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

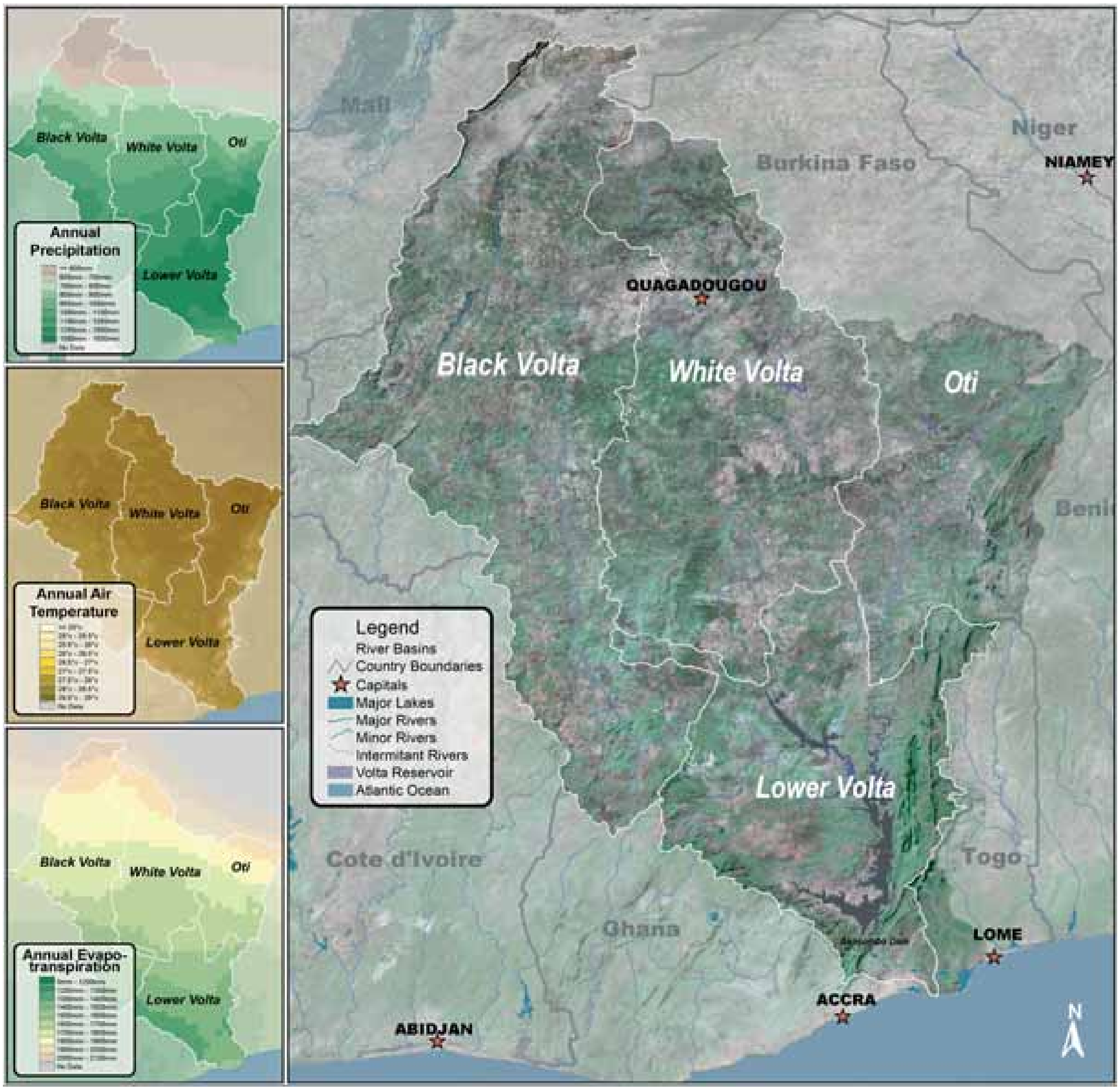
Characteristics of the Volta River megabasin

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 m³/sec, and is based on the smallest area, 63 642 km²;
- The Black Volta River basin covers the largest drainage area, 154 886 km², but contributes the smallest annual mean flow, at 243 m³/sec;
- The White Volta basin is comprised of a slightly smaller area, 111 092 km², but contributes a slightly greater mean flow of 240 m³/sec annually;
- The Lower Volta basin, including the reservoir, encompasses the smallest drainage area, 80 855 km², and discharges 1 150 m³/sec regulated by the Akosombo Dam; and
- The Volta river in general has an average annual outflow of 1 230 m³/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.

