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STATUS AND DEVELOPMENT OF THE WATER RESOURCE DATABASE FOR AFRICA

SUMMARY

The purpose of this paper is to provide a summary of the status and development of the Water Resource Database in order to determine its use and future development. The present work is an expansion and enhancement of the work by ALCOM's Water Resource Database (WRD) for sub-equatorial Africa. This new WRD has been extended to cover the entire African continent. The core datasets which populate the WRD now include: various depictions of surface waterbodies, multiple watershed models; aquatic species; rivers; administrative boundaries; population density; soils; satellite imagery; and a host of other physiographic and climatological data types. To display and analyze the data, the AWRD contains an assortment of new custom-designed applications and tools. These tools are aimed at facilitating responsible inland aquatic resource management and thus promote food security. A set of applications that illustrate various decision support scenarios using the WRD are being developed as examples and aids to training. Benefits that can be derived from the use of the AWRD are listed and short-term and long-term developments are proposed along with some suggested actions for consideration by the Committee.

INTRODUCTION

1. It is well recognized that solutions to many of the fundamental issues in the development and management of aquaculture are wholly or partially spatial (e.g., siting, zoning, water quality and quantity, and diseases). Similarly, inland fisheries management has many spatial components such as movements and migrations of resources, definition of fishing grounds, transportation networks, and markets. Habitat loss and environmental degradation are serious issues, and each of these problems has spatial dimensions. Aquaculture and inland fisheries issues are dynamic so that time is an additional factor. The result is great complexity for administrators and managers in attempting to address the issues. In this regard, it is well accepted that GIS, is a technology that can help to clarify the issues and lead to solutions by treating many factors simultaneously in all three spatial dimensions and in time, as well (Kapetsky and Aguilar-Manjarrez, 2002).

2. The purpose of this paper is to provide a summary of the status and development of the Water Resource Database in order to determine its use and future development.

3. The paper is structured as follows: It describes ALCOM's Water Resource Database for sub-equatorial Africa (SADC-WRD), the new Water Resource Database for Africa (AWRD) and then provides a general comparison between the SADC-WRD and the AWRD. The paper then mentions the benefits that can be derived from the use of the AWRD and the development of applications that will illustrate various decision support scenarios using the AWRD as examples and aids to training, it concludes with proposed short-term and long-term developments and some suggested actions for consideration by the Committee.

SADC WATER RESOURCE DATABASE

4. Starting in 1992, ALCOM began conducting pilot activities in the member states of the Southern African Development Community (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).

5. 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 betterment 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 geographic information system (GIS[1]).

6. The overall aim of the SADC-SWB was to provide fisheries and water resource managers with a means of producing and manipulating digital aquatic species distribution maps. The production and analysis of aquatic species distribution maps provides local managers with the ability to assess what fish species are potentially present within a certain catchment, and therefore what species can be recommended for the sustainable stocking of

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[1] A GIS is an integared assembly of computer hardware, software, geographic and personal data designed to acquire, store, manipulate, anaylze, display and report all forms of geographically referenced information.

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.

7. By late 1995, the conceptualization for what was to become known as the SADC Water Resources Database (WRD) had completed, and development of the SADC-WRD 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, to a large degree the ALCOM would also need to develop the watershed, river, and aquatic species databases before the SADC-WRD could be realized.

8. 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 & Technical Advisory Unit of the UN-FAO--which was later folded into the nascent SADC Regional Remote Sensing Unit (SADC-RRSU)-- and lastly, the JLB Smith Institute of Icthyology (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.

9. Throughout a lengthy development cycle of almost three years, ALCOM maintained overall coordination of the effort. A responsibility that 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[2])/GIS interface (for details see: Johnson and Verheust, 1998; Verheust and Johnson, 1998a; Verheust and Johnson, 1998b).

10. 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); the UN-FAO; and WWF.

11. As released, the SADC-WRD was much more than the sum of its component databases. It was in fact designed to be 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 programs 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, a upstream and/or downstream watershed regime, or a larger

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

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.

12. 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.

13. 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.

AFRICAN WATER RESOURCE DATABASE

14. 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 the release of the SADC-WRD, it was recognized that a major revision of the SADC-WRD might need to be considered.

