Utilizing GIS for the Collection of Key Variables in the Analysis of an International Freshwater River Basin Spatial Database

by

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Keywords: multidimensional GIS, population, international river basins, freshwater cooperation and conflict

Abstract

The Geographic Information System (GIS) is an invaluable tool in manipulating and interpreting world scale datasets. In recent years it has become the standard link between water resource study and the ever-increasing numbers of high quality data sets. This paper describes the use of Geographic Information Systems for gathering and analyzing spatial information to facilitate identification of international river basins at risk for future conflict over freshwater resources. The methodology and data described here was produced as part of the Basins at Risk (BAR) project, an offshoot of the Transboundary Freshwater Dispute Database (TFDD), directed by Dr. Aaron T. Wolf, Oregon State University. In order to better ascertain variables to predict which international river basins may be at risk of water related conflict, the GIS was used to: 1) Update the international river basins of the TFDD, allowing the best fit to the most recent USGS hydrography coverage of the world; 2) Link current and historical spatial and non-spatial information of the BAR project by formulating a temporal GIS that demarcates international river basins on a one-year resolution dating from 1946 to the present; and, 3) Aggregate selective gridded datasets in order to better ascertain key variables associated with cooperation or conflict over freshwater resources. Where possible, the most recent and up to date world scale datasets were used. The combination of GIS techniques and manipulation of recently available datasets proved to be extremely effective in the production of potential variables for the assessment of water related cooperation and conflict.

Introduction

With the improvement of Geographic Information System (GIS) technology and an advance in global scale datasets it is proving to be both easy and effective to interpret characteristics of large regions at a global scale. At the forefront of natural resource assessment is the study of water and its distribution among the world's continents. The enviable GIS capabilities to deal with spatial data have led to extremely effective manipulation of those datasets crucial to the decision making process in the allocation of the world's water. In 1993, at the *Symposium on Geographic Information Systems and Water Resources,* it was demonstrated that GIS has allowed a multitude of new perspectives in the realm of water resource study. Since that time, GIS has become the standard link between the large-scale collection of data and wide-ranging conclusions of water resource related studies. These conclusions are limited only by the quality of the most recent data on hand.

The GIS exercise detailed in this paper was created as part of the *Basins at Risk* (BAR) project, under the auspices of the *Transboundary Freshwater Dispute Database* (TFDD), directed by Dr. Aaron T. Wolf, Oregon State University. The BAR project has created a database of historic incidents of international water cooperation and conflict from the years 1948 to 1999. Using precise definitions of cooperation and conflict, these incidents were ranked by intensity and linked to the international basin in which they occurred. With the identification of leading variables responsible for these events, the BAR project has been able to create a framework for labeling those international basins at risk of future water related conflict. In addition to facilitating identification of the basins at risk, identification of the factors or sets of conditions that make water a source of conflict also provides insights into the linkages between water resources and other physical, social, economic, political and environmental factors in a region. Understanding these linkages will facilitate the development of management strategies for transboundary waters and enhance evaluation of whether particular management strategies are appropriate in some regions, but not in others. The GIS has proven to be an exceptional tool in linking the specific needs of the BAR project.

The key unit of analysis in the BAR project is the international river basin. A river basin comprises all the land that drains through that river and its tributaries into the ocean or an internal lake or sea. An international river basin is one that includes territory of more than one country. Currently, the world encompasses 261 international river basins, covering at least 45.5% of the total land area of the earth, excluding Antarctica (Wolf et. al.1999).[1]

The idea of analyzing political, socioeconomic, and biophysical elements via watershed boundaries is relatively new in the field of political geography. For many years the dominant polygon for the display, and hence, the output of manipulated data has always been defined by national borders. Readily available water data is only at the country level (Brunner et. al. p.1). This fact, in many cases, has limited the study of political conflict and anti-peaceful acts associated with water. By breaking away from the confines of this method, a better fit can be made between those variables that may be deemed important to water related social and political incidents and the spatial area made up by a particular watershed. As stated by Leif Ohlsson, in his book *Environmental Scarcity and Conflict: A Study of Malthusian Concerns*,

> ...the common wisdom of the literature on water negotiations is that the appropriate unit, both for analysis and negotiations, is the river basin as a whole (p.185).

Each task in the Geographic Information System exercise depicted in this paper has been from the standpoint of the international river basin.

Three separate GIS methods are described in the following sections of this paper. Each is accompanied by a general description of the methods, data, and approach used as well as a brief summary of how it aided the BAR project.

[1] Since the last publication of the TFDD basins, new basins have been "found." An updated version of the TFDD database of international rivers is in process. The current basin total is 263 (See Appendix 5).

Restructuring of the Watershed Boundaries

The first task in this succession of methods was to correct and update the TFDD international river basins to fit new data and better meet the needs of the BAR project. The basins of the TFDD project had their origin in a 1958 United Nations panel report titled *Integrated River Basin Developments*. This 1958 edition of the roster included 166 international basins, a number likely limited only by the quality of the data used in their delineation. In 1978, the United Nations revised this report and the total was updated to 214 basins. The most recent version of the International Basin dataset, prior to this study, was Wolf et al's *Register of International Basins*, completed in 1999 as part of the TFDD. The first edition to employ GIS to define and delineate international river basins, the *Register* used the recently released USGS world scale digital elevation model (DEM), GTOPO30, to define river basins matching GTOPO30's simulated flow pattern. The number of internationalized basins at the release of this document was refined to a total of 261 basins.

In task 1, the 261 basins depicted in the 1999 *Register* were manually matched, as accurately as possible, to the Hydro1k dataset (see figure 1). This on-screen exercise, completed one continent at a time, systematically linked each basin to a reasonable estimate of the real life drainage network and ameliorated inaccuracies produced in the original creation of the basin GIS.

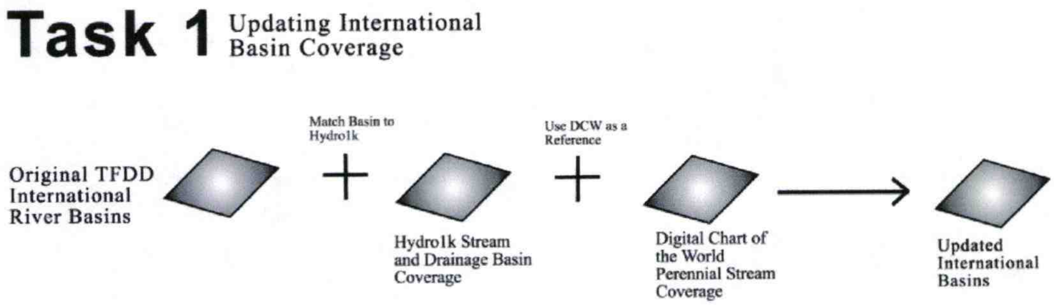

Figure 1: A basic model representing the steps taken to update the TFDD international basin coverage.

In all, less that half of the basins needed to be changed. Where confounding issues arose and there was uncertainty in the exact location of a basin boundary, outside sources were used to determine where it should lie. One of these sources was the perennial stream coverage of the Digital Chart of the World (DCW). The DCW, developed under a contract by Environmental Systems Research Institute (ESRI) and available through the U.S. Defense Mapping Agency, is considered to have a minimum resolution of 500m (Kemp in Goodchild et. al. p.369). This level of detail proved particularly useful in settling most questions of a basin's international status. Where this digital source failed to provide an acceptable answer, hard copy map sources, including National Geographic's *7th Edition Atlas of the World* and various others from the Oregon State University Valley Library, were consulted. In the end, the result of scrutinizing each individual basin led to; 1) The best possible fit of each basin boundary to the Hydro1k dataset (see figure 2); 2) The addition of three basins that were determined to have international status; 3) The merging of the Benito and Ntem river basins of West Africa; and, 4) the best possible attempt at creating a sound coverage for the further collection of information for the BAR project.

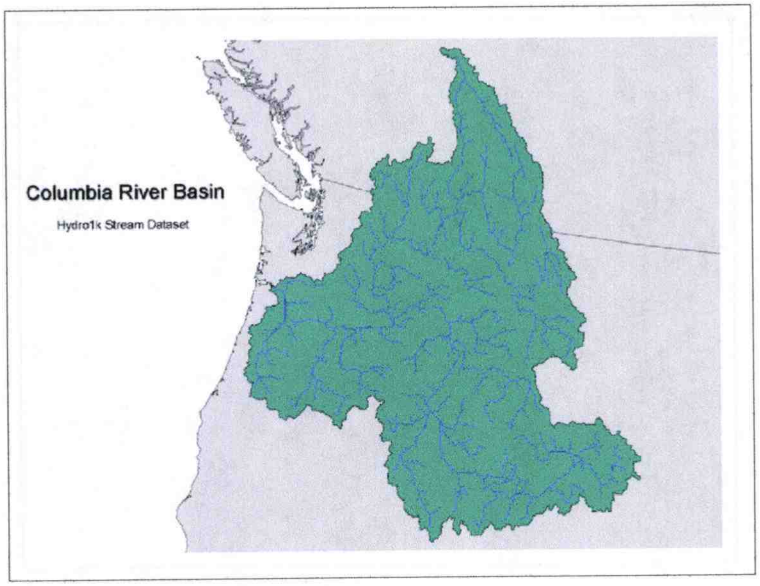

Figure 2: This image indicates a close match between TFDD international river basin to the USGS Hydro1k dataset.

