THE AFRICAN WATER RESOURCE DATABASE

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ABSTRACT

The African Water Resource Database (AWRD) is a Geographical Information System (GIS) that is an expansion and enhancement of the work contained in ALCOM's Water Resource Database (WRD) for the SADC Region, which has been extended to cover the entire African continent. The core datasets which populate the AWRD include: various depictions of surface water bodies; multiple watershed models; aquatic species; rivers; administrative boundaries; population density; soils; satellite imagery; and many other physiographic and climatological data types. To display and analyse these data, the AWRD contains an assortment of new custom-designed applications and tools. These tools are designed to facilitate integrated water resource management and planning, as a means of promoting the responsible management of inland aquatic resources and increasing food security. Currently, there are six sets of analytical modules and tool sets which comprise the core of the AWRD: 1) a surface waterbodies statistics module; 2) a watersheds statistics module and selection tool; 3) an aquatic species module; 4) a data classification and statistical analysis module; 5) a metadata module; and 6) various customization and user data enhancements tools. This last set of tools contains several additional statistical, data visualization, and locational referencing tools which enhance the overall analytic and data output capabilities of the AWRD. Through the AWRD's main interface, users will maintain 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 to users as examples and aids to training. Potential future enhancements to the AWRD include: a river systems analytical module; a water demand and irrigation analyzer; a run-off and flood predictor; and a basemap viewer and output module. Other possible enhancements include the development of: an on-line collaboration and data maintenance system; an internet map server; and the eventual global expansion of relevant data layers.

1. INTRODUCTION

1.1 General background

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 conceptualization for the AWRD is based on groundwork laid by a project entitled the "SADC Water Resource Database (WRD)" coordinated by the Aquatic Resource Management for Local Communities Development Programme (ALCOM) for the Southern African Development Community (SADC) region. The AWRD represents both the continuation and enhancement of the body of work resulting from ALCOM's earlier efforts. Development of the AWRD is a work in progress being carried out under the guidance of the Inland Water Resources and Aquaculture Service (FIRI) of the Food and Agriculture Organization of the United Nations (FAO).

Starting in 1992, ALCOM began conducting pilot activities in the member states of SADC. The purpose of these activities was the demonstration of new techniques, technologies and methodologies for improved water resources management at both the national and local levels.

Developed in conjunction with SADC host country institutions and other local collaborators, one of the first major outputs based on these activities was the SADC surface waterbodies database (SADC-SWB). The SADC-SWB was, and still is, the most comprehensive database of surface waterbodies available for the SADC region. However, as the overall goal of ALCOM is the enhancement of standards of living for rural populations through the practice of improved water resource management, it became apparent that the overall utility of the SADC-SWB could be significantly enhanced by the development of an interface to help maintain the database and its integration with additional datasets, that together would support spatially-based data retrieval and analysis using a GIS.

The overall aim of the SADC-SWB was to provide fisheries and water resource managers with the means of producing and manipulating digital aquatic species distribution maps. The production and analysis of such maps provides local managers with the ability to assess the fish species potentially present within a certain catchment, and thereby identify those areas to be recommended for the sustainable stocking of dams and rivers. It was postulated that the adoption of such sustainable management practices would be a key factor influencing ALCOM's ability to achieve its stated goal.

By late 1995, the conceptualization of what was to become known as the SADC Water Resources Database (WRD) was completed and its development was instituted in early 1996. As originally designed, the SADC-WRD was to be based on the integration of four principal databases: a Surface Water Body database; a Watershed database; a River database; and an Aquatic Species Distribution database. With the exception of the SADC-SWB, which had already been formalized, ALCOM also needed to develop the watershed, river, and aquatic species databases before the SADC-WRD could be realized.

In order to minimize the duplication of effort and maximize the use of locally available resources, ALCOM enlisted the support of three primary collaborators in addition to host country institutions within SADC during the overall development of the SADC-WRD. These three organizations were the Southern African Regional Programme Office (SARPO) of the World Wide Fund for Nature (WWF); the SADC Food Security and Technical Advisory Unit of FAO which was later folded into the nascent SADC Regional Remote Sensing Unit (SADC-RRSU) and lastly, the JLB Smith Institute of Ichthyology (currently known as the South African Institute for Aquatic Biodiversity). Respectively, these organizations either co-funded the development of, or contributed extensive baseline datasets for: the Watershed; Rivers; and, Aquatic Species component databases of the SADC-WRD.

Throughout a lengthy development cycle of almost three years, ALCOM maintained overall coordination of the effort. This responsibility included both the design and development of each database component, as well as their programming and integration via a central Relational Database Management Systems (RDBMS)/GIS interface (Johnson, *et al* 1998; Verheust, *et al.* 1998a ; Verheust, *et al.* 1998b).

The first draft release of the SADC-WRD took place in the first quarter of 1999, and was followed by a general release of both a CD and on-line version (http://www.fao.org/fi/alcom/wrd.htm) during the fourth quarter of the same year. The main sources of funding for the development of the SADC-WRD were: the Belgian Agency for Development Co-operation (BADC); FAO; and WWF.