15. However, as an SARPO-WWF led effort to expand the Watershed database component of the WRD in 1999 would highlight, the modifications necessary to overcome the above limitations would strain the institutional capacities of ALCOM and it's partners, and--given the geographic scope of the undertaking--would likely be non-sustainable. Accordingly, in the third quarter of 2001 the Inland Water Resources and Aquaculture Service of the FAO (FAO-FIRI) set out to expand the SADC-WRD continentally while at the same time reformatting the geographic data within the WRD into the ESRI shapefile[3]

[3] ESRI's ArcView is a GIS program used worldwide by thousands of different organizations for handling, managing and analyzing geographic information. As a result, the "shapefile" format is the most popular and widely available spatial data format used in GIS aplications.

format and reprogramming the interface into ESRI's ArcView [http://www.esri.com] software package. The expanded and reformatted SADC-WRD is entitled, the African Water Resources Database (AWRD).

16. The objectives of the WRD are to: (a) Provide fishery managers with powerful tools to analyze and foster the sustainable use of their natural resources, (b) improve the standards of living for rural populations through improved water resource management and (c) provide a medium whereby fisheries, water and terrestrial resource managers can share and evaluate information.

17. To display and analyze data, the AWRD provides an integrated interface which allows the free form access to an assortment of custom-designed applications and tools for use with the ESRI ArcView 3.x software. There are five main data viewers which comprise the core of the AWRD: (1) a surface waterbodies statistics viewer, (2) a watersheds statistics viewer and selection tool, (3) an aquatic species viewer, (4) a data classification & statistical analysis viewer, and (5) a metadata viewer. In addition to these five, there are also several additional statistics and data-viewing tools, and various user customizations that enhance the analytical capabilities of the AWRD. Through these viewers users can interface with core AWRD datasets to develop statistical output, create spatial distribution maps, and lastly, integrate and perform analyses of their own data from within the AWRD.

18. The core datasets which populate the AWRD now include: various depictions of surface waterbodies and rivers; multiple watershed models; aquatic species; administrative boundaries; population density; elevation; bathymetry; soils; satellite imagery; air temperature, and a host of other physiographic and climatological data types.

19. Programmatically, the main goal of the AWRD development effort is the migration of the original WRD from a data viewer and manager, to a true decision support tool. To this end, the AWRD will not only reference five different data types, including: shapefiles; grids; images; graphical data; and descriptive documents, but also provides tools specifically designed to address a wide variety of management issues pertaining to spatial characteristics of inland fisheries management and planning.

20. Through the AWRD's main interface, users will have the ability to access not only tabular and spatial data viewers, but will also gain the ability: to test and visualize complex spatial relationships; and to, conduct robust statistical analyses concerning the spatial extent and distribution of such relationships. All of the tools in the AWRD have been designed to facilitate a broad range of applications and user skill levels. Most tools come with simple and advanced options, and all are fully described in help menus.

COMPARATIVE DIFFERENCES BETWEEN THE SADC-WRD AND THE AWRD

21. The comparative differences between the SADC-WRD and the AWRD are substantive and go beyond the expansion of the core database components continentally. Perhaps the largest difference is the programmatic changes to the interface that move it beyond a data viewing and management tool into the realm of true decision support.

22. Similarly, although the motifs of separate "Database Components" and isolated "Data Viewers" can be used to describe both the SADC-WRD and the AWRD, in reality such

distinctions are much harder to differentiate within the AWRD. For example, the SADC-WRD had four distinct database components, each of which was associated with its own distinct data query and retrieval interface. As such there was both: a Surface Waterbodies Database and a Surface Waterbodies Viewer or interface; a Watershed Database and a Watershed Viewer; the River Database and a Rivers Data Viewer; and lastly, an Aquatic Species Database and an Aquatic Species Data Viewer. Also, the overall interface of the SADC-WRD was again based on macros written to run from the main RDBMS program, i.e. Lotus Approach, with the user choosing one of two mapping packages to display the results of the query spatially.

23. While such a two-step approach may have offered users a choice of mapping packages to use when displaying query results, it limited users to what are called "Show Me" queries. In a Show Me query, a user essentially fills in a RDBMS query form and then the results are "shown" to them on a map. However, because the SADC-WRD was RDBMS driven rather than integral to either a thematic mapping package or GIS, once a user was presented with the mapped results of a query, they could not--from within the interface--take advantage of mouse-clicks directly on the spatial features comprising the mapped result and run a so-called "Tell Me" query. A Tell Me query is essentially the reverse of a Show Me query, where the user selects a spatial feature and is then presented with tabular and/or graphical results that "tell" the user a story based on either: a simple listing of attributes about a single feature; or some complex mix of attributes derived from multiple types of spatial features.

