegal	1 396 529	50 431	36.1
Togo	140 074	5 000	35.7
Zimbabwe	392 725	13 023	33.2
Sierra Leone	477 147	14 000	29.3
Rwanda	241 584	7 071	29.3
Côte d'Ivoire	492 789	14 366	29.2
Cameroon	1 963 813	56 500	28.8
Tanzania, United Rep. of	10 101 489	287 446	28.5
Madagascar	1 055 501	30 000	28.4
Nigeria	5 848 020	166 193	28.4
Swaziland	3 272	70	21.4
Mali	5 403 449	101 974	18.9
Congo, Dem. Rep. of the	11 372 397	212 000	18.6
Malawi	2 752 591	48 391	17.6
Central African Republic	1 177 094	15 000	12.7
Gabon	852 413	9 493	11.1
Gambia	229 030	2 500	10.9
Zambia	7 306 469	65 334	8.9
Guinea	509 044	4 000	7.9
Niger	4 424 929	33 587	7.6
Sudan	7 123 654	52 200	7.3
Ethiopia	2 204 793	12 518	5.7
Chad	15 225 194	75 640	5.0
Congo, Republic of	5 921 210	25 765	4.4
Angola	2 297 559	8 800	3.8
Morocco	477 682	1 577	3.3
Mozambique	4 676 338	11 792	2.5
Mauritania	2 128 409	5 000	2.3
Namibia	1 635 322	1 500	0.9
Tunisia	1 036 609	894	0.9
South Africa	1 338 576	900	0.7
Guinea-Bissau	375 563	150	0.4
Somalia	1 290 341	200	0.2
Botswana	3 639 024	141	0.0

It is doubtful that Egyptian waters could be so much more productive than others in Africa. Thus, there may be a problem with over-reporting production (e.g. including aquaculture production with capture production), or the fishery habitat surface area may be underestimated. Most of the water surface in the Arab Republic of Egypt is in Lake Nassar (reservoir) and that amounts to about 5 200 km^2 at maximum water levels. The total Egyptian SWB area accounted for in the WCMC is about 7 500 km^2. The highest production tabulated for Lake Nassar by Latif (1984) was about 53 kg/ha. Therefore, over-reporting of production is the most suspect source of the error. In contrast, the fisheries productivities of other countries seem small, but reasonable considering that unfished habitats may be included and that wetlands make up a large part of the fishery habitat surface area.

Fishery productivity and the environment

Two environmental variables that have an obvious relationship to the fishery productivity of inland waters are temperature (setting the rate of biological production) and precipitation (determining fishery habitat availability and nutrients through rainfall runoff). These relationships were tested first by plotting fishery productivity by country with each environmental variable. In the plot of productivity with temperature the Kingdom of Lesotho is an outlier with a much higher productivity than would be expected, 62.7 kg/ha, for its annual average temperature of 11.8 °C that is more than 5 degrees cooler than any other African country. In the plot of productivity with annual precipitation the Arab Republic of Egypt is an outlier. The Arab Republic of Egypt has the least amount of rainfall in the data set, but has a relatively high productivity of 136.9 kg/ha. One of Egypt's most important fisheries is Lake Nassar, which is a desert reservoir. Therefore, the Kingdom of Lesotho and the Arab Republic of Egypt data were removed and the data re-plotted. A correlation matrix was calculated among the variables and the resulting coefficients were 0.44 for annual precipitation on fishery productivity and 0.22 for mean temperature on fishery productivity. Multiple regression of precipitation and temperature on fishery productivity was highly significant ($p=0.007$) and independent variables together accounted for about 22 percent of the variation in fishery productivity.

Given the weakness of the fishery productivity data and the fact that the environmental variables pertain to the entire area of each country and not to SWB areas, the low correlations and low coefficient of multiple regression are understandable. However, this exercise does illustrate how environmental variables can be combined with fishery data to develop useful models.

Conclusions

This case study has used Africa wide data to illustrate how SWB area and count data can be used to inventory fishery habitats across Africa and to relate fishery habitats to fishery productivities and environmental variables. The main point is that fisheries can be managed only when the characteristics of fishery habitats are known. Although relatively coarse data (1: 1 million) were used, remotely sensed data can be employed to acquire data for national and sub-national inventories at finer resolutions and during wet and dry seasons. Such data can be imported and incorporated into AWRD.

The AWRD provides a solid framework for inland fisheries and environmental information in Africa. One of the next steps should be to find ways to assist countries to facilitate the organization of national level fisheries and environmental data collection, storage, and the manipulation and analysis of data within a version of AWRD specifically modified for that purpose for countries in Africa. In effect, AWRD has the potential to become a national level fisheries and aquaculture geographic information system.

Looking over a broader geographic area, a world wide data set of surface waterbodies comparable from country to country and continent to continent would greatly facilitate applied research on comparative inland fisheries. For this purpose the DCW data set could provide a starting framework given its global coverage and despite its few habitat types, but the WCMC could not because its scope is limited to Africa.

References

Latif, A.F.A.1984. Lake Nasser (Egypt). pp 193-246. *In*: Kapetsky, J.M. & Petr, T. (eds.). *Status of African reservoir fisheries*. CIFA Technical Paper. No. 10. FAO, Rome. 326 pp.

FAO. 2006. FISHSTAT PLUS [online]. Universal software for fishery statistical time series [Version 2.3]. Release date: March 2006. (available at http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp).

Predicting potential fish yield

Introduction and objectives

This case study discusses estimation and prediction of potential fish yield from standing surface waterbodies in Africa, demonstrating several potential methods based on the amount of historical catch data available and the morphological and topographic characteristics of those surface waterbodies. This case study also illustrates how estimates of potential fish yield for certain waterbodies can be obtained from reference sources or, when better data are not available, estimated directly using the potential fish yield prediction tools or the statistical analysis tools.

Materials and methods

The examples in this case study use surface waterbody data from the FAO Lakes and Rivers Database, the Water Resources in Africa shapefile “Wria_swb.shp” and the Source Book for the Inland Fishery Resources of Africa (SIFRA). One example utilizes the Water Resources in Africa watershed model “Faoawria.shp” to determine drainage basin boundaries.

This exercise makes use of tools available in the AWRD’s Watersheds Module, Surface Waterbodies Module and Statistical Analysis Module, as well as data from the SIFRA Compendium references.

Results

a) Obtaining estimates of potential fish yield from reference sources

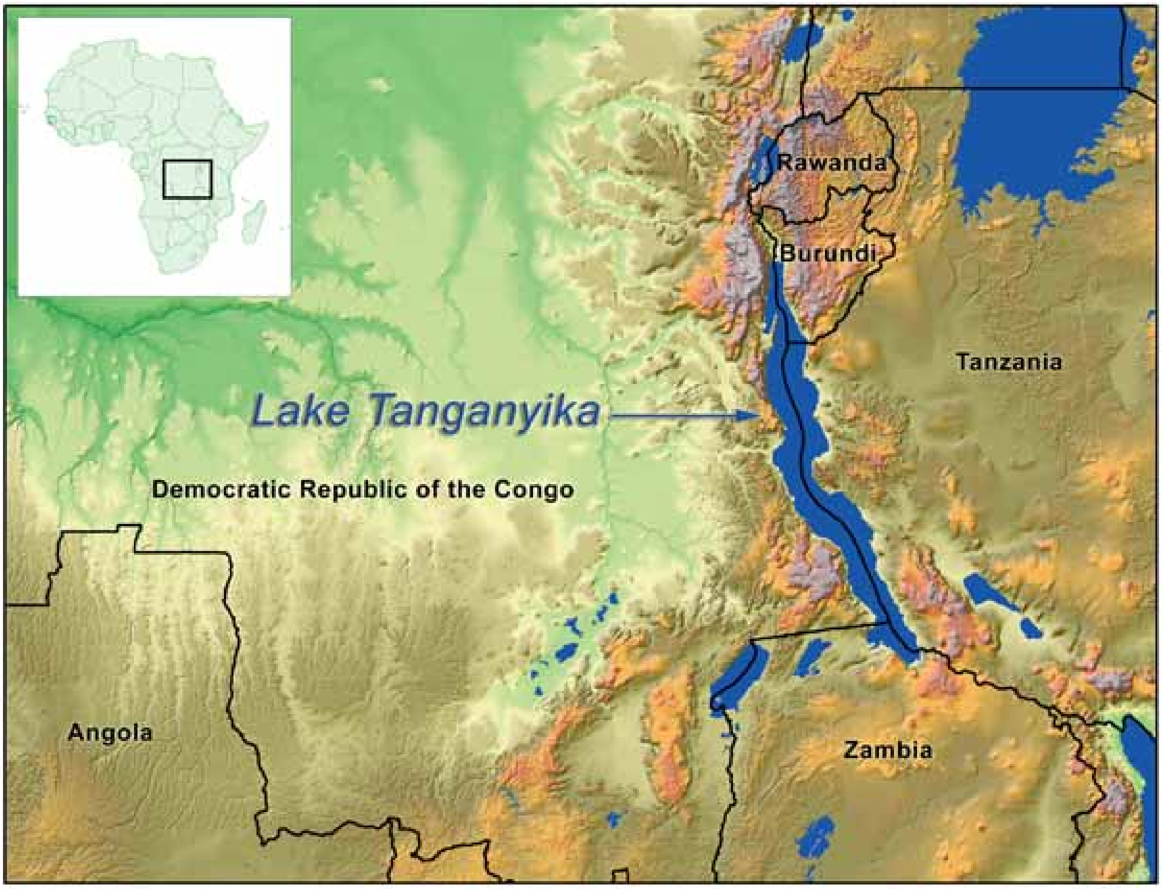
Many waterbodies in Africa have already had potential fish yield analyses conducted on them. The AWRD includes two sources of data that provide potential fish yield estimates for many of the major waterbodies in Africa, and it is possible that users of the AWRD may be able to find detailed information on a waterbody of interest directly in these sources.

The FAO Lakes and River Fisheries Database is a comprehensive database of temperate and tropical lakes and rivers around the world, compiled from research efforts conducted by FAO and MRAG Ltd. The database is included with the AWRD in Microsoft Access format (see file ZOCSRC.mdb, available in the “Docs” folder of the AWRD data archive. The history of this database, and definitions of the various datasets included within, are detailed in the Technical Database Specification Document for the FAO Lakes and River Fisheries Database (MRAG Ltd. 1997), available in the AWRD Documents folder.

The Source Book for the Inland Fishery Resources of Africa (SIFRA) is a compendium of information on physical characteristics, limnology and fisheries in Africa, organized by country. This source provides detailed and comprehensive information on inland fisheries and fishery potential in a concise and organized manner, and was created by FAO to promote fisheries management and to serve as a reference source for fisheries managers.

One of the largest waterbodies in Africa, Lake Tanganyika covers portions of the Republic of Burundi, the United Republic of Tanzania, the Democratic Republic of the Congo, and the Republic of Zambia, and supports one of Africa's most important lake fisheries (Figure 2.35). A discussion of this lake may be found in the SIFRA Source Book data for any of these four countries.

FIGURE 2.35
Lake Tanganyika, bordering the Republic of Burundi, the Democratic Republic of the Congo, the United Republic of Tanzania, and the Republic of Zambia



The SIFRA discussion of Lake Tanganyika includes a description of two independent analyses of potential fish yield based on annual catch data (Corsi, Dunn and Felicioni, 1986; Mikkola and Lindquist, 1989), each of which produced very similar estimates. These analyses also break down the potential fish yield estimates by country (Table 2.25).

TABLE 2.25
Lake Tanganyika potential annual fish yield

Country	(Corsi, Dunn and Felicioni, 1986) (tonnes per year)	(Mikkola and Lindquist, 1989) (max. tonnes per year)
Burundi	21 000	23 000
Tanzania	122 000	121 000
Democratic Republic of the Congo	135 000	133 000
Zambia	19 000	18 000
Total	297 000 (90 kg/ha)	295 000

Furthermore, Hanek and Kapetsky (1999) found significant increases in annual catch data in the 1990s. Total annual catch on Lake Tanganyika was estimated at 167 000 tonnes in 1992, increasing to 196 670 tonnes in 1995.

b) Estimating potential fish yield based on historical catch data

If an existing analysis or estimate of potential fish yield is not available, then it may be possible to estimate the potential fish yield based on historical catch data. The simplest estimate of potential fish yield would be the mean catch from previous years. However, the mean value itself does not give any sense of how variable the catch is from year to year, so the AWRD includes tools to calculate a confidence interval around that mean value. This confidence interval provides a range of potential fish yield values, and the confidence level specifies the certainty that the true potential fish yield lies within that range.

It should be noted, however, that this simple method assumes that the mean annual fish yield of previous years provides a valid estimate of the annual fish yield for future years. This may be reasonable in many cases, but Grainger and Garcia (1996) describe how fisheries often go through four distinct phases in which the year-to-year change in fish yield can vary greatly (see Grainger and Garcia (1996) Section 3.1 – Generalised fishery development model). Lake Tanganyika (above) is an example of a fishery passing through developmental phases. If enough recent years of data are available, Grainger and Garcia recommend using that data to estimate the current developmental phase of the fishery (undeveloped, developing, mature or senescent). Based on the developmental phase, the fishery manager may predict that fish yield may decline, stay level, or increase in the future.

The following example illustrates the use of historical catch data for Nokoue Lagoon. Nokoue Lagoon is located near the southern coast of the Republic of Benin (Figure 2.36).

The FAO Lakes and River Fisheries Database (ZOCSRC.mdb) includes catch data for seven years between 1959 and 1989. Five of these years (i.e. 1959, 1964, 1965, 1969 and 1976) come from SIFRA data (Vanden Bossche and Bernacsek, 1990a, b, 1991) and two years (i.e. 1972, 1989) come from the Coastal Lagoon and Brackishwater Statistics for the Republic of Benin(Gbaguidi, 1990). The predicted fish yield for Nokoue Lagoon, calculated using the AWRD Field Summary Statistics tool, is detailed in Table 2.26.

FIGURE 2.36
Nokoue Lagoon, on the southern coast of the Republic of Benin

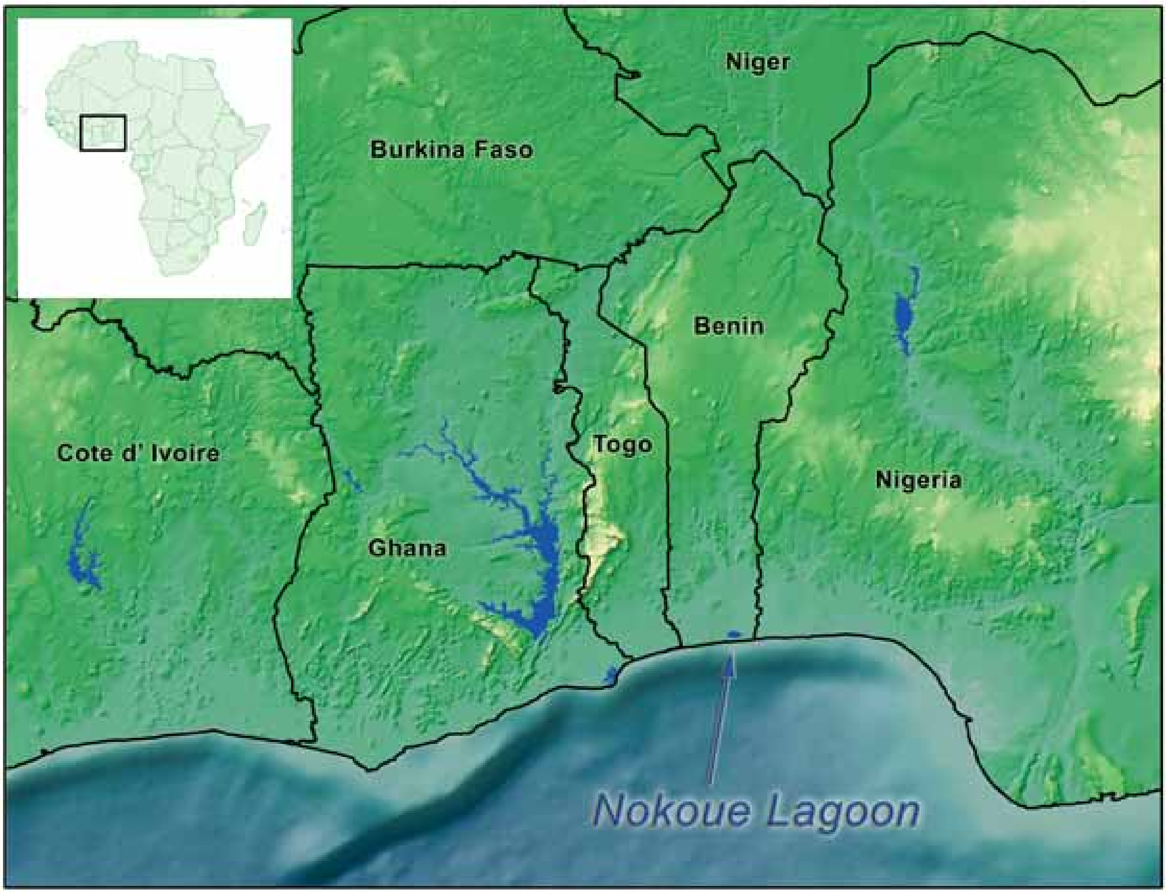


TABLE 2.26
Summary statistics for historic catch: Nokoue Lagoon

Mean	11 312 tonnes per year
Std. Error of Mean	2 103 tonnes per year
Lower 95% Conf. Limit	6 166 tonnes per year
Upper 95% Conf. Limit	16 457 tonnes per year

The mean value (11 312 tonnes per year) is the best estimate of potential fish yield, but the 95 percent confidence interval (6 166–16 457 tonnes per year) indicates that there is a large amount of variability in the historic record. Therefore if the conditions that led to the historic catch levels are still present today, then we can be 95 percent certain that the current potential fish yield is somewhere between 6 166 and 16 457 tonnes per year.

The SIFRA Compendium data for the Republic of Benin includes an estimate of potential fish yield based only on the five years of data used in that analysis. Their estimate (6 000–16 000 tonnes per year) is very close to this one.

c) Estimating potential fish yield

The potential fish yield prediction tools provide users of the AWRD with the ability to estimate the potential fish yield of a particular surface waterbody, in tonnes per year, based on two regression models developed by Halls (1999). It should be emphasized that these models are intended to be used only in instances where historical fishery statistics are lacking. The first model is based entirely on the surface area of the waterbody and does not consider any outside influences on that waterbody. The second model incorporates the mean air temperature of the waterbody drainage basin and therefore is sensitive to an external environmental factor.

Model development

Halls (1999) analyzed potential fish yield values for 94 African lentic waterbodies (lakes, reservoirs, and lagoons) ranging in size from 1–69 640 square kilometers, using simple linear regression and backwards stepwise multiple linear regression methods. He analyzed 31 potential explanatory variables including:

- Surface area of the waterbody;
- Drainage basin area of the waterbody;
- Shoreline length of the waterbody;
- Human population density in the catchment area;
- Mean annual precipitation over the waterbody and over the catchment area;
- Mean annual air temperature over the waterbody and over the catchment area;
- Total length of six categories of roads over the catchment area;
- Density of six categories of roads over the catchment area;
- Total density of all roads in the catchment area;
- Mean soil fertility index;
- Amount and density of catchment area containing planted crops;
- Amount and density of catchment area containing natural vegetation mosaic;
- Amount and density of catchment area containing either planted crops or natural vegetation mosaic;
- Total population number within the catchment;
- Shoreline development index; and
- Drainage basin area as a proportion of waterbody area.

Halls found that that *surface area of the waterbody* was the best predictor of potential fish yield with an $R^2 = 0.804$ (Halls, 1999), meaning that approximately 80.4 percent of the variation in potential fish yield among surface waterbodies could be explained by the surface area of those waterbodies.

$$\text{Model 1: In } (Y_{new}) = 2.688 + 0.818 \text{ x In (Area)}$$

When looking at combinations of potential predictor variables, Halls found that a model using both *Surface Area* and *Mean Annual Air Temperature over Catchment Area* did marginally better at predicting potential fish yield than a model containing *Surface Area* alone ($R^2 = 0.817$) (Halls, 1999).

$$\text{Model 2: In } (Y_{new}) = 2.3.881 + 0.790 \text{ x In (Area)} + 2.21 \text{ x In (TempDB)}$$

The 94 waterbodies used by Halls in his analysis ranged from 1–69 649 km^2 in size, and from 14.6–27.7 °C in mean annual drainage basin air temperature.

Potential fish yield prediction precision

In general, predictive models should be used with caution because models, by their nature, are rarely perfectly accurate. The actual fish yield of a waterbody will be influenced by many factors that are very difficult to capture and quantify into a model. The variables identified by Halls (1999) appear to be by far the most influential factors affecting potential fish yield and so we may have some confidence in using them in a general predictive model. However, upon back-transforming the confidence intervals, it becomes evident that the predictions of potential fish yield are imprecise (Table 2.26). This imprecision is likely to reflect a number of factors including natural variability among waterbodies unrelated to waterbody area and temperature, and possibly imprecise and inaccurate estimates of annual catch used to build the models. Halls (1999) discusses further sources of error. It is important that users are aware of the uncertainty surrounding the model predictions.

Users should also always be aware that the model prediction is only a statistically "best estimate" based on a relatively small set of data. This is why the use of confidence intervals is often considered more appropriate and informative than the basic predicted value. Confidence intervals provide a more realistic estimate of potential fish yield by generating a range of values within which there is a specified probability that the true potential fish yield will be contained. Furthermore, different ranges of values can be generated reflecting different confidence levels, and in general, ranges with high confidence levels will be wider than ranges with lower confidence levels. For a description of how these confidence intervals are calculated, please refer to the Surface Waterbodies Module in part 2 of this publication for a more detailed description of Prediction Precision.

To illustrate the uncertainty surrounding the model predictions we compare the predicted potential fish yield for a number of surface waterbodies with the actual measured potential fish yield of those waterbodies, using Halls' original data (Halls, 1999). Table 2.27 shows actual potential fish yield values, predicted values and confidence intervals (at 90 percent and 95 percent) using Model 2 on 14 of Halls' original 94 waterbodies. These 14 were selected only because they reflect a good range of waterbody sizes. This table is intended only to demonstrate the uncertainty of the model predictions based on the magnitude of the confidence interval ranges. Confidence intervals generated using Model 1 are similar in size to those generated using Model 2, so only Model 2 predictions are shown here.

TABLE 2.27
Original data for 14 sample waterbodies

Waterbody name	Country	Waterbody area (km²)	Drainage basin air temperature (°C)	Actual catch (tonnes/year)	Predicted values (using Model 2)		
					Potential fish yield (tonnes/year)	Confidence intervals (tonnes/year)	
						95%	90%
Mgori	Tanzania	1	19.68	43	15	2–117	3–84
Sake	Rwanda	12	19.61	175	109	15–806	20–581
Luhondo	Rwanda	22	15.86	100	110	14–831	20–597
Itasy	Madagascar	30	17.27	990	169	23–1 261	32–908
Kachira	Uganda	46	18.88	1 043	289	39–2 132	54–1 538
Burero	Rwanda	50	15.8	100	204	27–1 555	37–1 116
Kitangiri	Tanzania	102	22.13	2 320	771	104–5 703	145–4 112
Nyumba-YaMungu	Tanzania	155	20.60	6 676	915	124–6 742	172–4 865
Jebel	Sudan	216	24.94	8 108	1 819	241–13 706	336–9 853
Upemba	Democratic Republic of the Congo	577	21.16	5 479	2 742	370–20 315	513–14 645
Kainji	Nigeria	1 409	27.45	6 629	9 889	1 275–76 725	1 781–54 898
Aswan	International	3 942	25.10	28 994	18 274	2 387–139 925	3 328–100 335
Malawi	International	29 315	20.11	57 900	54 425	6 982–424 214	9 766–303 304
Victoria	International	69 694	19.92	228 571	105 654	13 309–838 726	18 671–597 881

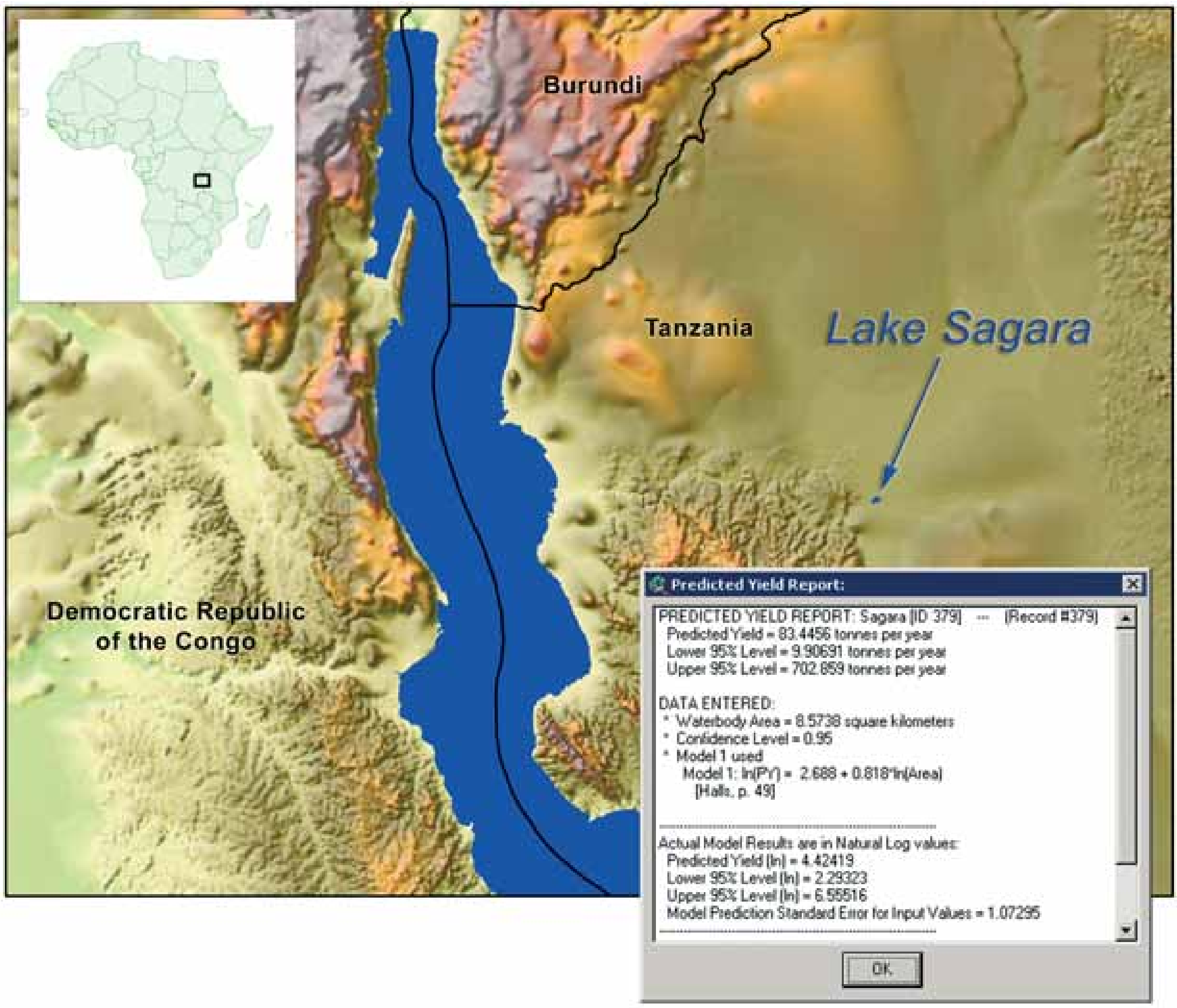
Source: Halls (1999).