As released, the SADC-WRD was much more than the sum of its component databases. It was in fact designed to be a data management and analysis interface supporting fisheries and general water resource management. The interface combined RDBMS modules using turn-key database software with a choice of simple mapping programmes for spatial visualization, and did not require the use of a major GIS software package. Briefly, the interface enabled: the visualization of upstream and downstream watersheds and aquatic species distributions; the retrieval of spatial statistics specific to a watershed or surface waterbody, and the calculation of various related statistics based on aquatic species, elevation, or climatological datasets; the output of selected data records and related statistics for a single watershed, an upstream and/or downstream watershed regime, or a larger megabasin for further analysis; and lastly, the straightforward visualization of data from the four component databases onto either country specific basemaps, a watershed, or a drainage megabasin. Additionally, through the interface, users could access all the attributes of the harmonized database components of the WRD, to retrieve and manage data ranging from surface water bodies, rivers, fish species, bibliographic records, a mailing list, and many other water and fisheries-related resources.

Three versions of the tool were initially developed and released. The first used basic commercial software, i.e. Lotus Approach© and Mapviewer©. The second depended on software developed with public funding and packages that were nominally within the public domain, i.e. dBaseIII and Windisp3, while the third version was an HTML Browser-based version for access via the Internet. Overall, the functionality of the tool tended to decrease as one moved from the commercial, through the public-domain, down to the Internet-based interface.

The WRD has been used by Fisheries SADC and National Departments, Water Departments, International Development Agencies and NGO's. It has been mainly used for localized fisheries management, training and education and assessment of related water issues, e.g. as an input to flood monitoring in Mozambique.

Despite the overall success of the SADC-WRD and the ground-breaking functionality of the interface, the SADC-WRD suffered from a number of limitations. The most obvious limitation was the self limiting nature of a SADC focus for the tool. While not always of concern, this focus did, in some cases, prevent a holistic assessment of certain water-related issues that could be addressed using a basin or watershed approach. Outweighing this limitation, however, were those which resulted from the choice of format made for the overall modules of the interface, and perhaps more importantly, the format(s) used to store spatially referenced information.

Specifically, over time it came to be acknowledged that this latter choice of spatial formats was potentially preventing users from utilizing the data contained in the WRD for purposes not primarily accommodated through the interface, and was negatively impacting the onward dissemination of the data. Due to these factors, within two years of its release, it was recognized that a major revision of the SADC-WRD was necessary.

However, as noted by the SARPO-WWF effort to expand the Watershed database component of the WRD during 1999, the modifications necessary to overcome the above limitations would strain the institutional capacities of ALCOM and its partners, and given the geographic scope of the undertaking would be non-sustainable. Accordingly, in the third quarter of 2001 FIRI set out to enhance and expand the SADC-WRD to cover continental Africa and the island states. The expanded SADC-WRD is entitled, the "African Water Resource Database" (AWRD).

1.2 Objectives

The main objective of the AWRD effort 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 living aquatic resources and increasing food security.

2. MATERIALS AND METHODS

2.1 Spatial data

In addition to the SADC-WRD data baseline, the core datasets which populate the AWRD have been expanded continentally and the geographic data within the WRD was reformatted into the ESRI Shapefile[1] format. As currently structured, with the exclusion of the 168 ortho-rectified LandSat Thematic Mapper (OrthoTM) satellite images, the AWRD archive currently contains over 1.6 gigabytes of data comprised of over 75 unique data layers. The core data layers include: various depictions of surface water bodies; multiple 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 1:1,000,000 to 1:5,000,000 for vector data, and a nominal resolution of 1 to 5 kilometers for raster data.

Table 1. Summary of AWRD Component Databases.

Name of Database Component	Types of spatial feature representation						
	Annotation	dBase/Event	Image	Line	Point	Polygon	Raster
Surface Waterbody Component	-	-	-	-	6	5	-
Watershed Model Component	-	-	-	-	-	5	-
Rivers and Drainage/Flow Component	-	-	-	6	2	-	-
Aquatic Species Component	-	-	-	-	1	2	-
Gazetteer/Named Location Component	-	1	-	-	1	-	-
Ancillary Vector Component	1	-	-	11	7	15	-
Ancillary Raster Component (Primary)	-	-	-	-	-	-	7
Ancillary Raster Component (Sample)	-	-	-	-	-	-	44
Ancillary Image and Map Graphic (Primary)	-	-	8	-	-	-	-
Ancillary Image and Map Graphic (OrthoTM)	-	-	160	-	-	1	-
Total for all Component Databases	1	1	168	17	17	28	51

[1] The ESRI "Shapefile" format is one of the most popular and widely available spatial data format used in GIS applications. Although proprietary to ESRI, the Shapefile format is in general compatible with "Open-GIS" standards for the exchange of vector spatial data.

Terminology: VMAP0 (Vector Map Level 0); DCW (Digital Chart of the World); WCMC (World Conservation Monitoring Centre); NIMA (U.S. National Imagery and Mapping Agency); ESAD (Earth Science Applications Directorate);ORTHO (orthographically-rectified, i.e. flattened or adjusted for elevation changes); MODIS (Moderate resolution imaging spectroradiometer sensor aboard the Terra satellite);GTopo30 (Global 30 arc second topography database); ETOPO2 (global elevation data base gridded at 2-minute resolution); DEM (Digital Elevation Model).

Organizationally, and in keeping with the format established for the SADC-WRD, the data contained within the AWRD can still be divided into separate database components, including: a Surface Waterbody component; a Watershed component; a River component; and an Aquatic Species component. However, in addition to these traditional database components, the AWRD also contains four new database components: the Gazetteer component; the Ancillary Vector component; the Ancillary Raster component; and lastly, the Ancillary Image and Map Graphic component. Together these eight database components have been expanded to provide coverage of continental Africa and Madagascar, as well as broadened to provide a richer variety of datasets from more diverse data sources. Table 1 provides a summary of AWRD component databases.