Estimating Changes in the International Status of River Basins with the Aid of Temporal GIS

A key component of the BAR project was the creation of a database of historic incidents of international freshwater cooperation and conflict from the years 1948 to 1999 (hereinafter referred to as the "Event" database). Using precise definitions of cooperation and conflict, these incidents are ranked by intensity and linked to the international basin in which they occurred. The *Events Database* of the TFDD dates from 1948 to the present. Events, ranging from the most cooperative (e.g., treaties) to the most conflictive, are coded by those international river basins and countries involved. In order to relate this database to the spatial variables that are being introduced by the BAR project, it was necessary to link the GIS data as accurately as possible to the BAR event database. To incorporate both temporal and spatial variability into the analysis required the creation of a temporal GIS, one that would identify spatially all the international basins that existed for each year of the study and what countries, for each year, were riparian to those basins. This historic GIS facilitated the creation of the event database by identifying whether a specific event occurred in an international basin, as many events researched turned out to be related to intranational, rather than international waters and as not all basins were international across the entire time period of the study. More importantly, the historic GIS allowed the linkage of the incidents of international water conflict and cooperation with socioeconomic, biophysical, and political data specific to the year in which the event occurred. This linkage allowed for comprehensive spatial and parametrical statistical analyses.

In short, the most recent GIS coverage of international river basins had to be modified to fit the political boundary status of each year included in the BAR event database. The 1999 register of the *International Basins of the World* indicates that 47 basins became international, and were therefore added to the *Register*, due to the breaking up of countries such as the former Soviet Union and the former Yugoslavia (Wolf p.3). Likewise, two international basins were removed from the list as the result of the unification of once segregated countries (i.e., Germany and Yemen). To account for these and other political boundary changes that have altered international status of river basins during the period covered by the BAR project, it was necessary to employ the temporal dimension within the GIS data. The multi-coverage/multi-time period techniques were particularly effective in tracking such a dynamic phenomena.

In current GIS study, the idea of exploring the temporal dimension is becoming more established. By delineating the internationalization or de-internationalization of basins as international political boundaries change, a better fit can be made between the spatial and non-spatial portions of the BAR database. Spatial analysis of an inventory of socioeconomic, geopolitical, and environmental data can be more accurately represented and understood with the use of a dynamic information format that considers change throughout time. The concept of a changing inventory is one of the fundamental portions of a temporal GIS. As quoted from Gail Langran, *Time in Geographic Information Systems*:

> A critical temporal GIS function is to store the most complete possible description of a study area, including changes that occur in the living world and in the database. A temporal GIS should be able to supply the complete lineage of a single feature, the evolution of an area over time, and the state of a specified feature or area at a given moment (p.6).

Indeed this concept was fully utilized when spurred by the recognition that the *Conflictive and Cooperative Events* of the BAR Event Database could only be associated with basins that were international at the time the event occurred. Moreover, the spatial basin and country level data must also be temporally matched to conduct relevant statistical analyses. Therefore, the GIS had to account for all changes in international river basins and national political boundaries from 1948 to the present, both spatially and temporally.

The GIS coverages that comprise the temporal portion of this study are divided into nine time segments (see figure 3), which were chosen to capture periods of significant world political boundary and polity changes (See Appendix 7). Dates of significant changes in boundary locations include, among others: 1990, East and West Germany united; 1990, North and South Yemen united; 1991, break up of the former Soviet Union; 1992, former Czechoslovakia break up; 1992, break up of the former

Yugoslavia; 1993, formation of Eritrea.[2] The GIS contains correct attributes for all the polity and boundary changes.

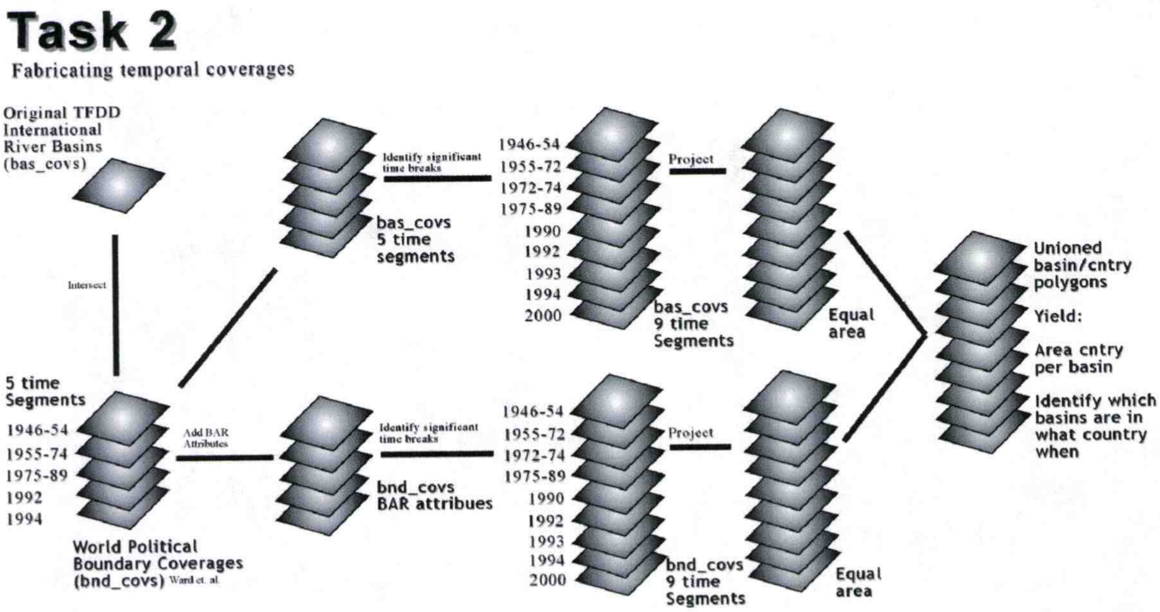

Figure 3: A basic model showing the steps taken in the creation of a temporal spatial database for the *Basins at Risk* Project.

For each time segment, a complete coverage of world political boundaries and international river basins was created. These coverages most accurately represent the status, both through their spatial characteristics and their attributes, of the political boundaries of the time period. For durations of time where no change, either in polity ownership of an area or political boundary location, existed then the years could be grouped into a common coverage. Where otherwise, a yearly coverage was established.

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[2] Other less significant boundary changes, which were included in the original political boundary coverages, but are not incorporated into the nine, final temporal political boundary coverages, include spatial changes that happened along the border of India and China and in other controversial boundary zones. Current border disputes are captured, however, in the most recent version of the TFDD basin coverages.

The result of this method applied to the years between 1946 and the present yielded nine time segments and their associated basin and country coverages.

The construction of the world international basin and political boundary coverages were built from a base map, which came in the form of Arc/Info coverages spanning five time segments (1946-54, 1955-74, 1975-89, 1992, and 1994) and was graciously shared by Dr. Michael Ward, Professor of Political Science, University of Washington (see figure 3). The coverages delineate political boundaries for each time segment from the volatile period of the early nineties (which saw the break up of the Soviet Union and Yugoslavia) back to 1946 (Ward et. al. 00). These crude, yet fully viable, delineations of the political boundaries of each time period were particularly valuable in the success of Task 2. Boundaries locations were comparable to BAR country coverages and attributes contained labels showing the political ownership of each region. From this starting point the compulsory manipulation of the country and basin coverage for each time segment could be built.[3]

A link was created between the polygon attribute data of the donated coverages and BAR country coverages and data via BAR country codes and the Polity 3 dataset country codes (McLaughlin, et al, 1988) used by Ward. Polity 3's country codes were converted to BAR's country codes in the final coverages, as BAR country codes provide a key linking all spatial and tabular country-level data used in the BAR project. The linking of the two sets of country codes allowed the polygon attribute tables of each time segment's country coverage to be restructured to reflect the critical attributes of the BAR database.