Note especially that the confidence intervals are large when compared to the predicted values, reflecting the imprecision of the actual predicted values.

Model 1 to predict potential fish yield for Lake Sagara

Lake Sagara is located in the United Republic of Tanzania, approximately 140 km east of Lake Tanganyika. According to the Water Resources in Africa shapefile (Wria_swb.shp), Lake Sagara has a surface area of approximately 8.5 km^2. With this information, we can use the AWRD Potential Fish Yield prediction tool to generate a predicted fish yield report for Lake Sagara (Figure 2.37). Therefore, our best estimate of potential fish yield for Lake Sagara is approximately 83 tonnes per year, and we can be 95 percent confident that the true potential fish yield lies between 10–703 tonnes per year.

FIGURE 2.37
Lake Sagara, in the United Republic of Tanzania



Model 2 to predict potential fish yield for Lake Kabamba

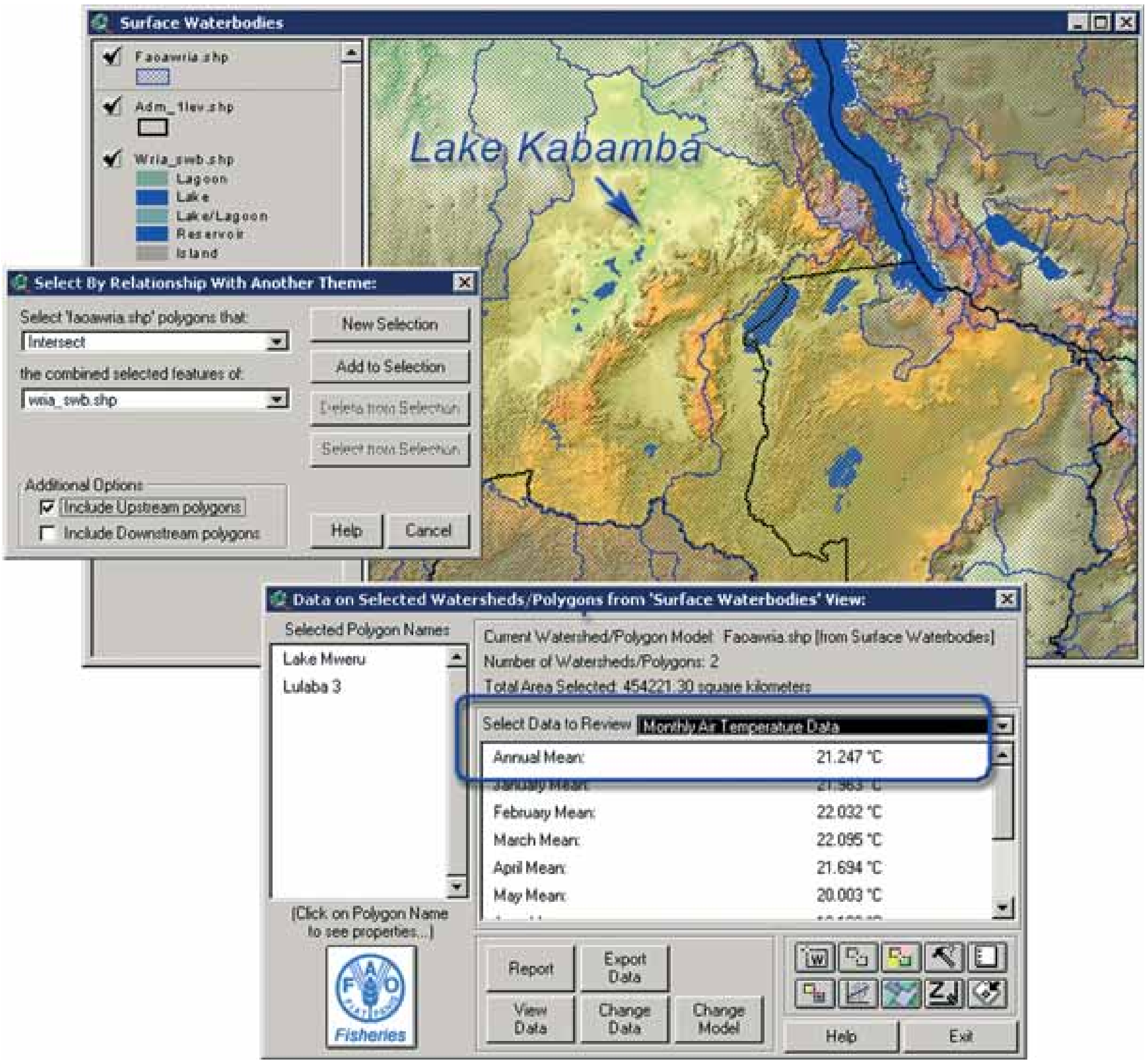
Lake Kabamba is located in the Democratic Republic of the Congo, approximately 300 km southwest of Lake Tanganyika.

Model 2 is slightly more complicated and requires both the waterbody surface area and the mean annual air temperature in the waterbody drainage basin. The AWRD provides two methods for calculating the mean annual air temperature in this region:

1) The AWRD Watershed Selection tools can be used to select all those watersheds that comprise the drainage basin contributing to Lake Kabamba (Figure 2.38a). First select Lake Kabamba, then use the "Select by Relationship with Another

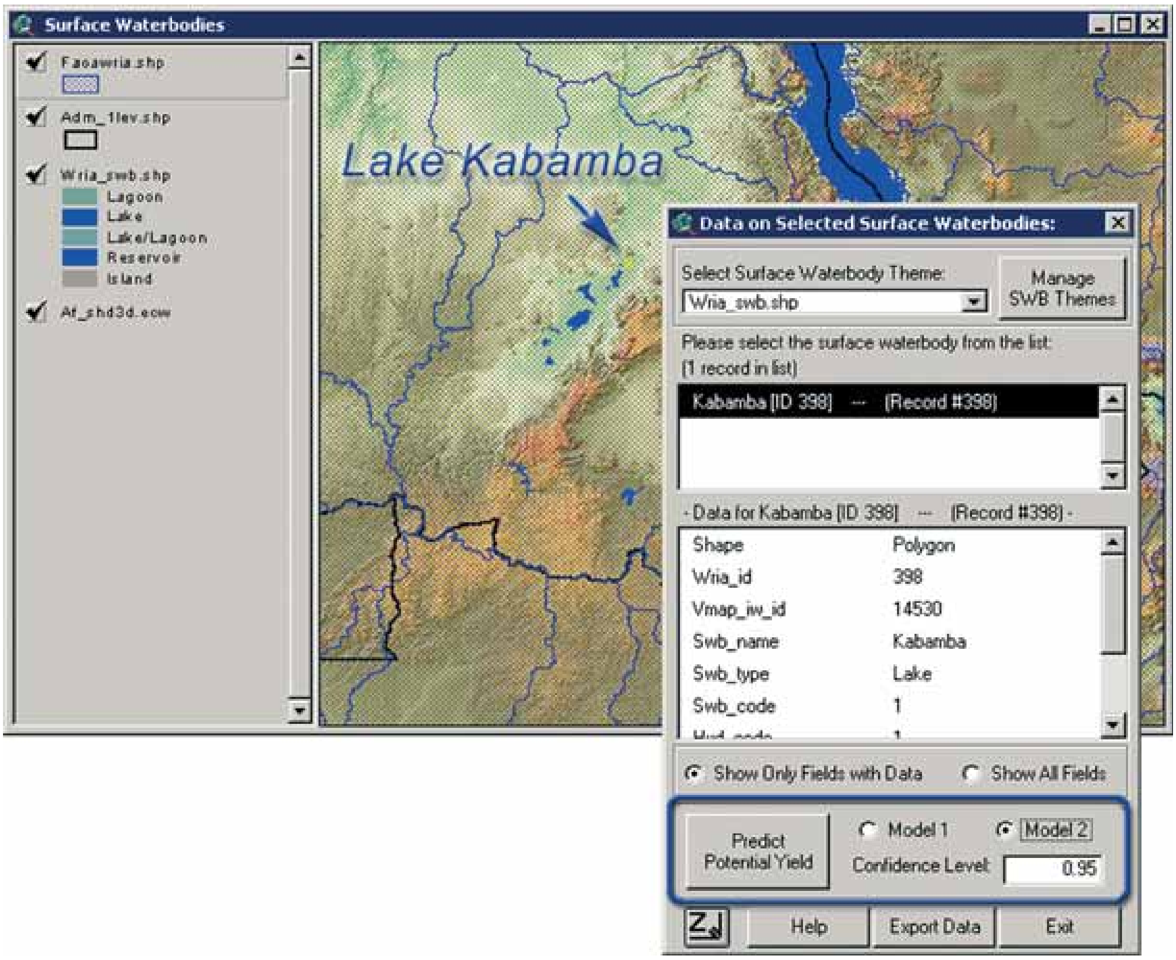
Theme" button (or the identical AWRD Modules menu item) to select the upstream watersheds that form the drainage basin. The Watershed Statistics Viewer can then be used to calculate the mean annual air temperature in those selected watersheds, based on the current watershed model (for a detailed discussion of the AWRD Watershed tools, please refer to part 2 of this publication).

FIGURE 2.38A
Selecting the drainage basin for Lake Kabamba



2) Alternatively (Figure 2.38b), the Surface Waterbodies Viewer can be used to calculate the air temperature and the predicted fish yield report automatically (please refer to the Surface Waterbodies Module part 2 of this publication for a detailed discussion of the AWRD Surface Waterbody tools).

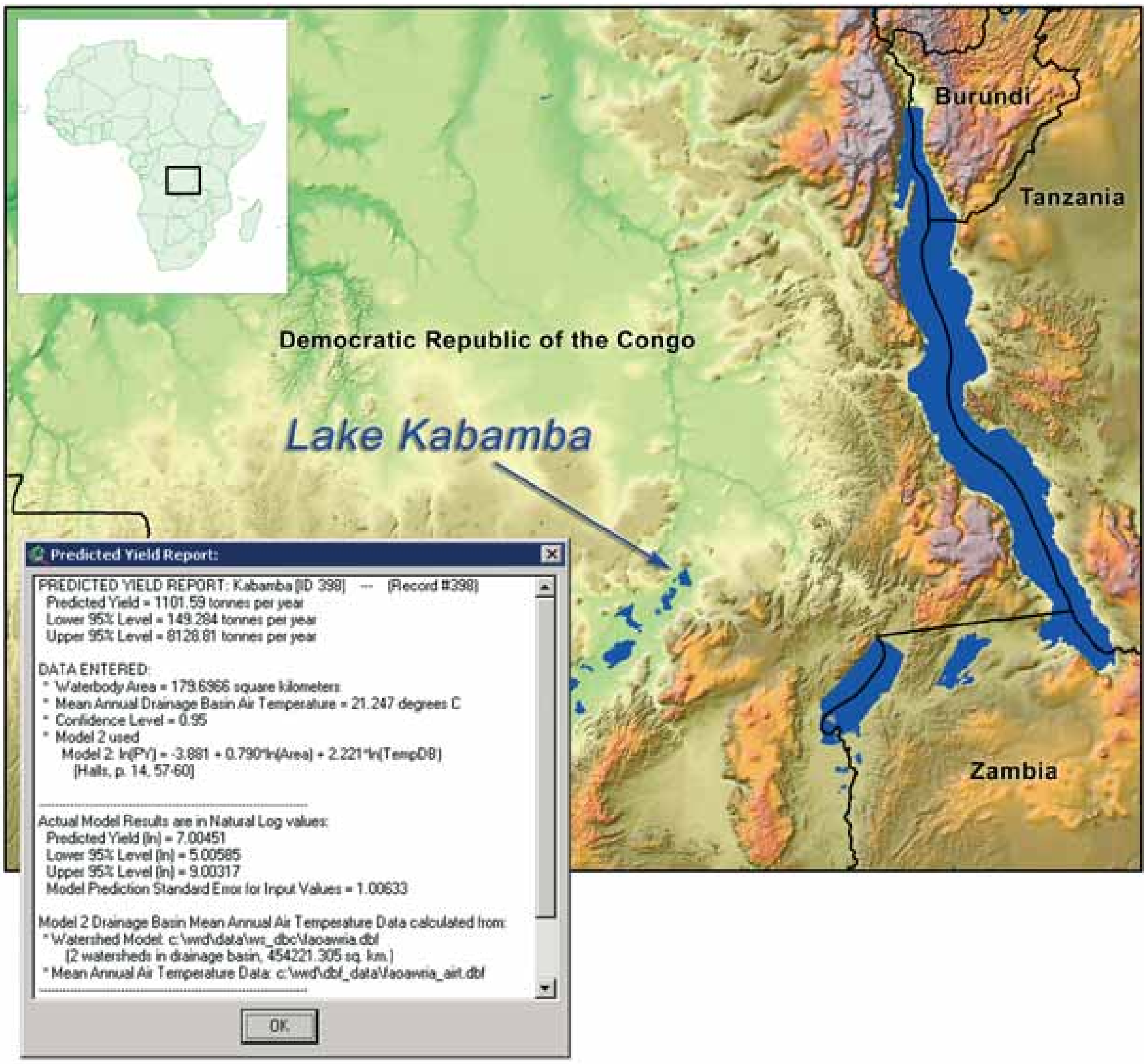
FIGURE 2.38B
Calculating potential yield directly with Surface Waterbodies viewer



Either method tells us that the mean annual air temperature in the Lake Kabamba drainage basin is approximately 21.247 °C. According to the Water Resources in Africa shapefile (Wria_swb.shp), Lake Kabamba has a surface area of 180 km². Given this information, we can use the AWRD Potential Fish Yield Calculator to generate a predicted fish yield report for Lake Kabamba (Figure 2.38c).

Our best estimate of potential fish yield for Lake Kabamba is approximately 1 102 tonnes per year, and we can be 95 percent confident that the true potential fish yield lies between 149 to 8 129 tonnes per year.

FIGURE 2.38C
Lake Kabamba, in the Democratic Republic of the Congo



Conclusions

Potential Fish Yield is a critical value for fisheries managers, and can be influenced by a large number of factors including the developmental stage of the fishery. The best estimates of potential fish yield can generally be found in reference sources such as SIFRA, reports such as Hanek and Kapetsky (1999), or calculated from historical catch data from that fishery. When such data is not available, however, the AWRD provides tools to estimate this value based on the surface area of the waterbody and, possibly, the mean annual air temperature of the waterbody drainage basin. Historical data or existing analyses should generally provide more accurate and precise estimates of potential fish yield than the AWRD models, but these models provide a statistically based guide when better data is unavailable.

Acknowledgements

Much of the data contained within the African Lakes database were compiled under two DFID-funded projects funded through the Fisheries Management Science Programme: (1) Synthesis of Simple Predictive Models for River Fish Yields in Major Tropical Rivers; (2) Synthesis of Simple Predictive Models for Fisheries in Tropical Lakes.

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Mikkola, H. & Lindquist, O.V. 1989. Report on a Project Mobilization Mission. Preparatory Phase: Lake Tanganyika Regional Fisheries Research Project, GCP/RAF/229/FIN, FAO, Rome.

MRAG Ltd. 1997. Technical Database Specification Document for the FAO Lakes and River Fisheries Database.

Vanden Bossche, J.-P. & Bernacsek, G.M. 1990a. *Source book for the inland fishery resources of Africa*: 1. CIFA Technical Paper. No. 18.1. Rome, FAO. 240 pp. (also available at http://www.fao.org/docrep/005/T0473E/T0473E00.htm).

Vanden Bossche, J.-P. & Bernacsek, G.M. 1990b. *Source book for the inland fishery resources of Africa*: 2. CIFA Technical Paper. No. 18.2. Rome, FAO. 411 pp. (also available at http://www.fao.org/docrep/005/T0360E/T0360E00.htm).

Vanden Bossche, J.-P. & Bernacsek, G.M. 1991. *Source book for the inland fishery resources of Africa*: 3. CIFA Technical Paper, No. 18.3. Rome, FAO. 219 pp. (also available at http://www.fao.org/docrep/005/T0361E/T0361E00.htm).

Preliminary hydrological reporting

Introduction and objectives

Introduction

This case study illustrates some of the basic capabilities of the Watersheds Module of the AWRD, and the integration of results with the other spatial data and reference information contained in the AWRD archive to create descriptive reports for preliminary hydrological analyses. The Volta River megabasin in southern west Africa and the countries of the Republic of Ghana and Burkina Faso are used as examples. The study begins with an overview of the primary contributing basins comprising the Volta megabasin and then proceeds with an examination of information specific to the Volta Reservoir in the southern Ghana. Descriptive reports of the Republic of Ghana and Burkina Faso are also included for a comparative analyses of climate data between these two countries within the Volta megabasin.

Objective

The purpose of the case study is to introduce some of the options available to users of the AWRD for preliminary hydrological analyses. The methods used here may serve as a model that can be applied elsewhere in Africa.

Materials and methods

Data utilized

The watershed model used throughout this case study is the ALCOMWWF medium resolution 3-level watershed model. The National Boundary dataset is the VMap0 National-Ad1 Polygonal Boundaries shapefile. For reference purposes, river and surface waterbody features may be added from the 1:3 m RWDBII, the 1:1 m VMap0/DCW or the 1:100 000 SRTM surface waterbody datasets. This case study also uses various raster data layers from the ARAS-DBC, textual information from the SIFRA Compendium, and tabular data from the FAO Lakes and River Fisheries database (MRAG ltd, 1997).

Methods

The primary AWRD tool-sets employed in this exercise include the suite of tools available through the AWRD's Watersheds Module, the Statistical Analysis Module, and the Image Export and Base Mapping tool-set. These tools are used to both define the extent(s) of the analyses and to provide the baseline statistics for the various graphic figures, charts and text presented in the case study. In addition to these native AWRD tools, the case study also employs the charting/graphing functions of Microsoft Excel.

Results

Overview of the Volta River megabasin

The Volta River megabasin is an international waterway with flows originating from six countries: the Republic of Benin, Burkina Faso, the Republic of Côte d'Ivoire, the Republic of Ghana, the Republic of Mali and the Togolese Republic. The overall river system is comprised of three principle contributing basins: the Black Volta, the White Volta and the Oti River basins, which all drain into Volta River proper through the Lake Volta Reservoir – termed the Lower Volta River basin in this case study – before discharging into the Atlantic Ocean via the Gulf of Guinea. The countries, contributing basins, reference hydrology and major cities surrounding the megabasin are presented in Figure 2.39.

FIGURE 2.39
Overview map of the Volta megabasin

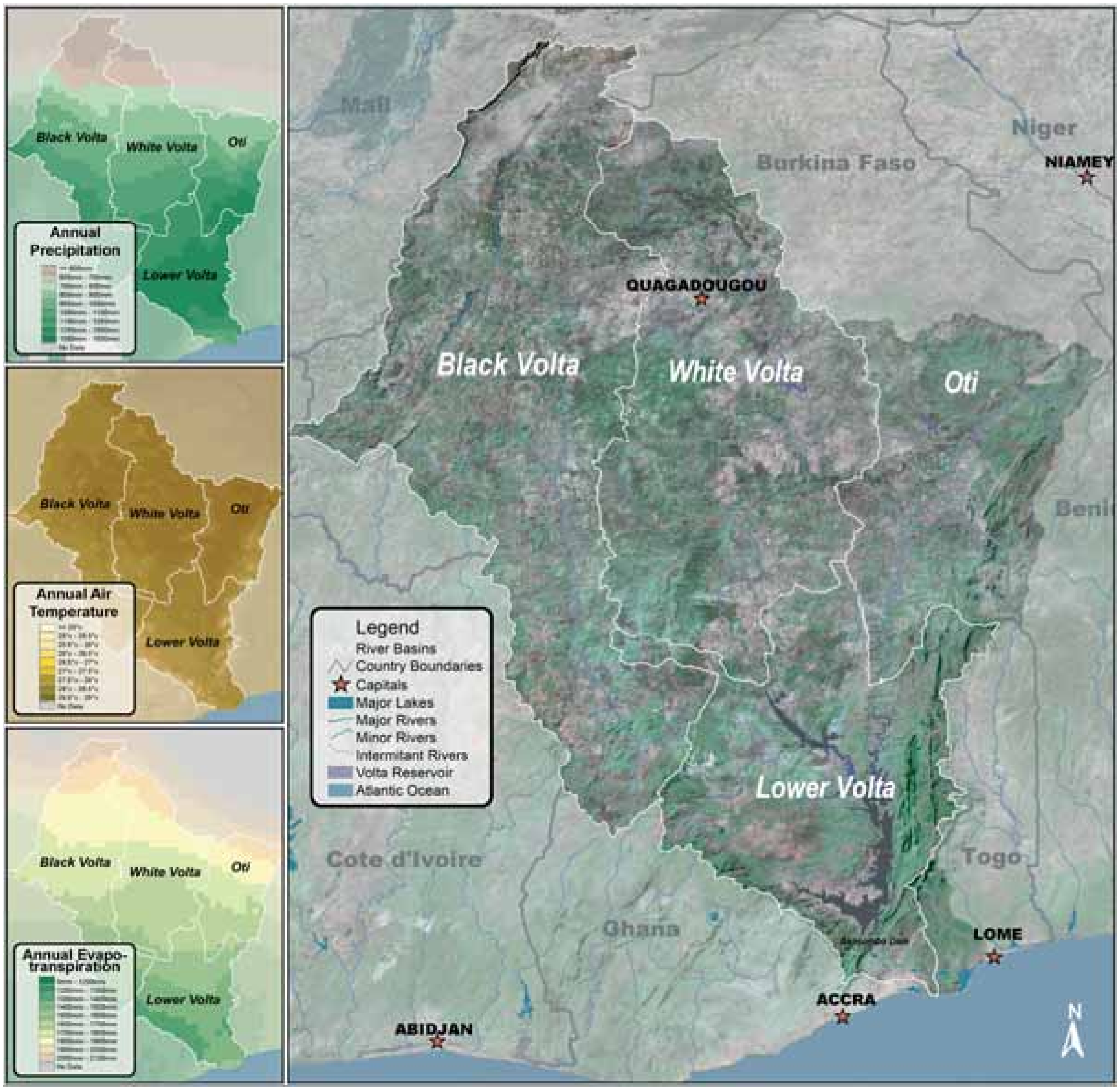
Characteristics of the Volta River megabasin

The Source Book for the Inland Fishery Resources of Africa (SIFRA) provides users of the AWRD with an important source of reference information on the general hydrology of river basins and certain limnological and fisheries characteristics specific to surface waterbodies. Although organized on a country by country basis, this resource can provide users with a valuable historic baseline for conducting analyses of surface hydrology or inland fisheries. The summary text provided below was drawn from the SIFRA Compendium for the Republic of Ghana, and the area values provided from the geo-statistics tools of the AWRD.

- The Oti River basin constitutes the greatest mean annual flow, 500 m^3/sec, and is based on the smallest area, 63 642 km^2;
- The Black Volta River basin covers the largest drainage area, 154 886 km^2, but contributes the smallest annual mean flow, at 243 m^3/sec;
- The White Volta basin is comprised of a slightly smaller area, 111 092 km^2, but contributes a slightly greater mean flow of 240 m^3/sec annually;
- The Lower Volta basin, including the reservoir, encompasses the smallest drainage area, 80 855 km^2, and discharges 1 150 m^3/sec regulated by the Akosombo Dam; and
- The Volta river in general has an average annual outflow of 1 230 m^3/sec, peaking in September and October.

Figure 2.40 exhibits an overview of some of the climatological data sources compiled for the AWRD relevant to the Volta megabasin.

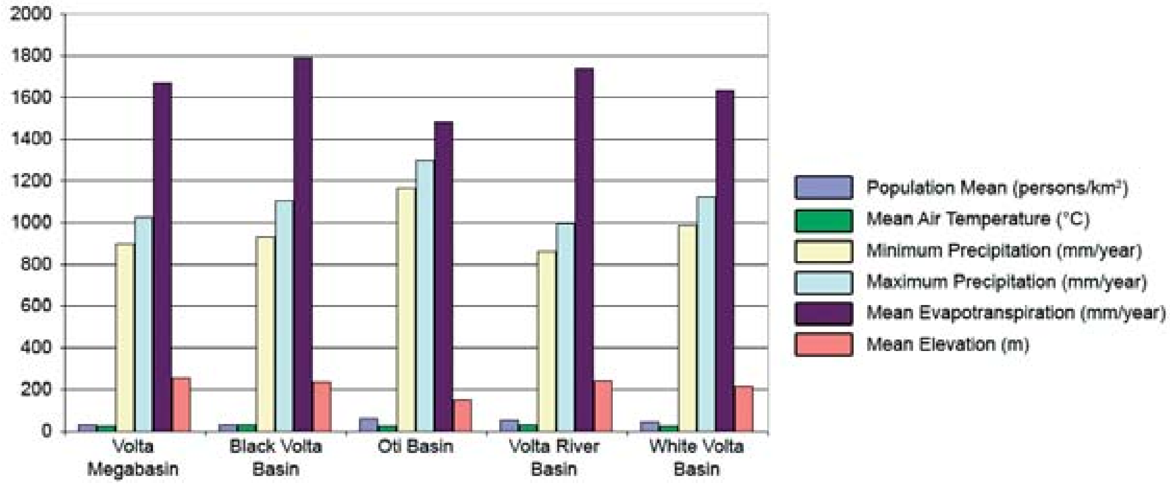
FIGURE 2.40
Composite map of the Volta megabasin



Since the intermediate basin level of the ALCOMWWF watershed model contains names for each of the river basins listed above, users can select the attributes of the model to create summary statistics for the data depicted in Figure 2.40 using the toolsets of the AWRD Watersheds Module. These data can be visually represented in ArcView, or exported to a spreadsheet program such as Microsoft Excel for graphing. Figure 2.41 shows the charted results of summary statistics exported to Excel for each of the primary river basins comprising the Volta megabasin, as well as the megabasin itself, based on the climatological data mapped in Figure 2.40.

