AN ABSTRACT OF THE DISSERTATION OF

Shira B. Yoffe for the degree of Doctor of Philosophy in Geography presented on October 12, 2001.

Title: Basins At Risk: Conflict and Cooperation Over International Freshwater Resources

Abstract approved: ______________________________

Aaron T. Wolf

In the policy literature and the popular press, the issues of water and conflict are being raised together with increasing frequency. Geographic, international relations, and environmental security theories speculate on the linkages between geographic features, natural resources, spatial relationships, and war or acute conflict. Little quantitative or global-scale research exists, however, to test these theories regarding the relationship of water to international conflict. Moreover current literature often lacks consideration of water cooperation or spatial variability. The Basins at Risk (BAR) project addressed this gap by empirically identifying historical indicators of international freshwater conflict and cooperation and creating a framework to identify and evaluate international river basins at potential risk for future conflict. To accomplish this task, we created a database of historical incidents of water-related cooperation and conflict across all international river basins from 1948 to 1999, delineated an historical Geographic Information System (GIS) of international river basins and associated countries, derived biophysical, socioeconomic, and geopolitical variables at multiple spatial and temporal scales, and tested these variables against our event data.

We found that international relations over shared freshwater resources were overwhelmingly cooperative. Although conflicts over water occurred, violent conflict was rare and far outweighed by the number of international water agreements. International cooperation over water resources covered a wide range of concerns, including quantity, quality, hydropower, and infrastructure development. Conflict, especially acute conflict, centered on issues of quantity and infrastructure (e.g., dams, reservoirs). The majority of commonly cited indicators (e.g., climate, water stress, government type, relative power relationships) showed no statistically significant association with international water conflict or cooperation. Rather, the tendency towards conflict was associated with rapid or extreme changes in physical or institutional systems (e.g., the building of large dams or the internationalization of a basin). The propensity for such conflict was mitigated by the presence of institutional mechanisms, such as freshwater treaties. From the results of our analyses, we identify three categories of basins at risk and present a framework for further evaluation of the potential for international water conflict in these basins.

Basins at Risk:
Conflict and Cooperation Over International Freshwater Resources

by

Shira B. Yoffe

A DISSERTATION

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Presented October 12, 2001
Commencement June 2002

Doctor of Philosophy dissertation of Shira B. Yoffe presented on October 12, 2001.

APPROVED:

Major Professor, representing Geography

Chair of Department of Geosciences

Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Shira B. Yoffe, Author

ACKNOWLEDGEMENT

Spanning three years, the Basins At Risk project involved the efforts of a number of faculty and student researchers at Oregon State University, many of whom spent long hours immersed in BAR project tasks. I would like to acknowledge the insights, assistance and support of Dr. Jon Kimerling, Dr. Phil Jackson, Dr. Dawn Wright, Case Bowman, Kuuipo Burleigh, Becci Dale, Meredith Giordano, Greg Fiske, Jeanne Hoadley, Kelli Larson, Kyoko Matsumoto, Marc Rothgery, Brian Ward, and Daniel Wise. In addition, others gave of their time and/or data to facilitate this research project. I would like to extend thanks to George Taylor, Oregon State Climatologist, and his assistants Nathaniel De Young and Melanie Mitchell; Mark Levy, Center for International Earth Science Information Network; Jake Brunner and Kirsten Thompson,World Resources Institute; Petra Doell, University of Kassel, Germany; Glenda Pearson, University of Washington Library; David B. Kynoch, President, Pacific Northwest GIS Consulting, Inc.; Dr. Michael D. Ward, Department of Political Science, University of Washington (Seattle); Balazs Fekete, Complex Systems Research Center, University of New Hampshire; Dr. Jerome E. Dobson, Oak Ridge National Laboratory; Joe Toth and Carrie Ottow, Oregon State University Valley Library; Jeff Danielson and Kent Lethcoe, EROS Data Center; and, The Global Event Data System, University of Maryland. I would also like to acknowledge the National Science Foundation Graduate Research Traineeship (GRT) Fellowship in Landscape Studies, for financial support of my doctoral studies.

I extend special thanks to members of my committee, Dr. Gordon Matzke, Dr. Chuck Rosenfeld, and Dr. Court Smith, for their insights, encouragement, and "reality-checks," and Dr. Julia Jones, for all the above and her discerning and patient editiorial eye. Last, but certainly not least, I thank my advisor, Dr. Aaron Wolf, for his energy, enthusiasm, creative use of the English language, encouragement, advice, patience, and friendship.

CONTRIBUTION OF AUTHORS

Kelli Larson assisted with the compilation of the event data, specifically the identifying, obtaining, coding, and entering of the information from electronically searchable news databases. Greg Fiske provided Geographic Information System expertise to the project, including the updating of the TFDD basin layers, manipulation of the historical GIS country and basin coverages, data layer calculations for a number of spatial indicator variables, and creation of map images associated with these tasks. Mark Giordano participated in the coding of the event data and provided statistical expertise in data manipulation and running of some of the statistical analyses.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT.)

LIST OF FIGURES

LIST OF FIGURES (CONT.)

LIST OF TABLES

LIST OF APPENDICES

LIST OF APPENDIX FIGURES

A12.9: Population Density by Basin-Country Polygon vs. BAR Scale (n = 344, R-square = 0.02, Coeff. = -0.19, p-value = 0.00) 148

LIST OF APPENDIX FIGURES (CONT.)

LIST OF APPENDIX TABLES

LIST OF APPENDIX TABLES (CONT.)

DEDICATION

This dissertation is dedicated to my parents, Graenem and Helene Yoffe, for their support, encouragement, and chocolate chip cookies.

BASINS AT RISK: CONFLICT AND COOPERATION OVER INTERNATIONAL FRESHWATER RESOURCES

CHAPTER 1 INTRODUCTION

In the policy literature and popular press, issues of water and international conflict are linked with increasing frequency (Westing 1986; Elliott 1991; Gleick 1993; Homer-Dixon 1994; Remans 1995; Butts 1997; Elhance 1999). In particular, the past few decades have seen an increase in geopolitical, international relations, and environmental security literature on water's role in international conflict. This literature often stresses various indicators for conflict, including proximity, government type, aridity and rapid population growth. Yet despite the number of case studies analyzing and comparing water-related conflict in various international river basins, little global-scale or quantitative evidence has been compiled. Existing work often consists of case studies from the most volatile basins and excludes examination of cooperation, spatial variability and precise definitions of conflict.

My dissertation research, the Basins at Risk project (BAR), addresses a series of overarching gaps in research on freshwater resources and international conflict by providing a quantitative, global scale exploration of the relationship between freshwater resources and conflict – in essence, asking whether the theories and claims hold true. I also incorporate a spatial perspective and consider the full spectrum of interactions, using precise definitions of conflict and cooperation.

The specific purpose of my dissertation research was threefold:

- To identify historical indicators of international freshwater conflict and cooperation;
- To use these indicators to create a framework to identify and evaluate international river basins at potential risk for future freshwater conflict;
- To enhance understanding of the driving forces that may cause water to become a focus of conflict or cooperation.

It is hoped such information can contribute to the development of international management approaches designed to mitigate the potential for international water conflict.

To accomplish these goals required three main elements: creation of an event database documenting historical water relations, including a methodology for identifying and classifying events by their intensity of cooperation and conflict; construction of a geographic information system (GIS)[1] of countries and international basins, both current and historical; and the collection or creation of indicator variables (biophysical, socioeconomic, and geopolitical) for testing of hypotheses about factors associated with water conflict.

The accompanying chapters describe the methods and findings of my dissertation research. Chapter 2, "Basins at Risk: Water Event Database Methodology," describes the backbone of my dissertation research – the water-event database. This database catalogs historical incidents of international water cooperation and conflict for all countries from 1948-1999. For the purposes of the Basins at Risk Project, water events were defined as instances of conflict and cooperation that occur within an international river basin, involve the nations riparian to that basin, and concern freshwater as a scarce or consumable resource or as a quantity to be managed. These events were classified by the international river basin in which they occurred, the countries involved in the event, the date, level of intensity of conflict or cooperation, and the main issue associated with each event. All the event information collected and coded was compiled in a relational database to allow for analyses at an array of spatial and temporal scales. The database methodology is described in detail in order to facilitate evaluations of the project's findings, to facilitate others' use of the data in further research, and to offer a model for those interested in following a similar methodology for exploration of other issues. The chapter concludes with a detailed picture of patterns of historical conflict and cooperation over international freshwater resources.