[3] Indeed finding coverages of historically accurate international political boundaries was a time consuming portion of this project. World scale historic GIS coverages are rare. Many studies have been conducted

With BAR attributes (most significantly the BAR country code) added to the donated country coverages, it was then possible to determine which time segments saw the addition or subtraction of international basins due to their spatial relation to contemporary political boundaries. A Union of the current basin coverage with the political coverage of each time segment yielded a list of basin codes and country codes. Analysis of these basin and country code pairs determined the political status of each basin. In order to bring the resolution of the time segments to one year, additional coverages were created to represent other boundary changes. The final time segments are as follows: 1946-54, 1955-72, 1972-74, 1975-89, 1990, 1992, 1993, 1994, and 2000. Each time segment reflects those basins that were international at that time period. In all, a sequence ending in a total of 30 basins was deleted traveling backwards in time (See Appendices 3 and 6). Again, this sequence was guided by the breakup of nations and political boundary shifts. Going back in time, only two basins were added. One spanned the boundary of the former East and West Germany – the Weser. The other spanned the boundary of the former East and West Yemen – the Tiban (see figure 4). The Tiban and the Weser are non-existent as international basins beginning in 1990, with the unification of their respective nations.

that label the change in political boundary status over the past 50 years but few have utilized GIS technology.

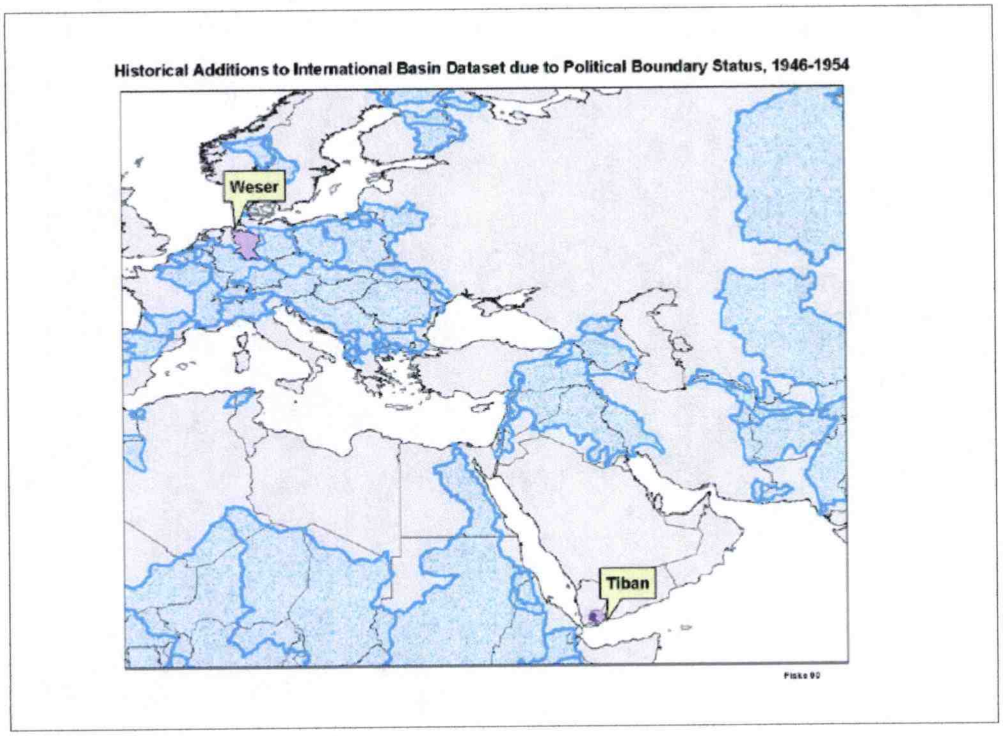

Figure 4: This map indicates those basins that were introduced to the temporal international basin coverages due to changes in political boundary status between the years of 1946 and 1989. When both Germany and Yemen reunited in the early 1990's, both basins were removed from the list of international basins.

With a reasonably accurate estimate of the international river basins that existed in each year, from 1946 to the present, the applications of such a dataset to the BAR and other projects are vast. It is possible that interactions between pairs and groups of countries involved in shared river basins could be more accurately linked with the use of these coverages. At the time of this report, utilization of these historic coverages included linking riparian countries to their associated basins for each year, calculating the area of each riparian nation's portion of historical international river basins, and aggregating some ancillary datasets to those basins that once existed but now have become *de-internationalized.* Additional applications to BAR and other, similar research projects are measureless.

Aggregating Data per Basin

With the establishment of updated basin boundaries and a reasonably correct estimate of international basin status (past and present), accurate aggregation of various datasets to the basin boundaries was possible (see figure 5). Aggregation of data at the basin level includes, but is not limited to, population, number of climate zones, runoff, and number of dams (See Appendix 4).

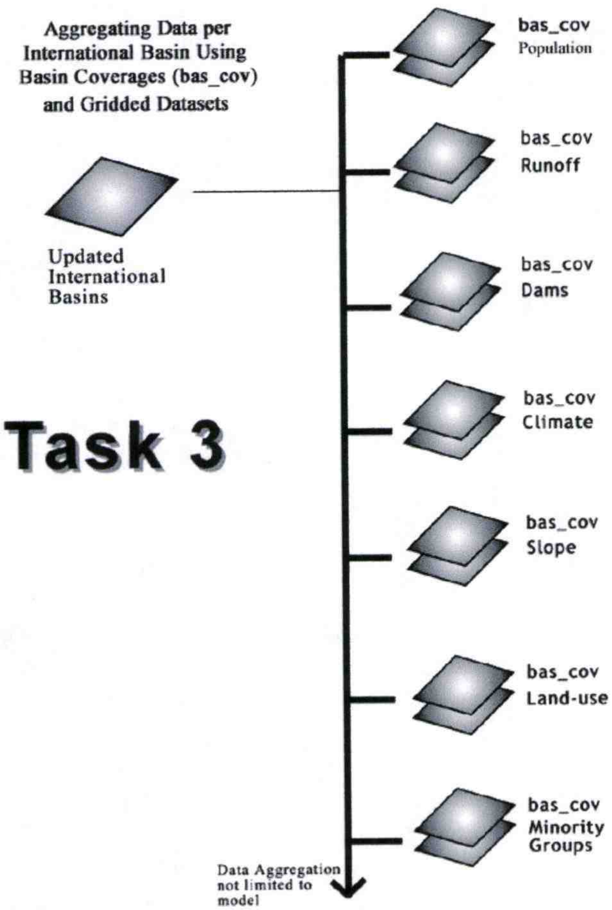

Figure 5: A basic model showing some of the datasets that were merged with the updated basins coverages to obtain data values at the basin level.

Population

Recent studies have shown that population growth is a key factor in assessing the increasing problem of water scarcity (Brunner et. al. p.1). In general, the population of the world is focused near, or in relative close proximity, to a water source that should conceivably support its need for water. Work conducted under a joint effort of the World Resources Institute (WRI) and the University of New Hampshire

(UNH) has concluded that, in order to best evaluate the problem of water scarcity an investment in the monitoring of socioeconomic data should be as important as the hydrologic information gathered (Brunner et. al.). The idea of where the water exists in a given region ought to be coupled with the knowledge of the population distribution. Population assessments have traditionally been conducted within the spatial boundaries of a political unit (e.g., the nation-state). These political units are completely out of sync with that of the spatial variation of the world's fresh water resources.

The population data produced by BAR surpasses previous measures of Water Stress in two ways. The first is that population is evaluated on the scale of the TFDD international watershed. By evaluating the population of a region in comparison to its relative location in a river basin those inaccuracies produced by linking country population values to water resource supply can be partially ameliorated. The second is by using the most current and truthful approximation of the world's population distribution yet available -- the 1998 Landscan gridded population of the world. This 30 by 30 second resolution data was produced by the Landscan Global Population Project and funded by the United States Department of Defense. The project, lead by Jerome Dobson of Oakridge National Laboratories, was aimed towards estimating populations at risk during both natural and human induced disasters. Accuracy of the dataset can be partially attributed to the utilization of recent remote sensing data. With the help of GIS, it was possible for the Landscan team to use remotely sensed slope, land cover, road proximity, and night time lights to further refine the gridded population cell values (Dobson p.849). The Landscan project is an excellent example of the strength of GIS in assessing spatially distributed phenomena using recent remotely sensed images. Indeed the goals and results of the Landscan project were ideally suited for the task at hand in this study. The relative accuracy of aggregating population values in the international river basins was due, in large part, to the success of the Landscan project.

With use of Arc/Views Spatial Analyst extension, the summation of gridded population density values could be tabulated per TFDD international river basin. Due to the relatively fine resolution of the LandScan dataset, a summation of gridcell values could be produced for all 263 international river basins including those of the smallest spatial extent. By combining this table with the area of each basin, a population density could be calculated (see figure 6 and 7).