The specific data layers which have been either improved upon and/or expanded to the continental level for the AWRD include seamless: 1:1m scale surface waterbodies (SWB), rivers, inundated areas, and related hydrological features rigorously harmonized between the VMAP0 and DCW data libraries; various watershed delineations and models; WCMC wetlands; as well as various other SWB and 1:5m scale river data layers obtained from other sources. In addition to these seamless baselines, the AWRD also contains seamless translations of: almost all the other VMAP0 data layers including contours, populated places, roads, etc.; the complete annotation contained within all of the various layers of the DCW; the DCW gazetteer; a spatially "corrected" version of NIMA's gazetteer database including both diacritical and non-diacritical names; the complete ESAD OrthoTM 30m image archive; an 3d enhanced MODIS continental image mosaic; integrated GTopo30 terrestrial and ETOPO2 bathymetry DEM data; various multi-scale shaded relief image map backdrops; and lastly, a 1:750,000 scale virtual basemap of VMAP0 data with shaded relief for the continent.

Figure 1 provides an overview of some of the spatial data compiled for the AWRD. The data presented in this figure are depicted against a variety of the pre-classified shaded relief image map backdrops superimposed over the enhanced MODIS continental image mosaic. Data for the Niger, Lake Chad, Nile, Congo, and Zambezi megabasins are highlighted.

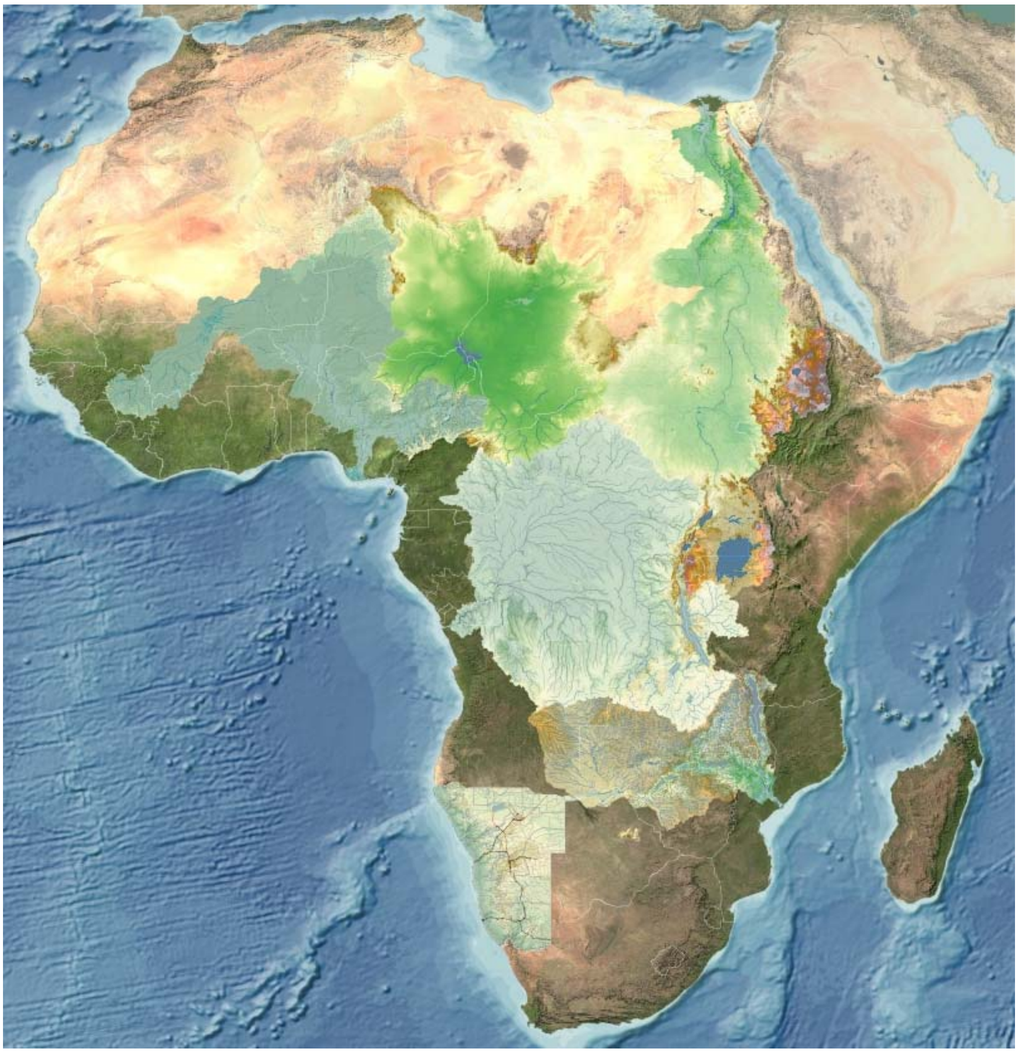

Figure 1. AWRD data overview and MODIS satellite image map.