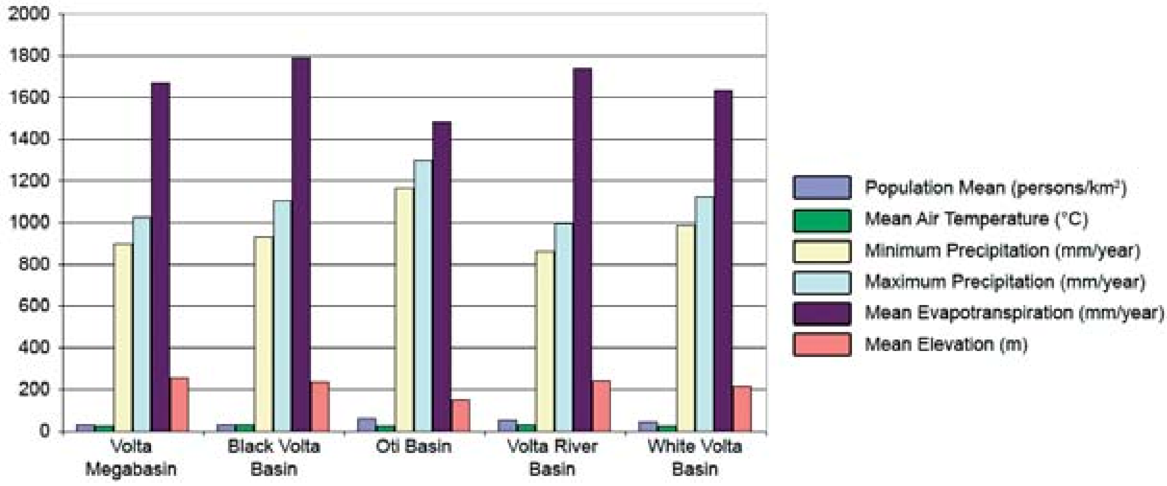
FIGURE 2.40
Composite map of the Volta megabasin



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



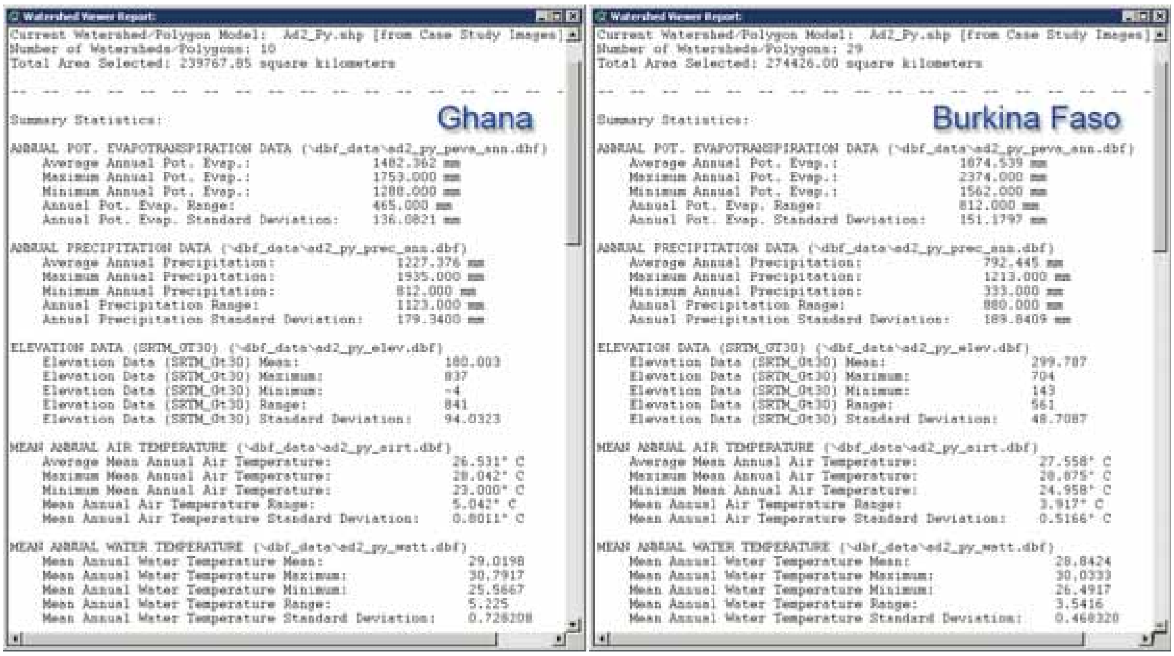
In order to demonstrate that many types of data can be easily summarized via the AWRD, Figure 2.41 also summarizes each basin according to mean population density, mean air temperature, mean precipitation, mean evapotranspiration, and mean elevation.