FIGURE 2.41

Summary river basin statistics of the Volta megabasin

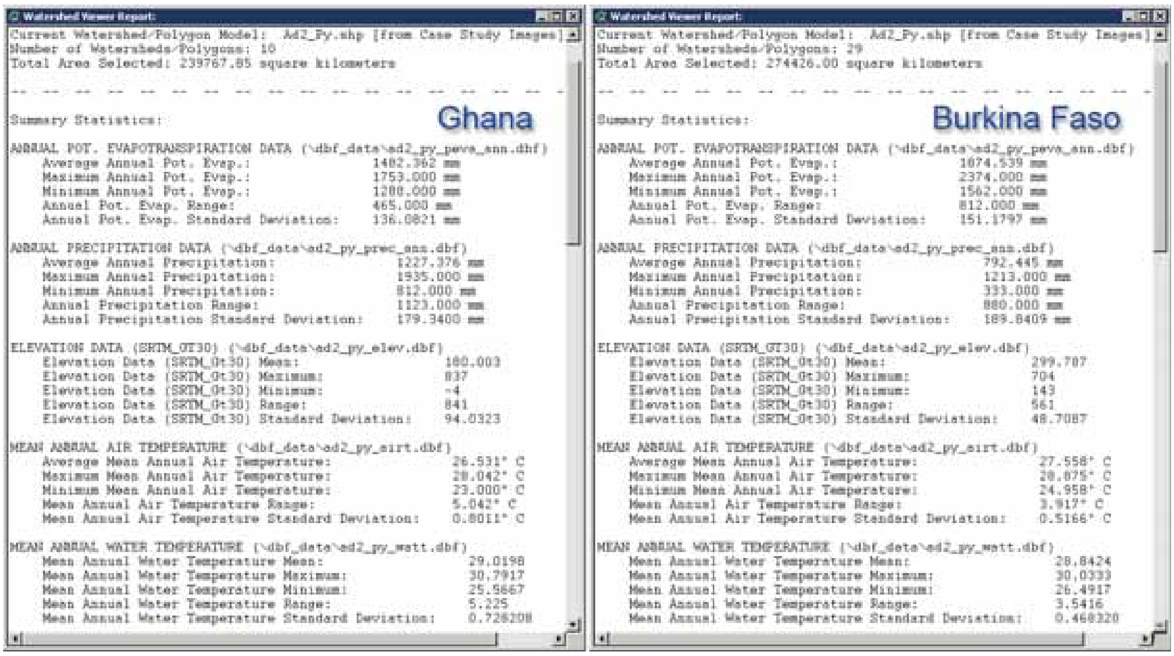


In order to demonstrate that many types of data can be easily summarized via the AWRD, Figure 2.41 also summarizes each basin according to mean population density, mean air temperature, mean precipitation, mean evapotranspiration, and mean elevation.

The Volta megabasin overlays 6 countries, but the majority of the northern portion lies in Burkina Faso and the majority of the southern portion lies in the Republic of Ghana (Figure 2.39). Climatological conditions may change with increasing distances from the ocean, so it may be interesting to examine the climatological conditions just within the boundaries of Burkina Faso and the Republic of Ghana. The Watershed Module statistical tools can generate reports within national boundaries as easily as they can on watersheds, so this question is addressed simply by setting the current "watershed model" to be the national boundary theme, and then selection the regions of the Republic of Ghana and Burkina Faso and calculating statistics for them (Figure 2.42).

Based on this quick analysis and comparison of the Republic of Ghana and Burkina Faso, it is apparent that the Republic of Ghana has a much lower rate of mean annual potential evapotranspiration (1 482 vs. 1 874 mm/year), a much higher annual precipitation rate (1 227 vs. 792 mm/year), a lower average elevation (180 m vs. 299 m), a slightly lower mean annual air temperature (26 °C vs. 27 °C), and a slightly higher mean annual water temperature (29 °C vs. 28 °C) than does in Burkina Faso.

FIGURE 2.42
Summary of climatological statistics for the Republic of Ghana and Burkina Faso


Watershed Viewer Report:
Current Watershed/Polygon Model: Ad2_Py.shp [from Case Study Images]
Number of Watersheds/Polygons: 10
Total Area Selected: 239767.85 square kilometers

Summary Statistics: Ghana

ANNUAL POT. EVAPOTRANSPIRATION DATA (\dbf_data\ad2_py_peva_ann.dbf)
Average Annual Pot. Evap.: 1482.362 mm
Maximum Annual Pot. Evap.: 1753.000 mm
Minimum Annual Pot. Evap.: 1288.000 mm
Annual Pot. Evap. Range: 465.000 mm
Annual Pot. Evap. Standard Deviation: 136.0821 mm

ANNUAL PRECIPITATION DATA (\dbf_data\ad2_py_prec_ann.dbf)
Average Annual Precipitation: 1227.376 mm
Maximum Annual Precipitation: 1935.000 mm
Minimum Annual Precipitation: 812.000 mm
Annual Precipitation Range: 1123.000 mm
Annual Precipitation Standard Deviation: 179.3400 mm

ELEVATION DATA (SRTM_GT30) (\dbf_data\ad2_py_elev.dbf)
Elevation Data (SRTM_Gt30) Mean: 180.003
Elevation Data (SRTM_Gt30) Maximum: 837
Elevation Data (SRTM_Gt30) Minimum: -4
Elevation Data (SRTM_Gt30) Range: 841
Elevation Data (SRTM_Gt30) Standard Deviation: 94.0323

MEAN ANNUAL AIR TEMPERATURE (\dbf_data\ad2_py_airt.dbf)
Average Mean Annual Air Temperature: 26.531° C
Maximum Mean Annual Air Temperature: 28.042° C
Minimum Mean Annual Air Temperature: 23.000° C
Mean Annual Air Temperature Range: 5.042° C
Mean Annual Air Temperature Standard Deviation: 0.8011° C

MEAN ANNUAL WATER TEMPERATURE (\dbf_data\ad2_py_watt.dbf)
Mean Annual Water Temperature Mean: 29.0198
Mean Annual Water Temperature Maximum: 30.7917
Mean Annual Water Temperature Minimum: 25.5667
Mean Annual Water Temperature Range: 5.225
Mean Annual Water Temperature Standard Deviation: 0.728208

Watershed Viewer Report:
Current Watershed/Polygon Model: Ad2_Py.shp [from Case Study Images]
Number of Watersheds/Polygons: 29
Total Area Selected: 274426.00 square kilometers

Summary Statistics: Burkina Faso

ANNUAL POT. EVAPOTRANSPIRATION DATA (\dbf_data\ad2_py_peva_ann.dbf)
Average Annual Pot. Evap.: 1874.539 mm
Maximum Annual Pot. Evap.: 2374.000 mm
Minimum Annual Pot. Evap.: 1562.000 mm
Annual Pot. Evap. Range: 812.000 mm
Annual Pot. Evap. Standard Deviation: 151.1797 mm

ANNUAL PRECIPITATION DATA (\dbf_data\ad2_py_prec_ann.dbf)
Average Annual Precipitation: 792.445 mm
Maximum Annual Precipitation: 1213.000 mm
Minimum Annual Precipitation: 333.000 mm
Annual Precipitation Range: 880.000 mm
Annual Precipitation Standard Deviation: 189.8409 mm

ELEVATION DATA (SRTM_GT30) (\dbf_data\ad2_py_elev.dbf)
Elevation Data (SRTM_Gt30) Mean: 299.787
Elevation Data (SRTM_Gt30) Maximum: 704
Elevation Data (SRTM_Gt30) Minimum: 143
Elevation Data (SRTM_Gt30) Range: 561
Elevation Data (SRTM_Gt30) Standard Deviation: 48.7087

MEAN ANNUAL AIR TEMPERATURE (\dbf_data\ad2_py_airt.dbf)
Average Mean Annual Air Temperature: 27.558° C
Maximum Mean Annual Air Temperature: 28.875° C
Minimum Mean Annual Air Temperature: 24.958° C
Mean Annual Air Temperature Range: 3.917° C
Mean Annual Air Temperature Standard Deviation: 0.5166° C

MEAN ANNUAL WATER TEMPERATURE (\dbf_data\ad2_py_watt.dbf)
Mean Annual Water Temperature Mean: 28.8424
Mean Annual Water Temperature Maximum: 30.0333
Mean Annual Water Temperature Minimum: 26.4917
Mean Annual Water Temperature Range: 3.5416
Mean Annual Water Temperature Standard Deviation: 0.468320

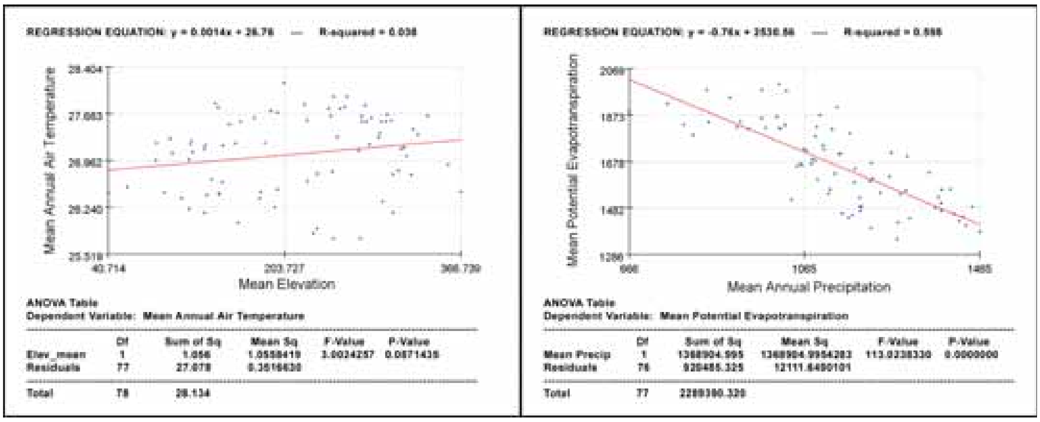
To assist users with the interpretation of such outputs, the AWRD also includes an extensive suite of tools under the Statistical Analysis Module. In the case of the Volta megabasin above, because the climatological, hydro-physiographic and population characteristics of the river basins comprising the Volta megabasin appear to vary widely, users may be interested in investigating patterns between these variables. The linear regression tools of the AWRD provide a powerful means to explore the relationships between any pairs of variables.

The AWRD contains both simple and more robust versions of the tool-sets residing under the Statistical Analysis Module. In the example below, the use of the simple linear regression (SLR) tool is demonstrated. SLR calculates a quantitative measure of how much a dependent variable changes as an independent variable changes, as well as a measure of what proportion of the variability of the dependent variable can be explained by corresponding variability in the independent variable. Such information may be useful for predicting the conditions within a particular watershed based on measurements of some set of variables, or possibly to simply understand the behaviour of these variables within the megabasin.

For example, these watersheds range in value with regards to annual potential evapotranspiration, annual precipitation, elevation and mean annual air temperature. Managers may suspect that the air temperature decreases as the elevation changes, and that potential evapotranspiration would likely change as precipitation decreases. An SLR analysis (Figure 2.43), on the left) shows that in the Volta megabasin, contrary to expectations, temperature rises slightly as elevation increases (at the rate of 0.0014 °C/m). However, the rise in temperature is not statistically significant, i.e. a *P*-value = 0.087 reflects an 8.7 percent probability that the relationship is due to random chance. It also appears that very little of the change in air temperature can be explained by the change in elevation ($R^2 = 0.038$). There is a much stronger relationship between potential evapotranspiration and precipitation (Figure 2.43, on the right), with potential evapotranspiration decreasing by approximately 0.76 mm for every 1 mm increase in precipitation. The probability is strong that this relationship is not due to random chance (*P*-value < 0.00001) and most of the variation in potential evapotranspiration can be explained by the corresponding change in precipitation ($R^2 = 0.598$).

FIGURE 2.43

Regression analyses comparing mean annual air temperature to elevation (left), and mean potential evapotranspiration to mean annual precipitation (right) for the 79 watersheds in the Volta megabasin



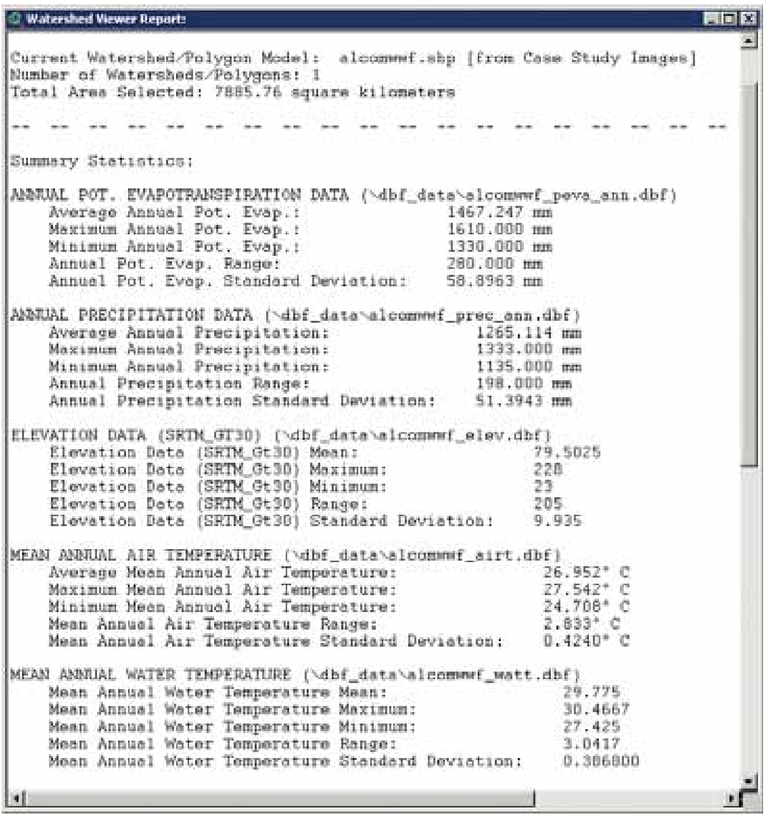
Examining reference information for Lake Volta

Previous case studies demonstrated the use of the Surface Waterbody Module tools and potential yield calculators. The purpose of this section is to outline some of the other capabilities of the AWRD as they relate to examination of large waterbodies such as Lake Volta.

The ALCOMWWF watershed model integrates large waterbodies into its attributes structure. Therefore, it is possible to use the base tool of the Watershed Module to rapidly output a report of available summary statistics. Figure 2.44 contains a subset of the output report produced for Lake Volta via the Watershed Module.

FIGURE 2.44

Summary statistics report for Lake Volta from ALCOMWWF watershed model



Watershed Viewer Report

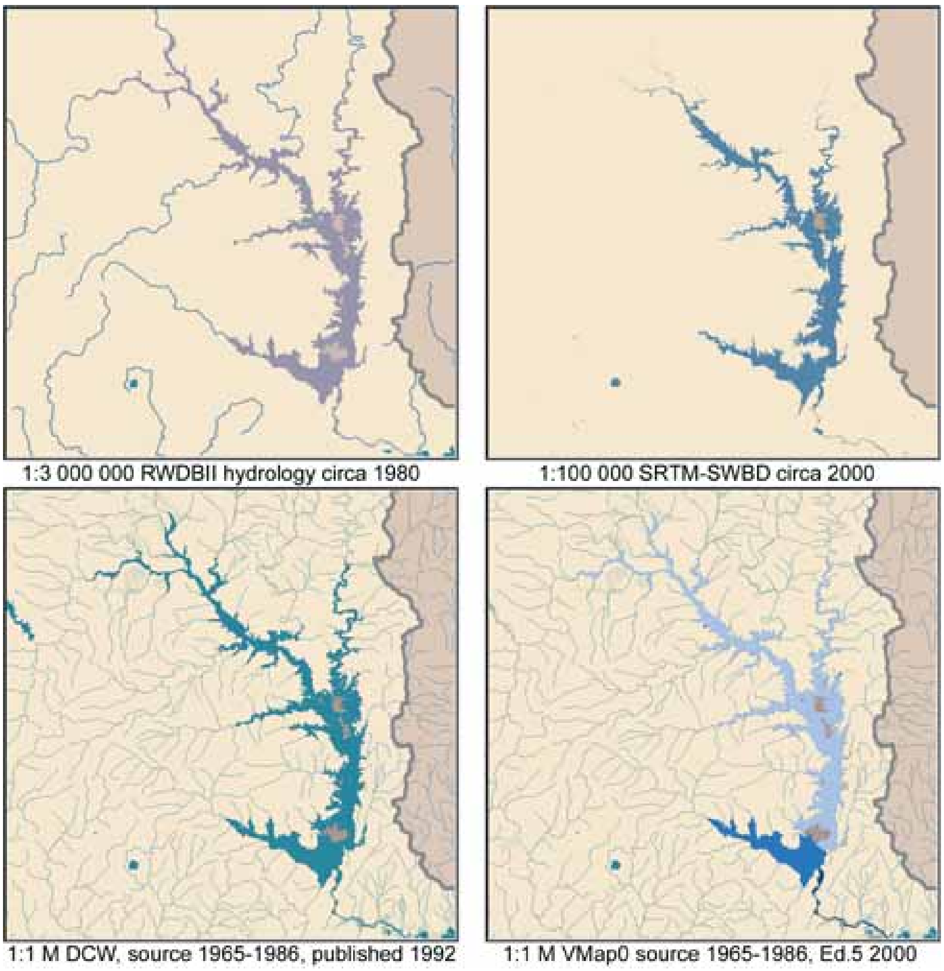
```
Current Watershed/Polygon Model:  alcomwwf.shp [from Case Study Images]
Number of Watersheds/Polygons: 1
Total Area Selected: 7885.76 square kilometers

-- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --

Summary Statistics:

ANNUAL POT. EVAPOTRANSPIRATION DATA (\dbf_data\alcomwwf_peva_ann.dbf)
    Average Annual Pot. Evap.:              1467.247 mm
    Maximum Annual Pot. Evap.:              1610.000 mm
    Minimum Annual Pot. Evap.:              1330.000 mm
    Annual Pot. Evap. Range:                280.000 mm
    Annual Pot. Evap. Standard Deviation:   58.8963 mm

ANNUAL PRECIPITATION DATA (\dbf_data\alcomwwf_prec_ann.dbf)
    Average Annual Precipitation:              1265.114 mm
    Maximum Annual Precipitation:              1333.000 mm
    Minimum Annual Precipitation:              1135.000 mm
    Annual Precipitation Range:                198.000 mm
    Annual Precipitation Standard Deviation:   51.3943 mm

ELEVATION DATA (SRTM_GT30) (\dbf_data\alcomwwf_elev.dbf)
    Elevation Data (SRTM_Gt30) Mean:                  79.5025
    Elevation Data (SRTM_Gt30) Maximum:               228
    Elevation Data (SRTM_Gt30) Minimum:               23
    Elevation Data (SRTM_Gt30) Range:                 205
    Elevation Data (SRTM_Gt30) Standard Deviation:    9.935

MEAN ANNUAL AIR TEMPERATURE (\dbf_data\alcomwwf_airt.dbf)
    Average Mean Annual Air Temperature:              26.952° C
    Maximum Mean Annual Air Temperature:              27.542° C
    Minimum Mean Annual Air Temperature:              24.708° C
    Mean Annual Air Temperature Range:                2.833° C
    Mean Annual Air Temperature Standard Deviation:   0.4240° C

MEAN ANNUAL WATER TEMPERATURE (\dbf_data\alcomwwf_watt.dbf)
    Mean Annual Water Temperature Mean:                  29.775
    Mean Annual Water Temperature Maximum:               30.4667
    Mean Annual Water Temperature Minimum:               27.425
    Mean Annual Water Temperature Range:                 3.0417
    Mean Annual Water Temperature Standard Deviation:    0.386800
```

The following textual information is extracted from the SIFRA compendium for Lake Volta.

- Completed in 1966, the 14.3 m high Akosombo Dam backs up the largest man-made reservoir in Africa;
- The reservoir is over 400 km long and has drowned much of the lower courses of the various rivers of the Volta system. The reservoir is used as a water store to generate electricity and has an average depth of 19 m, a volume of 165 km^3, and an estimated area of 8 482 km^2; and
- Some 70 fish species are endemic to the reservoir, which has an approximate median water temperature of 29.5 °C. The fisheries potential for the lake is estimated at 50 000 tonnes per year. In 1975, it was reported that 41 945 tonnes were harvested using 20 615 fishermen employing 13 814 boats.

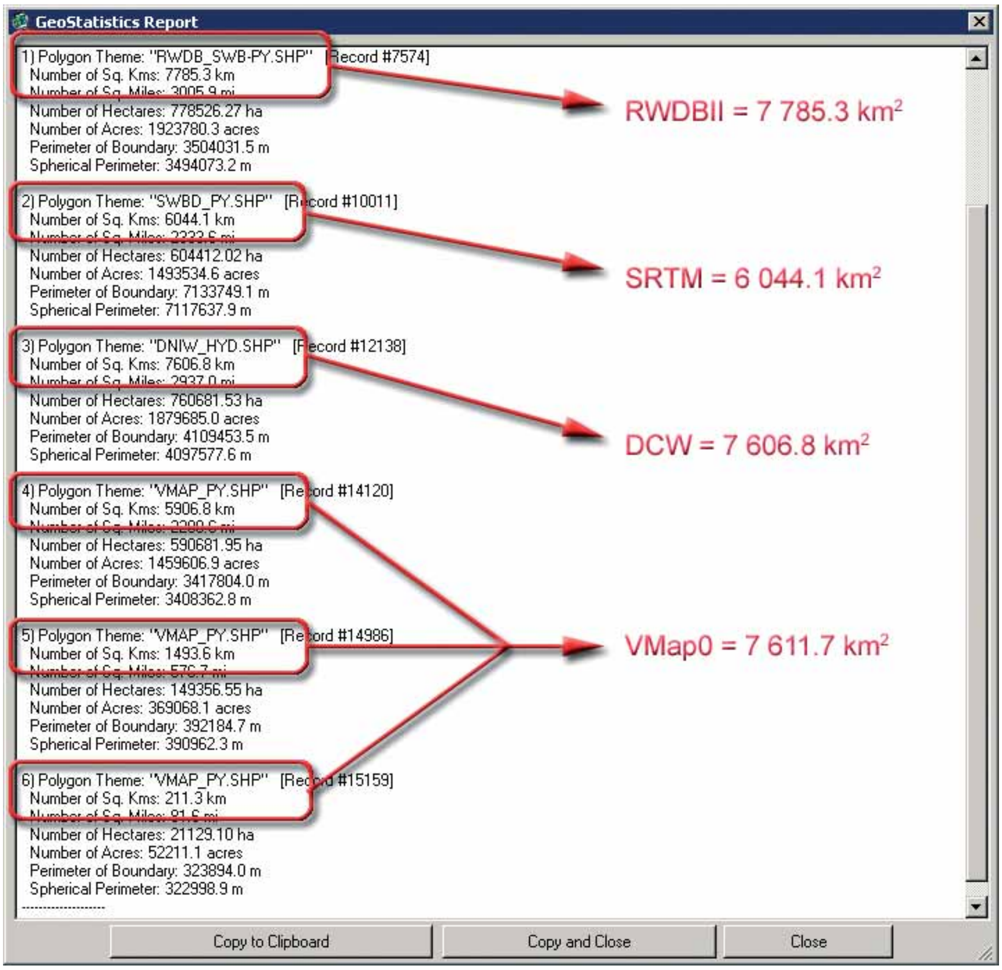
The integration of this information with the subset of summary statistics shown in Figure 2.44 demonstrates the initial value of the AWRD interface for rapidly summarizing information from both the spatial and textual data contained within the archive. On a comparative basis, however, it is interesting to observe the differences in total surface areas amongst these various sources. Our summary statistics report for Lake Volta indicated that the lake was 7 885 km^2 (see the 3rd line down on Figure 2.44) while the SIFRA report estimates the area at 8 482 km^2. Such differences in the data might be explained by the variety dates and sources, and even editions of the same source, from which the data were drawn from. Figure 2.45 highlights the differences in *area* values that users might expect from different data sources.

FIGURE 2.45
Lake Volta as represented by four different datasets



The top of Figure 2.45 displays the two extremes of surface waterbody data available from the AWRD, the 1:3 000 000 RWDBII circa 1980 and the 1:100 000 SRTM-SWBD circa 2000 derivative data. The bottom of Figure 2.45 compares the 1:1 000 000 scale DCW and VMap0 SWB data. Both of these databases are based on the same original map sources, compiled in 1965 and updated between 1975 and 1986. The DCW data are in fact the digital baseline for the VMap0, but the evolution of the datasets over time have resulted in differences between them. Figure 2.46 quantifies these differences by comparing the area values for each of the datasets depicted in Figure 2.45. Also of note in the comparison of the VMap0 SWB data to the other sources shown in these figures is the separation of Lake Volta into three separate polygons. The dark blue polygon in the lower right of Figure 2.45 segregates the Volta River below Akosombo Dam from the larger reservoir and lake. Because of this separation, Figure 2.46 sums the three separate polygons to get the total area of Lake Volta.

FIGURE 2.46
Comparison of lake area and shoreline statistics for Lake Volta



Based on the above measures of area from both different time periods and scale, plus the area calculated from the ALCOMWWF watershed model (7 885.76 km^2), the average area for Lake Volta, excluding islands, is 7 407 km^2. Both this average as well as all the other measures of area listed are below the area value of 8 482 km^2 from the SIFRA compendium. This remains true even when the area of island features are included.

It is important to note that Volta is a reservoir and its surface area varies both seasonally and inter-annually, so these area differences are likely to occur when comparing datasets of different time periods.

Establishing a reference baseline for Lake Volta

The above examination demonstrates that it is necessary to use some care in terms of which dataset is selected for any specific analysis, but more specifically when attempting to establish any type of baseline reference using the data of the AWRD archive and the SIFRA data. Another good example of this is the fisheries yield produced by Lake Volta. Both the SIFRA and MRAG source materials cite the 1980 value of 40 000 metric tonnes per year as a presumably representative value for fisheries yields from Lake Volta. However, fisheries yield data is actually available for many more years than just 1980. A detailed review of these source materials via the AWRD shows that fisheries yield values are actually available from: 1970 through 1987 within the SIFRA compendium; and 1964 through 1980 – and in one case 1991 – within the FAO-MRAG resource. Moreover, using these values and the reference citations provided in conjunction with an Internet based search yielded the following quote from de Graaf and Ofori-Danson (1997) from the www.nefisco.org.site:

It is however certain that the previous used production figure of 44 000 tonnes/year for Lake Volta is an under-estimation, as the actual total catch of Stratum VII is already 33 800 tonnes/year.

The total production of Lake Volta most likely will be around 150 000–200 000 tonnes/year (180–240 kg/ha) with a total annual value of 30 million USD. This is a substantial quantity, if compared with the annual marine catches of 300 000–400 000 tonnes/year, and it justifies that serious action is taken in order to protect the productivity of this natural resource.

A production of 180–240 kg/ha/year is high but not un-common for African lakes as can be seen from the examples below:

Lake Albert (Uganda)	*182 kg/ha/year*
Lake George (Uganda)	*108 kg/ha/year*
Lake Nakawali (Uganda)	*236 kg/ha/year*
Lake Kainji (Nigeria)	*100 kg/ha/year*

Conclusions

The tool-sets and data compiled for the AWRD allow users to define the extent of any hydrological analysis to encompass an area of interest based on a single watershed, a larger river system or basin, or a complete megabasin. Alternatively, users can apply the Watershed Module statistics tools to analyse any polygonal theme that has been registered with the Watershed Module, including the national boundary dataset "VMap0 National-Ad1 Polygonal Boundaries" used in this case study. These features also allow users to effectively summarize statistical information across a range of human, environmental, and climatological factors, and to evaluate the resulting data via a host of robust statistical analyses.

While fairly straightforward in content, the text and graphics prepared for this case study demonstrate that the AWRD can provide a wide range of options to users for the production of contextual reports and establishing baselines for informing or testing inland fisheries related analyses.

Although an extensive archive of data has been compiled for the AWRD, due to the currency and/or relative scale of the spatial and reference material compiled, analyses using these datasets should generally be considered preliminary or exploratory. Internet searches can be used to find updated information, as shown above. Taking this into consideration, however, only the best sources of currently available data were considered for the AWRD data archive and efforts are continuously underway to improve the spatial resolution and timeliness of the data to ensure more robust outputs.

References

de Graff, G.J. & Ofori-Danson, P.K. 1997. Catch and Fish Stock Assessment in Stratum VII of Lake Volta. IDAF/Technical Report/97/I. Rome, FAO.

MRAG Ltd. 1997. Technical Database Specification Document for the FAO Lakes and River Fisheries Database.