<table>
<tr><td colspan="4">The basic analytical unit of the AWRD is the drainage basin or watershed, which allows users to focus their analyses on specific river reaches, larger-scale river systems (i.e. the White Nile River), 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 data into any analysis. In addition to watersheds units, users can also analyze data based on any polygonal, e.g. administrative boundaries, or point data types.</td></tr>
<tr><td>The Niger River Megabasin is the first river system depicted on Figure 1. The river & surface waterbody data shown have been integrated from the FAO Water Resources & Irrigation in Africa database.</td><td></td><td>The Congo River Megabasin is the largest river system in Africa. The flow network depicted for this system have been derived from the USGS-Hydro1k database for integration in the AWRD.</td><td></td></tr>
<tr><td>The Lake Chad Megabasin and the adjoining Tebesti massif to the north are internal continental sinks. The river and surface waterbody data depicted are based on the CIA World Databank II which for Africa are at a scale of 1:3m.</td><td></td><td>The Zambezi Megabasin is the final river system on Figure 1. The surface waterbody & river data presented are based on layers rigorously harmonized from the DCW/VMAP0 libraries.</td><td></td></tr>
<tr><td>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.</td><td></td><td>Two examples using Algeria to the north with ancillary hydrological layers depicted, and in the south Namibia with roads, rail, & sub-national areas show the use of administrative polygons.</td><td></td></tr>
</table>

2.2 GIS interface

Programmatically, the main goal of the AWRD development effort was the migration of the original WRD from a data viewer and manager to a true decision support tool. To this end, the overall functional capabilities of the interface were increased and then reprogrammed into ESRI's ArcView[2] software package. This resulted in a much tighter integration of the GIS decision support tools within the interface, allowing robust statistical, visualization, and spatial locator functionality. As well, in addition to providing enhanced tools specifically designed to address a wide variety of management issues pertaining to spatial characteristics of inland fisheries management and planning, the AWRD can now reference five different data types including: shapefiles; grids; images; graphical data; and descriptive documents.

Due to the enhancements made to the AWRD interface, users can now access through a single interface not only tabular and spatial data viewers for the creation of spatial distribution maps, but can also 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. 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. Most of the analytical modules and tools come with simple and advanced options and are fully described in help menus.

Much of the functionality of the AWRD is premised on so-called "Tell-Me" type queries, where a single feature is selected by the user, and this feature is then used in turn to potentially select features from multiple other databases and then report on them. Within the AWRD, the results of such spatial "Tell-Me" queries include a various mix of tabular reports, statistical calculations and distributions, and of course, various spatial visualizations. These "Tell-Me" queries are then augmented by "Show-Me" type queries in which the user can visualize the distribution and generate maps depicting various spatial phenomena across the landscape based on a combination of analytical and tabular criteria.

Since the AWRD interface is based on a GIS rather than a RDBMS, both spatial and tabular queries can be accommodated with users posing "Show-Me" and "Tell-Me" queries seamlessly if not simultaneously. This allows for a much tighter integration between the component databases and the interface, the result of which is a distinct blurring of the lines between what were in the SADC-WRD component specific data viewers. In particular, although there are items within the AWRD that can still be referred to as Aquatic Species, Watershed, and SWB viewers, a user can now move seamlessly between such items and, perhaps more importantly, access all of the AWRD's many database components and tools from within a single integrated interface. Table 2 provides a brief overview of the differences between the SADC-WRD and the AWRD.

[2] Environmental Systems Research Institute's (ESRI) ArcView software is a GIS programme used worldwide by thousands of different organizations for handling, managing and analyzing geographic information; reference www.esri.com.

Table 2. Expansion and Enhancements to the SADC-WRD.

Topic	**SADC Water Resources Database (SADC-WRD)**	**African Water Resources Database (AWRD)**
Authors	Verheust and Johnson, 1999	Jenness, Dooley and Aguilar-Manjarrez, 2003
Spatial Coverage	Southern African Development Community	Continental Africa, Madagascar and Island States
Foundation GIS or Thematic Mapping software employed	Edition1: commercial, MapViewer {time-out} Edition2: public domain, WinDisp3. Edition3: HTML browser based.	ESRI ArcView version 3.3 and Spatial Analyst. Note: Spatial Analyst is only required for the production of revised statistics & advanced grid functionality.
Vector Data Format(s)	Proprietary, BNA, flat ASCII	ESRI Shapefile {OpenGIS}
Grid Data Format(s)	WinDisp-IML and IDRISI {OpenGIS}	ESRI Grid, proprietary but export to ASCII/BIL
RDBMS Data Format(s)	Lotus Approach, dBaseIII, ASCII text file	DBaseIII
Programming Software	Approach-Macro's, n/a, QBasic	Avenue
Number of database components/data layers	4 database components/~10 unique data layers	8 database components/40+ unique data layers
Surface water bodies Database Component	2 data layers	10 data layers
Watershed Database Component	1 watershed model	5 watershed models
Rivers Database Component	1 data layer	6 data layers
Aquatic species	1 data layer	1 data layer, and 2 web based resource "layers"
Spatial Reference locator/Gazetteer	No Provision/~15,000 named surface waterbodies	Detailed/~15,000 named surface waterbodies and ~800,000 other named locations
Satellite Reference Images and Map Graphics	Not Provided	MODIS Continental, OrthoTM, 2x1:750,000-1:55,000,000 virtual base maps, multiple pre-classified relief and shaded image backgrounds

Terminology: SADC (Southern African Development Community); WRD (Water Resources Database); ESRI (Environmental Systems Resource Institute); GIS (Geographic Information System); HTML (Hyper-text markup language); ASCII (American Standard Code for Information Interchange); BNA (an early vector graphics data format); RDBMS (Relational database management system); BIL (Band Interleave by Line raster data format); MODIS (Moderate resolution imaging spectroradiometer sensor aboard the Terra satellite).