This water event database represents a unique resource that allows evaluation of historical incidents of water conflict and cooperation and exploration of relationships

---

[1] A GIS is a computerized system that enables storage, management, analysis, modeling, and display of spatial and associated data.

between these incidents and a wide range of biophysical, socioeconomic, and political data. Chapter 3, "Use of GIS for Analysis of Indicators of Conflict and Cooperation Over International Freshwater Resources" describes the spatial complement to the water event database – the creation of an historical GIS that delineates all current and historical international basins and their riparian countries, from 1948-1999, and the use of this GIS to calculate variables for statistical analysis.

Because not all basins were international across the entire time period of the study and many events researched for the event database (Chapter 2) turned out to be related to intra-national, rather than international water resources, 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. Creating these temporal GIS layers facilitated our ability to associate events with basins that were international at the time the event occurred. More importantly, the historical GIS allowed the linkage of the incidents of international water conflict and cooperation with socioeconomic, biophysical, and political indicators specific to the year in which the event occurred.

While the GIS allowed analyses at a range of spatial scales, including country, region, and basin-country polygon,[2] the key unit of analysis considered was the international river basin. An international river basin comprises all the land that drains through that river and its tributaries into the ocean or an internal lake or sea and that includes territory of more than one country. Most of the broad analyses of international water conflict have examined data compiled at the country level. The historical GIS allowed questions to be framed in terms of river basins and provided some accountability of within-country variation. Geomorphologists have long considered the river basin to be a natural framework of study when considering the physical aspects of water resources (Leopold, Wolman et al. 1964). The same consideration holds true when considering the relationship of freshwater to international conflict and cooperation.

BAR's GIS includes 263 current international basins and two historical basins. This historical GIS enabled incorporation of both temporal and spatial variability into our analyses. It allowed us to derive data, including population, climate, or water

---

[2] A basin-country polygon refers to a country's territorial share of an international basin. It is the smallest spatial grain used in the BAR study.

availability, at the basin level or other scales and to explore correlations between these variables and the event data. This ability to explore why an event occurred is integral to the power of the BAR Event Database, and the lack of such an ability has been a major criticism of the utility of event datasets in the past (Lanphier 1975; Andriole and Hopple 1984; Laurance 1990).

Exploring the question of why an event occurred is a key part of Chapter 4, "Cooperation and Conflict Over International Freshwater Resources: Indicators and Findings of the Basins at Risk Project". After describing the project's methodology and statistics, Chapter 4 discusses the commonly cited theories and indicators linking water to conflict and our own hypothesis, which concerns infrastructural development and institutional mechanisms. Based on the results obtained, I present a framework for identifying and evaluating basins at potential risk for future international conflict over freshwater resources. I identify three categories of basins at risk. The first are basins negotiating current conflicts, well known "hot spots" where the potential for continued dispute, at least in the near term, is therefore considered likely. The second category are basins in which factors point to the potential for future conflict and in which up-coming development projects or other stresses upon the water system have raised protests among the riparians. The third category is similar to the second in that there is a confluence of factors which indicate the potential for future conflict. Unlike category 2 basins, however, there is no evidence of existing tensions in public policy or media fora. When all the categories are viewed together, what stands out is that the majority of basins at risk fall in southern Asia and central and southern Africa.

Categorizing a basin as "at risk" does not presume to identify basins in which acute conflict *will* occur, but to point to basins worth more detailed investigation. Assessing basins at risk is as much art as science and requires a mix of quantitative and qualitative research approaches.

Chapter 5 provides an overview and conclusion to this dissertation. Further details of the statistical methodologies and data sources associated with the indicators used and BAR findings may be found in the Appendices. These data and methodological information, in addition to that contained in the previous chapters, will become part of the

TFDD website (http://www.transboundarywaters.orst.edu), where the Basins at Risk project data and findings will be made publicly available.

CHAPTER 2 BASINS AT RISK: WATER EVENT DATABASE METHODOLOGY

Shira Yoffe and Kelli Larson
Department of Geosciences, Oregon State University

Submitted for publication, as part of set of three articles, to *Water Policy*, World Water Council, October 1, 2001, 47 pages, in review.

KEYWORDS

Event Data, International Rivers, Water Conflict, Cooperation, Quantitative Analysis

ABSTRACT

To better understand conflict and cooperation over international freshwater resources, we created a database of historical incidents of international water cooperation and conflict spanning the years 1948 to 1999. These incidents were ranked by intensity using precise definitions of conflict and cooperation and linked to the international basin in which they occurred. This research is part of the Basins at Risk (BAR) project and was conducted under the auspices of the Transboundary Freshwater Dispute Database, Oregon State University. The purpose of this paper is to describe the process by which data were collected and coded and to highlight some summary findings. This water event database represents a unique resource that allows exploration of relationships between historical incidents of water conflict and cooperation and a wide range of biophysical, socioeconomic, and political data. Initial summaries of the data indicate that international water relations over the past fifty years have been overwhelmingly cooperative, belying claims that water is mainly a source of international conflict. Cooperative water relations concern a wide range of issue areas, including water quantity, infrastructure, joint management, and hydropower. Conflict over water tends to center on quantity- and infrastructure- (e.g., dams) related concerns.

INTRODUCTION

In the policy literature and popular press, issues of water and international conflict have been linked with increasing frequency (Westing 1986; Elliott 1991; Gleick 1993; Homer-Dixon 1994; Remans 1995; Butts 1997; Elhance 1999). Yet despite the number of case studies analyzing and comparing water-related conflict in various international river basins, little quantitative, global-scale evidence has been compiled. Existing work often consists of case studies from the most volatile basins and excludes examination of cooperation, spatial variability and precise definitions of conflict. The purpose of the Basins at Risk project is to identify historical indicators of international freshwater conflict and, from these indicators, create a framework with which international river basins at potential risk for future freshwater conflict may be identified and further evaluated (see Chapter 4).

This chapter describes one component of the Basins At Risk (BAR) project – the creation of an event database documenting historical water relations. The goal in creating this database was to identify all reported instances of conflict or cooperation over international freshwater resources for the entire world for the past fifty years, to classify those events by the international river basin in which they occurred, the countries involved in the event, the date, level of intensity of conflict or cooperation, and the main issue associated with each event. All the event information collected and coded was compiled in a relational database to allow for analyses at an array of spatial and temporal scales.

There are two reasons for providing such detailed descriptions of the data sources and methodologies behind the creation of the BAR Water-Event Database. The first is that the findings of the Basins At Risk Project are grounded in this database. For this reason, this chapter is as explicit as possible about how the event data were obtained and coded, in order to facilitate any evaluations of the project's findings. The second is to offer a possible model for those interested in following a similar research methodology for other issues or resources.

For the purposes of the Basins At Risk Project, water events are defined as instances of conflict and cooperation that occur within an international river basin, that involve the nations riparian to that basin,[3] and that concern freshwater as a scarce or

[3] In incidents involving a country that is a topographic, but not functional, riparian (i.e., the country's territorial share of a basin does not regularly contribute water to that basin), the country is not treated as riparian, and so that incident would not be considered an event. An exception to this rule are situations in which the country acts as a riparian, such as Egypt in the Jordan River basin during the course of the Huleh Swamp drainage dispute.

consumable resource (e.g., water quality, water quantity) or as a quantity to be managed (e.g., flooding or flood control, managing water levels for navigational purposes). Incidents that did not meet the above criteria were not included as events in the analyses (e.g., third-party (i.e., non-basin country) involvement, delineation of rivers as boundaries, fisheries, issues internal to a country, construction of ports or waterfront facilities).[4] The time period covered by the event database, 1948-1999, was chosen for its relevance to potential future instances of cooperation and conflict and for data manageability and availability. The spatial coverage is global and concerns all international river basins.