Invasive and introduced aquatic species

Introduction and objectives

Introduction

To support sustainable and integrated development of freshwater resources, fishery managers need to produce specific location and potential distribution maps on a species-by-species basis. Two different approaches to meet these requirements have been tested and built into the AWRD. The first approach is encapsulated by the data retrieval and management tools built into the Aquatic Species Module of the AWRD, which displays potential species distributions based on actual observed locations, overlaid with either polygonal watershed or political boundaries. The second approach combines tools from the Aquatic Species Module with tools from other modules of the AWRD, and allows users to develop potentially more realistic species distributions based on observed occurrences of a species within the range of water temperatures required for spawning or the flow regimes associated with larger river systems.

Objectives

The Aquatic Species Module and its associated tools for mapping species distributions are summarized in Section 2.3 and described in detail in part 2 of this publication. The purpose of this case study is to demonstrate the second approach available to users of the AWRD for mapping the distribution of freshwater fish species. This is accomplished via three analyses that examine: (a) potential distribution of exotic fish species; (b) potential spread of invasive fish species; (c) potential impact on vulnerable or endangered fish species, and (d) potential distribution of fish species within preferred spawning temperatures and flow regimes.

Materials and methods

Data utilized

The data employed during this case study are drawn from both within and outside the AWRD. The primary data layers used from within the AWRD archive are the SAIAB Aquatic Species layer of the AQSP-DBC, the ALCOM-WWF and the USGS HYDRO1k watershed models of the WS-DBC and various image backgrounds in the AIMG-DBC. The primary data drawn from outside the AWRD are the freshwater fish species locations made available via an AWRD hot-link from the Aquatic Species Module to the FishBase online resource database, http://www.fishbase.org.

Methods

Given the discontinuous nature of the distributions of most freshwater fish species, the approach built into the AWRD for mapping potential species distributions, and in particular the range of indigenous species, is based on historical observations where a particular species has been caught or sampled. Unfortunately, because such mapping relies only historical observations from museum records, it is therefore subject to potential sampling and other biases (Scott *et al.*,2004). Quantitative data that would allow us to determine the probabilities of a species being present at any point in the river system are currently not available.

For this reason, the approach chosen for mapping species distributions within the Aquatic Species Module is to simply select those watersheds from the ALCOMWWF watershed (WS) model which contain historical observations of a species. This approach minimizes the aggregate area mapped in reference to each species and in testing has been shown to be more realistic than distribution maps based on administrative units, or extrapolation based on dominant environmental factors. The analysis and reporting of freshwater fish species using the AWRD is limited to data covering the Southern African Development Community (SADC) – based on the SAIAB's Atlas of Southern African Freshwater Fish. The use of tools from the other modules of the AWRD to extend the mapping of species data to areas outside of the SADC region is demonstrated in the following subsections.

Results

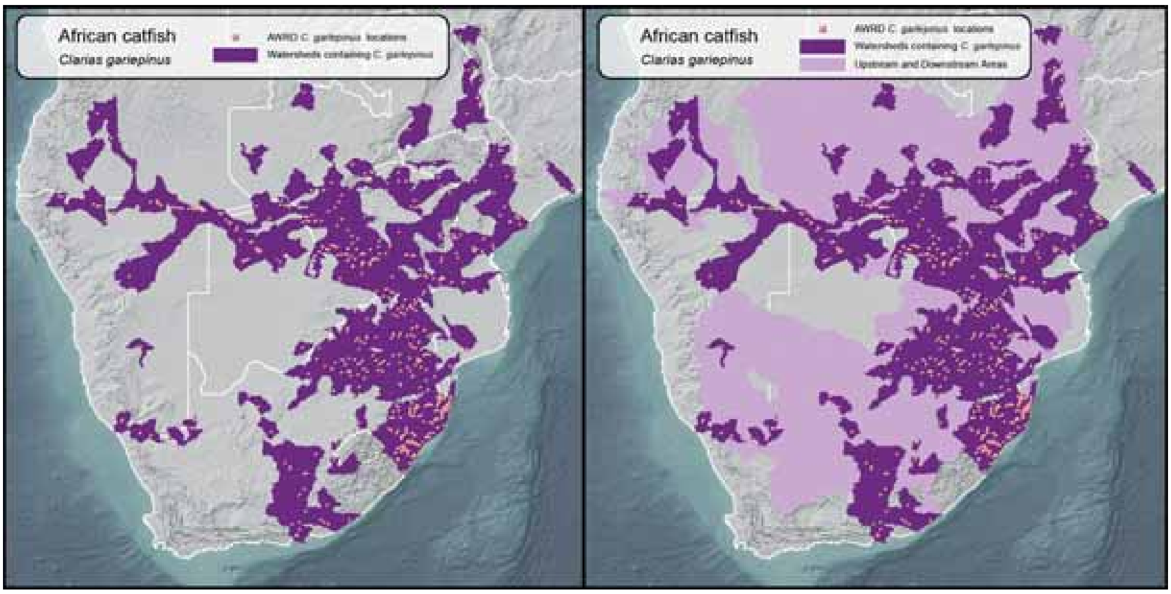
a) Potential distribution of exotic fish species

Within the SADC region the African catfish, *Clarias gariepinus* is considered a very aggressive exotic,. This species has become a dominant predator of many indigenous species, including other *Clarias* species, throughout the region.

The AWRD approach to mapping the potential distribution of the African catfish based on museum capture records is depicted at the left in Figure 2.47. The sample point locations are shown in light red, and the distribution based on the ALCOMWWF WS model, is colored dark purple.

FIGURE 2.47

Comparison of standard and potential aquatic species distributions of African catfish



Many environmental factors determine suitable fish habitat, but the simple aggregation of the individual watersheds within which the species is known to occur provides a defensible approach for analysing its potential distribution. However, for a species such as the African catfish, which has a fairly wide range of environmental tolerance, both its endemic distribution as well as its potential spread can be much broader.

To more accurately map the potential distribution of such a species, we must be able to identify both the areas containing historical locations, as well as those areas that are upstream or downstream of the historical observations. The AWRD "Select by Relationship with Another Theme" tool is available throughout the interface and allows users to select watersheds based on their spatial relationship with the selected features of another theme (i.e. the observed catfish locations), and includes functions to select watersheds which may lie both upstream and/or downstream of these features. This tool identifies all watersheds that contain historic catfish locations as well as all areas that are either upstream or downstream from those historic locations (see the right side of Figure 2.47).

Mapping of fish species data outside of the SADC region

There are a number of options available for evaluating the distribution of fish species data which are not currently a part of the AWRD archive (i.e. outside of the SADC Region). One option would be for users to take advantage of resources such as FishBase (www.fishbase.org), which provide actual geo-referenced species locations which can be integrated into an analysis via the AWRD.

The importation and evaluation of species data into the AWRD via FishBase is a relatively simple procedure, which basically requires four steps (described in part 2 of this publication). Once integrated into the user's project, the imported fish species sampling records from FishBase can be analysed using the "Select by Relationship with Another Theme" tool to map species distributions using either the standard containment within a watershed or political boundary approach, or to expand their analysis systematically to include the creation of more robust scenarios of potential distribution using specific flow regime and environmental criteria.

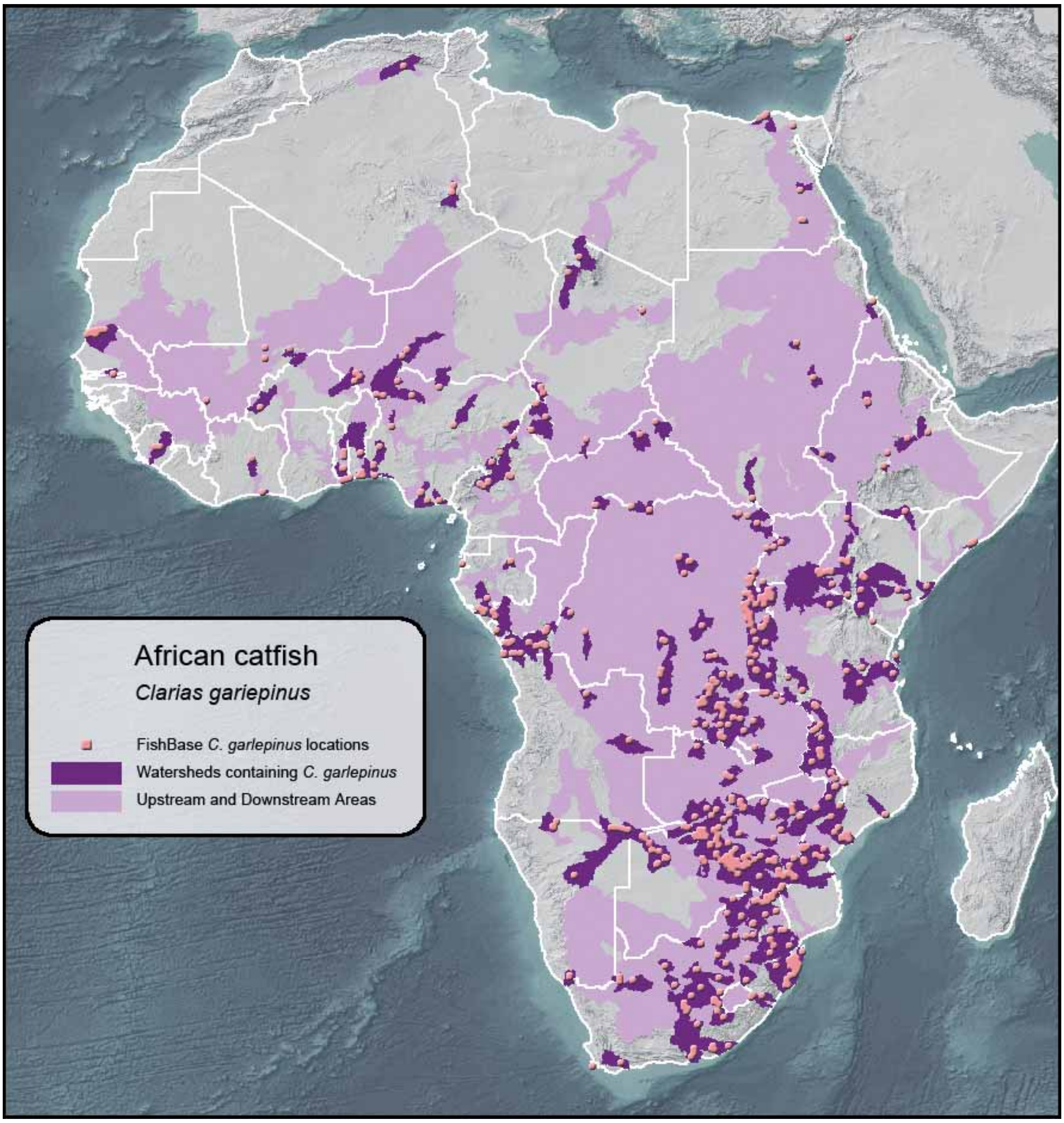
Figure 2.48 depicts just such a potential distribution map for African catfish, using the ALCOMWWF WS model and data imported from FishBase into the AWRD. The upstream and downstream flow regime function was used in conjunction with these data to produce the "extended" potential distribution.

This example also illustrates a problem with relying solely on watershed networks to identify potential species distributions. Watershed networks show how water would flow through a landscape if water were there, but they do not guarantee that water is present. The top of Figure 2.48 shows potential catfish distribution reaching north through the deserts of Libya, where the habitat may not actually support catfish populations.

A wealth of general and specific information is available from within FishBase and can be easily integrated for analysis, mapping, and reporting via the AWRD. Such integration is, in fact, central to the design focus of the AWRD Aquatic Species Module and other AWRD tools, and is intended to allow users in a straightforward manner to access a wide variety of data which are centrally maintained and updated[12]. The key benefit of this design is that while the users are potentially freed of data maintenance tasks, they maintain full control over any analytical processes.

[12] Future revisions of the AWRD are expected to be fully compliant with the international standard, ISO 23950, on Information Retrieval: Application Service Definition and Protocol Specification. This and the similar ANSI/NISO Z39.50 standard, allow for the direct retrieval and seamless integration of data from participating databases via the Internet.

FIGURE 2.48
Potential distribution of African catfish based on FishBase



b) Potential spread of invasive fish species

AWRD provides an excellent means to address transboundary issues, such as assessing the risks and benefits of using of alien species (i.e. introduced or exotic species) in fisheries and aquaculture. In short, the methods outlined above were built specifically into the AWRD to facilitate the exploration, mapping and potential monitoring of invasive species.

As alien species may impact areas very far away from the area where it was originally introduced, international codes of practice on the introduction of alien species, such as the ICES Code of Practice on the Introductions and Transfers of Marine Organisms (ICES, 2004) and the FAO Code of Conduct for Responsible Fisheries (CCRF) (FAO, 1995), call on users of alien species to notify downstream states which may be impacted by such introductions. The AWRD can provide users with a clear indication of which countries should be notified, which waterbodies may be impacted, and the type of species which might be affected.

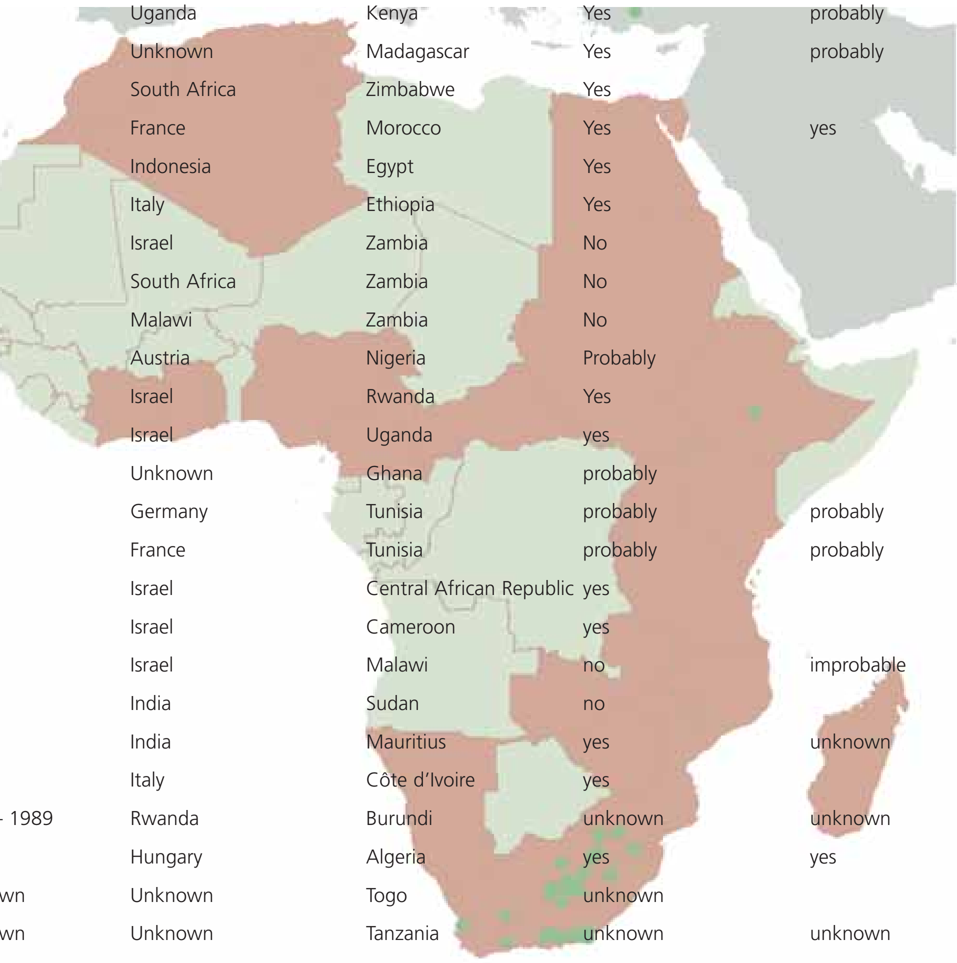
Assessing the introduction of common carp, Cyprinus carpio

The following section reports on the historical introduction of the common carp, *Cyprinus carpio*, in Africa and assesses the potential impact of a hypothetical introduction of the species into a river system.

Common carp was first introduced into Africa in 1859 from the Federal Republic of Germany to the Republic of South Africa; it has now been introduced into 27 African countries and has become established in 15 of those countries (Table 2.28). The table is presented against a map background where the countries into which the species was introduced are shown in brown. The green points highlighted on this map, represent the relatively few FishBase sample locations, which are available for this species across the continent.

TABLE 2.28

Introductions of common carp in Africa based on FishBase and FAO's Database on Introductions of Aquatic Species



Time period of introduction	Country introduced from	Country introduced to	Has species become established	Ecological effects
1859	Germany	South Africa	Yes	yes
1910	South Africa	Kenya	Yes	probably
1910	Uganda	Kenya	Yes	probably
1914	Unknown	Madagascar	Yes	probably
1925	South Africa	Zimbabwe	Yes	
1925	France	Morocco	Yes	yes
1934	Indonesia	Egypt	Yes	
1940	Italy	Ethiopia	Yes	
1946	Israel	Zambia	No	
1946	South Africa	Zambia	No	
1946	Malawi	Zambia	No	
1954	Austria	Nigeria	Probably	
1960	Israel	Rwanda	Yes	
1962	Israel	Uganda	yes	
1962	Unknown	Ghana	probably	
1965	Germany	Tunisia	probably	probably
1965	France	Tunisia	probably	probably
1966	Israel	Central African Republic	yes	
1970	Israel	Cameroon	yes	
1970	Israel	Malawi	no	improbable
1975	India	Sudan	no	
1976	India	Mauritius	yes	unknown
1976	Italy	Côte d'Ivoire	yes	
1980 – 1989	Rwanda	Burundi	unknown	unknown
1985	Hungary	Algeria	yes	yes
Unknown	Unknown	Togo	unknown	
Unknown	Unknown	Tanzania	unknown	unknown
Unknown	South Africa	Mozambique	unknown	unknown
Unknown	South Africa	Namibia	yes	unknown
Unknown	South Africa	Swaziland	unknown	
Unknown	Unknown	Lesotho	unknown	unknown

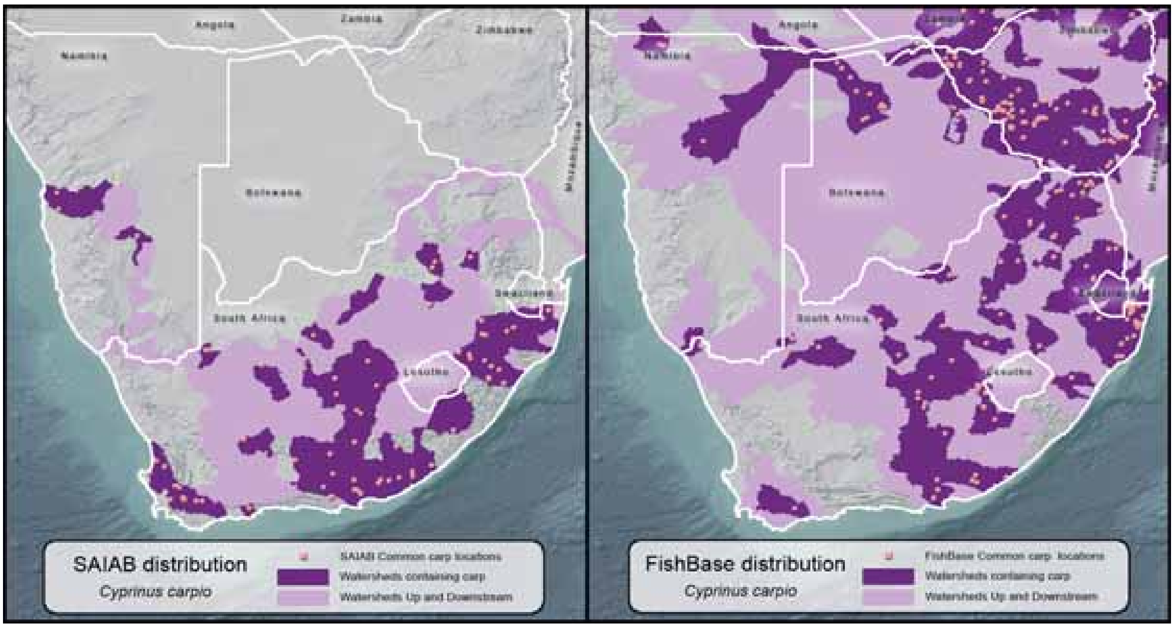
Source: FAO Inland Water Resources and Aquaculture Service (2003).

Potential distribution of common carp in the SADC region

From Table 2.28 it can be seen that the actual sample points available from FishBase do not include references for all the countries into which this species has been introduced. This disparity also highlights a potential limitation in the use of museum-based reference data from either FishBase or the freshwater fish species data from the SAIAB that is made available within the AWRD AQSP-DBC. Users of the AWRD should be aware of the potential limitations of their analyses and should understand that results will vary from species to species depending on the source data included.

Figure 2.49 compares the potential distribution of common carp across the SADC region, based on data from FishBase and the SAIAB. The actual sample point locations are shown in light red, while the minimum distribution based on the watersheds actually containing an observed point are highlighted in dark purple. Watersheds lying either upstream or downstream of observed carp locations are shown in pink.

FIGURE 2.49
Comparison of potential distribution of common carp based on data from SAIAB and FishBase

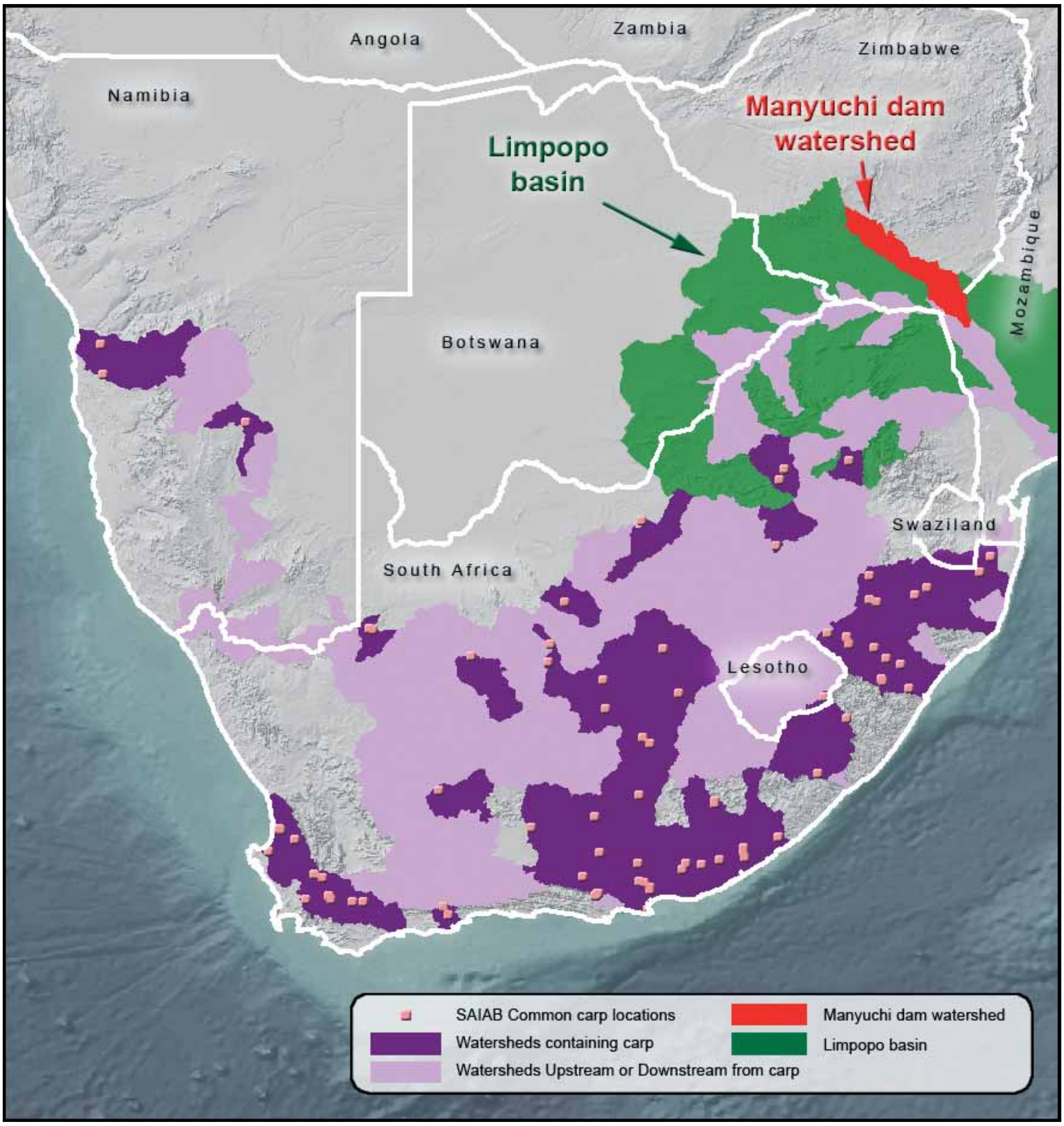


ICES Codes of practice for the introduction of exotic species

Figure 2.50 depicts the potential "current" distribution of common carp within SADC based on the sample locations from SAIAB. This figure uses the same colour coding as the previous figures, with the exception that a point representing a hypothetical planned introduction of this species into the Manyuchi Dam watershed in the southern Zimbabwe has been added. This dam is located in the Nuanetsi River which is part of the greater Limpopo basin.

Common carp introduced into the Manyuchi Dam watershed could conceivably travel downstream into Mozambique. The ICES and the FAO-CCRF call upon the implementing agency to notify the responsible authority in states that may be impacted by such an introduction. In this case, even though common carp may already be established within the Limpopo River basin – based on the potential distribution of the species – authorities in Mozambique should be notified before such an introduction would take place.

FIGURE 2.50
Potential distribution of common carp, following a hypothetical further introduction of the species into the Limpopo River basin



c) Potential impact on vulnerable or endangered fish species

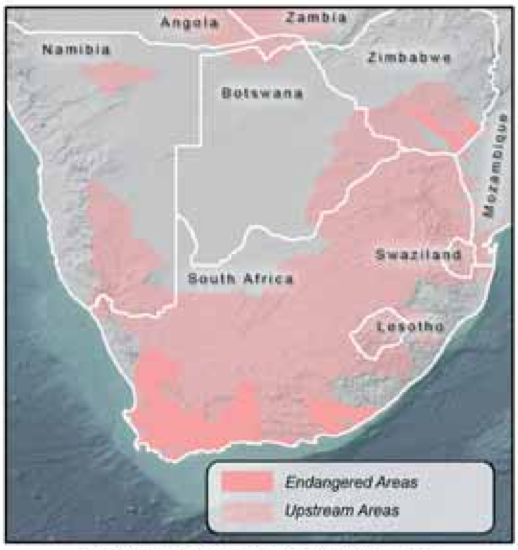
According to the SAIAB's Atlas of Southern African Freshwater Fish (Skelton, 1993; Scott *et al.,* 2004), there are: 9 critically endangered, 7 endangered, 9 vulnerable, and 7 near threatened[13] species of fish within the SADC region. To determine the potential hazards to these at-risk fish species associated with the introduction of an exotic species, researchers would need to examine the risk that the introduced species could have a negative impact on any of these species. To simplify this analysis, this case study will assume that threats could arrive at these at-risk fish species only by flowing down to them from upstream.