3. RESULTS

3.1 GIS based tools

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 and visualization tool; 3) an aquatic species module; 4) a data classification and statistical analysis module; 5) a metadata module; and 6) various customization and user enhancement tools.

The Surface Waterbodies (SWB) module (Figure 2) is designed to give users of the AWRD quick and easy access to data on surface waterbodies in Africa. The module is designed to work with both polygon and point feature types, and there are currently eleven SWB layers resident within the AWRD archive.

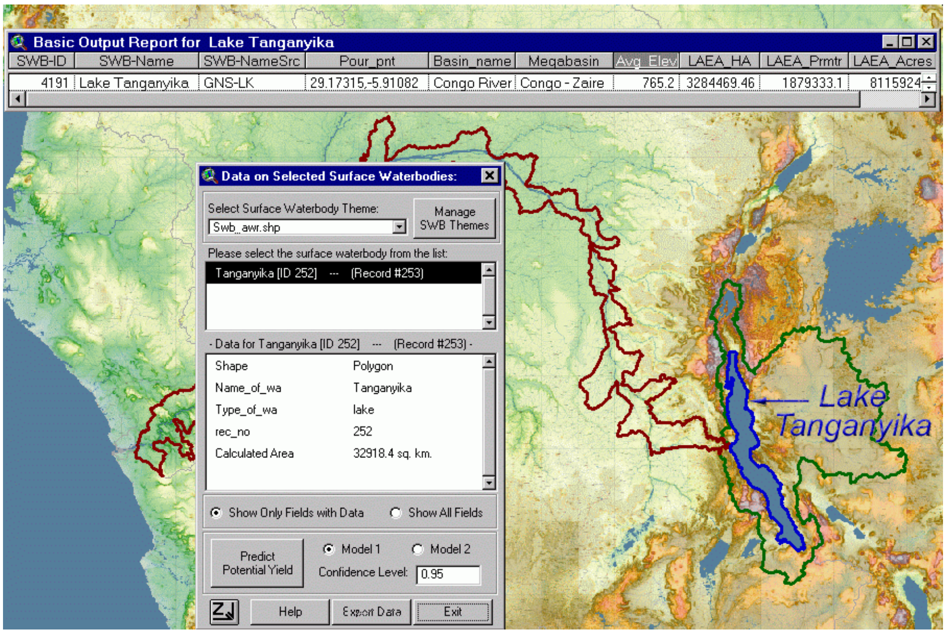

Figure 2. Surface Waterbodies module.

The Watershed Statistics Module and related analytical tools (Figure 3) represent perhaps the most comprehensive and intensive programming development undertaken regarding the interface of the AWRD. 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. The user can choose one of five watershed delineations to work with.

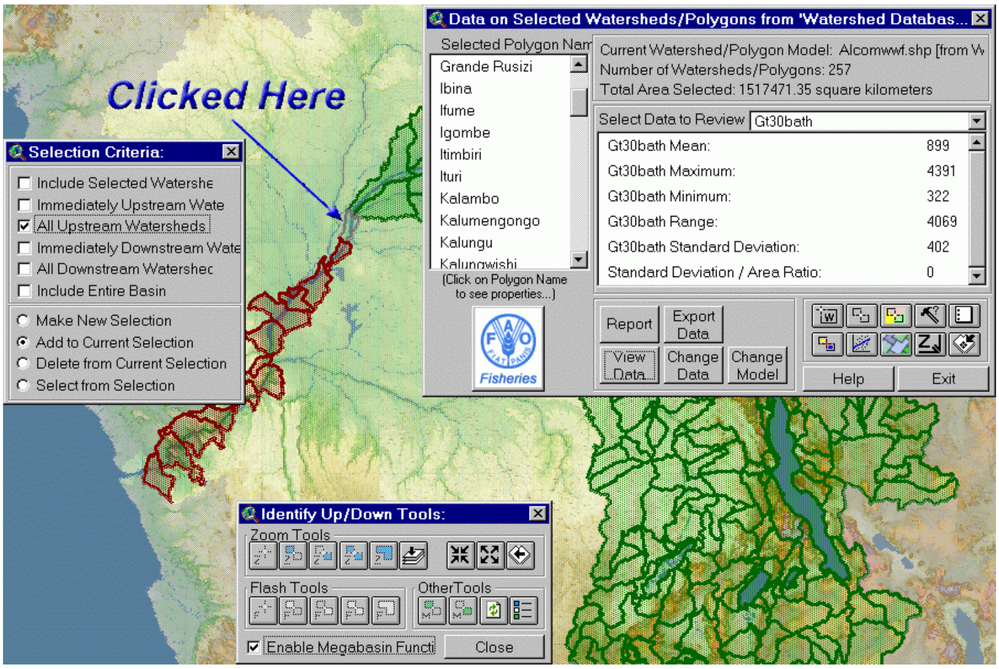

Figure 3. Watershed statistics module.

The Aquatic Species Module (Figure 4) 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 and either potential distribution maps based on a watershed model or broader containment maps from a administrative data layer.