24. Much of the functionality of the AWRD is premised on complex tell-me type queries, where a single feature is selected by the user, and this feature is then in turn used to select features from multiple other databases. Within the AWRD, the results of such spatial tell-me queries include a various mix of: tabular reports, statistical calculations, and of course various interpretive spatial distributions and/or visualizations.

25. 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.

26. Comparatively, the largest difference overall between the SADC-WRD and the AWRD would likely be that a user no longer has an option to choose either a commercial or non-commercial mapping program which can be associated with the interface. Otherwise, all of the database viewers and functions of the SADC-WRD can be correlated to dialogs and tools developed for the AWRD, with the possible exception of the River Database Viewer. However, as both this database component and interface were the least developed of those contained within the SADC-WRD, and were "created to *simply* provide background mapping

facilities for other database components", users should experience no loss in functionality. In fact, given: the tighter integration of the interface; the addition of robust statistical and

spatial locator functionality; and, the greatly expanded number and types of data that can be viewed and analyzed from within the interface, the two products could be said to be related only as regards versioning.

BENEFITS AND APPLICATIONS

27. Some examples of the benefits that the use of the AWRD could provide are:
a) improved inland fisheries and aquaculture management
b) improved inland fisheries and aquaculture statistics
c) improved information for inland fisheries and aquaculture planning
d) sustainable use of natural resources
e) 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
- increasing community level responsibility for management of watersheds.

28. A set of applications that could illustrate various decision support scenarios using the AWRD are currently being developed for the following topics:

(a) Base maps. There are a number of watershed models available, so a decision is being made to propose a hierarchical standard coding scheme for hydrographic features for Africa to use as a standard.
(b) Predictions of potential fish yield. Develop and validate empirical spatial management and evaluation models for African lentic water bodies: lakes, reservoirs, swamps and lagoons from estimates of potential yield and poptential yield per unit area (Kapetsky 1997, Halls, 1999).
(c) Introduction of Aquatic species. Create scenarios with the use of the AWRD to assist in the development of guideliens for the responsible use of genetically alterted (improved) fish and alien (introduced) fish in African aquaculture.
(d) Inventory and management of inland water bodies. A number of statitsics will be derived from a number of water bodies.
(e) Conflict resolution in river basins. Create relevant scenarios that illustrate these conflicts.

PROPOSED DEVELOPMENTS

29. The present version of the AWRD is the result of eight months of work of two consultants and one FIRI staff member. Work began in December 2001. An FAO Technical Paper that will summarize the work done to date is currently being written. It is estimated that it will be released to the general public in the first quarter of 2003. The paper will also include a CD-ROM and or DVD-ROM that will contain the spatial data compiled.

30. Further developments prior to the dissemination of the technical paper include: (a) testing and fine tuning the applications and tools, (b) finalizing the development of applications, including a variety of statistical tests and procedures, (c) field testing and (d) Identify potential applications that can benefit from the use of the AWRD (e.g. integrated irrigation aquaculture).
The following list of activities have been identified for the future development of the AWRD:

Short-term activities (approximately 2 months are required in total):

- Promote a decision on which hierarchical standard coding scheme for hydrographic features can be implemented for Africa and globally; 10 days
- Formalize some existing ArcView tools which have proven generally useful, e.g. a grid surface extension, and a few watershed or river naming and checking tools) as add-ons to the AWRD, as well as, making a function that allows the user to load them up similar to loading any other extension; 8-12 days.
- Improve the statistical tools to handle multiple regression and create additional tools to include: critical values for Normal, Logistic, Binomial, Chi-square distribution as was called for at the recent fisheries symposium in the UK ; 10-15 days
- Create a link to an ArcScripts site; 1 day.
- River Reach/Stretch Compiler: Build a semi-automated river feature connectivity enhancing and naming tool that would allow for the development of river networks. The development of such networks would allow the AWRD to be expanded to include network type analyses and allow various calculations of runoff and river flow, water demand/surplus, flood prediction, pollution/nutrient loading, and discharge; 8 -10 days

Long-term activities (approximately 6 months are required in total):