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

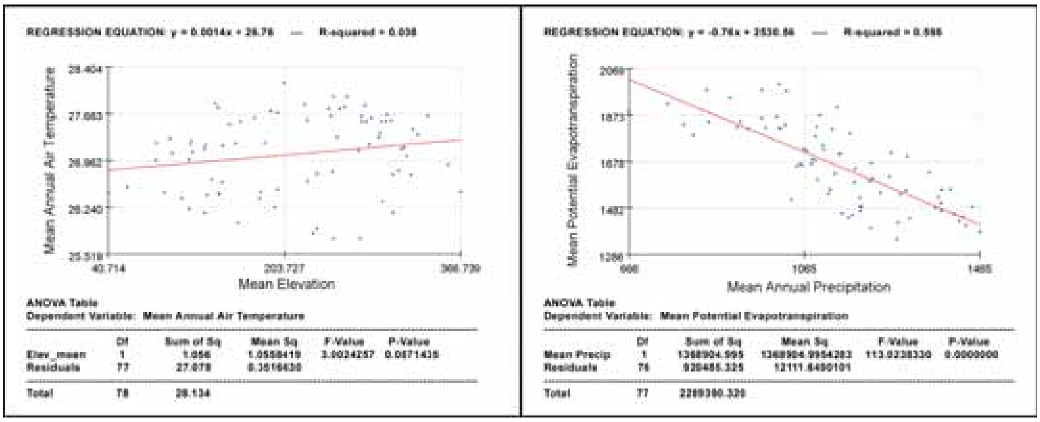


To assist users with the interpretation of such outputs, the AWRD also includes an extensive suite of tools under the Statistical Analysis Module. In the case of the Volta megabasin above, because the climatological, hydro-physiographic and population characteristics of the river basins comprising the 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