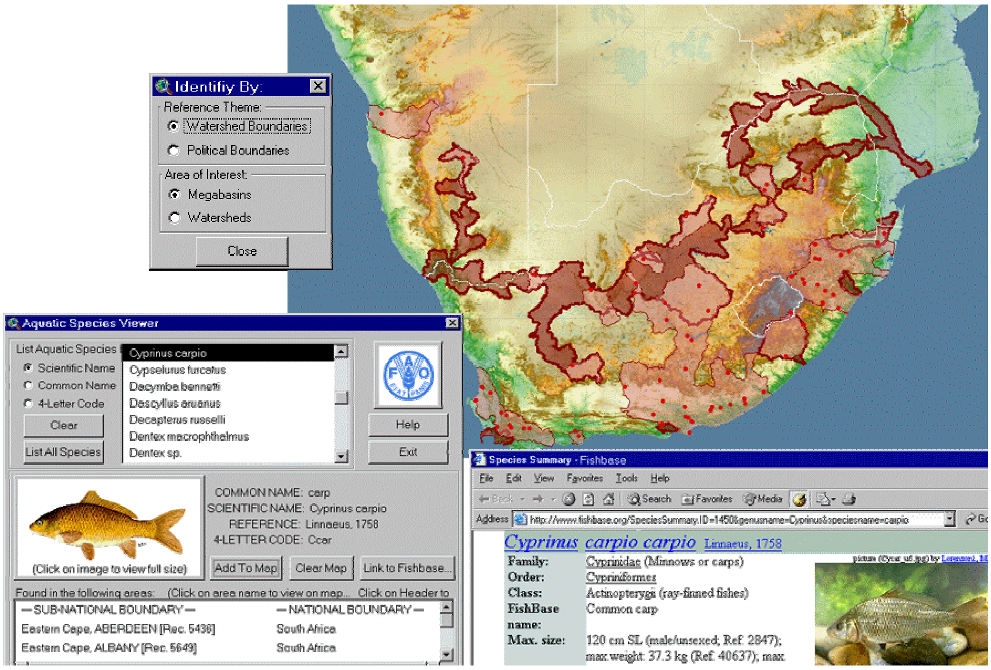

Figure 4. Aquatic Species Module.

The Data Classification and Statistical Analysis module (Figure 5) has four main analytical components which allow users to: generate summary statistics for any set of records; calculate probabilities based on a choice of twelve different 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.

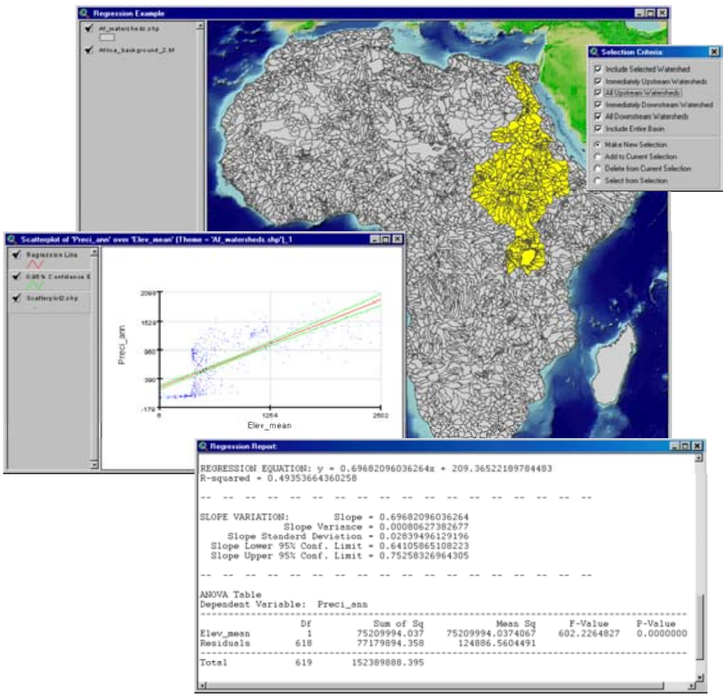

Figure 5. Data Classification and Statistical Analysis module

The AWRD provides a new custom-designed metadata collector and visualization tool and the metadata used follows the ISO 19115 metadata standard. This tool allows the storage of metadata for all datasets archived in the AWRD and it is also possible to add new datasets and complete a metadata form. This tool also generates an HTML summary report of the metadata for display in a web browser as shown in Figure 6. The HTML format used is identical to that of GeoNetwork, a gateway to spatial information at FAO that is under construction. The AWRD also contains several additional statistical, data visualization, and locational referencing tools including multiple gazetteer and advanced coordinate querying functions which enhance the overall analytic and data output capabilities of the AWRD (Figure 7).

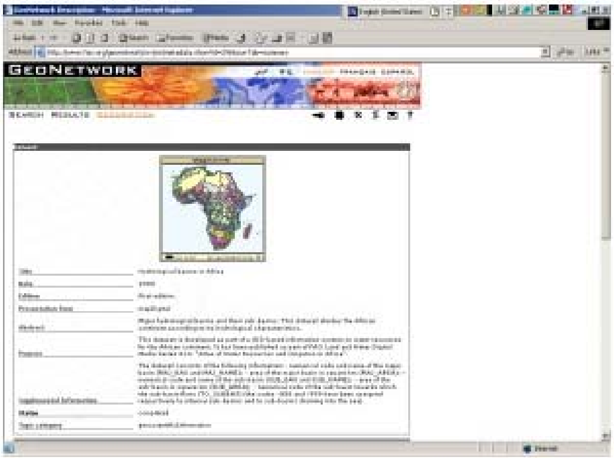

Figure 6. Metadata documentation tool.