To locate event data information, a multi-step approach was used. We searched multiple existing political science datasets and conducted primary searches of several electronically-searchable news databases. Both approaches were necessary, as we found little overlap between events in the political science databases and information obtained from primary news sources. Moreover, while the earliest electronically-searchable news sources begin with 1978 information, some of the political science datasets provided event information as far back as 1948, facilitating the incorporation of earlier decades into the Event Database. In addition, we incorporated information from historical analyses and case studies of international river basins.

EVENT DATA

A number of political science datasets exist that document interactions among countries. These "event data" are widely used in quantitative political science analyses. Originally developed by Charles McClelland in the early 1960's, event data serve as a bridge from traditional diplomatic history to quantitative analyses of international politics. Unlike traditional foreign policy studies, which primarily use documents,

[4] Other examples of incidents that were not included as events in the BAR database (unless they concerned water as a scarce, consumable and/or manageable resource) include: incidents concerning foreign aid; water as a weapon/victim/target of warfare; navigation; creation of free trade zones in border river areas; territorial disputes (e.g., control over river islands); water supplies or water purification equipment for refugees; and, purchasing and selling of hydroelectricity.

histories, memoirs and other narrative sources, event data allow analysis in a statistical framework. As stated by Schrodt:

> Event data are generated by examining thousands of newspaper reports on the day to day interactions of nation-states and assigning each reported interaction a numerical score or a categorical code. … When these reports are averaged over time, they provide a rough indication of the level of cooperation and conflict between two states (Schrodt 1993 1).

Many of the existing event datasets were created under the Data Development for International Research (DDIR) project, which was funded by the National Science Foundation in the late 1980's and early 1990's. The goal of the DDIR was to provide empirical data that would facilitate understanding and predicting of international conflict (Merritt, Muncaster, & Zinnes 1993). Datasets produced under the DDIR project's auspices are available to the public through the Inter-University Consortium for Political and Social Research (ICPSR), at website: http://www.icpsr.umich.edu/. Event data assumed a central role in studies of correlates of national and international unrest and violence and in the study of foreign policy decision-making. Event datasets cover a number of interaction types (e.g., military, political, economic) and issue areas (e.g., trade, scientific exchange, border disputes). Many of them, however, focus only on crisis events or, more specifically, on military interactions among nations, and thus do not provide any information on cooperative events. Moreover, none of the existing event datasets code specifically for water resource issues, and many are limited by the small number of countries included or the time periods covered.

One event dataset – the International Crisis Behavior Project (ICB) – provides appropriate temporal and spatial coverage, along with textual summaries, of conflictive events. Two other event datasets, however, include cooperative as well as conflictive events, contain searchable event summaries, and provide broad spatial and temporal coverage – the Conflict and Peace Data Bank (COPDAB) and the Global Event Data System (GEDS). These three event datasets contain coding that allowed us to distinguish whether an interaction between nations is related to freshwater resources. Using multiple search criteria, we pulled relevant events from these databases and merged them into our own water-event database.

In the BAR Event database, incidents of conflict and cooperation over freshwater may be considered in two basic formats: interactions, which break out each incident by the country-pairs (dyads) and basins involved; and, events, which provides one entry for each incident in a basin, regardless of the number of country-pairs involved. Table 2.1 lists the number of events and interactions obtained from each of the datasets described here.

Table 2.1: Database Search Results

Database	*Approx. Years Covered*	*Total Records*	*Initial Search Results*	*Number of Events*	*Number of Inter-actions*
ICB	1918-1988	412	412	4	4
COPDAB	1948-1978	256,373	5,300	388	549
GEDS	1979-1994	82,778	9,500	144	225
TFDD	1874-2000	200	126	126	535
FBIS	1978-1995	n/a	1,817	439	770
WNC	1995-1999	n/a	9,589	321	629
LEXIS-NEXIS	1978-present	n/a	2,745	16	17

EVENT DATA: SOURCES AND SEARCH METHODOLOGIES

Political Science Datasets

The ICB dataset was developed by Brecher and Wilkenfeld (2000) to aid investigation of twentieth century interstate crises and the behavior of states under externally generated stress. The dataset categorizes all international crises from 1918-1988 and includes variables that describe the sources, processes, and outcomes of all military-security crises involving nation-states. Of the 412 crises identified in this dataset, Wolf (1998) found only four disputes where water was, at the least, a partial cause.

The COPDAB, created by Edward E. Azar, codes inter- and intra-state events for approximately 135 countries from the years 1948-1978 and contains 256,373 event records.[5] Event information was derived from a wide range of U.S. and foreign news sources and includes event date, initiating actor, event target, information source, issue areas, brief event description, and a numeric code assigned from a 15-point categorical scale, hereafter referred to as the COPDAB scale, ordered by the intensity of event conflict or cooperation. The dataset does not include any water-specific coding, however the brief textual summary provided a guide to identify possible water-related events. In cases where it was questionable whether or not an incident was actually water-related, we researched the original news article for clarification. Only incidents that could be positively identified as relating to water conflict or cooperation in an international basin are included in the BAR Event Database.

The COPDAB data was downloaded from the ICPSR website as a text file and imported into Microsoft Access. The database contains a summary field consisting of a brief sentence or phrase describing the event. The COPDAB data was filtered, in a series

[5] Coverage is not consistent for all countries for all years. For more detailed information on the methodology associated with the creation of the COPDAB data, please refer to Azar (1980).

of queries, by searching this field for the specific words or parts of words. The initial query searched for water terms (e.g., desalting, irrigation, river, dam, barrage, reservoir). Because parts of words were considered in this query, the list needed to be further filtered to delete events that included the water search terms, but were not actually water-related (e.g., Pots*dam*, fun*dam*ental, international waters, *dam*age, Sh*river*, *River*o). The resulting list was then filtered again to remove events that did not fit BAR's definition of a water event (e.g., events referring to: salt water canals, including Suez and Panama; river traffic; construction of shipping facilities; movement of troops described as being in the vicinity of rivers or lakes). Table 2.2 presents a more detailed list of the search criteria. The search results are listed in Table 2.1.

Building on the COPDAB, the GEDS Project, directed by John Davies (1998) at the University of Maryland, tracks day-to-day interactions among nation-states and other international actors using on-line news reports. The GEDS database contains 82,778 event records, covering the years 1979 to 1994. GEDS codes for the same fields as COPDAB, with some additions, including a more comprehensive event summary. The event data in the GEDS archive was derived mainly from Reuters, with some event data from BBC sources.[6] Although GEDS was not created to capture water resource issues specifically, the detailed textual summary enabled us to search for water-related events.

Similarly to COPDAB, the GEDS data was filtered by searching the Event Summary field for water-specific words or parts of words (e.g., desalting, reservoir, river, hydro). A large number of irrelevant event records were retrieved, more so than with COPDAB, because the search was conducted on a more detailed textual summary describing each event. Irrelevant records included terms such as: Amster*dam*, Fitz*water*, water canon, cold water, water-tight, *hydro*carbons, and Sa*dam*. These words were used as search terms to facilitate identification and deletion of a portion of the irrelevant records. Also deleted were records that did not fit the definition of a BAR event (e.g., river blindness, refugees crossing a border river, fish quotas, dignitaries taking tours of

[6] Coverage is not consistent for all countries for all years. Additional information about the creation of the GEDS Archive, including the methodology for creation of the database and the years and countries covered, may be found on the GEDS website (http://geds.umd.edu/geds/).

lakes/rivers). Table 2.2 presents a more detailed list of the search criteria. The search results are listed in Table 2.1.