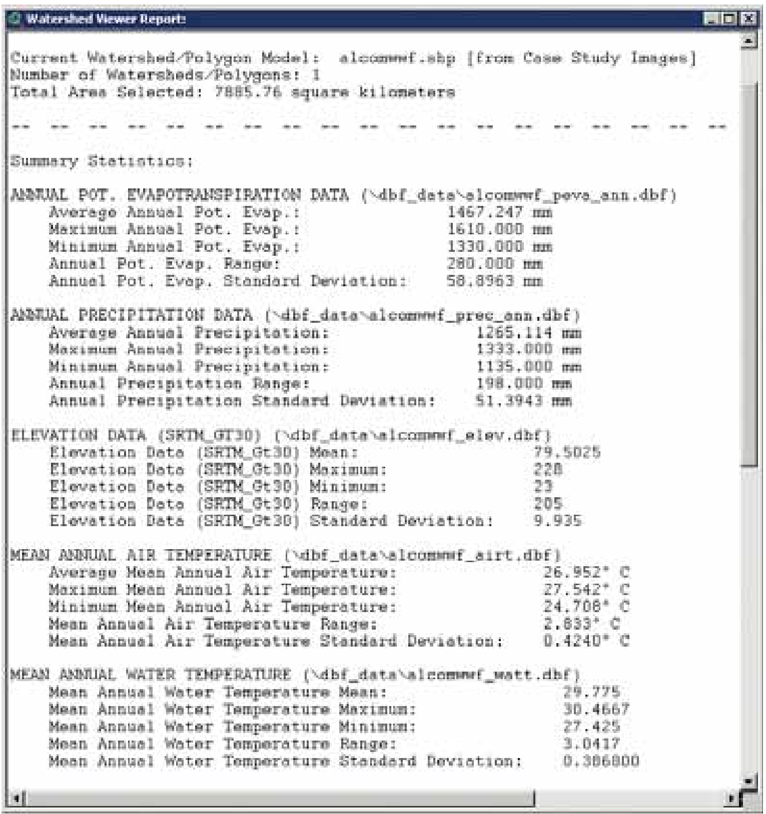


Examining reference information for Lake Volta

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



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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

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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

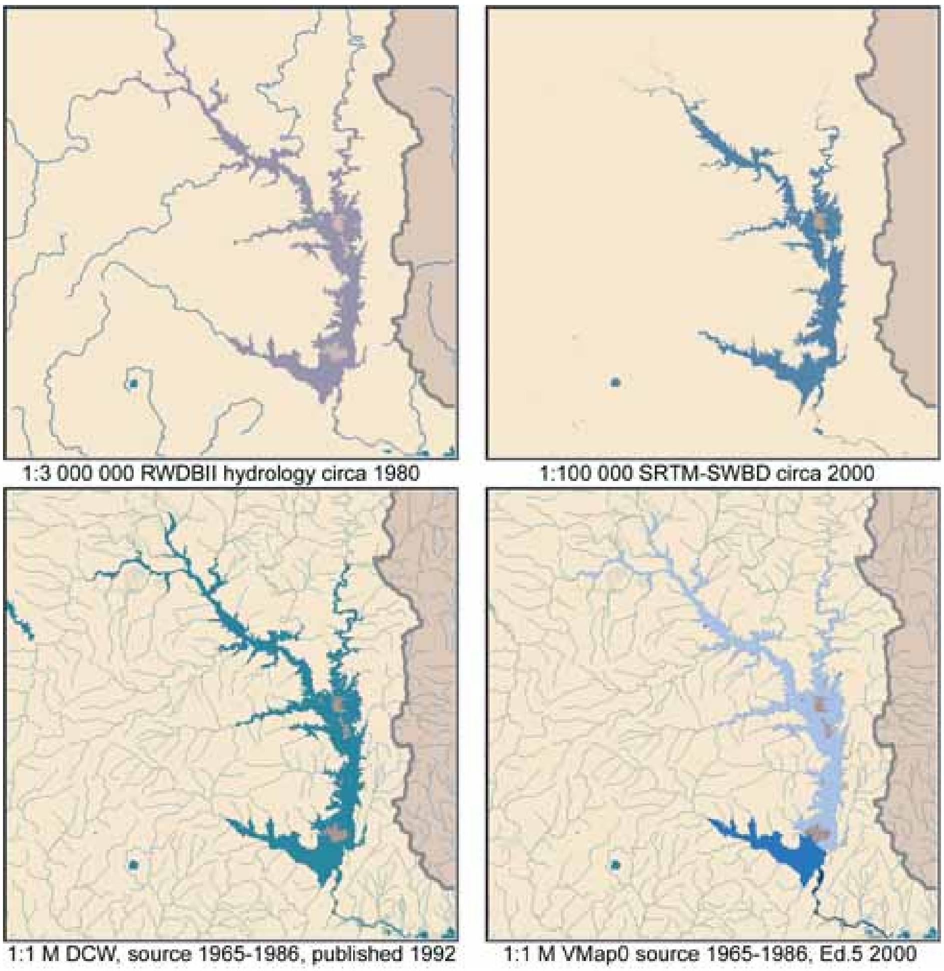
MEAN ANNUAL WATER TEMPERATURE (\dbf_data\alcomwwf_watt.dbf)
    Mean Annual Water Temperature Mean:                   29.775
    Mean Annual Water Temperature Maximum:                30.4667
    Mean Annual Water Temperature Minimum:                27.425
    Mean Annual Water Temperature Range:                  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 ^{o}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.