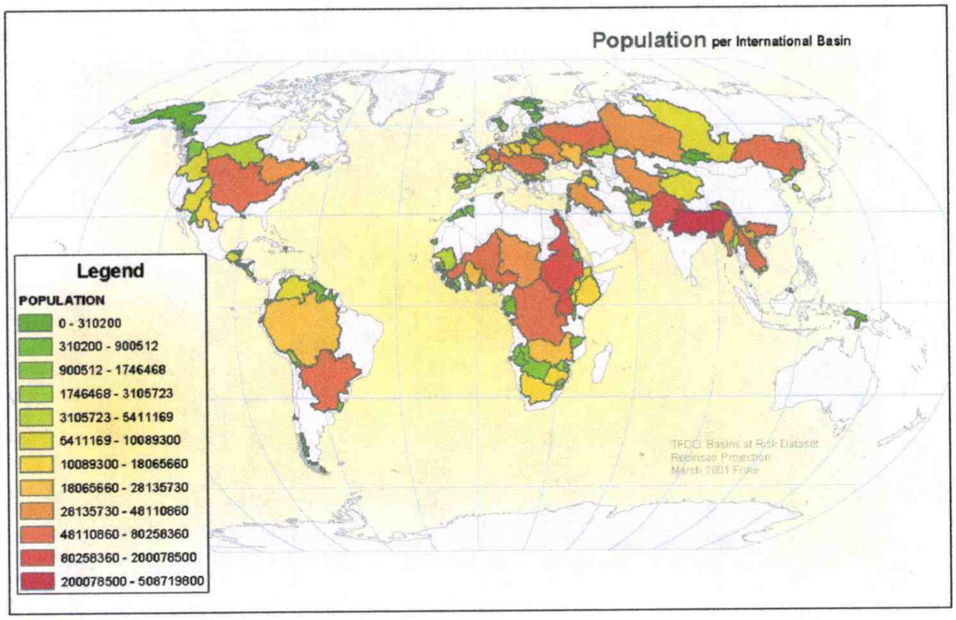

Figure 6: A map showing population per international basin.

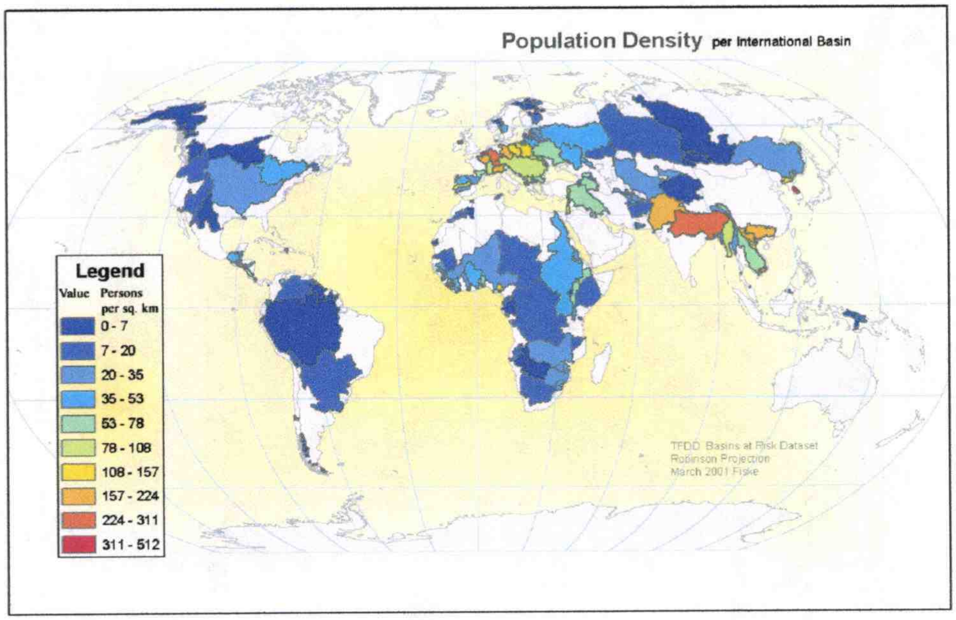

Figure 7: A map showing population density per international basin.

Runoff

Any assessment of a water resource related issue would be incomplete without that of some approximation of runoff in the study area. The *Symposium on Geographic Information Systems and Water Resources* in 1993 promulgated the many burgeoning attempts at estimating a river basin flow via hydrologic models. With the basics of watershed modeling (i.e. watershed boundaries and flow direction) being old news, the next challenge of the GIS community is to accurately simulate and quantify the runoff in a watershed. Modern hydrologic models are mathematical simulations that may use rainfall data, land use/land cover, soil type, topography, and drainage coverages to make an estimation runoff amounts (Luker et. al. p.303). With increasing technological capabilities it is becoming easier for the GIS to handle these types of applications, which have multiple complex spatial parameters. GIS is the link between the spatial parameters of the natural hydrologic cycle and a decent estimation of a region's runoff. Output data of this quality can create a plethora of new opportunities for GIS analyses, including the correlation of water availability to conflict occurrence.

Though widespread discharge gauging stations give the approximate yield of many of the world's rivers, the spatial distribution of runoff amounts for obscure river basins and within large watershed systems is relatively less abundant. In modern environmental modeling, estimating runoff (or flow amounts) stands as a formidable challenge to the GIS. For this data-gathering task, BAR utilized a world scale gridded flow dataset to acquire estimated runoff per international river basin. This world scale dataset was in the form of a 30-minute spatial resolution grid of composite runoff fields produced through a joint effort of the Complex Systems Research Center at the University of New Hampshire (UNH) and the Global Runoff Data Center (GRDC) in Koblenz, Germany. Fekete et. al. (2000) were able to produce the composite runoff fields by accessing the archives of the GRDC discharge data, selecting significant global gauging stations, and geo-registering the discharge information to locations on a simulated topological network (p.1). To produce a disaggregated spatial distribution of runoff, they employed a water balance model. With the exception of regional inaccuracies due to climate fluctuations (e.g., evaporation and precipitation) and man-made removal of water (e.g., for irrigation and municipal uses), the combination of observed discharge and a simulated runoff model will produce a reasonable estimate of runoff in a large region. As quoted in the report written by Fekete et. al., "The combination of the two sources of information (observed discharge and simulated runoff) to estimate continental runoff has the possibility of yielding the most reliable assessment at present" (p.22). The use of this gridded dataset was the most reasonable path to be taken in the search for a summation of water availability per international river basin.

For the purposes of this study, GIS was used to manipulate the composite runoff fields produced by Fekete et. al. and to sum runoff amounts per international basin. Runoff is considered to be the total amount of surface flow in a given area. The cell values are in mm/yr for the annual composite runoff field grid. These values (mm/yr depth) were multiplied by the area of the associated grid cell (sq. km) to produce a runoff volume grid (mm*km2/yr). An estimate of basin discharge is produced by converting the cell value units of the runoff volume grid to km3/yr. Discharge is considered to be the output of the river basin's main stem channel at the ocean. The discharge values are ranked and evaluated accordingly (see figure 8). Due to the resolution of the 'Standard Topological Network' in which the composite runoff fields were derived, a reasonably accurate assessment of discharge amounts is restricted to areas greater than 25,000 sq. km. (Fekete et. al. p.5). This confined our calculation of runoff per international river basin to approximately half the 263 watersheds. Furthermore, as an added caveat to the estimated discharge amounts per international river basin >25,000 sq. km., it must be stated that the nature of the employed dataset does not account for those river basins that have a decrease in river discharge towards the outlet. River basins such as the Colorado that are deemed 'exotic' loose a great deal of water volume at the end of their path due to the previously mentioned natural and man-made extractions.

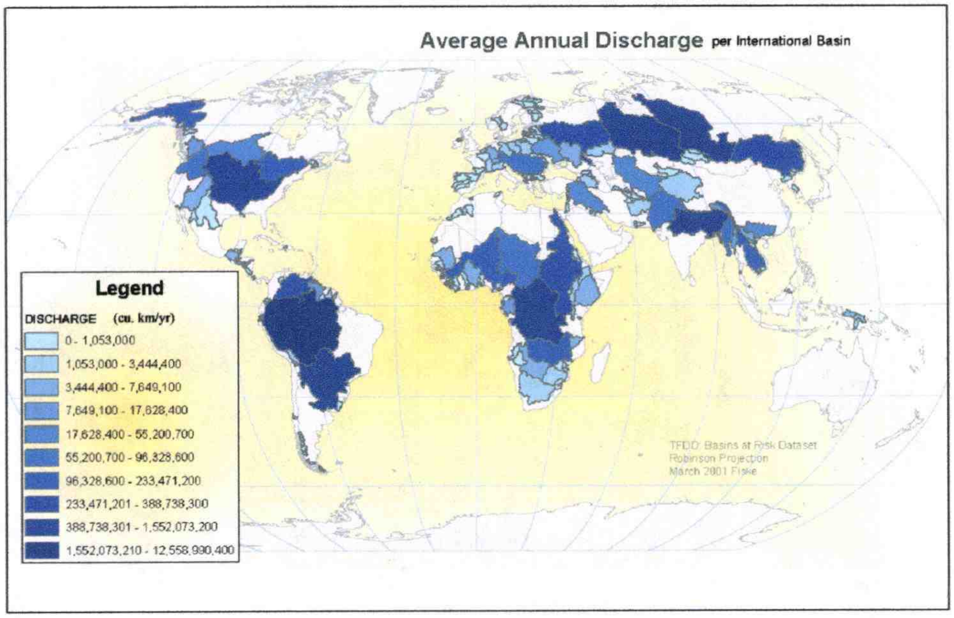

Figure 8: A Map showing estimated discharge per international basin in cu.km/yr.