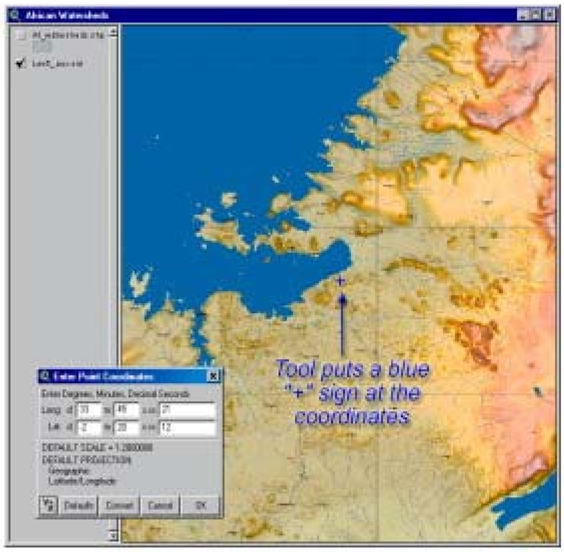

Figure 7. Locational referencing tools.

3.2 Applications

A set of key applications illustrating various decision support scenarios using the AWRD are being developed as user aids and training examples specifically designed to address a wide variety of management issues pertaining to spatial characteristics of inland fisheries and aquaculture. The following three sections provide a brief overview for some of these applications.

3.2.1 Transboundary issues

The AWRD is an excellent means to address 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. The use of alien species may impact areas very far removed from the area originally planned for their use. Figure 8 shows the area that the introduced silver carp species could potentially access once introduced into the Limpopo drainage in southern Africa; a local introduction into coastal Mozambique or highlands of Zimbabwe would provide access to four countries. International codes of practice on alien species, such as the ICES codes of practice (ICES 1995) and the FAO Code of Conduct for Responsible Fisheries, call on users of alien species to notify States that may be impacted by the introduction. The AWRD would provide clear indication of which countries should be notified and which waterbodies may be impacted.

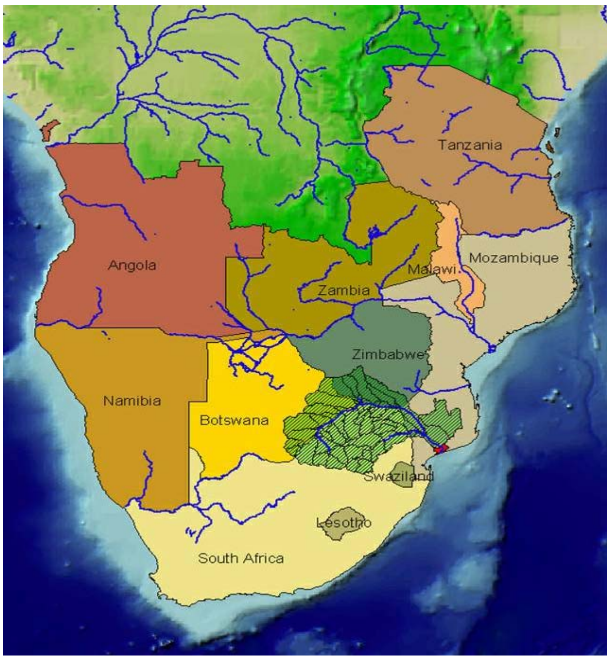

Figure 8. Transboundary issues.

3.2.2 Spatial models for the evaluation and management of inland fisheries

The SWB module is being used to develop and validate empirical spatial management and evaluation models for African water bodies: lakes, reservoirs, swamps and lagoons, from estimates of potential yield (PY) and potential yield per unit area (PYPUA) taken from the FAO lakes and Rivers Database (MRAG, 1997), and GIS-derived *a priori* hypothesized explanatory variables: water body morphology, demography, climate and catchment characteristics. The analytical function developed for the SWB module to estimate potential fish yield represents the continuation of the work resulting from Kapetsky (1997) and Halls (1999) earlier efforts. Essentially, using the SWB module it is possible to estimate potential fish yields based on one of two models developed by Halls. Model 1 uses only the surface area of a waterbody, while Model 2 uses both the surface area and the mean annual air temperature of the drainage basin. Two of the point data layers and the three principle polygon layers of the SWB-DBC can currently be used for the estimation of potential fish yields. A potential fish yield analysis is started by clicking on the "Predict Potential Button" displayed on the viewer in Figure 9, by clicking on any water body (in this case Lake Tanganyika) the output results similar to those displayed in Figure 9, below. Basically, the potential yield report provides users with detailed information on the model applied, the data and values used to generate the predicted yield output, as well as the results in the original natural log values.