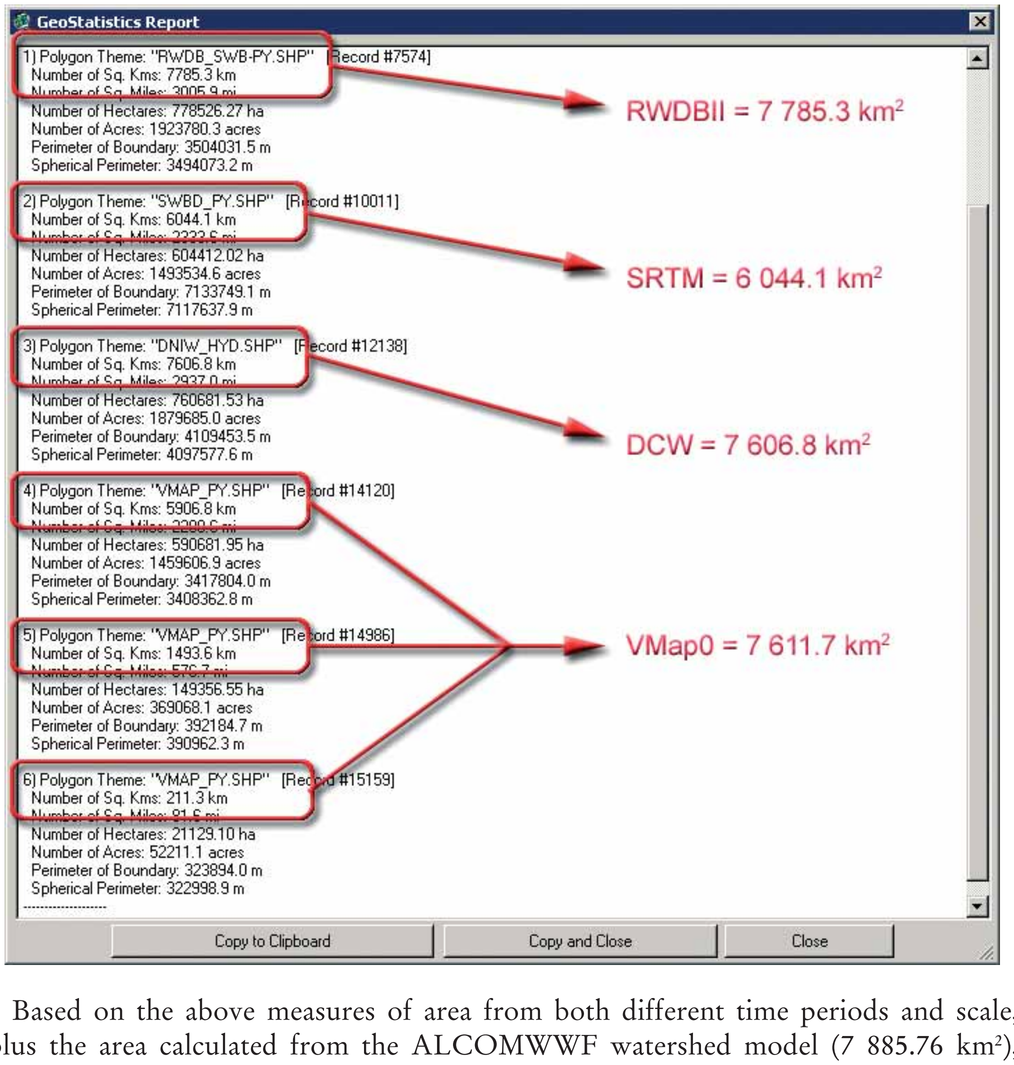
The integration of this information with the subset of summary statistics shown in Figure 2.44 demonstrates the initial value of the AWRD interface for rapidly summarizing information from both the spatial and textual data contained within the archive. On a comparative basis, however, it is interesting 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