Other Datasets

Similar GIS techniques to those described above were used to gain data from additional gridded and polygonal coverages. These data were gathered as part of the Basin At Risk project's analysis of potential indicators of conflict and cooperation over international freshwater resources. At the time of this report the datasets that have been aggregated per international river basin include: 1) A completed table of climate zones per basin based on a Koeppen Classification of Climate Grid (FAO SDRN dataset 1997) (See Appendix 8); 2) The Number of Dams per basins derived via the Digital Chart of the World (see figure 9); and, 3) The number of minority groups per basins derived via the Global Events Data System world minority data. In some cases, the derivation of these datasets was limited to large international basins (area of 25,000 square km or greater) due to the resolution of the input data.

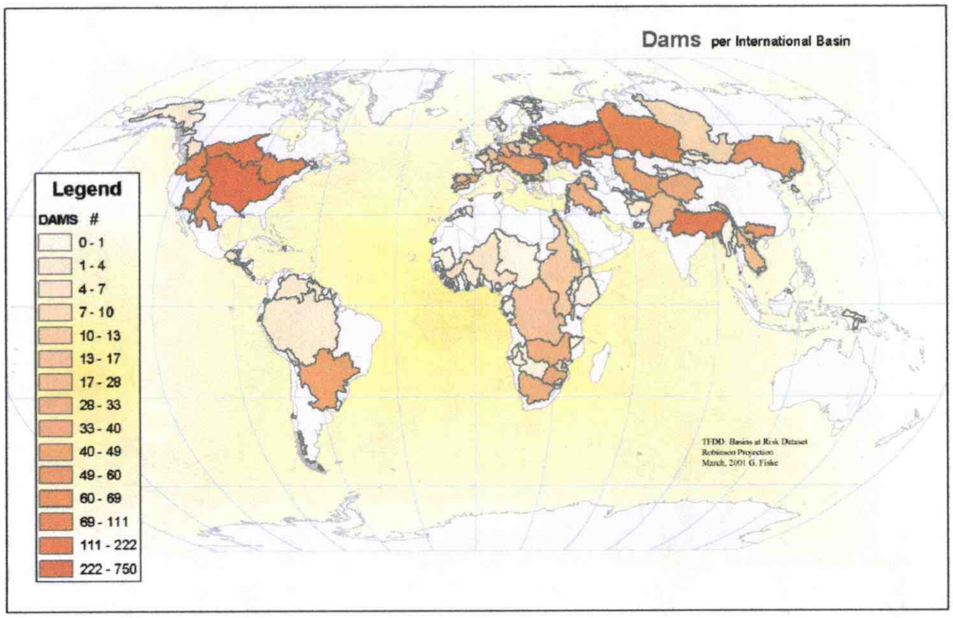

Figure 9: A map showing estimated dams per basin.

Conclusion

The GIS has proven to be an invaluable tool in assessing world scale spatial data and applying it to the *Basins at Risk* project. Currently available world scale datasets are at a level of accuracy that allow for the manipulation and derivation of variables that may or may not relate to water conflict or cooperation in an international basin. For the BAR project, the GIS was used to, 1) update the international basins of the TFDD, allowing the best fit to the most recent USGS hydrography coverage of the world, 2) better match the spatial and non-spatial information of the BAR project by formulating a temporal GIS that demarcates the international river basins on a one-year resolution dating from 1946 to the present, and 3) aggregate selective gridded datasets in order to better ascertain key variables associated with cooperation or conflict over international freshwater resources. Each successfully completed task demonstrates the efficacy of standard GIS methodology to assess one of our planet's most critical natural resources. Furthermore, this exercise has yielded information that can conceivably benefit further research in world-scale, water-related study.

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Appendices

Appendix 1 - Data Caveats to TFDD Basins version II, 2001

Below are the changes made to the basins coverage since the TFDD register was first published in 1999/2000.

Each basin was corrected using the U.S.G.S. Eros Data Center Hydro1k dataset. The Hydro1k data set was derived topographically and includes both basin (polygon) and stream (arc) coverages of the globe. The Hydro1k stream networks were the standard for accuracy of the basins. Dissolving the hyrdro1k basin polygons into six levels of sub-basin polygons and then choosing those sub-polygons that better defined the boundaries allowed the redefinition of questionable basins yet still retain the association with the Hydro1k dataset. The correction procedure was run for each continent. In cases where the Hydro1k did not provide enough information to correct the basin, discrepancies between the basin boundaries and the stream networks were resolved using *National Geographic's Atlas of the World* (7th ed.).

The basins that were changed and the Hydro1k levels used to redefine their boundaries are as follows: Asia-level 2, Ob, Amur; level 3, Indus, Hsi, Red, Karnafauli, Fenney; level 4, Oral, Saigon; level 5, Sulak, Samur; level 6, Asi; Africa-level 2, Dra; level 3, Benito; level 5, Medjerda; level 6, Atui, Tano, Umbeluzi; South America-level 6, Amacuro, Essequibo, Tumbes, Zarumilla; Europe-level 6, Gauja, L_Prespa, Lielupe, Venta; level 5, Vardar, Po, Parnu; North America- level 5, Negro; level 4, Alesek. The Ntem basin of Africa was merged with the Benito based on the NGS map and is now called the Benito-Ntem basin.

Adding new basins is an on-going process that evolves as information and data is made available. Three recent additions are the Skagit River basin that crosses the border of the United States and Canada, the Wiedau River basin that makes up a portion of the border between Denmark and Germany, and the Glama basin of Norway that shares approximately 1% of its tributaries with Sweden. The basin total is now at 263.

Afghanistan has been added as riparian to the Aral Sea basin.

The Kura-Araks, Samur, Sulak, and Terek basins, which were listed under Europe, are now listed under Asia. They appear on both the Asia and Europe maps.

Basin-Name changes since 1999-2000 TFDD:
St. John change to St. John (North America)
Saint John changed to Saint John (Africa)
Rio Grande changed to Rio Grande (North America)
Rio Grande changed to Rio Grande (South America)
Merauke changed to Tjeroaka-Wanggoe

Appendix 2 - Data Caveats to BAR Temporal GIS

The historical international basins of the BAR project are broken into 9 time sections. Each year segment represents all changes in polity and political boundaries from the year indicated by its name to the day before the beginning of the following time year(s) segment. For example Time segment 55 represents all polity and boundary changes between the time 1/1/55 to 12/31/71.

Data Caveats to BAR Temporal GIS: Countries

The major political boundary changes occurred between the years of 1990 and 1993. They are depicted as accurately as possible within their respective time segment coverage name. Each nation is represented by its BAR Country Code (CCode) (Wolf et. al 2000). The spatial political boundary changes are as follows: 1972 East Pakistan separated from Pakistan and formed Bangladesh, therefore, changing CCode PAK for the Bangladesh area to BGD; 1990 German Democratic Republic (East Germany) and German Federal Republic (West Germany) united, therefore dissolving CCodes GDR and GFR to create DEU (Germany); 1990 Yemen Arab Republic (North Yemen) and Yemen People's Republic (South Yemen) united, therefore dissolving CCodes YAR and YPR to create YEM (Yemen); 1991 The breakup of the former Soviet Union, creating the CCodes ARM, AZE, BLR, GEO, KAZ, KGZ, MDA, RUS, TJK, TKM, UKR, UZB; 1992 The breakup of the former Yugoslavia, creating the CCodes BIH, HRV, MKD, SVN, YUG; 1992 The breakup of Czechoslovakia, creating CCodes CZE and SVK; 1993 Eritrea became an independent nation, created CCode ERI.

Data Caveats to BAR Temporal GIS: Basins

Based on the above changes in country boundaries, the following basin changes (deviation from the 2000 international basin coverage) were made for each time segment:
1946 to 1989 addition of the Weser basin DEU, and the Tiban basin YEM; 1946 to the present equals the subtraction of basins labeled: BANN, BNGU, BRTA, CSTL, DNPR, DONX, DUGV, ELNK, ERNE, FANE, FLRY, FOYL, GUJA, KGNK, KRKA, LLUP, MIUS, NRTV, NRVA, ORAL, PNDR, PRNU, REZV, SALC, SAMR, SRTA, SULK, VENT, VLKA, VOLG.

Appendix 3 - Temporal Changes to Basin Coverage

This chart indicates those basins that were either added or subtracted from the complete list of basins due to the status of the political boundaries during the respective year. Traveling through time from 1948 to the present, the dates that each basin began and ended its existence is also indicated.