Figure 2.51a illustrates the watersheds where critically endangered, endangered, threatened, and vulnerable species of fish have been recorded. The watersheds containing at-risk species are depicted with a solid color, while watersheds representing "upstream" areas are shown using a semi-transparent color.

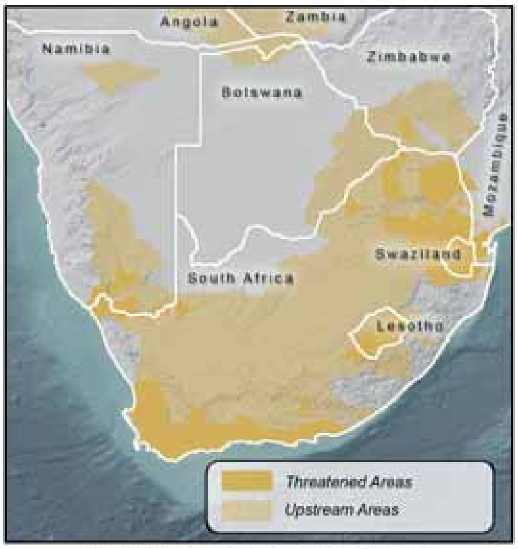
FIGURE 2.51A

Endangered and threatened fish species within southern Africa

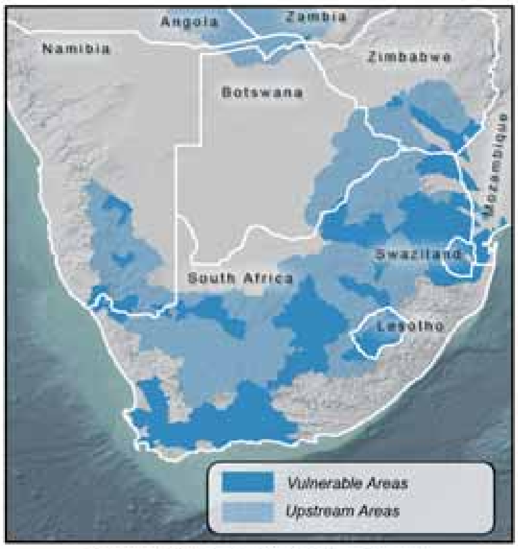
Sensitive Areas for Critically Endangered Species



Sensitive Areas for Endangered Species



Sensitive Areas for Threatened Species



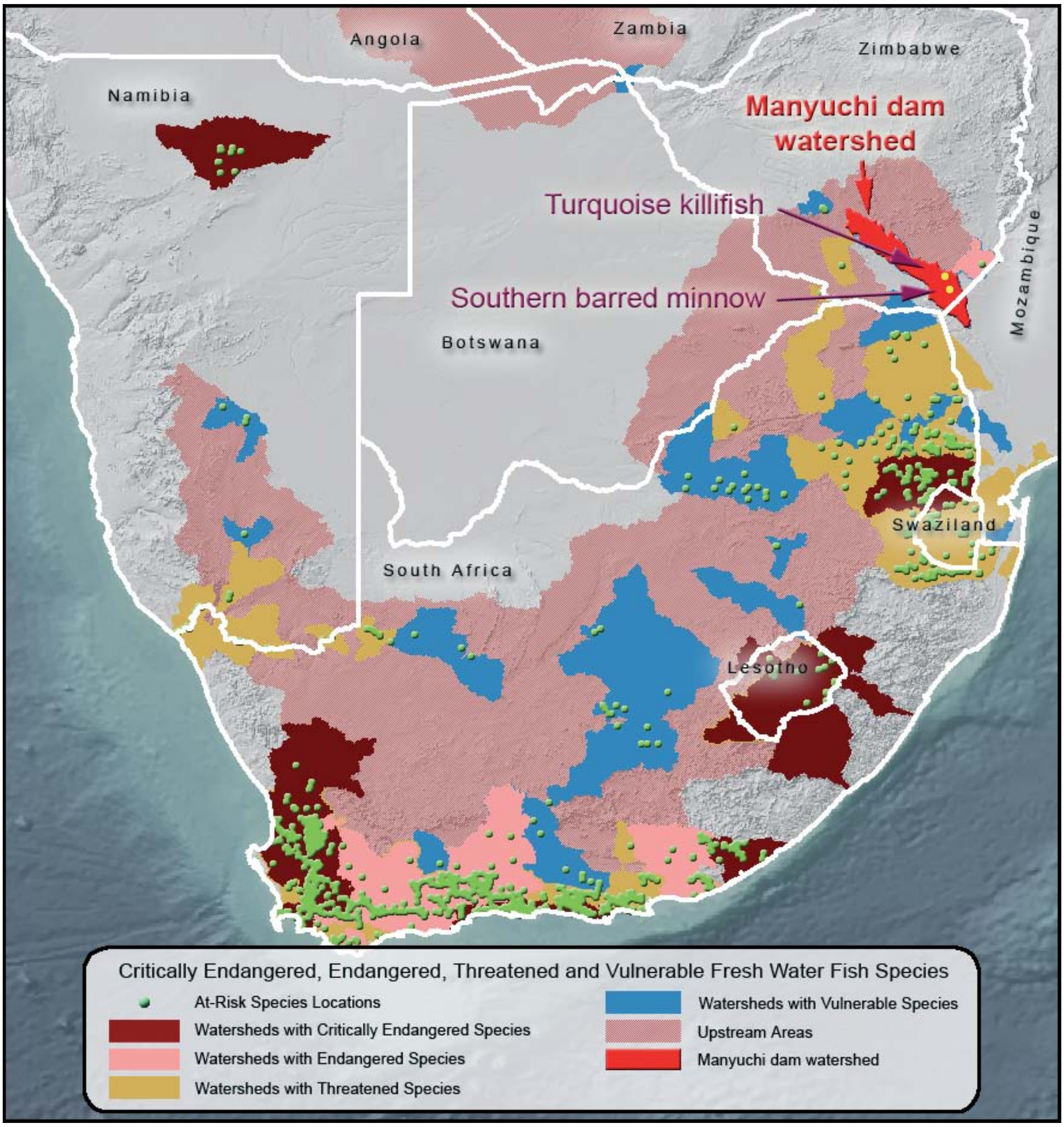
Sensitive Areas for Vulnerable Species

[13] (i) *Critically Endangered* = extremely high risk of extinction in the wild; (ii) *Endangered* = very high risk of extinction in the wild; (iii) *Vulnerable* = high risk of extinction in the wild; (iv) *Near Threatened* = close to qualifying, or likely to qualify for threatened status in the future. All categories are based on whether a species demonstrates (A) declining populations, (B) fragmentation, decline or fluctuations in geographic range, (C) fragmentation, decline or fluctations in population size, (D) very small populations or very restricted distribution, and (E) quantitative analysis of extinction risk (Standards and Petitions Working Group, 2006).

Figure 2.51b represents a composite map of the watersheds containing critically endangered, endangered, threatened and vulnerable fresh water fish species across the SADC region depicted on Figure 2.51a. These watersheds are again highlighted using solid colors with the upstream contributing areas represented by a semi-transparent color. On this figure, the actual locations for these species are shown as green points. Also depicted on this figure is Manyuchi Dam watershed, representing the location for a hypothetical introduction of the common carp. An examination of this figure shows that, although the proposed introduction will not affect any critically endangered species, i.e. the areas depicted in dark red, such an introduction may have an impact on the endangered Turquoise killifish (*Nothobranchius furzeri*) and/or the vulnerable Southern barred minnow (*Opsaridium peringueyi*) depending on the extent to which there is an actual overlap in habitats between them. Both of these species occupy the Manyuchi Dam watershed, and therefore may be affected by carp that are introduced into this same watershed.

FIGURE 2.51B

Upstream and endemic watersheds directly associated with critically endangered, endangered, threatened and vulnerable fresh water fish species within southern Africa



In Figure 2.51b, the point locations for these two species are coloured yellow rather than green and it should be noted that for both of these indigenous species, the potential impact is based on their actual occurrence within the Manyuchi Dam watershed. The threat would likely be less immediate if the carp were introduced upstream of Manyuchi dam because carp would then have to expand their range downward to reach the watershed. If carp were introduced below the dam, the presence of the dam would likely inhibit the movement of carp upstream.

Information resources for defining, refining, and supporting analyses
In addition to providing a potential source of species location information, FishBase and other web-based resources available from institutions such as the FAO also provide important sources of species-specific information which can be used to help refine potential impact criteria based on any ecological relationship between the species in question.

With regard to issues associated with the potential introduction of common carp, the rapid retrieval of reference information from these resources provided numerous potential negative impacts of this species. In summary, this species can be considered a potential pest due to:

- The omnivorous feeding and grubbing habits of adults where submerged aquatic vegetation maybe uprooted and destroyed (IUCN, 2006; Kottelat, 1997);
- The relatively wide spawning temperature range of between 13 and 28 °C, with an optimum range of between 17 and 23 °C (Table 2.29);
- The wide tolerance to varying environmental conditions, where the species may favour large waterbodies with slow flowing or standing water and soft bottom sediments, and yet also thrive in large turbid rivers (IUCN, 2006; Kottelat, 1997);
- The introduction of many fish parasites into the freshwaters of southern Africa caused by the introduction of the species (De Moor and Bruton, 1988); and
- The crowding out or direct replacement of native tilapias and other indigenous species (Welcomme, 1988; FAO Inland Water Resources and Aquaculture Service, 2003).

In addition to the above factors, the feeding habits of common carp may also have a direct negative impact on the spawning habitat of the Turquoise killifish and may affect some of the weedy pool habitats favoured by the Southern barred minnow at certain times of the year. Considering the risks mentioned above and the very broad environmental requirements of common carp that allows it to survive and spread outside a reservoir environment, this species might not be the best choice for introducing into the Manyuchi Reservoir.

As a historical note, because of the potential benefits for both sport fishing and as a relatively inexpensive commercial source of protein, and despite its potential negative impacts, this species was initially introduced into the Republic of South Africa in 1859 and has since been introduced and reintroduced repeatedly across the SADC region (see Table 2.28).

d) Potential distribution of fish species within preferred water temperatures for spawning and flow regimes.

After identifying the potential distribution based on historical observations of carp, it would be reasonable to expand the analysis to identify which watersheds would be most likely to contain carp. Two data sources included in the AWRD data archive that might help answer this question are monthly water temperatures and the presence of perennial water.

TABLE 2.29
Common carp spawing temperature ranges

Min	Max	Notes	Source	Uniform Resource Locator (URL) of Source
13	NG	Actual range given is 12 to 14; Atrek River	1	http://www.caspianenvironment.org/biodb/eng/fishes/Cyprinus%20carpio/main.htm
13	21	Temperature range for reproduction	6	http://www.state.nj.us/dep/fgw/pdf/fishfact/carp.pdf
15	22	Volga and Ural Rivers	1	http://www.caspianenvironment.org/biodb/eng/fishes/Cyprinus%20carpio/main.htm
15	NG	Kubyshev Reservoir (Osipova, 1979)	2	http://www.issg.org/database/species/ecology.asp?si=60&fr=1&sts=
15	28	(Swee and McCrimmon 1966; Moyle 1976)	3	http://nis.gsmfc.org/nis_factsheet.php?toc_id=183 http://elib.cs.berkeley.edu/kopec/tr9/html/sp-common-carp.html
15	20	Balon, 1990	9	http://www.fishbase.org/Reproduction/FishReproSummary.cfm?ID=1450&GenusName= Cyprinus&SpeciesName=carpio%20carpio&fc=122&stockcode=1643
16	26	Spawning can occur at these temperatures	4	http://www.natureserve.org/explorer/servlet/NatureServe?searchName=Cyprinus%20carpio
16.5	28	(Lubinski *et al.*, 1984).	10	http://fisc.er.usgs.gov/Carp_ID/html/cyprinus_carpio.html
17	NG	Balon (1995)	2	http://www.issg.org/database/species/ecology.asp?si=60&fr=1&sts=
18	22	Optimum; Berg 1964; Mansueti and Hardy 1967);	3	http://elib.cs.berkeley.edu/kopec/tr9/html/sp-common-carp.html
18	22	Optimal; (Shields 1957, Sigler 1958, Swee and McCrimmon 1966, Jester 1974)	4	http://www.natureserve.org/explorer/servlet/NatureServe?searchName=Cyprinus%20carpio
18	20	Clawford Vinyard and Fisheries, England	5	http://www.clawford.co.uk/carp.htm
18	22	Most favourable temperature in Iran	7	http://www.briancoad.com/Species%20Accounts/Cyprinus.htm
18	NG	Scotland, no reference	8	http://www.frs-scotland.gov.uk/FRS.Web/Delivery/display_standalone.aspx?contentid=885
22	26	Peaking	3	http://elib.cs.berkeley.edu/kopec/tr9/html/sp-common-carp.html

Thresholds selected

Min	Max	Classes
13	28	Minimum and maximum found in the literature
17	23	Optimum minimum and maximum found in the literature

Source: Web sites assembled and thresholds set by J.M. Kapetsky

Water temperature

Two general analytical procedures are available to incorporate water temperature into our analysis of the potential distribution of common carp. The first method would be to use ESRI's Spatial Analyst add-on extension to directly access the extensive set of raster/grid-based data residing in the AWRD archive; specifically the water temperature data to determine areas of suitable spawning habitat based on the criteria above. However, Spatial Analyst is an expensive add-on to ArcView and some users may not have the necessary funds to purchase this extension. Therefore the second method is to use the vectorized versions of these raster data also provided in the AWRD archive, and that method will be presented here. Using these vectorized data will slow the processing time but will yield the same results.

To conduct this analysis, the Classification and Ranking tool of the AWRD Statistical Analysis Module was used to formulate a query by using the consolidated table of vectorized Water Temperature (WT) values. The data classification query was broken down into three simple criteria:

a. Set a broad spawning range for common carp to a minimum of 13° and a maximum of 28 °C, in at least one month out of the year, and classify the criteria as "Critical" such that the area must meet this temperature requirement or else be considered unusable for carp;
b. Classify areas with monthly water temperatures that are always between 13° and 28 °C as being better than areas with monthly water temperatures that are only occasionally within this range; and
c. Classify the optimal spawning range for common carp as lying between 17° to 23 °C over the four month period of November through February.

Areas not meeting the critical criteria (a) were excluded from further analysis. If only the critical critera was met, then a score of 10 was assigned to the landscape. If criteria (a) and criteria (b) were met, then a score of 50 was assigned. A score of 1 was added for each month meeting the optimal temperature range from criteria (c), such that scores ranging from 51 to 54 indicate that the optimal spawning range criteria have been met for anywhere from one to all four months over the monthly target period from November through February. Figure 2.52 illustrates how the African continent was classified according to these water temperature-based classification criteria.

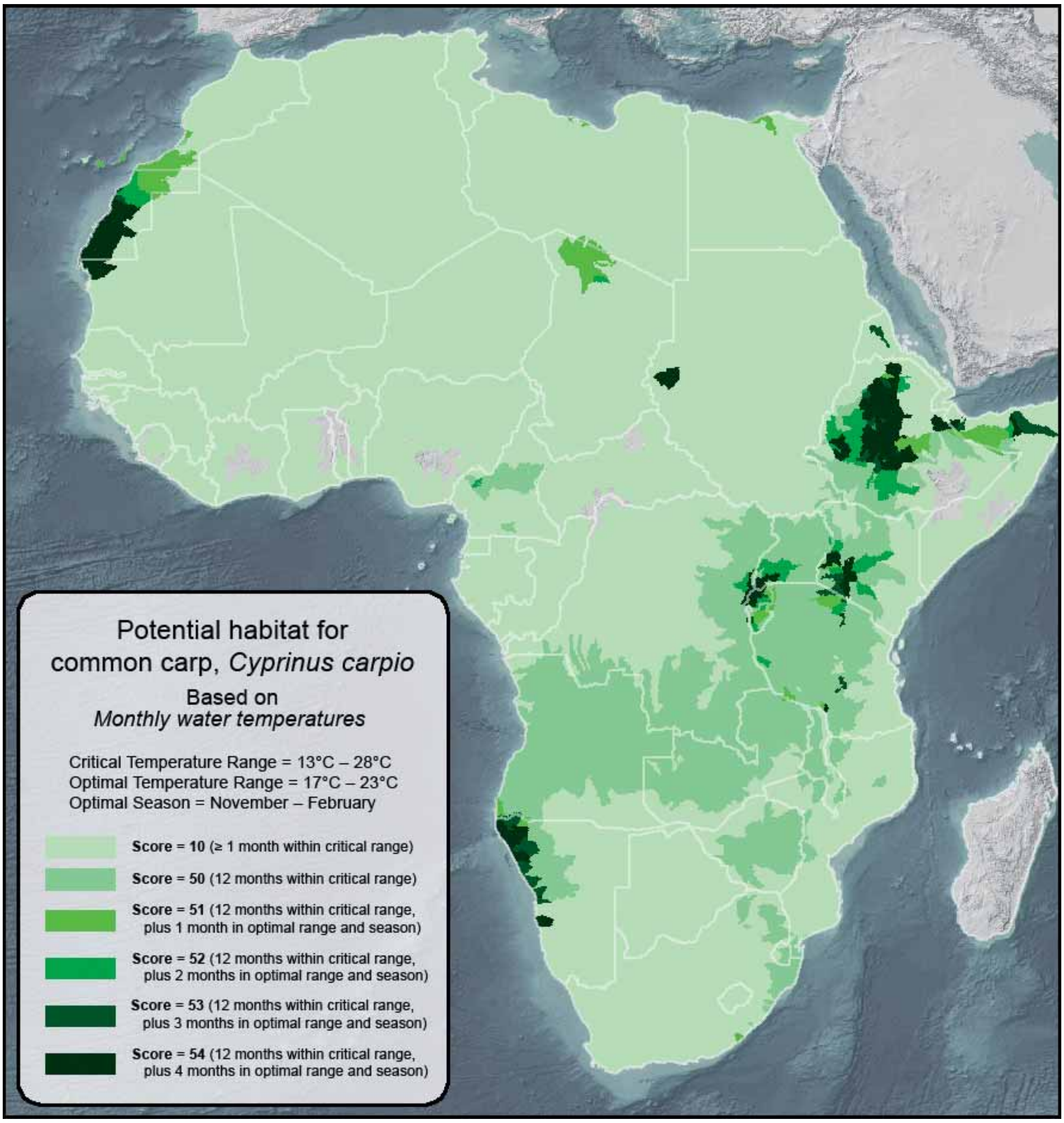
The gray patches extending along the central portion of Africa are areas that did not meet the critical criteria that they must have a monthly water temperature between 13° and 28 °C in at least one month out of the year.

Presence of perennial water

The AWRD data archive includes several datasets that identify perennial rivers and streams in Africa, and this example will use the Wria_riv.shp dataset derived from the FAO Atlas of Water Resources and Irrigation in Africa.

It is a simple matter to refine the analysis above so that it only considers watersheds with perennial water. Using standard ArcView query and selection tools, the user would first query the Wria_riv.shp dataset to select all those rivers that contain perennial water, and then use the "Select by Theme" tool to identify all the watersheds that do not intersect with these perennial streams. The user would then simply delete the watersheds that do not intersect, as in Figure 2.53.

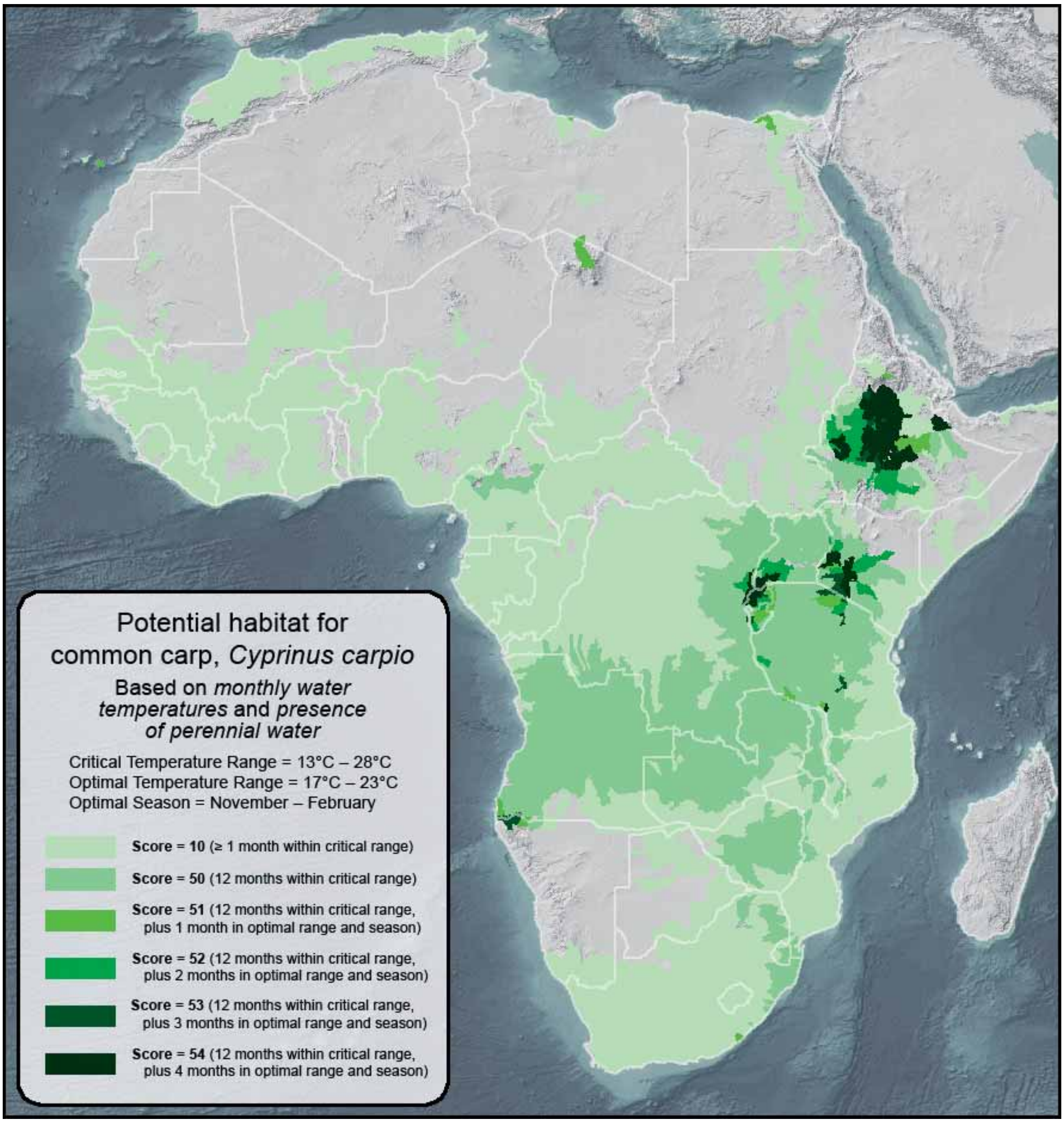
FIGURE 2.52
Potential distribution of common carp based on monthly water temperature



By this simple process, the user easily eliminates much of the unlikely carp habitat in the deserts of the Republic of Namibia and Northern Africa. There is an interesting anomaly in northern Chad, where the river dataset indicates a small 18km stretch of perennial water. This is the only perennial river indicated within hundreds of kilometers. The authors of the AWRD have not visited this area so we cannot say with any certainty whether this is an interesting and unusual hydrological feature, or simply an error in the data.

It is important to note that factors other than temperature and the presence of water can influence reproductive behaviour such as day length, and availability of spawning habitat. Therefore the thresholds set are an assumption for the purposes of simplifying this case study.

FIGURE 2.53
Potential distribution of common carp based on monthly water temperature and presence of perennial water



Conclusions
This case study illustrates how the use of the AWRD vectorized archival data, used in combination with the AWRD Data Classification tools and the standard ArcView query and selection tools, enable users of the AWRD to formulate complex geospatial- and attribute-based queries in a simple and intuitive manner. Further, because the Data Classification tools allow users to specify whether a criterion represents a critical knockout constraint (i.e. temperatures below 13 ºC, or above 28 ºC, in at least one month of the year) versus a more general non-critical one (i.e. temperatures outside of the optimal range of 17 ºC – 23 ºC, during the optimal season of November – February), they can more easily harness the power of a GIS platform to leverage local knowledge with greater spatial specificity. Additionally, complex sets of classification criteria can be easily saved and shared with others using the "Save Criteria" function of the Data Classification tools. Lastly, due to the generic nature of the vectorization approach,

users could easily expand the query to include anthropogenic, physiographic, land use and climatological parameters into any analysis.

A watershed-based approach provides an ecologically appropriate technique for analysing species distributions in river systems at various scales. The AWRD allows users to focus their analyses on specific river reaches, larger-scale river basins (e.g. the White Nile River) or, at the broadest scale, entire river systems or megabasins (e.g. the entire Nile). Therefore, the AWRD provides a robust baseline approach to the analysis of aquatic species, and one which can be further refined using the statistical and data classification toolsets of the AWRD. The AWRD can also support the analysis of species distributions using either administrative political boundaries or other polygonal datasets, although these datasets do not allow users to identify "upstream" or "downstream" regions.

Resources such as FishBase hold great promise and may offer cost-effective mechanisms for expanding the analysis of species data via the AWRD continentally as well as the potential consideration of *taxa* other than freshwater fish species.

The AWRD may also be able to accommodate the further refinement of the potential distribution of aquatic species based on the inclusion and/or combination of structural features and environmental conditions which may impede the movement of certain species. For example, the presence of a dam may block species from moving past a certain point on the river. With creative use of the AWRD selection tools, users may easily identify regions along a hydrological network which are isolated by such structures.

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Production of simple map graphical outputs and base mapping

Introduction and objectives

Introduction

A map conveys geographic information, highlights important geographic relationships, and presents analysis results, and any GIS analyst will at some point end up with some results that need to be communicated. A user can fulfil the purpose of their map by using proper placement elements and choosing symbols and cartographic elements that are tailored for the message that wants to be communicated. Cartography is very much an art, with a long history and with much literature devoted to it.

How a map is designed depends on the particular objectives of the mapmaker. One obvious objective for creating a map is to simply show where things are. Other map objectives may be to share information, guide people, or illustrate the results of an analysis. The primary objective is usually not to create a beautiful map but to create a product that communicates effectively, efficiently, and clearly.

Webster's Dictionary defines a base map as, "an outline map of an area to which specific information is added for any of various purposes" (Webster, 1992). In practice, the term base map connotes some baseline or foundation level of spatial information. Traditionally, the components of a base map include: the "map"; the scale of the representation presented as a ratio; some type of measurement graticule and/or scale bar; an interpretive legend if necessary; projection information; a title; a date; and other related source information. The most popular form of base map is the type used by most people as a desktop or wall reference. These can be best described as atlas-style reference maps, and are most commonly the maps that are copied and/or reduced for use in presentations and internal reports.

The term base map has, however, devolved a bit and today can also be used to describe what are little more than sketches, hand drawn by an individual or a group, which help to convey some important spatial relationship or demarcation, and have proven to be valuable tools for community meetings, discussions with local leaders, and strategic planning sessions with administrative authorities.

Within the original SADC-WRD, the interface provided users with the ability to select a watershed or a country from the database, and to then have the selection automatically centred on the screen with a number of pre-classified data layers presented in overlay. The AWRD provides users with the same facility, but with a much greater number of data layers which can be added to the map and a much more sophisticated means to generate map graphics.