Table 2.2: Search Terms – Political Science Datasets

	COPDAB	**GEDS**
Water Terms	desalting, irrigation, lake, river, canal, pollution, dam, hydro, water, desalination, barrage, reservoir, river, cholera, swamp, wetland, delta, Aral[7]	desalting, irrigation, lake, river, canal, pollution, dam, hydro, water, desalination, barrage, reservoir, river, cholera, swamp, wetland, delta, Aral Sea
Irrelevant/ Excluded Terms	Potsdam, Rotterdam, Amsterdam, fundamental, hydrocarbons, heavy water, territorial waters, international waters, damage, driver, Khaddam, Khadam, Modderdam, Shriver, Goldwater, Sadam, Damascus, hydrogen, waterloo, Rivera, Rivero	Potsdam, Rotterdam, Amsterdam, Fitzwater, water canon, cold water, water tight, fish, underwater, watered down, Adam, fundamental, hydrocarbons, heavy water, territorial waters, international waters, waters, damage, driver, Khaddam, Khadam, Modderdam, Shriver, Goldwater, Sadam, Agdam, Damascus, hydrogen, waterloo, Rivera, Rivero
Non-BAR-Event Terms	salt water canals, including Suez and Panama; navigation, river traffic; construction of river ports or shipping facilities; border disputes or boundary settlements that happened to involve rivers; delineation of rivers as boundaries; movement of troops described as being in the vicinity of rivers or lakes; events relating to cholera or river blindness	Suez canal; Panama canal; cholera or river blindness; Palestinian autonomy along Jordan River; refugees crossing a border river; dignitaries taking tours of lakes/rivers; conflict over control of West Bank of Jordan River; water-related relief aid, including requests for water purification equipment; creation of free trade zones in border river areas; pollution of saltwater, unless freshwater specifically mentioned; fish licensing or quotas

[7] Aral was included as a search term because it represents an internal drainage for a number of large river basins.

Electronic News Databases

Although useful, existing political science datasets were not created to explore cooperation or conflict over international freshwater resources. About half of the event data compiled by BAR were gathered from news articles identified using electronically-searchable news data bases. BAR researchers conducted keyword and subject searches of these databases, identified potentially relevant news articles, obtained these articles electronically or from microfiche, and then coded and entered each article into the BAR event database. To ensure coding consistency, each article entered was double-checked by one or more BAR researchers. The electronic news databases – the Foreign Broadcast Information Service (FBIS), the World News Connection (WNC), and Lexis-Nexis – are described in further detail below.

Developed by the US Central Intelligence Agency as part of their responsibility to monitor and translate foreign news reports and government statements, the Foreign Broadcast Information Service (FBIS) contains translated broadcasts, news agency transmissions, newspapers, periodicals and government statements on political, economic, scientific and cultural issues and events from nations around the globe. FBIS articles are available through two different databases: earlier years covering 1978 to 1995 are available on microfiche and catalogued in a searchable cd-rom index of titles and subject terms for individual foreign news articles. Articles from October 1995 to the present are available through an on-line subscription to the World News Connection (www.wncfedworld.gov). An initial list of relevant articles was created by searching the keyword and title fields in the cd-rom database using a set of water terms (e.g., water resources, hydropower, etc.) and cooperation/conflict terms (e.g., dispute, war, accord, treaty), and excluded terms such as sea, navigation, or nuclear. The resulting list was then further refined by BAR researchers and used to obtain articles from microfiche. The search results are listed in Table 2.1. Table 2.3 presents a more detailed list of the search criteria.

The World News Connection (WNC), the later, on-line, electronic version of FBIS, contains full-text articles spanning October 1995 through December 1999. Although there is some overlap between FBIS and WNC in the time periods they cover, all events entered into the BAR database were double-checked to insure that the same event was not erroneously entered multiple times. A greater number of search terms was required for the WNC searches, as compared to FBIS, because the search was conducted on textual summaries, rather than subject headings. In addition, because the WNC search engine limits search parameters to five fields, a series of three full searches were conducted, using subsets of the search parameters detailed in Table 2.3. As with FBIS, search parameters included water terms (e.g., dam, water quality, diversion), cooperation and conflict terms (e.g., secretariat, collaboration, dispute, sanction, hostility), and excluded irrelevant terms (e.g., "hold water", ocean, Rivera, oil, "Three Gorges"). The search results are listed in Table 2.1. Table 2.3 presents a more detailed list of the search criteria.

Both because FBIS coverage focuses on non-US news sources and since Central America appeared under-represented by FBIS articles, Lexis-Nexis was used to search articles for water-related events in North and Central America. The Lexis-Nexis Academic Universe is an on-line searchable database of full-text articles from a wide range of US and international news sources. Searches were conducted using the "World News" option, North/South American region and the single publication searched was the *New York Times*. The earliest year for which articles were retrieved was 1981. The sheer number of "hits" from each search made finding relevant articles difficult and, given the diversity of the subjects covered by the New York Times, much of the material retrieved had to be discarded as irrelevant. Lexis-Nexis returned up to 1,000 hits per search, so searches were narrowed by one-year intervals to limit the number of hits for each search.

The search terms used for Lexis-Nexis are the same as those described above for the WNC searches, with some additional terms excluded (e.g., Wye, New Mexico, Anthony Lake, and others), because they returned irrelevant articles. Search results were further narrowed by adding the names of all North and Central American countries, except the United States, using the 'or' Boolean operator. The relevance of the articles retrieved could usually be determined by Lexis-Nexis extended citations, although sometimes the full-text was retrieved and reviewed to determine the article's relevance.

Table 2.3: Search Terms – Electronic News Databases

	FBIS	WNC/LEXIS-NEXIS
Water Terms	water resources, hydropower, hydroelectricity, and, if not included under the heading "water resources," irrigation and river	water, river*,[8] lake, dam, stream, tributary, diversion, irrigation, pollution, water quality, flood*, drought*, channel, canal, fish (rights), hydroelect*, reservoir
Cooperation and Conflict Terms	relations, development, dispute, conflict, war, accord, negotiation, treaty, cooperation, hostility	treaty, agree*, negotiat*, resolution, commission, secretariat, joint management, basin management, peace, accord or "peace accord", settle*, cooperation, collaboration, dispute*, conflict*, disagree*, sanction*, war, troops, letter of protest, hostility, shots fired, boycott, protest*
Terms Excluded	sea or ocean or navigation or nuclear	sea, ocean, navigat*, nuclear, "water cannon", "light water reactor", "mineral water", "hold water", "cold water", "hot water", "water canister", "water tight", "water down*", "flood of refugees", Rivera, Suez, Panama, oil, drugs, "Three Gorges"

As Table 2.4 illustrates, there was a significant difference in search efficiency for the FBIS cd-rom index compared to the WNC database, specifically in terms of the number of hits returned with the initial search, the number of articles (or hits) collected, and the number of events returned from these articles.[9] In terms of search efficiency, the

[8]The * symbol allows for any possible combination of characters.

[9] Search efficiency statistics for Lexis-Nexis are not included here because of the small number of events retrieved relative to the number of articles searched.

number of hits returned per year for each database (100 for FBIS cd-rom and 1,900 for WNC), the percentage of hits actually collected due to relevancy (39% versus 10%, respectively), and the proportion of events entered relative to the initial list of returned hits (24% and 3.5%, respectively) illustrate the efficiency of searching subject terms and titles (in the FBIS cd-rom index) relative to the full-text searches provided by on-line databases (both the WNC and Lexis-Nexis). This difference is a function of the irrelevant material returned from searching for specific, water-related terms in entire articles, due to multiple uses of specific terms in the English language (e.g., in phrases such as "in hot water," "cold water reactor," "flood of refugees," etc.). Alternatively, the subject terms provided by the FBIS cd-rom index capture the main topics of each article, thereby eliminating the need to search through hundreds of topically-irrelevant hits.

Another point that is critical in terms of interpreting the analyses of the event data relates to the temporal coverage of the source databases. Comparing the hits returned to the years covered by each of the FBIS databases (Table 2.4) exemplifies not only a difference in search efficiency, but also a difference in the degree of coverage between the two databases. The average number of events per year for each of the FBIS databases (25 for FBIS cd-rom and 80 for WNC) also demonstrates a significant difference in news coverage over the time periods captured by the two databases. While it is difficult to determine the exact reason(s) underlying these differences, such considerations are necessary so that misinterpretations of the data do not occur.

With all the sources of BAR event data, the primary data source coverage is a key influence on the temporal and spatial coverage of the event data in the BAR database. A second influential factor is the structure of the search engines and information associated with each database. Despite the advantages of electronically searchable information sources, one should also be aware of the constraints that database (and search engine) structure place on the efficiency and accuracy of searching for specific information, especially if that information was not a key component in the initial creation of the data source being mined.