- Tighter integration of satellite imagery, i.e. MODIS Terra and OrthoTM images, into the AWRD interface. Including the expansion of the interface, such that the user is seamlessly moved between views of the different projections when they have OrthoTM viewing enabled, 8 -10 days for programming alone or 20 - 25 days if a continental mosaic is also created from the base OrthoTM images. The resulting mosiac could then be used in the further production of base mapping, and could be distributed without restriction.
- Development of a base mapping interface "add-on" to the AWRD which accommodates polygon masking and the output of digital base maps of: Watersheds or MegaBasins; Major Rivers and Flow Regimes; National & Sub-National Administrative Hierarchies; or any other ancillary polygonal or point data such a species distribution or sighting maps. The resulting outputs will be geo-referenced imagery and will be of publication quality; suitable for use in PowerPoint presentations, web based distribution, or publication reports; LOE 25-35 days. OR Create tools that are specific for the production of attractive graphics that can be used in both PowerPoint presentations and printed reports; [10 days but can be Deleted, if Base Map interface is done instead]
- Potential expansion of the effort to cover other regions globally, including:
  a) Creation of global database supporting hydrological, administrative, or other types of base mapping. Given that Africa has been completed by the FAO, and Central America, the Caribbean, and portions of South America have purportedly been largely completed by USAID, five further regional

compilations would need to be completed: India/Western Asia, with Tibet/Southern China & South Pacific Rim; Eastern Europe, Western Russia, and the Middle East; Eastern Russia and Mongolia; Central & Eastern China and the Koreas; and possibly, Mexico, Cuba, the Bahamas. Based on the database complied for the AWRD, the average time needed to complete a robust translation and integration of the various source databases for each compilation would be 35 days per compilation. A less rigorous translation could be accomplished, on the average of 15-20 days per compilation;

b) Production of presentation quality elevation and shaded relief map graphics, 2 days per compilation;

c) Production of seamless 1:750,000 base map of each compilation, 4 days, and lastly,

d) The expansion of the current AWRD program and interface to accommodate the extended global extent; 6 days.

- Inclusion of the AQUASTAT Water Resource Use and an Irrigation Analyzer, 20 days
- Development of a Run-Off & Flood Predictor, 40 days.

WHAT CAN DE DONE

31. The following specific actions could enhance the use of the AWRD:

Collaborative work

a) The South African Institute for Aquatic Biodiversity, in collaboration with ALCOM, has developed a database of freshwater fish for this region from museum collection data. The development of advanced computing and GIS technology has increased the scope of atlas projects by facilitating the integration of large amounts of spatial data to produce derived databases for many specific applications. The atlas has been developed from a database of freshwater fish, hydrological, topographical and climatological digital data layers, and has been demonstrated as a tool with multidisciplinary use.

b) The integration in FIGIS (http://www.fao.org/fi/figis/index.jsp) of the GIS layers required for continental fisheries and aquaculture (rivers, lakes, watersheds) will be tested using the AWRD database. Also (a) the Inclusion and adaptation of the AWRD viewing tools for use on the Internet using an Internet Map Server Version (ArcIMS) in FIGIS will be explored, along with (b) the development of an on-line collaboration and database maintenance system.

GIS Edification

a) Promote programs for research with the use of the AWRD for the rational utilization of natural resources;

b) Encourage education and training with the use of the AWRD;

c) In parallel to the development of the AWRD, FAO is currently developing a programme to strengthen the GIS capacities of fisheries biologists. This programme will consist of:
   - A training programme, using a manual on the use of GIS in inland fisheries management, developed by the Inland Water Resources and Aquaculture Service of FAO;
   - A community development programme, where community members will be able to exchange ideas, pose questions, develop policies on a national, regional, and global scale. Part of this community programme will be a

fisheries management assistance programme by means of experts assisting in setting-up, and assisting with, an integrated information and decision support system, using existing data, and identifying data needs, and;

- An information systems capacity assistance programme, to identify and solve bottlenecks in the exchange of information between people, institutes and nations.

Decision-making

a) Make use of the AWRD to strenghthen collaboration and decision making among stakeholders in water resources management. For example, it could be used in the African Basins project (Arthurton *et al*. 2002).

SUGGESTED ACTION BY COMMITTEE

32. The Committee is invited to review the status of the AWRD and suggestions described in the paper and to provide guidance to Members and FAO as well as other agencies and international organizations on how to fully benefit from the use of the AWRD to improve or ease fishery or integrated management decisions. In particular, the Committee may wish to emphasize on the following activites that were considered of importance for the future use and development of the AWRD:

- Determine whether FIRI will maintain overall coordination for the use, maintenance, and future development of the AWRD.
- Establish cooperation and collaboration for the use and development of the AWRD in CIFA countries.
- Promote research, educaction, training and decision-making using the AWRD.
- The committee is invited to consider the programme concept to strengthen the GIS capacities of fisheries biologists.

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