Basin Name	BCODE	Added	Removed
Bann	BANN	1992	n/a
Bangau	BNGU	1992	n/a
Barta	BRTA	1992	n/a
Castletown	CSTL	1992	n/a
Dnieper	DNPR	1992	n/a
Don	DONX	1992	n/a
Daugava	DUGV	1992	n/a
Elancik	ELNK	1992	n/a
Erne	ERNE	1992	n/a
Fane	FANE	1992	n/a
Flurry	FLRY	1992	n/a
Foyle	FOYL	1992	n/a
Gauja	GUJA	1992	n/a
Kogilnik	KGNK	1992	n/a
Krka	KRKA	1992	n/a
Lielupe	LLUP	1992	n/a
Mius	MIUS	1992	n/a
Neretva	NRTV	1992	n/a
Narva	NRVA	1992	n/a
Oral	ORAL	1992	n/a
Pandaruan	PNDR	1992	n/a
Parnu	PRNU	1992	n/a
Rezvaya	REZV	1992	n/a
Salaca	SALC	1992	n/a
Samur	SAMR	1992	n/a
Sarata	SRTA	1992	n/a
Sulak	SULK	1992	n/a
Venta	VENT	1992	n/a
Velaka	VLKA	1992	n/a
Volga	VOLG	1992	n/a
Weser	WESR	1946	1989
Tiban	TIBN	1946	1989

Appendix 4 - Results of Aggregating Datasets per International Basin

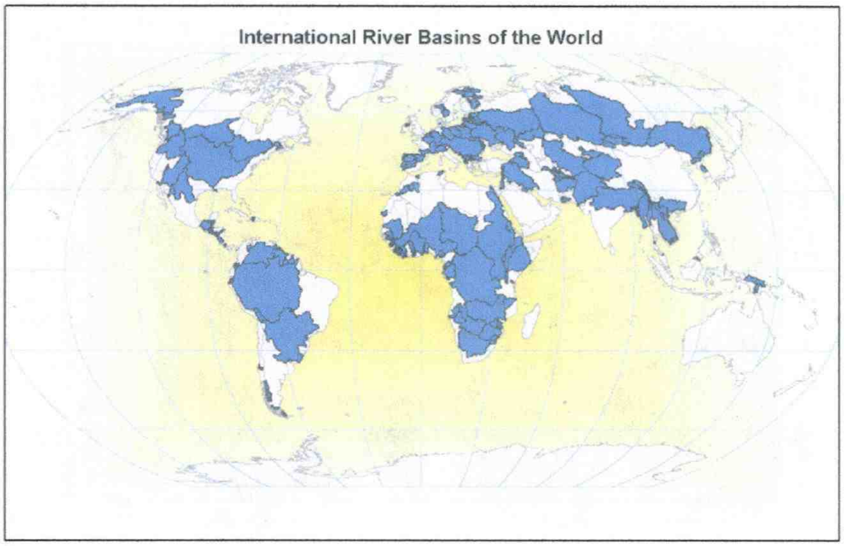
Basin Name	BCODE	Dams (#of)	Runoff (mm/yr)	Discharge (cu.km/yr)	Climate Zones (	Basin Area (sq.km)	Population (total)	Population Density (pop/sq.km)
Akpa Yafi	AKPA	0	No Data	No Data	1	4905	136162	27.76
Alsek	ALSK	0	6321	13792	3	28365	536	0.02
Amacuro	AMCR	0	No Data	No Data	1	5638	10283	1.82
Amur	AMUR	59	186368	368472	10	2085864	66087512	31.68
Amazon	AMZN	2	2134664	6490434	23	5883357	24583020	4.18
An Nahr Al Kabir	ANAK	1	No Data	No Data	1	1287	88880	69.06
Aral Sea (internal drai	ARAL	44	44828	105951	14	1231389	40126840	32.59
Asi	ASIX	6	4163	12137	4	37900	4694289	123.86
Artibonite	ATBN	1	No Data	No Data	4	8830	1093537	123.84
Astara Chay	ATCY	0	No Data	No Data	1	561	22441	40.00
Atrak	ATRK	0	605	1592	4	34215	1160722	33.92
Atui	ATUI	0	No Data	No Data	1	32645	8808	0.27
Aviles	AVLS	0	No Data	No Data	1	257	643	2.50
Awash	AWSH	2	7326	22702	7	154944	11766847	75.94
Aysen	AYSN	0	No Data	No Data	1	13596	14499	1.07
Baker	BAKR	0	11522	27295	2	30796	20168	0.65
Bann	BANN	0	No Data	No Data	1	5551	637028	114.76
Bidasoa	BDSO	0	No Data	No Data	1	525	43866	83.55
Benito_Ntem	BENT	0	10852	32639	2	45115	512316	11.36
Bia	BIAX	1	No Data	No Data	2	11062	567388	51.29
Beilun	BLUN	0	No Data	No Data	1	915	155062	169.47
Belize	BLZE	0	No Data	No Data	4	11463	96946	8.46
Bangau	BNGU	0	No Data	No Data	1	63	381	6.05
Baraka	BRKA	0	76	240	2	66248	1864721	28.15
Barima	BRMA	0	No Data	No Data	1	2088	2216	1.06
Barta	BRTA	0	No Data	No Data	1	1766	58981	33.40
Buzi	BUZI	1	2464	6821	2	27681	900512	32.53
Ca (Song-Koi)	CAXX	3	6084	17161	1	31028	3674502	118.43
Candelaria	CDLR	0	No Data	No Data	2	12755	70793	5.55
Changuinola	CGNL	0	No Data	No Data	1	3204	31637	9.87
Chico (Carmen Silva)	CHIC	0	No Data	No Data	1	1680	8065	4.80
Chira	CHIR	1	No Data	No Data	4	15705	448049	28.53
Choluteca	CHLT	0	No Data	No Data	2	7400	1386452	187.36
Chiriqui	CHRQ	0	No Data	No Data	1	1735	41860	24.13
Chuy	CHUY	0	No Data	No Data	1	175	12402	70.87
Colorado	CLDO	68	7074	17162	13	655030	7014887	10.71
Chilkat	CLKT	0	No Data	No Data	1	3776	201	0.05
Columbia	CLMB	111	107307	229896	10	668433	6355980	9.51
Chiloango	CLNG	0	No Data	No Data	1	11644	752156	64.60
Cancoso (Lauca)	CNCS	0	No Data	No Data	2	23509	126222	5.37
Congo	CNGO	16	420499	1270109	10	3691027	60222852	16.32
Coco (Segovia)	COCO	0	9483	24076	4	25389	611662	24.09
Comau	COMA	0	No Data	No Data	1	937	288	0.31
Corubal	CRBL	0	No Data	No Data	2	24004	518214	21.59
Cross	CROS	0	22013	58066	3	52756	8286256	157.07
Courantyne (Corantijn)	CRTY	0	12035	35903	1	41765	51101	1.22
Coruh	CRUH	0	No Data	No Data	3	22066	409916	18.58
Castletown	CSTL	0	No Data	No Data	1	381	29460	77.32
Cestos	CSTO	0	No Data	No Data	3	15012	610416	40.66
Coatan Achute	CTAT	0	No Data	No Data	1	1989	410759	206.52
Catatumbo	CTTB	0	5216	20192	4	30970	1322650	42.71
Cullen	CULL	0	No Data	No Data	1	594	6526	10.99
Cavally	CVLY	0	8977	27452	3	30580	728609	23.83
Danube	DANU	57	95465	205528	13	790119	80258360	101.58
Daoura	DAUR	0	No Data	No Data	2	34479	402291	11.67
Dnieper	DNPR	69	27357	52505	6	516281	31292984	60.61
Dniester	DNSR	15	5961	11922	4	62000	6458344	104.17
Don	DONX	83	15498	30963	7	425551	19618048	46.10
Dra	DRAX	3	1	3	3	96368	866277	8.99
Drin	DRIN	2	No Data	No Data	5	17917	1896715	105.86
Dasht	DSHT	0	No Data	No Data	1	33353	340966	10.22
Daugava	DUGV	1	7478	12920	2	58742	1814622	30.89
Douro (Duero)	DURO	27	10071	22627	4	98856	4340608	43.91
Ebro	EBRO	49	9997	24503	7	85787	2960721	34.51
Elbe	ELBE	36	12203	23388	5	132245	23291484	176.12
Elancik	ELNK	0	No Data	No Data	1	924	6508	7.04
Erne	ERNE	0	No Data	No Data	1	4784	158730	33.18
Essequibo	ESQB	2	73611	228940	4	239480	720069	3.01
Etosha/Cuvelai	ETOS	1	303	939	5	167417	776842	4.64
Fane	FANE	0	No Data	No Data	1	198	7064	35.68
Flurry	FLRY	0	No Data	No Data	1	61	6955	114.02
Fly	FLYX	0	46799	143998	3	64616	310200	4.80
Fenney	FNNY	0	No Data	No Data	1	2783	478059	171.78