Table 2.4: Search Statistics* For FBIS-CD-ROM and WNC Databases

	STATISTIC	FBIS CD-ROM (search titles & subject terms)	FBIS-WNC (full text on-line)
Initial Search	Years covered	18 years (1978-1996)	4-5 years (1996-present)
	Total hits returned	1,817 hits	9,289 hits
	Hits/year	100 hits/year	1,900 hits/year
Sort	Collected hits	>700 or ~39%	>190 or ~10%
Enter	# of BAR events	439 events	321 events
	Search efficiency (events/hits)	~24%	~3.5%
	Temporal coverage (avg. events/yr)	~25	~80

*These numbers only serve as rough estimates, as some individual articles contained multiple events.

International Freshwater Treaties

A database of water-related treaties is available through the Transboundary Freshwater Dispute Database Project (TFDD), at the Department of Geosciences, Oregon State University (Wolf 1999). The TFDD is a searchable database of summaries and/or the full text of approximately 200 water-related treaties, covering the years 1874 to 2000. Treaties in the TFDD address the fresh water needs of the signatories and, for the most part, do not include transportation, fishing, or boundary treaties. The treaties do deal with one or more of the following issues: water rights, water allocations, water pollution, principles for equitably addressing water needs, hydropower/reservoir/flood control development, and environmental issues and the rights of riverine ecological systems. All treaties entered into the BAR event database (126 treaties from the TFDD) were coded at the same level of intensity of cooperation.

BAR EVENT DATABASE STRUCTURE

Database Components

As described earlier, a BAR water event is an instance of conflict or cooperation between nations that occurs within an international river basin, involves the countries riparian to that basin, and concerns freshwater as a scarce, consumable resource or as a quantity to be managed. These incidents of conflict and cooperation can be considered in two basic formats for the statistical analyses: "**interactions**" and "**events**". Interactions break out an incident by the each country-pair (referred to in the political science literature as a "dyad") and basin involved in that incident. The other format used in our analyses groups these interactions into single "**events**," regardless of the number of countries involved in an incident. For example, a treaty involving four countries would consist of nine sets of interactions, because there are nine possible country-pair (i.e., dyad) combinations and the interactions between the countries are considered mutual.[10] The same treaty would consist of only one event for each basin it concerned. Because the grain of our study is the international basin, an event involving multiple basins is coded for all applicable basins.

---

[10]Treaties and agreements are considered events in which the interaction between the parties is mutual. In other events, interactions involve initiators (those who initiate the action) and recipients (the 'target' of that action). The number of initiators and recipients in an event will influence the number of dyadic interactions associated with that event. For example, in a case involving four countries where one country initiates an action (e.g., calls for a conference) and the other three countries receive that action (e.g., are requested to attend a conference), there would only be three interactions listed for that event. Each interaction would be coded for the initiator and one of the three recipients.

The database provides great flexibility in how incidents are grouped and sorted, allowing for a wide range of questions to be asked. Each incident in the BAR database includes the following information:

- the date of the incident;
- the riparian countries involved, including whether a country initiated an action, was the target or recipient of an action, or whether the action was mutual;
- the international basin(s) with which the incident is associated;
- a summary describing the incident, including additional locational information;
- the intensity (or category) of the incident – based on the COPDAB scale of cooperation and conflict;
- the main issue area of the event (water quality, water supply/development project, hydropower, navigation, fishing, flood control, economic development, joint management, and other); and,
- the source(s) of information from which the data was compiled.

The data can therefore be sorted and grouped, for example, by interactions (country-pairs), by events, by individual countries, by basin, by geographic region, by whether a country initiated an action, was recipient of an action, or whether an action was mutual, by macro-event (e.g., a whole series of events tied to a particular theme, such as the Gabcicovo Dam dispute), and/or by the intensity of events based on an adaptation of Edward Azar's COPDAB scale. In terms of time, the temporal grain of analyses may be structured as day-to-day interactions, monthly, annual, or multiple-year averages (see Table 2.5 for example of structure of Event Database).[11]

[11] More detailed information on the structure of the event database, may be found in Appendix 1.

Table 2.5: Event Database Example

DATE	BASIN	COUNTRIES INVOLVED	BAR SCALE	EVENT SUMMARY	ISSUE TYPE
12/5/73	LaPlata	Argentina-Paraguay	4	PRY AND ARG AGREE TO BUILD 1B DAM, HYDROELECTRIC PROJECT	Infrastructure
1/1/76	Ganges	Bangladesh-India-United Nations	-2	Bangladesh lodges formal protest against India with United Nations, which adopts consensus statement encouraging parties to meet urgently, at level of minister, to arrive at settlement.	Quantity
7/3/78	Amazon	Bolivia-Brazil-Colombia-Ecuador-Guyana-Peru-Suriname-Venezuela	6	Treaty for Amazonian Cooperation	Economic Development
4/7/95	Jordan	Israel-Jordan	4	Pipeline from Israel storage at Beit Zera to Abdullah Canal (East Ghor Canal) begins delivering water stipulated in Treaty (20 mcm summer, 10 mcm winter). The 10 mcm replaces the 10 mcm of desalinated water stipulated Annex II, Article 2d until desalinization plant complete.	Quantity
6/1/99	Senegal	Mali-Mauritania	-3	13 people died in communal clashes in 6/99 along border between Maur. & Mali; conflict started when herdsmen in Missira-Samoura village in w. Mali refused Maur. horseman use of watering hole; horseman returned w/ clansmen, attacking village on 6/20/99, causing 2 deaths; in following retaliation 11 more died.	Quantity

Categorizing the Intensity of International Cooperation and Conflict

Edward Azar's Conflict and Peace Databank (COPDAB) International Cooperation and Conflict Scale categorizes events in terms of the nature and intensity of conflict or cooperation. The COPDAB Scale provides a measure of the international conflict/cooperation intensity for individual nations and between pairs of nations over time periods ranging from single days to multiple years. Azar's interest was in "studying the characteristics of cooperation and … conflict between and within nations … and in tracing the relationships between these characteristics and other traits and behaviors of nations in … international systems" (Azar 1980). To assess an event's intensity of cooperation or conflict, the COPDAB scale was created to allow for grouping of events by intensity and nature, so that they might be dealt with as a class. The COPDAB scale differentiates categories of conflict and cooperation by an arbitrary set of numbers ranging from level 1, representing the most cooperative events, to level 15, representing the most conflictive events. Level 8 represents neutral events. To make the COPDAB scale more intuitive, we first inverted it and then shifted it along the number line so that neutral events were centered on zero. The BAR project's basic scale then ranges from –7 to +7, with –7 denoting the most conflictive events, 0 denoting neutral events, and + 7 denoting the most cooperative events. Other modifications made to the COPDAB scale include the addition of water terms (listed in italics in Table 2.6) specific to BAR events, and a new category, "formal declaration of war." To accommodate this category, which is not part of the original COPDAB Scale but which is relevant to BAR, category 13 (Small scale military acts) and 14 (Limited war acts) were merged into one category, number 13. Category 14 was given the heading and description of category 15 (Extensive war acts causing deaths, dislocation or high strategic costs), and Category 15 was changed to indicate a formal declaration of war.

The primary utility of the scale component in the database would seem to be in categorical analyses of event occurrences, for example in counts of the number of wars that have occurred within a particular timeframe or the number of treaties into which a particular pair of countries have entered. Calculations of average scale values by year, country, etc., beyond mere classification, would seem to be proscribed due to the categorical nature of the scaling system, as well as the arbitrary numerical values assigned the various classes. However, the categorization system is logically ordered with increasingly negative or positive categories of events assigned smaller or larger numeric values. With this ordering, it seems reasonable that information, even if imperfect, can in fact be derived from data summaries involving averages of scale values across event categories (again, for example, average values by year, country, etc.). In essence, this summarizing of information involves acceptance of the notion that the *ordinal* categorization of events can also be treated in principal as a *cardinal* system (Yoffe and Giordano 2001).

Given this notion, the problem becomes one of determining if the numeric spacing between category values assigned in our scaling system is appropriate. In other words, it must be determined if the difference between event categories 1 and 2 should be the same, in terms of intensity differential, as the difference between event categories 6 and 7 (the absolute difference being one in each case; the percentage differences being 100% and 17% respectively). It is our contention that the distance between any two events should increase as the intensity associated with those events increases. That is to say, the cardinal difference between event categories 6 and 7 should be greater than the difference between event categories 1 and 2, because, intuitively, the difference between the signing of a treaty and unification into one nation (categories 6 and 7) is far more significant than the difference between mild verbal support and official verbal support (categories 1 and 2). Therefore, for statistical analysis purposes, each event value was converted to its anti-logged equivalent so that the distance (or intensity) between values at the extremes of the scale is greater that the distance between values at the middle of the scale. Table 2.6 illustrates the correspondence between the original COPDAB scale, the revised (BAR) scale, and its anti-logged values (Yoffe and Giordano 2001).