Objectives

- Demonstrate the utilisation of the AWRD tools for the semi-automated production of reference map graphics;
- Illustrate some of the results that can be presented using AWRD data and tools to address a number of spatial issues for inland aquatic resource management; and
- Present a visual depiction of the integration of some of the data contained within the AWRD archive.

The mapping of climatological variables, river systems and administrative areas are discussed, as well as the production of rapid or simple graphics outputs versus the production of more complex outputs containing traditional map elements. Interested users are referred to the workbook section on Basemaps in part 2 of this publication for detailed instructions on how to create the maps presented in this case study.

Materials and methods

Data utilized

The river basin and climatological mapping portion of this case study features ALCOMWWF and Hydro-1K watershed models contained within the WS-DBC, and utilises the primary river and surface waterbody layers of the RIV-DBC and SWB-DBC, presented atop a variety of the image backdrops contained within the AIMG-DBC.

The production of the administrative country mapping examples presented in this case study draws heavily on data from across the various DBC's of the AWRD, and extensively utilises the ancillary mapping layers contained in the AVEC-DBC.

Methods

Throughout this case study, the Select by Relationship with Another Theme, Find Locations by Theme, and then Zoom to Gazetteer Locations tools of the AWRD are used in conjunction with the watershed selection and visualisation functions of the Watershed Statistics Module to define the mapping extent used for each example presented. In addition, various other AWRD user add-on tools are also used during the case study, including the Create Fitted Map tool available from the AWRD Image Export and Base Mapping toolset. The ESRI Legend Tool extension is used to assist in making attractive legends for the figures.

Results

Megabasin and river basin mapping

The river basin mapping portion of this case study demonstrates the use of the AWRD data archive and tools to output production quality geo-referenced images suitable for use in digital presentations and/or the generation of printed maps. To illustrate the diversity of data available within the AWRD data archive, differing watershed models and rivers data layers were used to create map graphics representing African megabasins, the Volta megabasin, the Lake Tanganyika megabsin and then the Nile River basin.

In each of the outputs presented, different watershed models are used to define the area of interest depicted, and a variety of vector-based river and surface waterbody data are integrated as reference layers.

In the final map graphics presented for the countries of the Republic of Ghana and the Republic of Uganda, a much greater level of detailed vector-based data is used to provide reference information such as populated places, road and rail infrastructure and rivers and surface waterbodies.

A river basin is a basic unit of analysis to achieve a holistic understanding of natural systems and how they interact with human activity. The AWRD data archive includes information on both "sources" and "uses" of water where sources include precipitation, evapotranspiration, surface water, groundwater and wastewater; and uses include rural and urban domestic, industrial, power generation, crop, livestock and fisheries production, and the preservation of wildlife habitat and ecological processes. Figure 2.54 illustrates the mean annual precipitation across the African continent, which is one of the primary "sources" of water.

The Hydro-1K watershed model from the AWRD's Watershed Database Component (WS) DBC is used to define the regions that are mapped at different levels of precipitation. The climatological data are overlaid on top of an image from the Ancillary Image (AIMG) DBC of the AWRD Archive, and national boundaries are delineated using data derived from the Ancillary Vector (AVEC) DBC. The nominal scale of Figure 2.54 is approximately 1 : 70 000 000.

FIGURE 2.54
Mean annual precipitation (mm/yr) in Africa

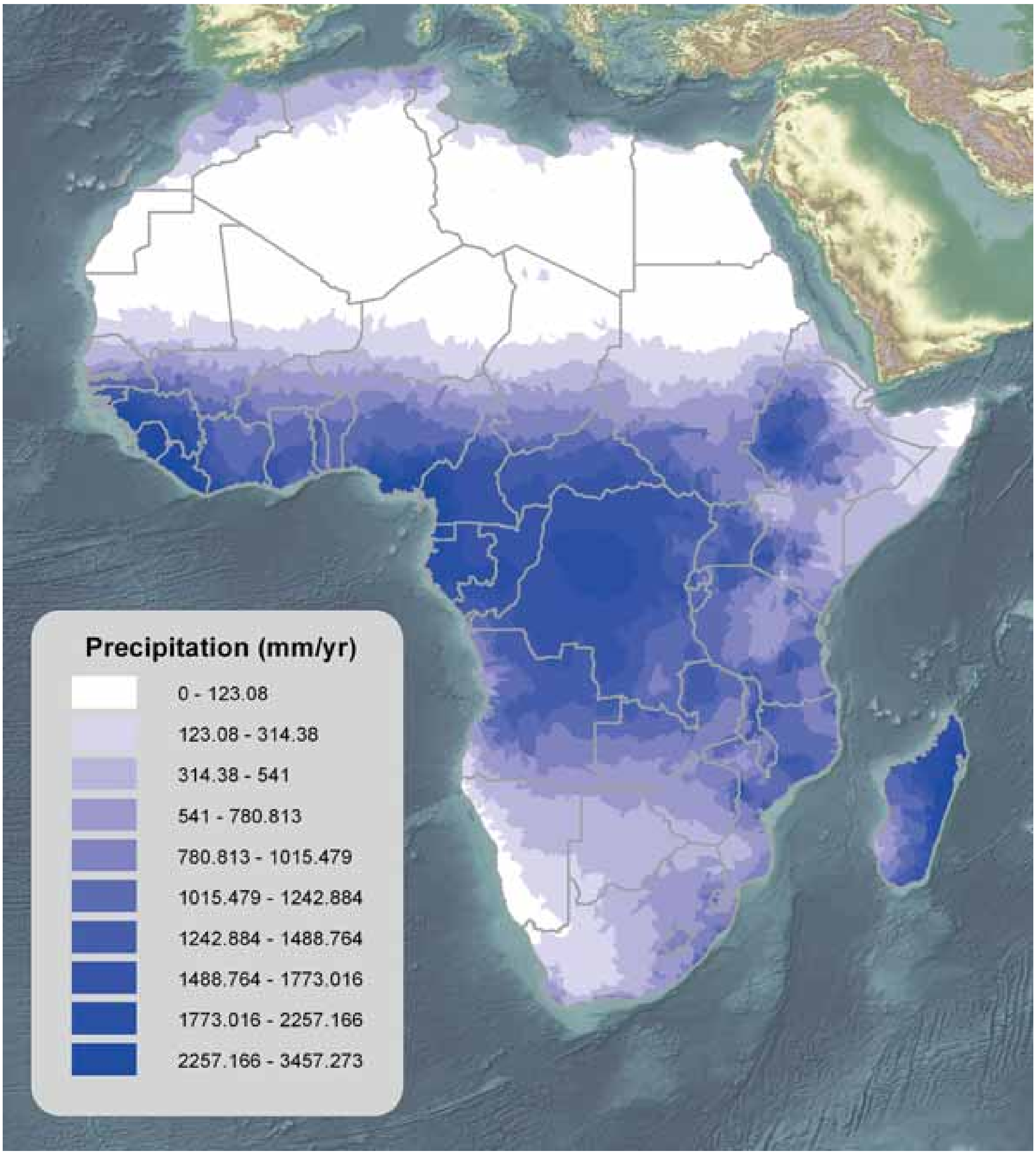


Figure 2.55 presents population density in the Lake Volta megabasin as depicted by the ALCOMWWF watershed model contained in the WS-DBC of the AWRD. The surface waterbody, national boundary and capital city data layers are derived from the harmonized DCW and Vmap0 datasets from the Surface Waterbody (SWB) DBC and AVEC-DBC.

The background image used on this map graphic is derived from the Space Shuttle Radar Topography 30 arc second (~1km) source DEM, to produce a coloured hill-shade theme for the AWRD. This background layer is one of a number of geo-referenced image map backgrounds which have been highly compressed for inclusion in the AIMG-DBC of the AWRD. The nominal scale of this map graphic is approximately 1 : 8 000 000.

The Volta basin is 1 400 km long and straddles six countries, although most of the land areas is in the Republic of Ghana and Burkina Faso. The basin suffers from extreme poverty, a growing population which is expected to double over the next 25 years, and a looming water crisis. The Volta basin is one of the poorest regions of the world. More than 60 percent of the people in Burkina Faso live on less than US$1 per day. Other countries in the basin are not much better off (Harrington *et al*., 2004).

Population density is the highest in the Okwe watershed (180 people/km²) followed by the Tahala watershed (174 people/km²). The Laboni watershed has the lowest population density (3.5 people/km²). These three watersheds are highlighted in yellow in Figure 2.55.

FIGURE 2.55
Population density in Lake Volta megabasin

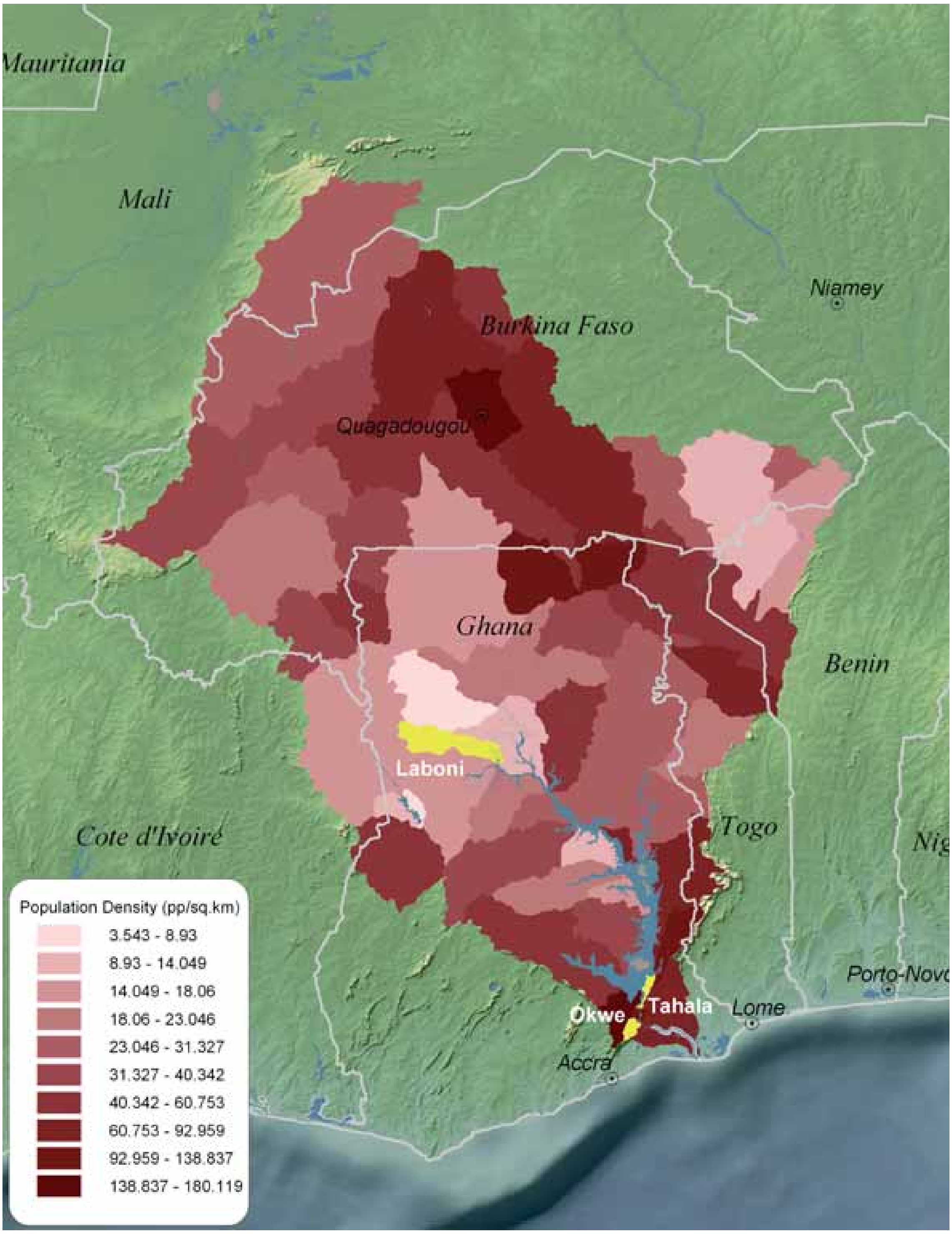


Figure 2.56 depicts the Flow regime associated with the Lake Tanganyika basin. In this figure the ALCOMWWF watershed model is used as the basis for defining the Lake Tanganyika basin. The FAO AquaStat waterbodies layer is used to represent lakes within the graphic, and the FAO AquaStat African Rivers dataset is used to represent the perennial and nonperennial rivers. Both of these data sources are included in the AWRD data archive.

The background image used on this map graphic has been changed to an image derived from the SRTM-GTopo30 source DEM by first reclassifying the DEM to a range of 256 elevation classes before producing a coloured hill-shade theme. This continental image backdrop theme is provided in the AIMG-DBC of the AWRD. The scale for this figure is approximately 1 : 20 000 000.

The actions of river basins inhabitants, taken together, affect the quantity and quality of water available at different points within the basin. The cumulative effects of people's actions on water resources increase as one moves downstream. As illustrated in the map, Lake Tanganyika's "downstream watersheds" cross the political boundaries of three countries; Congo, the Democratic Republic of the Congo, and Angola. When population pressure is high, the actions of upstream communities have strong downstream impact. The "upstream watersheds" of Lake Tanganyika cover parts of five countries: the United Republic of Tanzania, the Democratic Republic of the Congo, the Republic of Burundi, the Republic of Rwanda, and the Republic of Zambia. This illustrates the need for improved dialog and communication between upstream and downstream communities to address transboundary issues for the management of shared water resources.

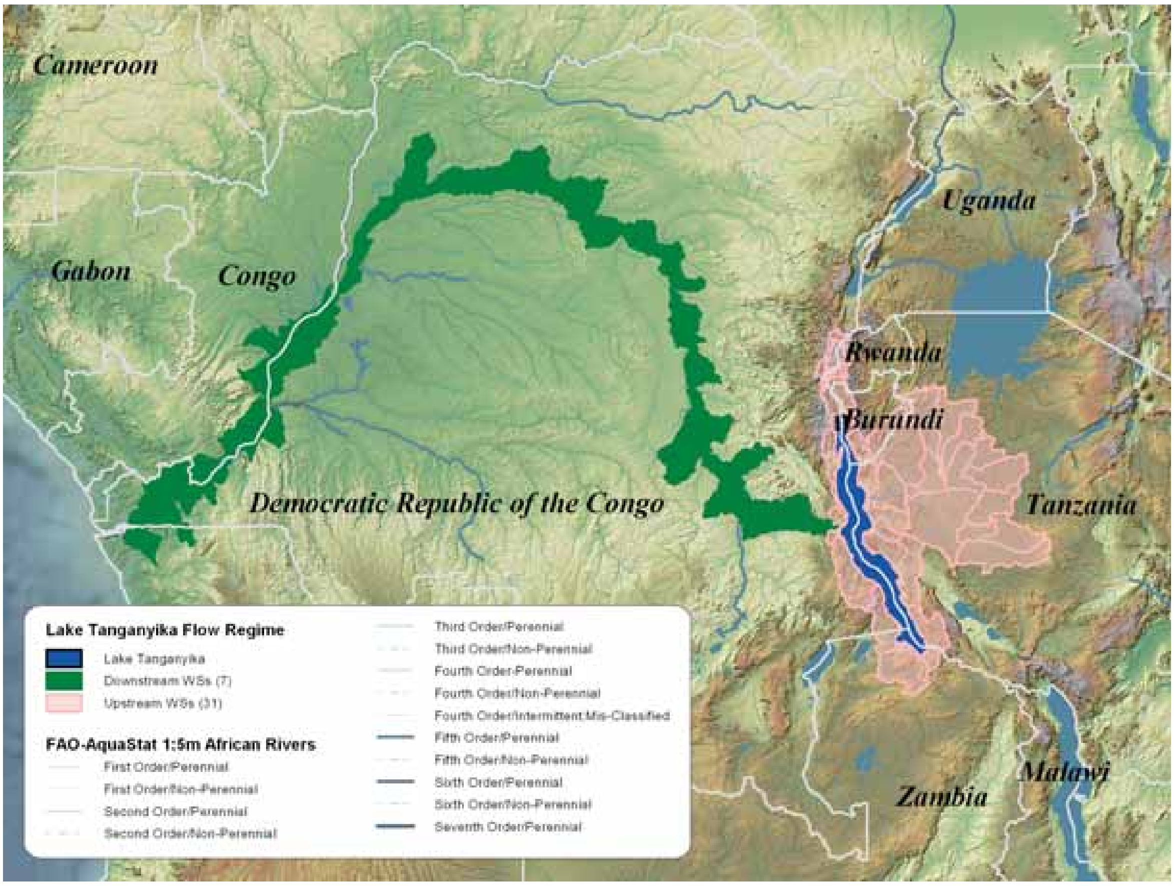
Cradled within the Western Rift Valley, Lake Tanganyika is in many ways a most remarkable feature of the African continent, and indeed of the world. It is:

- The longest lake in the world;
- The second largest (by area) of all African lakes (after Lake Victoria), and the fifth largest of the world's lakes;
- The deepest of all African lakes and the second deepest lake (after Baikal) in the world;
- The greatest single reservoir (by volume) of fresh water on the continent and one of the greatest in the world; and
- One of the most bio-diverse fresh water ecosystems on the planet.

The lake also plays a crucial role in sustaining human welfare and livelihoods.

- It hosts one of the largest inland fisheries in Africa (second only to Lake Victoria), and therefore provides a significant source of food security and livelihood for millions dwelling within and around its basin. Estimated annual harvest levels in recent years vary from 165 000 to 200 000 tonnes, yielding annual earnings reckoned at between US$80–100 million;
- In addition to its fisherfolk, the lake directly or indirectly provides income, food, drinking water, and a means of transport and communication for an estimated 10 million inhabitants of its catchment area; and
- Many more millions residing within the wider trading orbit of the Tanganyika basin are regular or occasional beneficiaries of its resources as consumers of fishery products. In many communities fish is the single most important source of animal protein (FAO/FishCode, African Development Bank, UNDP/GEF, IUCN, 2004).

FIGURE 2.56
Flow regime associated with the Lake Tanganyika basin

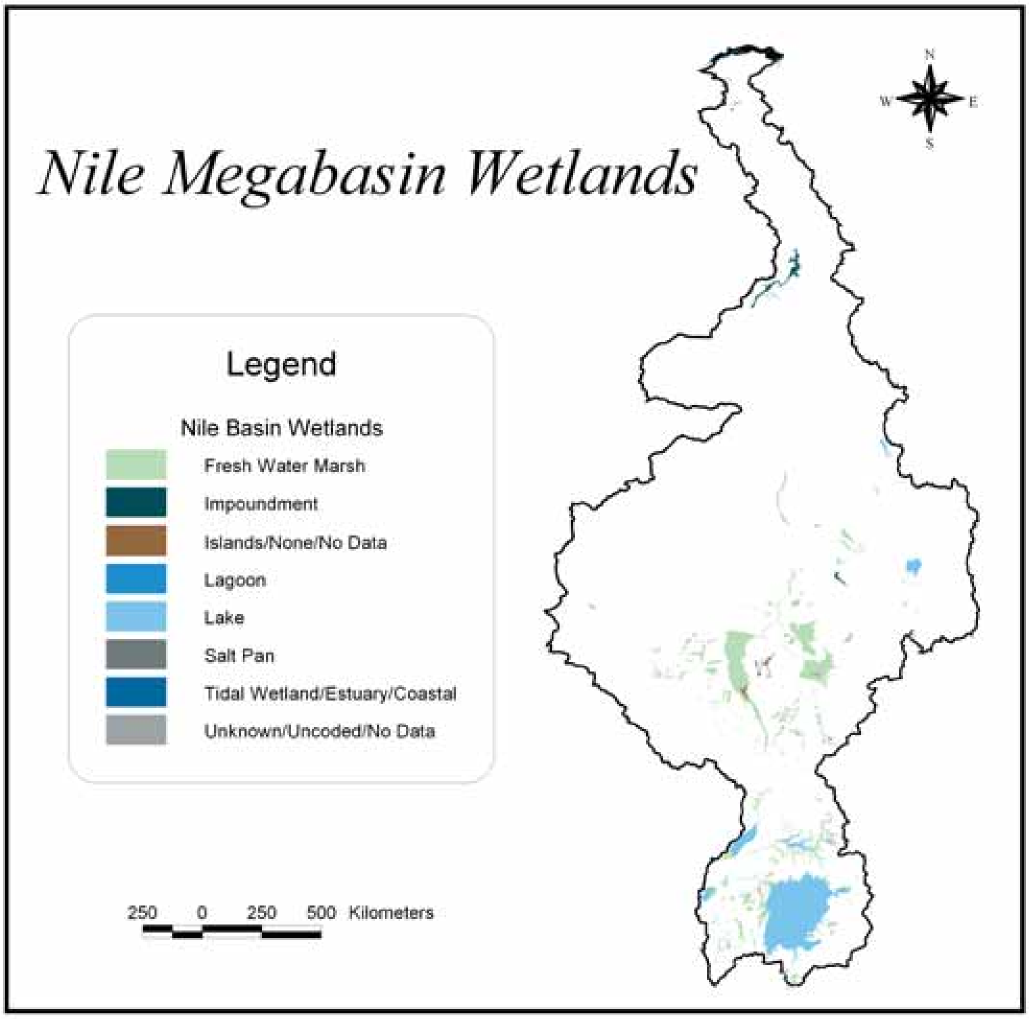


The Nile basin covers parts of 10 countries: the Republic of Burundi, the Democratic Republic of the Congo, the Arab Republic of Egypt, Eritrea, the Federal Democratic Republic of Ethiopia, the Republic of Kenya, the Republic of Rwanda, the Republic of the Sudan, the United Republic of Tanzania, and the Republic of Uganda. Basin water resources are fundamental to the livelihoods of nearly 160 million people. Five of the world's 10 poorest countries lie in the basin – about 80 million of its inhabitants earn less than US$1 a day (Harrington *et al*., 2004). The transboundary nature of the Nile basin is an important factor. The Nile basin initiative and similar arrangements form a sound basis for international cooperation in water management.

Regarding fished waterbodies, a traditional view of inland fisheries is evocative of the exploitation of perennial waters such as lakes, rivers, streams and ponds; however, in practice important quantities of aquatic products are taken from a variety of other kinds of waterbodies, both natural and artificial. Among other kinds of natural waterbodies that are exploited are swamps, freshwater marshes, and seasonally inundated waters including floodplains and floodplain lakes, flooded forests, and ephemeral streams. Additionally, channels among mangroves, salt marshes, coastal lagoons and estuaries are the province of inland fisheries as well. Among the fished artificial waterbodies are reservoirs, borrow pits, flooded quarries and surface mine pits, rice fields, village and household water supply ponds, stock watering ponds, irrigation canals and ditches. It is these systems that are relatively small, or that vary in size and in time, or that are remote, or in countries that lack means, that present the difficulties for fully accounting for inland fish production, threats to the sustainability of inland fisheries, and fishery potential. Inventories of such waterbodies are far from complete.

Figure 2.57 highlights the use of both an Area Of Interest (AOI) definition and the creation of map masks covering those areas not associated with the Nile River megabasin to illustrate the distribution of wetlands within the megabasin. The megabasin boundaries are defined using the ALCOMWWF watershed model, and the wetlands are portrayed using the Consolidated WCMC Wetlands data layer. The nominal scale of this map is approximately 1 : 30 000 000.

FIGURE 2.57
Wetlands in the Nile River megabasin



Administrative base mapping
In addition to a wealth of data on surface hydrology, the AWRD also contains an extensive archive of general purpose data layers such as: capital cities; urban areas and population centres; roads, rail and related transport infrastructure; national and sub-national administrative boundaries; and various vector-based elevation datasets. The purpose of this portion of the base mapping case study is to demonstrate the utility of data from across the AWRD archive for the rapid production of general reference atlas-style country and administrative map graphics.

Although the following sections focus on the production of such map graphics for the countries of the Republic of Ghana and the Republic of Uganda, the same process can be used to produce map graphics for any polygonal data or reference extent using the Create Fitted Map menu item tool under the AWRD's IEBM toolset.

Production of a reference map graphic for the Republic of Ghana

As discussed in the introduction to base mapping using the AWRD, scale is a potential issue users will need to consider during the production of any base maps. The AWRD includes a number of ArcView projects, feature legends, and object databases which have been developed to help ease the process of creating base maps. Perhaps the most valuable of these are the object databases which allow users to import pre-classified groups of themes and appropriately scaled map labels into a view. Used in conjunction with the Image Export and Base Mapping toolset, users can apply the source object databases as demonstrated in Figure 2.58, to rapidly produce map layouts meeting their small, medium, or larger scale mapping requirements.

In Figure 2.58 the large scale object database, **BaseMap-Large.odb**, was used as the baseline for producing the rapid base map graphic for the Republic of Ghana. The national and subnational boundaries were drawn from the RWDB2 administrative boundary dataset. The road network was represented by the Vmap0 Road dataset. Lake Volta and other large waterbodies were reprepresented using the DCW surface waterbodies dataset. The background image of off-shore bathymetry was portrayed using the image "Af_rlf3d.jp2". All these datasets were loaded automatically with BaseMap-Large.odb. The nominal scale of this image is approximately 1 : 6 000 000. From start to finish, the importation of the proper object database and then the production of this map graphic required approximately thirty minutes. It should, however, be recognised that the production of such map graphics is not a totally automated process. Also, in addition to the manipulation of the feature labels or annotation contained in the reference object databases, the creation of an actual map, with legends, titles, scale and geographic references can take significantly longer. A more detailed description of how the AWRD can used to facilitate base mapping is provided in part 2 of this publication in section 1.7, under the heading "Image Export and Base Mapping Extension".

FIGURE 2.58
Road network map of the Republic of Ghana

Production of rapid base map graphics of the Republic of Uganda

As was the case for the Republic of Ghana road network reference map, the process of mapping the Republic of Uganda was begun by simply selecting the country from the *Ad1–National and Soveriegn Boundaries* country boundary layer of the AVEC-DBC and then running the *Create Fitted Map* tool. The **BaseMap-Medium_Set1.odb** and **BaseMap-Medium_Set2.odb** databases were used to provide the baseline themes for the maps produced.

Figure 2.59 displays the major VMap0 hydrological, transport infrastructure, populated place, and vector-based elevation data layers which have been processed for inclusion into the AWRD archive. The nominal scale of this map is approximately 1 : 3 000 000.

FIGURE 2.59
Reference base map of the Republic of Uganda

Discussion

The text and map graphics presented in this case study demonstrate the utility of the AWRD base-mapping tools for the rapid production of map graphics which can be incorporated into digital presentations, web-sites, and reports. All of the map graphics presented could have been further enhanced to contain all of the traditional elements constituting “actual” base maps by using some of the native map layout functionality of ArcView. However, such map compositions are not often required for digital presentations and reports, and can even be distracting when added to map graphics used in PowerPoint-style presentations.

The illustrations presented in this section are intended to be reproducible by the users without too much time or effort. Therefore they are not too complicated, and in some cases they could easily be made to look better using other software (like Photoshop). AWRD authors deliberately kept them simple because it is assumed that some users will be limited to ArcView. All images presented in this case study are created using only ArcView and AWRD tools (i.e. "ImageExport"). The ImageExport tool of AWRD does a much better job at exporting images than ArcView itself does, and it saves a tremendous amount of time adding and arranging layers, and generating and positioning labels, so users will have valuable tools available to them.