Foyle	FOYL	0	No Data	No Data	1	2917	141525	48.52
Fraser	FRSR	4	49681	93049	10	239735	1221562	5.10
Firth	FRTH	0	No Data	No Data	2	6046	0	0.00
Gallegos	GALG	0	No Data	No Data	4	11597	17846	1.54
Gambia	GAMB	0	2886	9611	2	69932	1413293	20.21
Ganges	GANG	222	442060	1220844	13	1634936	508719840	311.16
Gash	GASH	0	387	1033	5	40045	2676104	66.83
Geba	GEBA	0	No Data	No Data	1	12784	410075	32.08
Grijalva	GJLV	3	35134	106063	10	126790	6211205	48.99
Glama	GLAM	0	10339	444598	5	43002	650934	15.14
Golok	GLOK	0	No Data	No Data	1	1842	253430	137.58
Goascoran	GOSR	0	No Data	No Data	1	2785	245454	88.13
Garonne	GRON	9	8378	17975	5	55783	3400137	60.95
Great Scarcies	GSCR	0	No Data	No Data	3	12068	458384	37.98
Guadiana	GUDN	17	2363	5945	1	67925	1677741	24.70
Guir	GUIR	1	No Data	No Data	2	78913	326304	4.13
Gauja	GUJA	0	No Data	No Data	4	11553	436658	37.80
Han	HANX	11	11915	28013	5	35266	18065656	512.27
Hari (Harirud)	HARI	2	2274	5399	5	92593	4870661	52.60
Helmand	HLMD	4	5009	13621	6	353513	6991007	19.78
Hondo	HOND	0	No Data	No Data	2	14590	182094	12.48
Har Us Nur	HRUN	0	716	1411	7	185252	241744	1.30
Hsi	HSIX	60	93657	266161	4	417755	79367008	189.98
Incomati	ICMT	3	1775	4879	6	46729	1457973	31.20
Ili (Kunes He)	ILIX	0	No Data	No Data	1	161221	4149595	25.74
Indus	INDU	28	58429	154026	19	1138805	200078528	175.69
Irrawaddy	IRWD	1	204433	577829	9	404189	35006484	86.61
Isonzo	ISNZ	0	No Data	No Data	2	3021	371742	123.05
Jacobs	JCBS	0	No Data	No Data	1	442	883	2.00
Jordan	JORD	2	736	1926	4	34016	5153450	151.50
Juba-Shibeli	JUBA	0	5101	15705	13	803543	12431128	15.47
Jurado	JURD	0	No Data	No Data	1	665	4580	6.89
Kaladan	KALD	0	23439	65024	3	30516	933627	30.59
Kemi	KEMI	1	15353	19015	2	55732	98942	1.78
Kogilnik	KGNK	9	No Data	No Data	2	6147	524750	85.37
Komoe	KMOE	0	1386	4708	2	78123	1963384	25.13
Karnaphuli	KNFL	1	No Data	No Data	2	12510	1932158	154.45
Kowl-E-Namaksar	KOWL	0	171	480	2	36455	396751	10.88
Krka	KRKA	0	No Data	No Data	1	1254	104886	83.64
Klaralven	KRLV	0	11310	18592	8	50960	1142571	22.42
Kunene	KUNE	3	5065	15057	8	109991	1200370	10.91
Kura-Araks	KURA	11	5964	14225	13	193197	13349132	69.10
Lava (Pregel)	LAVA	0	No Data	No Data	2	8578	755114	88.03
Lotagipi Swamp	LGPS	0	502	1389	3	38749	191702	4.95
Lima	LIMA	1	No Data	No Data	1	2284	118077	51.70
Lake Chad	LKCH	1	40327	117331	7	2388687	33139232	13.87
L_fagnano	LKFN	0	No Data	No Data	1	3189	3751	1.18
Lake Natron	LKNT	0	942	3072	8	55441	1225326	22.10
L_Prespa	LKPP	2	No Data	No Data	2	9035	894761	99.03
Lake Titicaca-Poopo System	LKTC	1	12783	38619	8	111781	2119984	18.97
Lake Turkana	LKTK	1	16646	52188	8	206923	14768555	71.37
Lake Ubsa-Nur	LKUN	0	781	1532	5	62784	106628	1.70
Lielupe	LLUP	0	No Data	No Data	3	14351	422161	29.42
Lempa	LMPA	2	No Data	No Data	2	18040	3960724	219.55
Limpopo	LMPO	38	3454	9681	6	414798	13210817	31.85
Lagoon Mirim	LMRM	0	10764	26889	3	54957	548307	9.98
Loffa	LOFF	0	No Data	No Data	2	11402	159465	13.99
La Plata	LPTA	46	258199	716280	16	2954460	57016904	19.30
Little Scarcies	LSCR	0	No Data	No Data	3	18872	729853	38.67
Mana-Morro	MANA	0	No Data	No Data	1	6847	213945	31.25
Massacre	MASS	0	No Data	No Data	1	798	202670	253.97
Ma	MAXX	0	5340	16164	1	30269	2416574	79.90
Mbe	MBEX	0	No Data	No Data	1	6981	21830	3.13
Medjerda	MDJD	2	2012	39081	1	174816	2343374	13.40
Mekong	MEKO	25	166550	478847	10	787776	52446340	66.58
Mino	MINO	13	5869	12651	1	15069	1044297	69.21
Mira	MIRA	0	No Data	No Data	2	12096	323366	26.73
Mississippi	MISS	750	255926	598762	17	3226293	69847144	21.65
Mius	MIUS	0	No Data	No Data	1	2787	106189	38.10
Moa	MOAX	0	No Data	No Data	2	22510	1283346	57.01
Mono	MONO	0	No Data	No Data	2	23430	1451172	61.94
Motaqua	MOTQ	0	No Data	No Data	5	16088	3566074	221.66
Maputo	MPUT	3	1446	3694	4	30656	1104265	36.02
Murgab	MRGB	3	1428	3222	6	60926	1237547	20.31