Table 2.6: Water Event Intensity Scale

COPDAB SCALE	RE-CENTERED (BAR) SCALE	ANTI-LOGGED, RE-CENTERED SCALE	EVENT DESCRIPTION
15	-7	-198.3	**Formal Declaration of War**
14	-6	-130.4	***Extensive War Acts causing deaths, dislocation or high strategic cost:*** Use of nuclear weapons; full scale air, naval, or land battles; invasion of territory; occupation of territory; massive bombing of civilian areas; capturing of soldiers in battle; large scale bombing of military installations; chemical or biological warfare.
13	-5	-79.4	**Small scale military acts:** Limited air, sea, or border skirmishes; border police acts; annexing territory already occupied; seizing material of target country; imposing blockades; assassinating leaders of target country; material support of subversive activities against target country.
12	-4	-43.3	**Political-military hostile actions:** Inciting riots or rebellions (training or financial aid for rebellions); encouraging guerilla activities against target country; limited and sporadic terrorist actions; kidnapping or torturing foreign citizens or prisoners of war; giving sanctuary to terrorists; breaking diplomatic relations; attacking diplomats or embassies; expelling military advisors; executing alleged spies; nationalizing companies without compensation.
11	-3	-19.8	**Diplomatic-economic hostile actions:** Increasing troop mobilization; boycotts; imposing economic sanctions; hindering movement on land, waterways, or in the air; embargoing goods; refusing mutual trade rights; closing borders and blocking free communication; manipulating trade or currency to cause economic problems; halting aid; granting sanctuary to opposition leaders; mobilizing hostile demonstrations against target country; refusing to support foreign military allies; recalling ambassador for emergency consultations regarding target country; refusing visas to other nationals or restricting movement in country; expelling or arresting nationals or press; spying on foreign government officials; terminating major agreements. *Unilateral construction of water projects against another country's protests; reducing flow of water to another country, abrogation of a water agreement.*

Table 2.6: Water Event Intensity Scale (cont.)

COPDAB SCALE	RE-CENTERED (BAR) SCALE	ANTI-LOGGED, RE-CENTERED SCALE	EVENT DESCRIPTION
10	-2	-6.6	**Strong verbal expressions displaying hostility in interaction:** Warning retaliation for acts; making threatening demands and accusations; condemning strongly specific actions or policies; denouncing leaders, system, or ideology; postponing heads of state visits; refusing participation in meetings or summits; leveling strong propaganda attacks; denying support; blocking or vetoing policy or proposals in the UN or other international bodies. *Official interactions only.*
9	-1	-1.0	**Mild verbal expressions displaying discord in interaction:** Low key objection to policies or behavior; communicating dissatisfaction through third party; failing to reach an agreement; refusing protest note; denying accusations; objecting to explanation of goals, position, etc.; requesting change in policy. *Both unofficial and official, including diplomatic notes of protest.*
8	0	0.0	**Neutral or non-significant acts for the inter-nation situation:** Rhetorical policy statements; non-consequential news items; non-governmental visitors; indifference statements; compensating for nationalized enterprises or private property; no comment statements.
7	1	1.0	**Minor official exchanges, talks or policy expressions–mild verbal support:** Meeting of high officials; conferring on problems of mutual interest; visit by lower officials for talks; issuing joint communiqués; appointing ambassadors; announcing cease-fires; non-governmental exchanges; proposing talks; public non-governmental support of regime; exchanging prisoners of war; requesting support for policy; stating or explaining policy.
6	2	6.6	**Official verbal support of goals, values, or regime:** Official support of policy; raising legation to embassy; reaffirming friendship; asking for help against third party; apologizing for unfavorable actions or statements; allowing entry of press correspondents; thanking or asking for aid; resuming broken diplomatic or other relations.

Table 2.6: Water Event Intensity Scale (cont.)

COPDAB SCALE	RE-CENTERED (BAR) SCALE	ANTI-LOGGED, RE-CENTERED SCALE	EVENT DESCRIPTION
5	3	19.8	**Cultural or scientific agreement or support (non-strategic):** Starting diplomatic relations; establishing technological or scientific communication; proposing or offering economic or military aid; recognizing government; visit by head of state; opening borders; conducting or enacting friendship agreements; conducting cultural or academic agreements or exchanges. *Agreements to set up cooperative working groups.*
4	4	43.3	**Non-military economic, technological or industrial agreement:** Making economic loans, grants; agreeing to economic pacts; giving industrial, cultural, or educational assistance; conducting trade agreements or granting most favored nation status; establishing common transportation or communication networks; selling industrial-technological surplus supplies; providing technical expertise; ceasing economic restrictions; repaying debts; selling non-military goods; giving disaster relief. *Legal, cooperative actions between nations that are not treaties; cooperative projects for watershed management, irrigation, poverty-alleviation.*
3	5	79.4	**Military economic or strategic support:** Selling nuclear power plants or materials; providing air, naval, or land facilities for bases; giving technical or advisory military assistance; granting military aid; sharing highly advanced technology; intervening with military support at request of government; concluding military agreements; training military personnel; joint programs and plans to initiate and pursue disarmament.
2	6	130.4	***International Freshwater Treaty;*** **Major strategic alliance (regional or international):** Fighting a war jointly; establishing a joint military command or alliance; conducting joint military maneuvers; establishing economic common market; joining or organizing international alliances; establishing joint program to raise the global quality of life.
1	7	198.3	**Voluntary unification into one nation:** Merging voluntarily into one nation (state); forming one nation with one legally binding government.

Space and Time

The geographic component is especially important to the power of the BAR Event Database. The key unit of analysis for the Basins At Risk Project is the international river basin. A river basin comprises all the land which drains through that river and its tributaries into the ocean or an internal lake or sea. An international river basin is one which includes territory of more than one country. Currently, the Earth encompasses more than 261 international river basins, covering greater than 45% of the total land area of the Earth, excluding Antarctica (Wolf, Natharius et al. 1999). Framing questions in terms of river basins offers a way to look at water issues that mitigates problems associated with the fact that most data is classified by country and fails to account for within-country variation. River basins, by providing a focus on the water resource, are a natural framework of study when considering the relationship between cooperation or conflict and freshwater resources.

Every event is linked to the basin(s), countries, and basin-country polygons with which that event is associated. A Geographic Information System (GIS) allows us to link the BAR event data with other country or basin-specific information, such as basin population, climate type, country GDP or government type, and perform statistical analyses of correlations between the event data and these other variables. The above spatial component is key because it allows us to explore the question of why a particular event occurred. The lack of such an ability has been a major criticism of the utility of event datasets in the past (Lanphier 1975; Andriole and Hopple 1984; Laurance 1990).

To incorporate both temporal and spatial variability into our analysis required the creation of an historical GIS (see Chapter 3), one which would identify spatially all the international basins that existed for each year of our study and what countries, for each year, were riparian to those basins. This historical GIS facilitated the creation of the event database by enabling us to identify whether a specific event occurred in an international basin, as many events we researched turned out to be related to intra-national, rather than international waters and as not all basins were international across the entire time period of the study. More importantly, the historical GIS allowed us to link our 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.

The GIS of international basins provided a key spatial component, enabling us to identify whether a particular basin was international in a given year and what specific countries shared that basin. To link an event, based on information in a newspaper article, for example, we also had to identify the names of all the tributaries within each international basin. A tributary names database was created to complete this task.

This tributary database, a continuing work, involves information from multiple sources. Two initial sources of information were National Geographic and the International Commission on Large Dams (ICOLD). Through a cooperative agreement with National Geographic, the BAR project was able to make use of electronic information from their *7th Edition Atlas of the World* (Geographic 1999). Using this atlas, a BAR researcher started at the mouth of each international river basin identified by the TFDD and followed each tributary as it branched off from the main river. Each tributary name, or names, noted is linked in the database to both the basin and country in which the tributary is located. Another source of information was ICOLD's (ICOLD 1998) *World Register of Dams* database, which lists the world's large dams and includes locational information such as country, river, and nearest city. Using this location information, in addition to atlases and a wide range of web-based information, BAR researchers were able to surmise which dams lay in international basins and from that, to link the river name associated with that dam to its international basin. Eventually, it is hoped to be able to link the tributary names to their drainage networks within the BAR GIS.