Inset attribute tables were not added to any of the figures in this case study because the standard ArcView "Table" display on the layout does not look aesthetically nice. Typically when a user add tables to the maps, he would take screenshots of them and add them to the map in other software like Photoshop. Because the figures in this case study need to be reproducible by the users using only ArcView and the AWRD, it was decided to leave out the addition of tables for this case study.

Users can easily generate any of the maps presented in this case study by working through the exercises in the Workbook section on Basemaps described in part 2 of this publication.

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2.5 AWRD PRESENT AND FUTURE

The AWRD builds on an established body of work and represents a second generation interface and design. In direct comparison to the original SADC Water Resource Database, the current AWRD encompasses both a greatly expanded set of archival data and a much tighter integration of the GIS decision support tools. The benefits expected to accrue from the AWRD can be broadly divided into two sets or areas. The first of these areas reflects those benefits which are expected to stem directly from the process of rigorously compiling multidisciplinary data for the continent as a whole. The second set of benefits is made possible through a modular GIS environment under which these data can be seamlessly accessed for visualization and analysis.

The following discussion focuses on the interpretation of the results, the lessons learned over the course of the development of the AWRD, and potential limitations, constraints and suggested improvements and recommendations which could be made.

Interpretation of results

Several factors, which are common to any GIS-based project, had a general effect on the results of this study. These can be broken into two main areas; data archive and interface development.

AWRD data archive

Section 2.2 presented an overview of the data compiled for the AWRD. The following subsections provide a very brief summary of some of the key issues related to the development of the archive which were not previously covered. These issues include: General presentation and access to archival data; Sources and structure of the data archive; Data format and standardization; Data coverage; and Data comparability.

General presentation and access to archival data

Although both the spatial extent and diversity of data compiled for the AWRD have been significantly increased over those provided under the SADC-WRD, in order to maintain at least some compatibility with the methodological approach used for this earlier effort, the term database component (DBC) has been retained. Also, the method of retrieving data by DBC has been maintained in an effort to assist less advanced users of the AWRD with any issues related to accessing data from multiple directories. Intuitively, the DBC method allows users to more easily access and harness the full range of thematic and/or library data of the AWRD.

Sources and structure of the data archive

The AWRD currently contains 156 unique datasets compiled from over 25 data sources or libraries. Because in some cases these thematic layers represent either a time-series or data derived from separate editions published by the source institution, the individual datasets comprising the AWRD number over 16 000[14]. Additionally, in the case of raster-based data, vector renditions of each dataset are also included in the archive to facilitate the analysis and open dissemination of raster-based resources without requiring expensive GIS add-on modules such as ESRI's Spatial Analyst extension.

Although the AWRD archival data are presented initially to users as segregated component databases, the data are maintained under a directory structure based on the original source or institution. This structure allows users to quickly identify AWRD data resources for use in other non-AWRD applications or analyses.

[14] The number of datasets is > 16,000 when referring to the full AWRD archive. If reference is made to the subset of the AWRD archive that is distributed in this publication, then the full number of datasets is about 700 (see Tables 2.3 and 2.4 for details).

Data format and standardization
Given the source diversity and number of datasets within the AWRD archive, an extensive level of effort was devoted to making the archival data viewable and, when possible, directly comparable. However, because of differences in the scale of the data sources compiled, a definitive standardization between all the data layers of the AWRD proved impossible. Forcing such standardization could even degrade the spatial accuracy, and therefore effort was instead expended to ensure that each data source was processed in a consistent manner. For example, in the case of vector data this included the maintaining the coordinate precision and tolerances of the base resources.

Data coverage
Many of the datasets compiled, enhanced or produced for the AWRD are global rather than specific to Africa. In cases where it proved more cost effective to process these data globally, these data are included in their entirety. The chief advantage of this approach is that future AWRD like frameworks envisioned for Latin America and Asia will no doubt benefit from the use of this data.

Data comparability
Because it was not possible to adopt either a single scale or accuracy standard for the AWRD, users should recognize that, independent of the issues related to the analysis of data based on varied scales, inconsistencies will exist between data derived from differing sources. This is of particular importance and should be kept in mind in cases where users manipulate the archival data to create derivative datasets meeting their own specialized requirements.

AWRD Interface
The AWRD interface is focused primarily on inland aquatic resource management, but was designed to be generic enough to be applicable in many fields. Despite this, some users might not find the tools that they need. However, because the AWRD interface is a customized GIS extension, it is therefore possible to make modifications and additions to the interface, or even entirely new interfaces, according to the needs of the user. Moreover, the AWRD interface is simple to understand and use, enabling less advanced GIS users to perform complex operations and standard statistical analyses.

Several of the tool-sets available in the "Additional tools and customization module" of the AWRD are similar to the standard ArcView tools but have been enhanced or expanded to increase accuracy, functions and features. Other tool-sets offer completely new analytical methods and opportunities, such as the "Mahalanobis Distances" tool which calculates exactly how similar the conditions on any point on the landscape are to some preferred set of conditions. This tool uses sound statistical methods to calculate these similarity values, and is especially useful for predicting where some phenomenon of interest (such as a wildlife species) might be found.

Final considerations and recommendations

The overall aim of the AWRD effort is to facilitate responsible inland aquatic resource management. Specific objectives are aimed at stimulating and/or supporting the development of two important planning schemes: (a) the development of regional, national and local level studies, and (b) the development of comprehensive plans for technical assistance by FIMA and other national and international organizations. Thus, the present publication aims to stimulate awareness and discussion within those national governments and financing institutions who are concerned with inland aquatic resource management, and who would benefit from supporting the adoption, practical use and maintenance of AWRD-like frameworks for countries in Africa.

The overviews, case studies and discussions presented in this publication set out some of the central inland aquatic resource management issues targeted by the AWRD, and demonstrate the benefits of using the AWRD data and tools to resolve them. However, given resource availability, the present publication by no means covers all the issues that could be resolved using the AWRD within either the narrow context of fisheries and aquaculture, or the broader integrated water resources management sector.

Despite this shortcoming, the AWRD does provide a solid reference base for inland fisheries and environmental information in Africa. Based on an early beta presentation of the AWRD, the potential utility of the AWRD for providing such a base was recently recognized by the Committee for Inland Fisheries of Africa (CIFA).

At its twelfth session, Yaoundé, Cameroon, 2–5 December 2002, CIFA presented the "Status and Development of the African Water Resources Database (AWRD)" (FAO, 2002b, paragraphs 32-38). The Committee acknowledged that such GIS-based products are "powerful tools for fishery and aquaculture management, planning and development" but also noted that there were still outstanding issues that will need to be resolved before AWRD can practically and effectively be used by Member Countries. The Committee recommended that:

i. further action should be taken to promote the use of GIS and RS in aquaculture and fishery development;
ii. partnerships and collaborative activities should be established among institutions, sub-regions and regions and other groups possessing relevant sources of information;
iii. workshops should be convened to address the issues related to effective cooperation and collaboration mechanisms, and to the maintenance of the AWRD. It was suggested that the outcome of these workshops would provide elements to develop pilot project proposals; and
iv. projects should be developed on the use of GIS and RS in responsible fisheries.

Based on these findings, a further internal review of the AWRD was conducted by FIMA and resulted in extensive modifications to the data archive, GIS tool-sets and composition of the case studies to be prepared for this publication. In addition to these revisions, strategies were developed to promote research, education, training and decision-making using the AWRD. In particular, strategies were discussed for assisting countries to facilitate the organization of national level fisheries and environmental data collection and storage, and then to manipulate and analyze those data using the AWRD.

A number of opportunities have been identified to provide such assistance. Two of these opportunities are the the Ghana National Aquaculture Strategic Framework (NASF) and the Regional Programme for Integrated Management of Lake Tanganyika, where the AWRD data archive and tools are to be show-cased and field tested. Additionally, FIMA plans to create AWRD-like frameworks for Latin America and Asia. An immediate next step will therefore be the creation of a global inland waters inventory based on the data and methodology developed for the AWRD.

Based on recommendations by the CIFA Committee, proposed future developments of the AWRD include: (i) Creation of an Internet based AWRD; (ii) Broadening the potential user base; Identification of partners and co-operators; (iii) Evaluation of the utility of the AWRD and reassessment of the user base; and (iv) Improved accuracy and functionality for inventory of water data.

Clearly most of the steps recommended are actionable given the current level of resources available to FIMA alone. However, several key actions are provided for consideration.

Creation of an Internet based AWRD

Rationale: A priority is the revision of the AWRD interface to support Internet based mapping and analysis. The Internet potentially represents the AWRD's largest "market" outside of Africa and an important consideration within Africa as the Internet connections and capacity continue to improve.

Actions:

- The entire AWRD data archive is included in Part 2 of this publication in two DVD's and it is also available in FAO's Spatial Data and Information Portal (http://www.fao.org/geonetwork/srv/en/main.search) for display and download;
- A Web page in the "Aquaculture" portal of FAO's Fisheries Department will be dedicated to the AWRD, to download (a) the AWRD publication (in PDF format) and (b) the AWRD extensions (i.e. AWRD tools);
- A link to the AWRD Web page will also be made available in GISFish, the FAO global gateway to GIS, Remote Sensing and Mapping for Aquaculture and Inland Fisheries;
- Extracts of the AWRD data and tools will be adapted for use via the Internet using Internet Map Server technology; and
- A mailing list will be created through the AWRD homepage to allow users to stay informed on future advancements on the software and the database.

Broadening the potential user base

Rationale: To broaden the potential user base for AWRD, opportunities should be exploited to demonstrate the potential of the AWRD via the production of expanded case studies focused on the following major water user groups: Fisheries and aquaculture; Wildlife (wetlands) management and recreation; Urban and rural domestic water supply; Irrigation; Water transportation; User environmental impacts; Agriculture; Forestry; and Industry (including hydropower).

Actions:

- The Nile River Awareness Kit (Nile RAK) Project is a collaborative partnership between the Nile Transboundary Environmental Action Project (NTEAP), and a project team led by Hatfield Consultants Ltd. (Hatfield). The Nile RAK project is designed to promote sustainable management of water resources within the Nile basin. This will be conducted through the development of a sustainable independent learning and training tool called the Nile River Awareness Kit CD-ROM (RAK-CD), as well as through the development of Earth Observation (EO) applications, and communication and awareness raising activities. The NileRAK will contain linkages to the AWRD and will help broaden the AWRD user base;
- As part of the AWRD Web site there will be an on-line collaboration and database maintenance system for the AWRD;
- ESRI has kindly donated ArcView licenses for use with this publication (details in introduction of part 2 of this publication). As ESRI is transitioning ArcView 3.x into the company's ArcGIS 9 environment, efforts should be exploited via user and other groups to encourage ESRI to release the base ArcView 3.x software for open distribution. Failing this, in order to further assist African countries, the eventual transition of the AWRD source code from Avenues into a GIS software compatible language that can be freely distributed, e.g. GRASS, should be explored; and
- As an improvement for the database available to AWRD users, FIMA could explore the possibility of integrating new data types. The aim will be that of integrating the global datasets already available with finer resolution datasets that would allow for more local analysis. One possibility could be that of integrating Landsat/Spot/Modis raw and/or classified imagery and indexes (e.g. NDVI, LSWI, etc.).

Identification of partners and co-operators

Rationale: As both the depth of data and GIS functionality of the AWRD increase so will the requirements for maintenance and out-reach. Based on lessons learned during the SADC-WRD, these requirements can overwhelm the resources of the publication agent (in this case FIMA) and lead to the stagnation of the effort. In recognition of this FIMA needs to identify partners and co-operators both within and outside of FAO, in fields other than fisheries in order to preserve the historic investment represented by the AWRD and to carry the already identified potential of the effort forward. Partners could help with: Promotion of AWRD; Preparation of case studies and GIS Interface examples; Determine user profiles and needs; Joint financing; Joint training; Joint dissemination of AWRD; Cooperative updating; and, the Utilization of data for other taxa and for the purposes of resource monitoring and assistance to further refine the spatial resolution of data available via the AWRD.

Actions:

- Plan for promotional activities to attract co-operators and additional funding (e.g. sister agencies like UNESCO and UNEP).
- Enhance and/or create additional modules and datasets of interest to potential partners. Examples:
  - A conservation biology module to perform gap analysis and reserve selection analysis, or a habitat modelling module to support species conservation planning;
  - Modification of the AWRD semi-automated river connectivity and naming tool. Such a modification could facilitate the creation of linear networks, which would in turn expand the analytical capabilities of the AWRD to network type analyses. This could then lead to various analyses of runoff, river flow, water demand/surplus, flood prediction, pollution/nutrient loading, and discharge. New tool-sets could include a River Flow and Hydrograph tool-set, a Runoff and Flood Prediction tool-set, and the inclusion of FAO AQUASTAT tools and techniques to assess available water resources and their use;
  - Development of a Base Mapping Module. Modification of the AWRD add-on Geo-Referenced Image Output tool to include the effortless production of publication quality reference and basemaps of: watersheds, river basins, megabasins, national and sub-national administrative units, or any user defined polygonal or reference extent;
  - Given the interest and importance of sustaining biodiversity and identifying effects of invasive species, a useful modification would be the addition of fish species distributions and attributes from the Royal Belgian Institute in Tervuren (Daget *et al*., 1986);
  - Explore the possibility of joining efforts with IUCN SSC freshwater biodiversity conservation related committees;
  - Modification of the interface to support the seamless integration/ingestion of data concerning fisheries or other taxa based on the ISO 23950 standard for the retrieval of information from databases over the Internet;
  - Integrate Global Lake and Reservoir Monitoring for water level data; Wetlands Monitoring with MODIS and Quikscat via the Dartmouth Observatory. Time series (monthly observations) on floodplain inundation would permit fishery forecasting one and two years ahead with important implications for food security;
  - Refining access to post-processed seamless 1: 250 000 vector data, where available from NIMA or other consistent sources; and
  - Consolidate a methodology for the utilization of full resolution datasets from multiple time periods, such as 15 meter ETM+ (2000); 28 meter TM (1990); and 80 metre MSS satellite image mosaics from the NASA/EarthSat OrthoTM/Geo-Cover data libraries (1980). Effort should also provide methods for utilization

of the current and on-going MODIS 250 meter image data for monitoring purposes.

Evaluation of the utility of the AWRD and reassessment of user base
Rationale: A post-publication assessment should be conducted of users actually adopting the AWRD, focused specifically on which data and tool-sets are most useful.
Actions:

- The Ghana National Aquaculture Strategic Framework (NASF) and the Lake Tanganyika basin projects will provide an excellent starting point to show-case the AWRD and to receive feedback for its use, maintenance and suggestions for additions and improvements; and
- Additionally, the AWRD has been recommended for the workshop and evaluation by the Okavango River basin Commission (OKACOM) due to the extent of spatial and ancillary data (e.g. human population statistics) in the data archive, as well as the extensive set of GIS and statistical analysis tools programmed into the interface. In addition to providing an essentially no-cost resource available to OKACOM, suitable for both non-technical managers and dedicated GIS technicians, the AWRD effectively shields users from some of the technical difficulties associated with spatially based water resource analysis.

Improved accuracy and functionality for inventory of water data
Rationale: In order for the AWRD to become an immediate and integral part of a fisheries planning and management schema it is necessary to refine the spatial resolution of the archival SWB data to enable the inventorying of surface waterbodies by type, administrative area, watershed, and user defined area.
Actions:

- The needs for higher resolution and more up-to-date data on surface waterbodies are critical to both the definition of community specific freshwater fisheries opportunities, and to the monitoring of species diversity and potential habitat degradation. Based on the data and methodology developed for the AWRD, FIMA has earmarked resources for the derivation of a global inland waters inventory consisting of: continental landmasses, islands, surface waterbodies, major rivers, coastlines and estuarine areas from the Space Shuttle Radar Topography Mission waterbody baseline. The various outputs to be derived from this baseline will provide medium to high resolution analytical and base mapping input data for use at scales ranging from 1:750 000 to 1:100 000;
- In conjunction with fisheries monitoring based on the efforts of the Committee For Inland Fisheries of Africa (CIFA), create a simple tool to monitor the status of fisheries within surface waterbodies, wetlands, etc. The interface will employ both basic and advanced indicator templates to facilitate the reporting of monitoring data;
- Creation of guidelines for the monitoring and collection of country and regional statistics focused specifically on current and projected reporting and analytical requirements;
- The extraction of the environmental parameter and fisheries statistical data contained in the SIFRA tables--and from other as yet to be identified sources--and the direct assignment of such information to a central set of appropriate watershed and surface waterbody spatial features;
- The identification of gaps in the spatial baselines required for the analysis and reporting of fisheries specific information; and
- The creation of an inventory of country and regional fisheries statistics, including key environmental factor data, which can be accessible on-line conforming to the ISO 23 950 standard for the retrieval of information over the Internet.

A summary of the AWRD in poster format is presented in Appendix.

3. Glossary

Active Theme. In an ArcView view, the Active Theme (or Themes) are the themes that are selected so that they appear to have a raised box drawn around them in the view Table of Contents. Some types of tools and buttons only work on active themes, so the theme must be set to active before the tool or button will become available.

Add-On. See Extension.

Ancillary Data. Any data which is accessory or related to the main topic and not of remote sensing origin.

ArcView Project. In ArcView 3, a file for creating and storing documents for GIS work. All activity in ArcView 3 takes place within project files, which use five types of documents to organize information: views, tables, charts, layouts, and Avenue scripts. A project file organizes its documents and stores their unique settings in an ASCII format file with the extension .apr.

ArcScript. See Script.

ASCII (American Standard Code for Information Interchange). The de facto standard for the format of text files in computers and on the Internet that assigns a 7-bit binary number to each alphanumeric or special character. ASCII defines 128 possible characters.

Attribute Table. The attribute table of a spatial dataset is the table containing all the descriptive data that is associated with each spatial feature. ESRI Shapefiles are actually composed of multiple files, one of which contains the attribute table in a dBASE database file.

Basin. In the context of hydrology and related subjects this includes a drainage area of a stream, river or lake.

Basemap. A map depicting background reference information such as landforms, roads, landmarks, and political boundaries, onto which other, thematic information is placed. A basemap is used for locational reference and often includes a geodetic control network as part of its structure.

Blue Marble. A NASA project to present a true-color image of the land surface, without cloud cover, of the entire planet. The final composite image is based on satellite images taken between June and September, 2001. Efforts are currently underway to generate a new generation of Blue Marble images depicting the earth at monthly intervals (see http://earthobservatory.nasa.gov/Newsroom/BlueMarble/).

Bitmap. An image format in which one or more bits represent each pixel on the screen. The number of bits per pixel determines the shades of gray or number of colors that a bitmap can represent. Bitmap files generally have the extension .bmp.

Catchment. See watersheds.

Cell. Element of a data grid or data matrix. Each cell corresponds to a portion of the ground surface. The value associated to each cell represents either a thematic attribute or the average value of a parameter, associated to the corresponding surface.

Confidence Band. In regression analysis, the width of the confidence interval for a given confidence level changes in size over the range of the predictor variable. The region defined within the confidence levels is referred to as a confidence band. The confidence band is narrowest at the mean predictor value, and expands as you move away from the mean.

Confidence Interval. A statistical measure reflecting an interval between two numbers with an associated probability value. Statistical analyses generally produce numerical values which predict or explain something about a statistical population, such as the predicted potential fish yield from a waterbody. However, due to the nature of statistics, these predictions always have some level of uncertainty about them. Confidence intervals show the amount of uncertainty. For example, we may be able to predict that a waterbody may have a predicted potential yield of 1 000 tonnes per year, but this value does not tell us anything about the variation or uncertainty about that prediction. A confidence interval might say that we are 95 percent certain that the true potential yield is between 800 and 1 200 tonnes per year, which gives us much more information about the true potential yield of that waterbody, and will let us plan management strategies accordingly.

Confidence Level. The probability value associated with a confidence interval. A confidence interval with a confidence level of 0.90 should be interpreted to mean that, if an infinite number of samples were drawn from a particular population, and 90 percent confidence intervals were calculated for each sample, then the true population statistic would lie within the confidence interval 90 percent of the time.

Cross Table. A table in the AWRD archive which contains attribute values that correspond with codes in other AWRD datasets. For example, the AWRD Surface Waterbody dataset "africvr.shp" contains LCID codes for each waterbody, and the "Cross Table of Unique AfriCover Attributes" table contains descriptions for those LCID codes.

Database. One or more structured sets of persistent data, managed and stored as a unit and generally associated with software to update and query the data. A simple database might be a single file with many records, each of which references the same set of fields. A GIS database includes data about the spatial locations and shapes of geographic features recorded as points, lines, areas, pixels, grid cells, or TINs, as well as their attributes.

dBASE. A simple database format which is used by ArcView 3.x. Shapefiles use dBASE tables to store attributes.

Decimal Degrees. A method of defining locations on the surface of the earth using degrees, which are angular measurements where the vertex of the angle is located at the center of the earth. Locations are defined by Latitude on the Y-coordinate (ranging from -90° at the south pole to 90° at the north pole), and Longitude on the X-coordinate (ranging from -180° to 180°, where 0° is located at Greenwich, England). See also DMS (Degrees Minutes Seconds).

DEM (Digital Elevation Model). Represents a topographic surface using a continuous array of elevation values, referenced to a common datum. DEMs are used typically to represent terrain relief.

DCW (Digital Chart of the World). Worldwide dataset produced from data by the U.S. Defense Mapping Agency along with data from Australia, Canada and the United Kingdom.

Dialog. The customized applications described in the present publication.

DMS (Degrees Minutes Seconds). A method of defining locations on the earth using degrees (see Decimal Degrees). In this case, latitude and longitude values are each expressed using 3 numbers; Degrees, Minutes and Seconds. Degrees are integer values and represent 1/360 of the length of the ellipse defined by the line of latitude or longitude. Minutes are integer values equal to 1/60 of a degree, and seconds are decimal values equal to 1/3 600 of a degree.

Drainage basin. See watersheds.

Ellipsoid. The Earth surface is approximately described by an ellipsoid, a closed surface all planar sections of which are ellipses. In general, an ellipsoid has three independent axes, and is usually specified by the length of the three semi-axes. If the lengths of two axes are the same, the ellipsoid is called "ellipsoid of revolution" or spheroid. Due to the rotation around its axis, the Earth has the shape of a spheroid. Several spheroids are used to model the Earth surface and project it onto a two-dimensional map; the choice of the reference spheroid depends on the region of the Earth to be represented and the required precision. The spheroids quoted in this work are Clarke 1866, WGS72 and WGS84. Clarke 1866 is used to map the North America and the Philippines. The World Geodetic System (WGS) spheroids have been developed to be used for global mapping; the number indicates the year of calculation. WGS84 is the most recent version, and is also used by the Global Positioning System.

ENVISAT (Environment Satellite). ENVISAT satellite is an Earth-observing satellite built by the European Space Agency. It was launched on March 1, 2002 aboard an Ariane 5 into a Sun synchronous polar orbit at a height of 790 km (+/– 10 km). It orbits the Earth in about 101 minutes with a repeat cycle of 35 days.

ESRI (Environmental Systems Research Institute). The largest GIS software company, and the maker of ArcView 3.x, ArcINFO and ArcGIS.

Extension. In ArcView 3.x, an extension is a separate add-on tool that can be loaded into your ArcView project. Extension are composed of scripts, dialogs, menus, buttons and/or tools, and generally provide additional functionality to the standard ArcView tools. The AWRD is an example of an ArcView extension.

Feature Attribute Table. See Attribute Table.

FishBase. An extensive online database of over 28 500 worldwide species of fish, intended for researchers, fisheries managers, zoologists and anyone who is interested in fish. This database may be viewed at http://www.fishbase.org/home.htm.

Fuzzy classification. Any method for classifying data that allows attributes to apply to objects by membership values, so that an object may be considered a partial member of a class. Class membership is usually defined on a continuous scale from zero to one, where zero is nonmembership and one is full membership. Fuzzy classification may also be applied to geographic objects themselves, so that an object's boundary is treated as a gradated area rather than an exact line. In GIS, fuzzy classification has been used in the analysis of soil, vegetation, and other phenomena that tend to change gradually in their physical composition and for which attributes are often partly qualitative in nature.

Gazetteer. A list of geographic place names and their coordinates. Entries may include other information as well, such as area, population, or cultural statistics. Atlases often include gazetteers, which are used as indexes to their maps. Well-known digital gazetteers include the U.S. Geological Survey Geographic Names Information System (GNIS) and the Alexandria Digital Library Gazetteer.

Geocoding. Procedures applied to a satellite image to generate a new image with the projection and scale properties of a map. In particular, map coordinates are associated to the center point of each element (pixel) of the resulting image.

Geodatabase. A collection of geographic datasets for use by ArcGIS. There are various types of geographic datasets, including feature classes, attribute tables, raster datasets, network datasets, topologies, and many others.

GIS (Geographic Information Systems). A computer system for capturing, storing, checking, integrating, manipulating, analysing and displaying data related to positions on the Earth's surface. Typically, a Geographical Information System (or Spatial Information System) is used for handling maps of one kind or another. These might be represented as several different layers where each layer holds data about a particular kind of feature. Each feature is linked to a position on the graphical image of a map. In aquaculture, it has been used to assess the suitability of geographical sectors, and also to investigate the suitability of a species to an area.

Geostatistics. A class of statistics used to analyze and predict the values associated with spatial or spatio-temporal phenomena. Geostatistics provides a means of exploring spatial data and generating continuous surfaces from selected sampled data points.

GeoTIFF. See TIFF.

GIF (Graphics Interchange Format). A type of image file usually used for charts or graphs. It uses a lossless compression format which works well with images with few colors, but poorly with photographs (see JPEG, JPEG2000, MrSID, PNG and TIFF for image formats usually used with high-color photographs). GIF files generally have the extension .gif.

GPS (Global Positioning System). A constellation of twenty-four satellites, developed by the U.S. Department of Defense, that orbits the Earth at an altitude of 20 200 km. These satellites transmit signals that allow a GPS receiver anywhere on Earth to calculate its own location. The Global Positioning System is used in navigation, mapping, surveying, and other applications where precise positioning is necessary.

GTOPO30 (Global 30 Arc Second Elevation Data). A global digital elevation model (DEM) with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometer). GTOPO30 was derived from several raster and vector sources of topographic information. GTOPO30, completed in late 1996, was developed over a three year period through a collaborative effort led by staff at the U.S. Geological Survey's Center for Earth Resources Observation and Science (EROS).

Grid. In cartography, any network of parallel and perpendicular lines superimposed on a map and used for reference. These grids are usually referred to by the map projection or coordinate system they represent, such as universal transverse Mercator grid. Grid also refers to a specific type of ESRI dataset, defined as a raster layer in which data values are arrayed across the landscape in square grid cells (analogous to pixels in a raster image).

HYDRO1k (Global Hydrological 1 kilometre database). Geographic database developed to provide comprehensive and consistent global coverage of topographically derived data sets, including streams, drainage basins and ancillary layers derived from the USGS' 30 arc-second digital elevation model of the world (GTOPO30). HYDRO1k provides a suite of geo-referenced data sets, both raster and vector, which will be of value for all users who need to organize, evaluate, or process hydrologic information on a continental scale. Developed at the U.S. Geological Survey's Center for Earth Resources Observation and Science (EROS), the HYDRO1k project's goal is to provide to users, on a continent by continent basis, hydrologically correct DEMs along with ancillary data sets for use in continental and regional scale modeling and analyses.