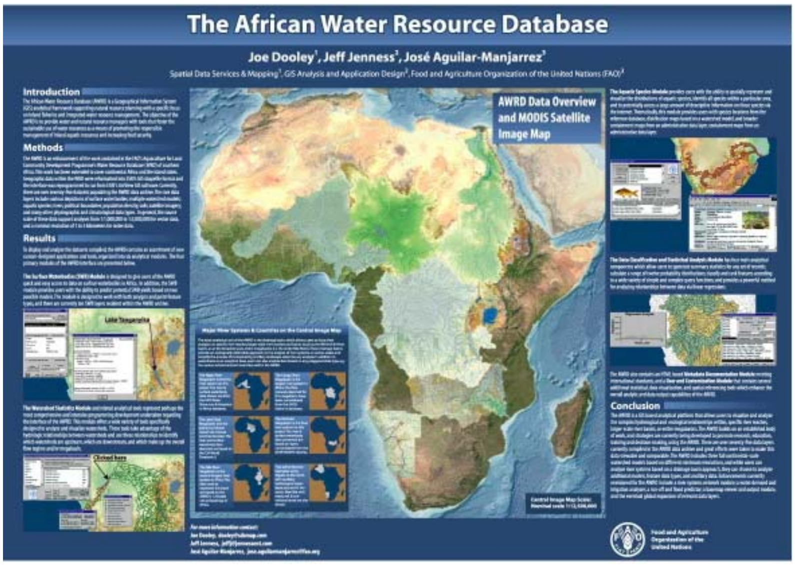

Figure 9. Predicting potential fish yield.

3.2.3 Internet map server

The Fishery Department of FAO, following the great demand to integrate large amount of data available in FAO and the need to provide spatial location to data related to the study of fishery resources, is currently involved in designing and developing a GIS component using Internet based technology. Its development will take advantages of various mechanisms to set-up spatial standards and will be integrated with other components presently available as part of the Fishery Global Information System (FIGIS) of the FAO (http://www.fao.org/figis/index.jsp). In this regard, the AWRD is currently being utilized to help construct a procedure to illustrate the spatial distribution of aquatic species. The procedure will produce a series of detailed GIS layers that will be incorporated into a GIS database containing maps of distribution of fishery resources currently available for the most important species, both oceanic and inland. Figure 10 shows the first stages of its development.

Figure 10. Internet map server for the AWRD.

4. CONCLUSIONS

There are over seventy-five 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 choose to analyze additional models, feature data types, and ancillary data. Currently, there are six analytical modules within the AWRD interface.

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.

Some examples of the benefits that the use of the AWRD could provide are: improved inland fisheries and aquaculture management; improved inland fisheries and aquaculture statistics; improved information for inland fisheries and aquaculture planning; sustainable use of natural resources; support decision-making aimed at: assessing the state of the inland fishery environment (e.g. climatic changes and human-induced changes, introductions, watershed vulnerability); 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 management of watersheds.

Efforts are being made to assess the use some of the core datasets of the AWRD (e.g. watersheds) to produce a consistent standardized hydrological database that can be distributed under copyright in the public domain. There are some opportunities for synergies between the standards that will be proposed through this AWRD effort within FAO and also with several task forces set-up by the United Nations Geographical Information Working Group (UNGIWG; http://www.un.org/Depts/Cartographic/english/htmain.htm), as it is one of the biggest users of spatial data within the UN system. The initial focal scale for these hydrological datasets will be from 1:1 million to 1:5 million.

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 basemap 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 AWRD will be made available in late 2003 as an FAO technical publication and a set of CD-ROM data disks.

5. ACKNOWLEDMENTS

Special thanks are due to Dr. Devin Bartley (Senior Fishery Resources Officer, Inland Water Resources and Aquaculture Service, Fisheries Department, FAO), and Mr. Fabio Carocci (Research Assistant, Marine Resources Service, Fisheries Department, FAO) for their contributions on the applications of the AWRD, specifically for the transboundary issues and the internet map server sections of this paper respectively.

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THE AFRICAN WATER RESOURCE DATABASE

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Biography

Dr. José Aguilar-Manjarrez is a Fishery Resources Officer (Inland Fisheries GIS) at the Inland Water Resources and Aquaculture Service (FIRI) at the Food and Agriculture Organization of the United Nations (FAO) in Rome, Italy.

Dr. Aguilar-Manjarrez has many years of experience on aquaculture planning and management using Geographical Information Systems (GIS). His experience with GIS began with the use of GIS for aquaculture site selection in Tabasco State, Mexico as the basis of his M.Sc. dissertation from 1991 to 1992 at the Institute of Aquaculture (IOA) in Scotland. He then carried out a Ph.D. dissertation from 1992 to 1996 at the IOA by developing GIS-based models for planning and management of coastal aquaculture in Sinaloa state, Mexico.

From 1996 to 1998 he worked with FIRI, first as a visiting scientist with focus on the use of GIS for estimating fish farming potential in Africa, and later as a consultant on spatial modelling of inland fishery potential. From November 1998 to July 2001 he worked with FAO's World Agricultural Information Centre (WAICENT) and designed and developed FAO's GIS map repository and carried out a GIS study to assess locations that have potential for the production of Bambara groundnut across the world.

Prior to joining FAO from 1990 to 1991, he worked in Mexico city as an aquaculture consultant at a private consulting company with focus on environmental impact studies of navigation ports and shrimp farming site selection for the states of Sinaloa, Chiapas and Veracruz and then worked at the Bank of Mexico (FIRA) also as an aquaculture consultant developing feasibility study reports for shrimp farming in Sinaloa.

Dr. Aguilar's technical responsibilities in FIRI focus largely on developing methodologies, technical guidelines and draft technical papers, reviews and training materials on inland fishery management and GIS applications to inland fisheries and aquaculture.