SUMMARY FINDINGS

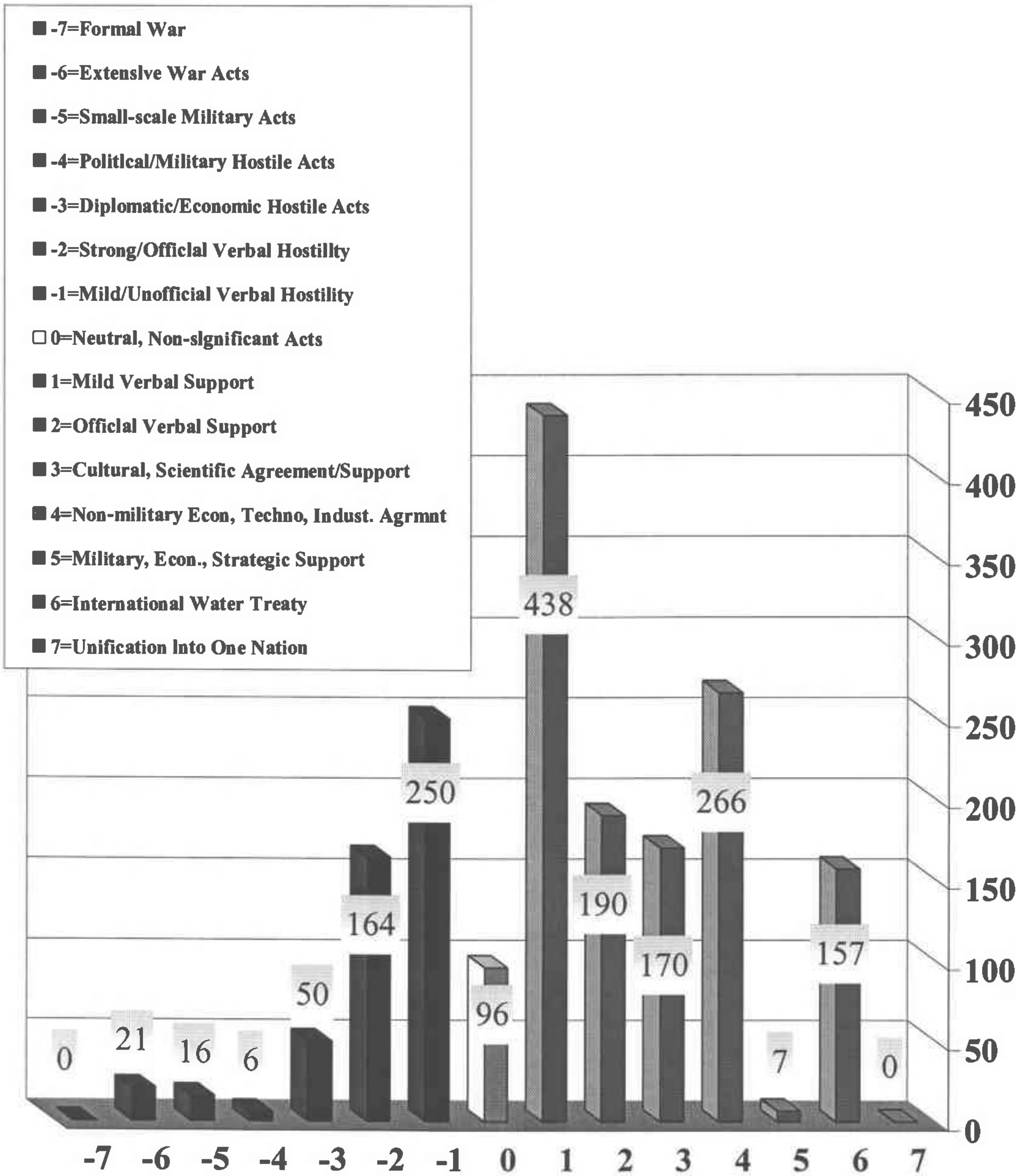
The BAR scale or index can be used to compare international conflict/cooperation levels across countries and across time and to statistically test the relationships between international conflict and cooperation and other quantifiable variables with which it is hypothesized to be causally or otherwise correlated. Even before conducting such analyses, however, we can obtain a picture of international water conflict and cooperation and better understand how information in the BAR Water Event database is distributed across time and space using simple summary statistics. Incidents of conflict and cooperation over freshwater were considered in two basic formats: interactions, which break out each incident by the country-pairs (dyads) and basins involved; and, events, which provides one entry for each incident in a basin regardless of the number of country-pairs involved. The BAR Water Event database contains approximately 1,800 events, which can be broken out into approximately 3,300 country-pair interactions. The data includes events for 124 countries and 122 out of 265 current and historical international basins. Please note that data coverage is not even across all basins and countries for all years.

What was found in the BAR analyses adds new insights into understanding of conflict and cooperation over international waters and belies some of the current wisdom. The findings of BAR's summary and statistical analyses are discussed in greater depth in Chapter 4, which provides an illustration of the power and potential of the BAR Event Database.

Conflict and Cooperation

For the years 1948-1999, cooperation over water, including the signing of treaties, far outweighs overall conflict over water and violent conflict in particular. Figure 2.1 displays the total number of events by the BAR Intensity Scale, with the dark bars indicating conflictive events and the lighter bars cooperative events. The lightest bar indicates neutral events. Overall the majority of events are cooperative. Out of 1,800 events, 28% are conflictive (507 events), 67% are cooperative (1,228), and the remaining 5% are neutral. Of the total events, two thirds represent verbal interactions, either mildly conflictive or cooperative.

Figure 2.1: Total Number of Events by BAR Intensity Scale



Events involve a wide range of issue areas, in particular water quantity, infrastructure, joint management and hydropower (see Figure 2.2). Cooperative events, which are indicated by the blue portion of the bars in Figure 2.3, cover a slightly wider range of issues than conflictive events. When looking at events at the extremes of the scale, there is a more dramatic difference. Figure 2.4 shows international freshwater treaties, the most cooperative event in our data set. These treaties cover a wide range of issue areas, with emphasis on water quality and quantity, hydropower, joint management and economic development, among others. The most extremely conflictive events in our database are extensive military acts. These events concerned quantity and infrastructure exclusively (see Figure 2.5), two issue areas closely tied together.