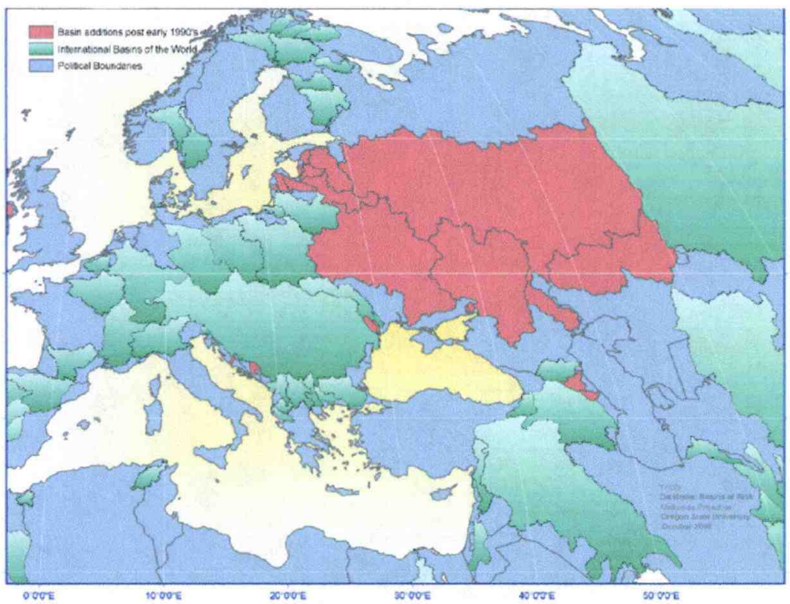
Maroni	MRNI	0	19674	58127	3	64999	10767	0.17
Maritsa	MRSA	30	5686	13441	8	49643	3359028	67.66
Mataje	MTJE	0	No Data	No Data	1	734	12254	16.69
Naatamo	NAAT	0	No Data	No Data	1	996	772	0.78
Negro	NEGR	0	No Data	No Data	2	5766	158764	27.53
Nelson-Saskatchewan	NELS	142	45993	87521	11	1109407	5164532	4.66
Niger	NGER	7	110480	328370	7	2113244	71496680	33.83
Nahr El Kebir	NHRK	0	No Data	No Data	1	1536	594630	387.13
Nile	NILE	12	107410	323692	14	3031691	144982480	47.82
Neman	NMAN	5	11660	21060	2	90310	4614951	51.10
Neretva	NRTV	0	No Data	No Data	2	5502	278296	50.58
Narva	NRVA	0	8249	12848	3	52955	1126515	21.27
Nestos	NSTO	0	No Data	No Data	3	10190	272275	26.72
Nyanga	NYGA	0	No Data	No Data	1	12340	36495	2.96
Ob	OBXX	88	262023	445127	11	2950834	31332126	10.62
Oued Bon Naima	ODBN	0	No Data	No Data	1	504	47599	94.44
Oder (Odra)	ODER	15	11049	20810	6	122425	16783652	137.09
Ogooue	OGOO	0	48951	153739	4	222987	618835	2.78
Okavango	OKVG	1	10821	31221	4	706879	1385033	1.96
Olanga	OLNG	0	No Data	No Data	1	18831	71450	3.79
Oral	ORAL	64	9587	18292	3	311001	3417159	10.99
Orange	ORAN	32	2952	8161	10	945475	13918971	14.72
Orinoco	ORIN	2	328617	995978	10	927430	10089300	10.88
Oueme	OUEM	0	2221	6957	2	59517	4641340	77.98
Oulu	OULU	0	7063	10662	1	28681	206014	7.18
Oyupock (Oiapoque)	OYPK	0	No Data	No Data	2	23251	34875	1.50
Paz	PAZX	0	No Data	No Data	1	2170	485232	223.61
Pedernales	PDNL	0	No Data	No Data	1	358	52430	146.45
Pakchan	PKCN	0	No Data	No Data	1	3912	128069	32.74
Palena	PLNA	0	No Data	No Data	5	13336	8045	0.60
Pandaruan	PNDR	0	No Data	No Data	1	371	7612	20.52
Po	POXX	3	21951	49010	7	87076	17313426	198.83
Prohladnaja	PRLN	0	No Data	No Data	1	619	23431	37.85
Parnu	PRNU	0	No Data	No Data	1	5842	162531	27.82
Pascua	PSCU	0	No Data	No Data	1	13696	3477	0.25
Pasvik	PSVK	1	No Data	No Data	1	16015	43718	2.73
Patia	PTIA	0	No Data	No Data	4	21289	1001301	47.03
Puelo	PUEL	0	No Data	No Data	3	8404	5061	0.60
Pu-Lun-T'o	PULT	0	224	464	6	89004	418476	4.70
Rudkhaneh-ye (BahuKalat)	RDKH	0	No Data	No Data	2	18018	77881	4.32
Red	REDX	11	31507	86839	2	157103	27153668	172.84
Rezvaya	REZV	0	No Data	No Data	1	671	7573	11.29
Rio Grande	RGNA	67	No Data	No Data	10	656109	11484489	17.50
Rio Grande	RGSA	0	No Data	No Data	1	8015	22590	2.82
Rhine	RHIN	16	39471	77572	6	172945	53590904	309.87
Rhone	RHON	6	24835	52956	6	100219	9621311	96.00
Roia	ROIA	0	No Data	No Data	1	647	29545	45.66
Ruvuma	RVMA	0	21536	73820	3	174816	1746468	9.99
Sabi	SABI	5	4330	12524	4	115695	3105723	26.84
Saigon	SAIG	2	10190	28462	2	25136	5411169	215.26
Salaca	SALC	0	No Data	No Data	2	2086	49117	23.55
Salween	SALW	1	49287	136668	9	244016	5013968	20.55
Samur	SAMR	0	No Data	No Data	2	6772	34428	5.08
Sassandra	SASS	0	9635	29858	2	68177	2715123	39.82
St. Croix	SCRO	1	No Data	No Data	1	4639	32239	6.95
Seine	SEIN	5	8550	17882	1	85749	16323425	190.36
Senegal	SENG	0	8532	25654	4	435979	4103053	9.41
Seno Union (Serrano)	SENO	0	No Data	No Data	3	6469	2293	0.35
Sepik	SEPK	0	31823	97274	2	73361	764375	10.42
Schelde	SHLD	1	No Data	No Data	1	17107	7507796	438.87
Sixaola	SIOL	2	No Data	No Data	1	2873	17624	6.13
St. John	SJAF	0	5546	17262	2	15563	471178	30.28
Saint John	SJNA	1	13181	28590	1	47719	458768	9.61
San Juan	SJUA	6	13726	48231	6	42166	2578821	61.16
Skagit	SKAG	2	No Data	No Data	2	8021	58108	7.24
St. Lawrence	SLAW	85	172648	356501	13	1055163	45094216	42.74
San Martin	SMAR	0	No Data	No Data	1	653	1786	2.74
Sembakung	SMBK	0	10497	26682	1	15251	125300	8.22
St. Paul	SPAU	1	No Data	No Data	2	21232	652205	30.72
Sarata	SRTA	1	No Data	No Data	1	1756	60348	34.37
Sarstun	SRTU	0	No Data	No Data	1	2070	37749	18.24
Stikine	STKN	0	28310	45002	2	50868	1950	0.04

Struma	STUM	1	No Data	No Data	3	14982	866392	57.83
Suchiate	SUCT	0	No Data	No Data	1	1554	640859	412.39
Sujfun	SUJF	0	No Data	No Data	2	18269	664807	36.39
Sulak	SULK	0	No Data	No Data	2	15075	228092	15.13
Song Vam Co Dong	SVCD	0	4210	10736	2	15300	4385538	286.64
Tafna	TAFN	0	No Data	No Data	2	9453	1434397	151.74
Tagus (Tejo)	TAGU	40	6532	16408	3	77871	9160948	117.64
Taku	TAKU	0	No Data	No Data	2	18145	12	0.00
Tami	TAMI	0	46146	138207	2	89850	338061	3.76
Tana	TANA	0	No Data	No Data	2	15633	6376	0.41
Tano	TANO	0	1185	4613	2	15571	1043531	67.02
Terek	TERK	0	6010	12935	5	38741	2344346	60.51
Tigris_Euphrates	TIGR	33	47447	120375	9	789017	48110860	60.98
Tijuana	TIJU	2	No Data	No Data	1	4390	841034	191.58
Tjeroaka_Wanggoe	TJWA	0	No Data	No Data	2	6568	32165	4.90
Torne	TORN	0	4374	5265	2	37316	85615	2.29
Tarim	TRIM	37	3199	7842	12	1051614	7804121	7.42
Tuloma	TULM	1	3272	3373	2	25772	412293	16.00
Tumbes	TUMB	0	No Data	No Data	1	4969	74654	15.02
Tumen	TUMN	0	1739	3895	2	29118	2062230	70.82
Umbeluzi	UBLZ	1	No Data	No Data	3	10914	1560038	142.94
Umba	UMBA	0	No Data	No Data	1	8185	512216	62.58
Utamboni	UTBN	0	No Data	No Data	1	7656	39472	5.16
Valdivia	VDVA	1	No Data	No Data	2	14971	1066300	71.22
Venta	VENT	0	No Data	No Data	2	9526	570293	59.87
Vijose	VJSE	1	No Data	No Data	1	7169	513935	71.69
Velaka	VLKA	0	No Data	No Data	1	695	10844	15.60
Volga	VOLG	135	179413	311346	7	1554883	62319276	40.08
Volta	VOLT	3	12417	37689	4	412799	19097806	46.26
Vardar	VRDR	2	2067	4780	6	32373	3510334	108.43
Vistula	VSTL	9	16757	32839	4	194010	24015210	123.78
Vuoksa	VUKS	0	14323	19122	4	62748	653566	10.42
Wadi Al Izziyah	WADI	0	No Data	No Data	1	576	33340	57.88
Whiting	WHIT	0	No Data	No Data	1	2553	0	0.00
Wiedau	WIED	0	No Data	No Data	1	1126	65023	57.75
Yalu	YALU	10	9271	22456	4	50865	6375738	125.35
Yaqui	YAQU	3	41	109	4	74662	643180	8.61
Yelcho	YELC	0	No Data	No Data	3	11139	7786	0.70
Yenisey (Jenisej)	YNSY	9	402987	641026	9	2557825	8042464	3.14
Yser	YSER	0	No Data	No Data	1	923	84695	91.76
Yukon	YUKN	3	154435	200846	9	829732	104639	0.13
Zambezi	ZAMB	30	105885	317489	6	1385275	28135732	20.31
Zapaleri	ZAPL	0	No Data	No Data	1	2636	8385	3.18
Zarumilla	ZARM	0	No Data	No Data	1	4311	567550	131.65

Appendix 5 - International River Basins of the World, 263 as of March 2001

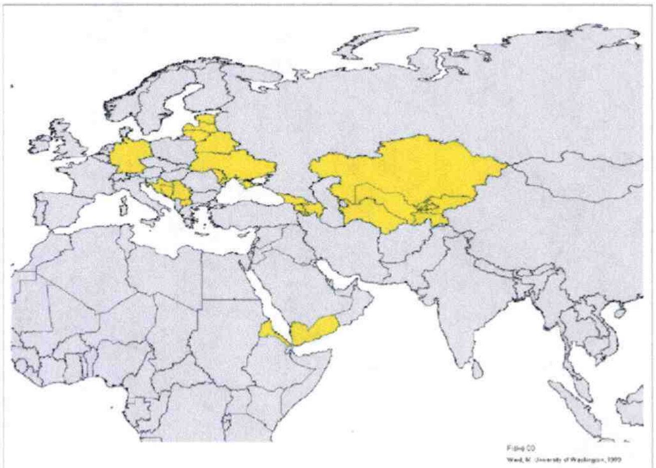


Appendix 6 - River basins that have become internationalized within the last 50 years due to political boundary changes



Appendix 7 - Countries that have had major political boundary changes within the last 50 years

New Countries due to Boundary Changes, 1989-1992



Appendix 8 - Number of climate zones per international river basin