Image. A representation or description of a scene, typically produced by an optical or electronic device, such as a camera or a scanning radiometer. Common examples include remotely sensed data (for example, satellite data), scanned data, and photographs.

JPEG (Joint Photographic Experts Group). A type of image file best suited for full color images such as photographs. It is a highly compressed format, which makes it useful for data storage and transmission, but it is uses a "lossy" compression method (meaning that some data is lost when it is compressed), which limits its use for GIS purposes. JPEG image files typically have the extension .jpg or .jpeg.

JPEG2000 (Joint Photographic Experts Group). An updated version of JPEG which offers more efficient compression of images and can use both lossless and lossy compression algorithms. The lossless compression method makes JPEG2000 images very useful in GIS applications. This is a new format, however, and therefore ArcView 3.x requires an add-on extension to view them. This add-on extension is automatically loaded by the AWRD. JPEG2000 image files typically have the extension .jp2 or .j2c.

KML (Keyhole Markup Language). Grammar and file format for modeling and storing geographic features such as points, lines, images, polygons, and models for display in Google Earth. A KML file is processed by Google Earth in a similar way that HTML and XML files are processed by web browsers. Like HTML, KML has a tag-based structure with names and attributes used for specific display purposes. Thus, Google Earth acts as a browser of KML files.

Landsat. The U.S. Landsat satellites are the first series of Earth Observation satellites providing global, repeated coverage of the Earth surface. The sensors onboard these satellites operate in the visible up to middle infrared wavelengths, and in the thermal infrared. The first satellite of the mission, ERTS-1 (later renamed Landsat-1) was launched in 1972. The current Landsat-7 mission hosts the Enhanced Thematic Mapper sensor; of its nine channels, seven acquire data in the visible up to middle infrared, at 30 m resolution. More information on the Landsat-7 mission can be found in the USGS Web pages (http://landsat7.usgs.gov/index.php) and in the NASA Web pages (http://landsat.gsfc.nasa.gov/).

Layout. In ArcView 3.x, one of the five types of documents that can be contained within a project file. The layout is where users create maps for export or printing, and usually include legends, titles and north arrows.

Legend. A theme legend shows the symbols that ArcView uses to display the theme in the view. These symbols are generally coloured boxes, lines or dots, and they are occasionally graduated by size or colour. Legends are shown in the view Table of Contents and often included on printed maps.

Line. On a map, a shape defined by a connected series of unique x,y coordinate pairs. A line may be straight or curved.

Maps. Graphic representation of the physical features (natural, artificial, or both) of a part or the whole of the Earth's surface, by means of signs and symbols or photographic imagery, at an established scale, on a specified projection, and with the means of orientation indicated.

Megabasin. The largest delineation of watershed, representing the entire landscape that contributes water to the final outlet (i.e. either the ocean or an internal basin). Landscape features that separate megabasins are sometimes referred to as continental divides.

MERIS (Medium Resolution Imaging Spectrometer). MERIS is a programmable, medium-spectral resolution, imaging spectrometer operating in the solar reflective spectral range. Fifteen spectral bands can be selected by ground command, each of which has a programmable width and a programmable location in the 390 nm to 1 040 nm spectral range. The instrument scans the Earth's surface by the so called "push-broom" method. Linear CCD arrays provide spatial sampling in the across-track direction, while the satellite's motion provides scanning in the along-track direction. MERIS is designed so that it can acquire data over the Earth whenever illumination conditions are suitable. The instrument's 68.5° field of view around nadir covers a swath width of 1 150 km. This wide field of view is shared between five identical optical modules arranged in a fan shape configuration.

Metadata. Information that describes the content, quality, condition, origin, and other characteristics of data or other pieces of information. Metadata for spatial data may describe and document its subject matter; how, when, where, and by whom the data was collected; availability and distribution information; its projection, scale, resolution, and accuracy; and its reliability with regard to some standard. Metadata consists of properties and documentation. Properties are derived from the data source (for example, the coordinate system and projection of the data), while documentation is entered by a person (for example, keywords used to describe the data).

MODIS (Moderate Resolution Imaging Spectroradiometer). is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. These data will improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. MODIS is playing a vital role in the development of validated, global, interactive Earth system models able to predict global change accurately enough to assist policy makers in making sound decisions concerning the protection of our environment.

MrSID (Multiresolution Seamless Image Database). An image format very similar to JPEG2000, in which full color photographic images can be compressed using a lossless compression format and then displayed in a GIS. One image dataset in the AWRD archive is provided in MrSID format. MrSID image files generally have the extension .sid.

Multipoint. A geometric element defined by a set of points. The entire set is treated as a single object, and there are generally several multipoint objects in a single multipoint shapefile.

ODB (Object Database). A special type of file used by ArcView 3.x, storing Avenue "objects" in a text file on the hard drive. In regards to the AWRD Load Theme Database tool, the "objects" stored are theme references, graphics, legends and scales at which themes are viewable. Loading the ODB causes all these objects to be loaded simultaneously.

ONC. NOAA's 1:1 000 000 Operational Navigation Charts, these charts are the cartographic baseline for both the original DCW and any subsequent updates of the VMAP0 spatial data libraries

OrthoTM. Ortho-rectified or flattened imagery based on the Universal Transverse Mercator (UTM) projection system using the WGS84 standard datum and spheroid, Thematic Mapper LandSat satellite sensor

Pixels. (Picture elements). Cells of an image matrix. The ground surface corresponding to the pixel is determined by the instantaneous field of view (IFOV) of the sensor system, e.g. the solid angle extending from a detector to the area on the ground it measures at any instant. The digital values of the pixels are the measures of the radiant flux of electromagnetic energy emitted or reflected by the imaged Earth surface in each sensor channel.

Pixmap. An internal ArcView object that defines what is shown on the monitor screen. The AWRD Image Export and Base Mapping tools use the Pixmap object to export high-quality image files of maps and layouts.

Point. A geometric element defined by a pair of x,y coordinates.

Polygon. In a GIS framework, a polygon is a closed line (or a closed set of lines) representing a surface. The surface is generally homogeneous with respect to some criteria; for example, land use or type, administrative units, etc. Map coordinates (easting, northing and height) are associated to the vertices of the polygon.

Polyline. In a GIS framework, a polyline is a set of straight line segments (connected or not) representing a linear geographic feature, such as a road or a railway. The polyline may also connect points homogeneous with respect to some criteria, such as a contour line. Map coordinates (easting, northing and height) are associated to the vertices of the segments.

PNG (Portable Network Graphics). A type of image format using a high-efficiency lossless compression algorithm. PNG files can be much larger than JPEG files, but have the advantage of not losing any data in the compression. PNG files generally have the extension .png.

Projection. A method by which the curved surface of the earth is portrayed on a flat surface. This generally requires a systematic mathematical transformation of the earth's graticule of lines of longitude and latitude onto a plane. Some projections can be visualized as a transparent globe with a light bulb at its center (though not all projections emanate from the globe's center) casting lines of latitude and longitude onto a sheet of paper. Generally, the paper is either flat and placed tangent to the globe (a planar or azimuthal projection) or formed into a cone or cylinder and placed over the globe (cylindrical and conical projections). Every map projection distorts distance, area, shape, direction, or some combination thereof.

R^2 (or R-Squared). A statistical measured referred to as the "coefficient of determination", and which reflects the proportion of variability in one variable that can be explained by the corresponding variability in another variable.

RADARSAT. Canada's series of remote sensing satellites. RADARSAT-1 was launched on November, 1995; RADARSAT-2 will be presumably launched on 2005. RADARSAT-1 hosts a Synthetic Aperture Radar (SAR), an active sensor operating in the microwave portion of the electromagnetic spectrum at C-band in HH polarization. The SAR operates in seven different acquisition modes, with spatial resolution ranging from 6.25 to 100 m. RADARSAT-2 will carry an enhanced version of the same sensor. More details on RADARSAT-1 and -2 are available in the Canadian Space Agency Web pages (http://www.space.gc.ca/asc/eng/csa_sectors/earth/radarsat1/radarsat1.asp and .../radarsat2/radarsat2.asp).

Raster. A spatial data model that defines space as an array of equally sized cells arranged in rows and columns, and comprised of single or multiple bands. Each cell contains an attribute value and location coordinates. Unlike a vector structure, which stores coordinates explicitly, raster coordinates are contained in the ordering of the matrix. Groups of cells that share the same value represent the same type of geographic feature.

Regression. See Simple Linear Regression (SLR).

Remote Sensing. The gathering and analysis of data from the study area or organism that is physically removed from the sensing equipment, e.g. sub-water surface detection instruments, aircraft or satellite.

Residual. In regression analysis, the difference between the observed response value and the predicted response value from the regression equation.

Resolution. The area of the ground surface corresponding to a pixel in a satellite image.

Revised/Relational World Databank II. A collection of vector representations of land outlines, rivers and political boundaries, originally compiled by the U.S. Government in the 1980's and regularly updated.

River basin. Total land area drained by a river and its tributaries.

River Order. See Stream Order.

RWDBSII. See Revised/Relational World Databank II.

RWDBS2. See Revised/Relational World Databank II.

SAR (Synthetic Aperture Radar). An imaging radar is an active instrument that transmits microwave pulses toward the Earth surface and measures the magnitude of the signal scattered back towards it. The return signals from different portions of the ground surface are combined to form an image. A Synthetic Aperture Radar (SAR) is a special type of imaging radar. It is a complex system that measures both the amplitude and phase of the return signals; their analysis exploits the Doppler effect created by the motion of the spacecraft with respect to the imaged surface to achieve high ground resolution. As the source of the electromagnetic radiation used to sense the Earth surface is the system itself, it can be operated during day and night. The atmospheric transmittance in the microwave interval used by remote sensing SAR systems (2 to 30 GHz) is higher than 90 percent, also in presence of ice and rain droplets (except under heavy tropical thunderstorms); thus, SAR can acquire data in all weather conditions.

Scale. The ratio between a distance or area on a map and the corresponding distance or area on the ground.

Scatterplot. A statistical plot illustrating the relationship between two variables as measured on a set of sampling points. In regression analysis, each sample is plotted on the scatterplot such that the X-value is equal to the value of the Predictor variable and the Y-value is equal to the value of the Response variable. Regression scatterplots often include a regression line illustrating the best-fitting line that goes through the data.

Script. In ArcView 3.x, one of the five types of documents that can be contained within a project file. An ArcView 3.x script contains Avenue code, which can be used to automate tasks, add new capabilities, and build complete applications.

Selection. ArcView 3.x and the AWRD both offer extensive analytical functions which can be applied to your spatial data. By selecting certain features before the analysis, you can restrict the analysis to only the data you are interested in. Often determining the correct feature selection set is one of the more complicated parts of the analysis, and the AWRD offers extensive tools to select by query or by selecting on the screen, as well as modifying the current selection set by adding, subtracting or subsetting from it.

Shapefile. A vector file format for storing the location, shape, and attributes of geographic features.

SIFRA (Source Book for the Inland Fishery Resources of Africa). A compendium of information on the physical characteristics, limnology and fisheries in Africa, organized by Country. SIFRA was originally compiled in 1990 by Vanden Bossche and Bernacsek, and published by FAO as CIFA Technical Paper No. 18.1. It can be viewed online at http://www.fao.org/docrep/005/T0473E/T0473E00.htm.

Simple Linear Regression (SLR). A statistical technique to estimate the relationship between a predictor variable and a response variable. The relationship is defined using the equation of a line, $Y = a + bX$, where a is the Y-intercept and b is the slope of the line. Using this relationship, you may estimate what the response variable would be given any particular value of the predictor variable. The accuracy of any predictions depends on the strength of the linear relationship, and predictions should generally include confidence intervals.

Spatial Resolution. The area of the ground surface corresponding to a pixel in a satellite image.

SRTM (Shuttle Radar Topography Mission). is a joint project between the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). The objective of this project is to produce digital topographic data for 80 percent of the Earth's land surface (all land areas between 60° north and 56° south latitude), with data points located every 1-arc second (approximately 30 meters) on a latitude/longitude grid. The absolute vertical accuracy of the elevation data will be 16 meters (at 90 percent confidence). The SRTM obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000.

SPOT (Système Pour l'Observation de la Terre). French Earth Observation satellites operating in the optical wavelengths. The first satellite, SPOT-1 was launched in 1986; the most recent satellite, SPOT-5, was launched in 2000. Among its instruments, the HRG acquires data in five channels useful to study land cover: a panchromatic channel (spatial resolution 2.5 or 5 m), three channels in the visible and near infrared wavelengths (spatial resolution 10 m) and one channel in the short-wave infrared (spatial resolution 20 m). More information on the SPOT satellites can be found at the SPOT Image Web site (http://www.spotimage.com) and at the CNES Web site (http://www.cnes.fr).

Stream Order. A method of ranking stream segments according to their location in the hydrological network. Stream segments that form the starting points of the hydrological network are assigned a stream order value of 1. When two stream segments with the same stream order value converge, they form a new segment with an incrementally higher value (i.e. two level-1 segments converge to form a level-2 segment, and two converging level-2 segments form a level-3 segment.). If stream segments with different order values converge, then the resulting segment has the same value as the higher of the two converging segments.

UTM (Universal Transverse Mercator). A commonly used projected coordinate system that divides the globe into 60 zones, starting at -180° longitude. Each zone extends north-south from 84° North to 80° South, spans 6° of longitude, and has its own central meridian.

TOC (Table of Contents). In ArcView 3.x, this is the list of themes available in a View. The TOC is located on the left side of a view. Themes in the view may be set to visible or invisible by checking boxes in the TOC.

Theme. In ArcView 3.x, a theme is a spatial dataset that has been loaded into a view, and is displayed with a customizable legend. Themes are analogous to Layers in ArcInfo or ArcGIS, and may be created from any type of spatial data.

TIFF (Tagged Image File Format). An image format commonly used for high-color digital photographs. TIFF images with embedded spatial information are referred to as "GeoTIFF" files, and are useful in GIS systems because they can contain a large amount of data. TIFF files tend to be large, however, and therefore are poor for data storage or transmission. TIFF files generally have the extension .tif or .tiff.

Vector. A data structure used to represent geographic features. Features are represented by points, lines or polygons. A line is made up of connected points (vertices), and a polygon of connected lines. Map coordinates (easting, northing and height) are associated to each point (or vertex) in a vector feature. Attributes are also associated with each feature (as opposed to the raster data structure, which associates attributes with grid cells).

Vector Map. A vector-based data product in vector product format (VPF) at several scales divided into groups, referred to as levels. For example, VMap Level 1 includes vector maps at a scale of 1:250 000, and VMap Level 2 includes vector maps at a scale of 1:50 000.

View. In ArcView 3.x, one of the five types of documents that can be contained within a project file. An ArcView View contains the actual map and themes, and is where spatial analysis usually takes place.

View Frame. The object in an ArcView Layout which displays the image from a View. View frames generally have live links to their respective view, such that changes in the view automatically are reflected in the layout.

Watershed. The area which supplies water by surface and subsurface flow from rain to any given point in the drainage system, and are most often delineated for distinctive points such as populations centers, lakes or river intersections. Watersheds provide a useful way to divide the landscape up into smaller hydrologically-related regions, which can then be analyzed in terms of in-flow and out-flow of moisture, energy and other parameters, such as nutrients and pollutants. Watersheds are also defined as the total land surface from which an aquifer or river system receives its water, and the term is synonymous with drainage basins, river basins or catchments.

Watershed management. (river basin management) Planned used of watersheds (river basins) in accordance with predetermined objectives.

Watershed model. A special type of vector dataset, in which the landscape is divided into watershed polygons and each polygon has attributes that identify its place in the overall hydrological network.

World File. A file associated with an image, defining the spatial attributes of that image. An image with a world file can be loaded into a GIS along with all other forms of spatial data. World files typically define the projection, coordinate system, ellipsoid and datum of the image, the spatial coordinates of one of the corners of the image, and the real-world size of the image pixels. The AWRD includes tools to export maps into a variety of image formats, and to create world files for these maps.

XML (Extensible Markup Language). A type of document format in which objects can be stored in a text file.

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Appendix - Summary of the African Water Resource Database

Introduction

The African Water Resource Database (AWRD) is a Geographical Information System (GIS) analytical framework supporting natural resource planning with a specific focus on inland fisheries and integrated water resource management. The objective of the AWRD is to provide water and natural resource managers with tools which foster the sustainable use of water resources, as a means of promoting the responsible management of inland aquatic resources and increasing food security.

Methods

The AWRD is an enhancement of the work contained in the FAO's Aquaculture for Local Community Development Programme's Water Resource Database (WRD) of southern Africa. This work has been extended to cover continental Africa and the island states. Currently, there are over one hundred and fifty datasets populating the AWRD data archive. The core data layers include: various depictions of surface water bodies; watershed models; aquatic species; rivers; political boundaries; population density; soils; satellite imagery; and many other physiographic and climatological data types. In general, the source scale of these data support analyses from 1:65 000 to 1:5 000 000 for vector data, and a nominal resolution of 1 to 5 kilometers for raster data.

Results

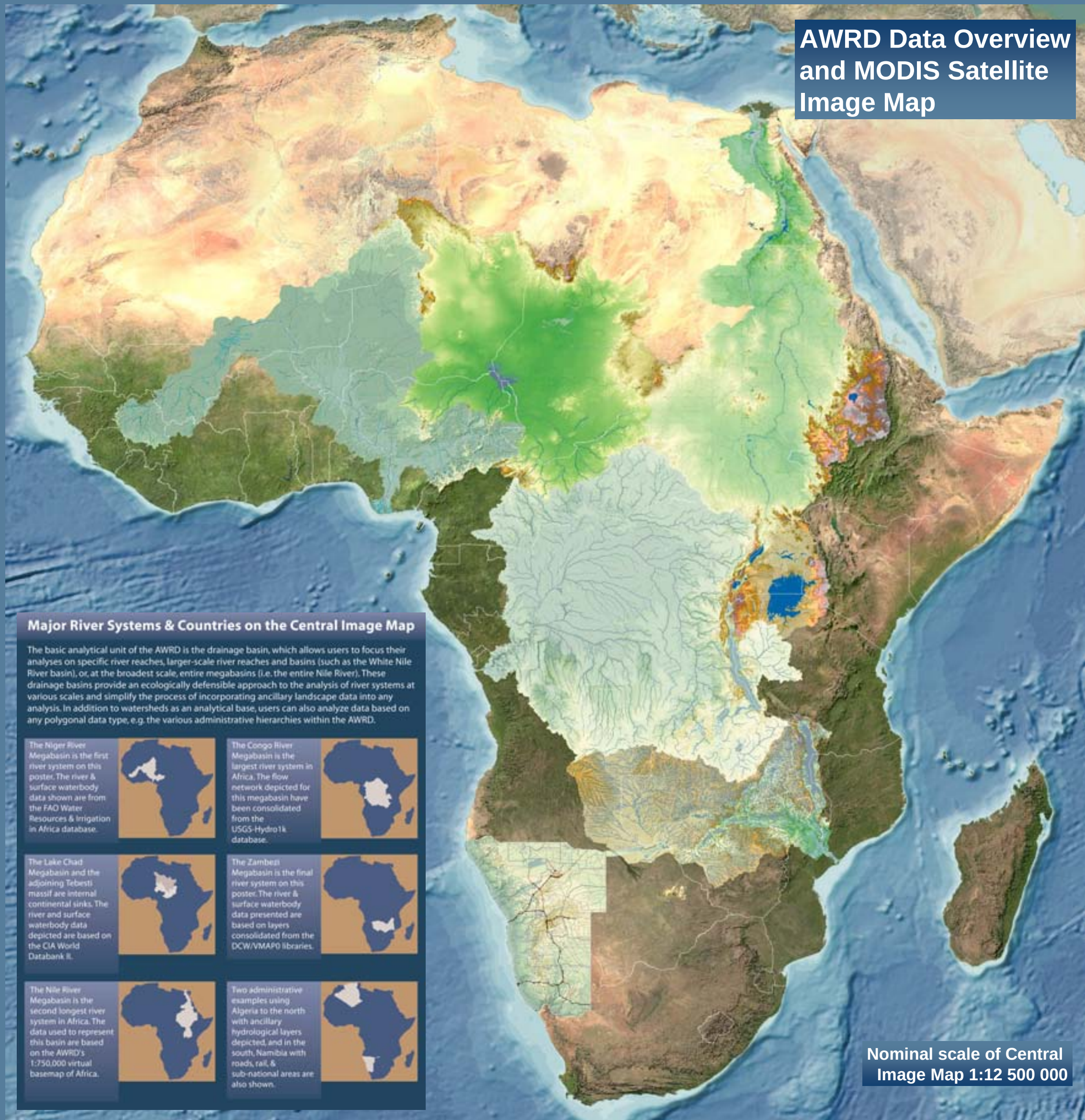
In addition to greatly expanding the data that can be viewed and analyzed, the AWRD also encompasses a much tighter integration of the GIS decision support tools within the interface and now includes robust statistical and spatial locator functionality. Through the AWRD interface users have the ability to access tabular and spatial data viewers, while also gaining the ability to test and visualize complex spatial relationships and conducting robust statistical analyses concerning the spatial extent and distribution of such relationships. Most tools come with simple and advanced options and are fully described in help menus. A set of six applications illustrating various decision support scenarios using the AWRD are available as users aids and training examples.

Discussion

To display and analyze the datasets compiled, the AWRD contains an assortment of new custom-designed applications and tools. Currently, there are six analytical modules within the AWRD interface: 1) a surface waterbodies statistics module; 2) a watersheds statistics module & visualization tool; 3) an aquatic species module; 4) a data classification & statistical analysis module; 5) a metadata module; and 6) various customization & user enhancement tools.

The Surface Waterbodies (SWB) Module is designed to give users of the AWRD quick and easy access to data on surface waterbodies in Africa. In addition, the SWB module provides users with the ability to predict potential SWB yields based on two possible models. The module is designed to work with both polygon and point feature types, and there are currently twenty-three SWB layers resident within the AWRD archive.

The Watershed Statistics Module and related analytical tools represent perhaps the most comprehensive and intensive programming development undertaken with respect to the AWRD interface. This module offers a wide variety of tools specifically designed to analyze and visualize watersheds. These tools take advantage of the hydrologic relationships between watersheds and use these relationships to identify which watersheds are upstream, which are downstream, and which make up the overall flow regime and/or megabasin.



Major River Systems & Countries on the Central Image Map

The basic analytical unit of the AWRD is the drainage basin, which allows users to focus their analyses on specific river reaches, larger-scale river reaches and basins (such as the White Nile River basin), or, at the broadest scale, entire megabasins (i.e. the entire Nile River). These drainage basins provide an ecologically defensible approach to the analysis of river systems at various scales and simplify the process of incorporating ancillary landscape data into any analysis. In addition to watersheds as an analytical base, users can also analyze data based on any polygonal data type, e.g. the various administrative hierarchies within the AWRD.

The Niger River Megabasin is the first river system on this poster. The river & surface waterbody data shown are from the FAO Water Resources & Irrigation in Africa database.

The Congo River Megabasin is the largest river system in Africa. The flow network depicted for this megabasin have been consolidated from the USGS-Hydro1k database.

The Lake Chad Megabasin and the adjoining Tebesti massif are internal continental sinks. The river and surface waterbody data depicted are based on the CIA World Databank II.

The Zambezi Megabasin is the final river system on this poster. The river & surface waterbody data presented are based on layers consolidated from the DCW/VMAP0 libraries.

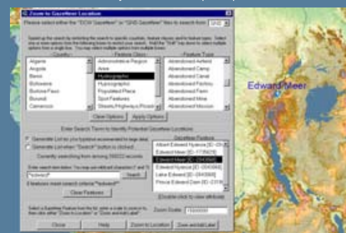
The Nile River Megabasin is the second longest river system in Africa. The data used to represent this basin are based on the AWRD's 1:750,000 virtual basemap of Africa.

Two administrative examples using Algeria to the north with ancillary hydrological layers depicted, and in the south, Namibia with roads, rail, & sub-national areas are also shown.

The Aquatic Species Module provides users with the ability to spatially represent and visualize the distributions of aquatic species, identify all species within a particular area, and to potentially access a large amount of descriptive information on those species via the internet. Thematically, this module provides users with species locations from the reference database, distribution maps based on a watershed model, and broader containment maps from a administrative data layer.

The Data Classification & Statistical Analysis module has four main analytical components which allow users to: generate summary statistics for any set of records; calculate a range of twelve probability distributions; classify and rank features according to a wide variety of simple and complex query functions; and provides a powerful method for analyzing relationships between data via linear regression.

In addition to providing an HTML based metadata documentation module meeting ISO international standards, the AWRD also contains several additional statistical, data visualization, and spatial referencing tools which enhance the overall analytic and data output capabilities of the AWRD.



Conclusion

The AWRD is a GIS based analytical platform that allows users to visualize and analyze the complex hydrological and ecological relationships within specific river reaches, larger-scale river basins, or entire megabasins. Thus, the AWRD can help improve or ease fishery or integrated management decisions. The AWRD builds on an established body of work, and strategies are currently being developed to promote research, education, training and decision-making, using the AWRD. There are over one hundred and fifty data layers currently compiled in the AWRD data archive and great efforts were taken to make this data viewable and comparable. The AWRD includes three full continental-scale watershed models based on different minimum resolutions, and while users can analyze river systems based on a drainage basin approach, they can also choose to analyze additional models, feature data types, and ancillary data. Potential enhancements to the AWRD include: a river systems network module; a water demand and irrigation analyzer; a run-off and flood predictor; and a base map viewer and output module. Other possible developments include: an on-line collaboration and data maintenance system; and the eventual global expansion of relevant data layers.

The African Water Resource Database (AWRD) is a set of data and custom-designed tools, combined in a geographic information system (GIS) analytical framework aimed at facilitating responsible inland aquatic resource management with a specific focus on inland fisheries and aquaculture. It thus provides a valuable instrument to promote food security.

The AWRD data archive includes an extensive collection of datasets covering the African continent, including: surface waterbodies, watersheds, aquatic species, rivers, political boundaries, population density, soils, satellite imagery and many other physiographic and climatological data. To display and analyse the archival data, it also contains a large assortment of new custom applications and tools programmed to run under version 3 of the ArcView GIS software environment (ArcView 3.x).

The database allows integration of different types of information into a cohesive program that, because of its visual nature, is easy to understand and interpret. Creative applications of these tools and data could deepen our understanding of inland aquatic resource management and be of immediate value in addressing a wide variety of management and research questions.

The AWRD was designed based on recommendations of the Committee on Inland Fisheries for Africa (CIFA) and is both an expansion and an update of an earlier project led by the Aquatic Resource Management for Local Community Development Programme (ALCOM) entitled the "Southern African Development Community Water Resource Database" (SADC-WRD).

The AWRD publication is organized in two parts to inform readers who may be at varying levels of familiarity with GIS and with the benefits of the AWRD. The first part describes the AWRD and is divided into two main sections. The first presents a general overview and is addressed to administrators and managers while the second is written for professionals in technical fields. The second part is a "how to" supplement and includes a technical manual for spatial analysts and a workbook for university students and teachers.

The primary AWRD interface, toolsets and data integral to the function of the AWRD are distributed in two DVDs accompanying part 2 of this publication, and are also available for download from FAO's GeoNetwork and GISFish GIS portals. A more limited distribution of the above primary database/interface, but divided among ten separate CD-ROMs, is available upon request from the Aquaculture Management and Conservation Service of FAO. Also, high resolution elevation datasets and images amounting to 38 gigabytes are available upon request.

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