Figure 2.2: Total Events By Issue Area

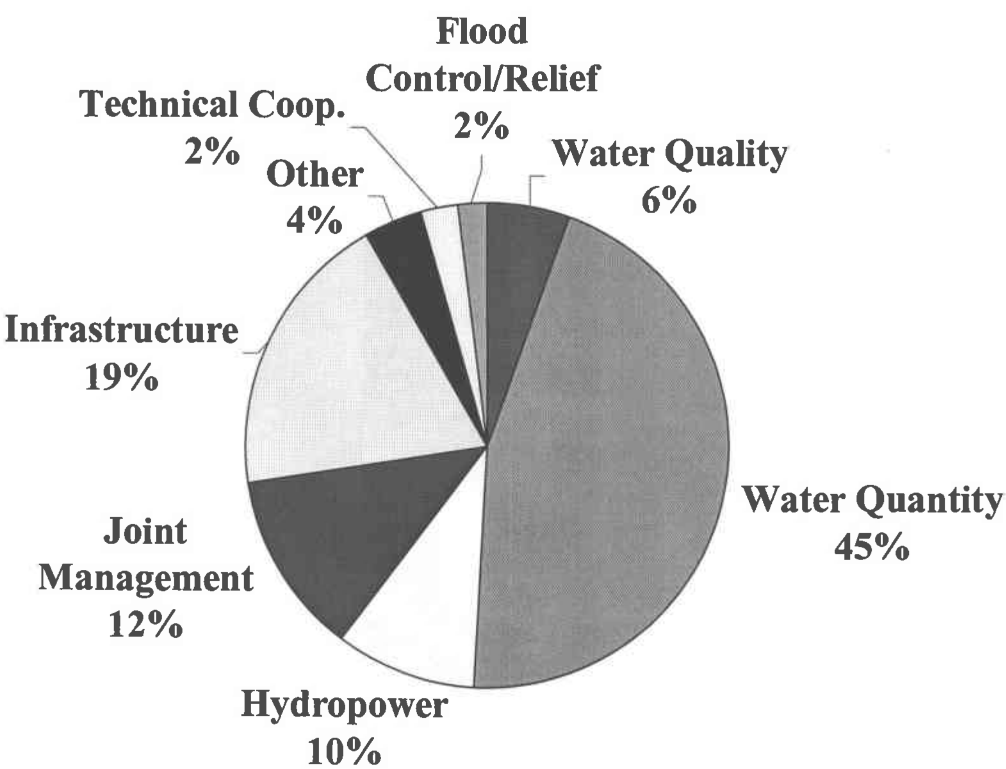


Figure 2.3: Cooperative, Conflictive and Neutral Events By Issue Area

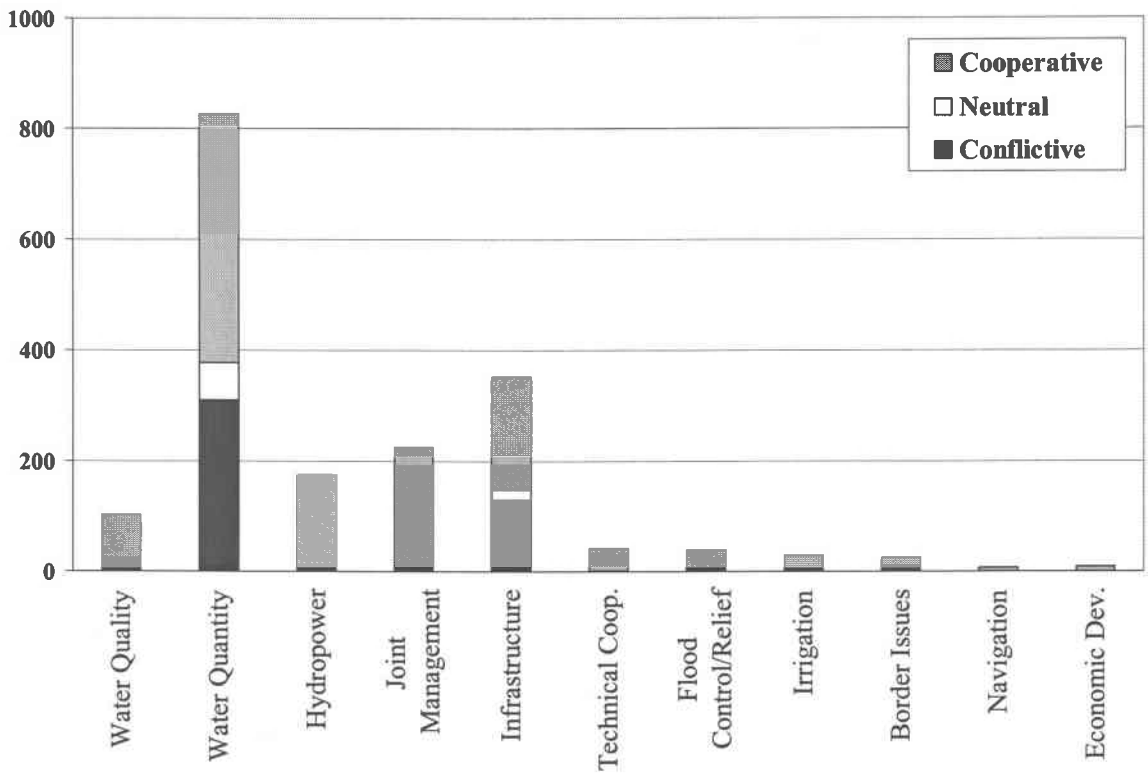


Figure 2.4: Extreme Cooperative Events By Issue Area (n= 157, BAR Scale +6)

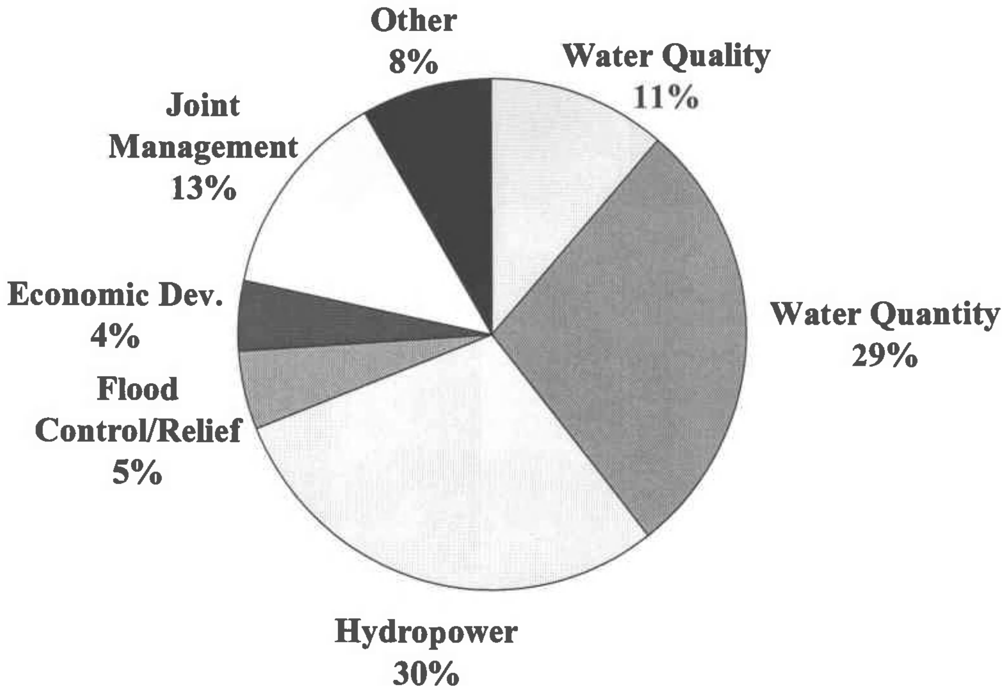
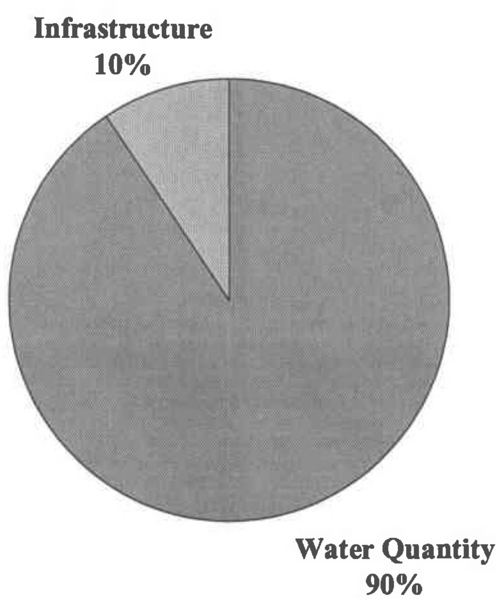


Figure 2.5: Extreme Conflictive Events By Issue Area (n=21, BAR Scale –6)



Across Time

Figure 2.6 shows the distribution of cooperative, conflictive and total events by year. Breaks in the lines indicate years for which there were no events recorded. This graph does not necessarily indicate that conflict or cooperation over water have been increasing over time. The skew towards later years in the temporal distribution reflects intensity of effort, in large part because of the availability of electronically searchable news databases, with searchable text or summaries, for the latter period of our study. The distribution may also reflect a growing importance of water, and environmental issues in general, in international news reporting.

Figure 2.7 addresses the temporal bias in the data by detailing what percent of the total events recorded for each year were cooperative. Broken down into three time periods, the graph illustrates that cooperation over water was relatively low in periods one and three, perhaps due to decolonization and the emergence of countries from the breakup of the former Soviet Union, and relatively higher in the 1970's and early 1980's. As always, it is important to keep in mind that event data for earlier periods is less comprehensive because of a relative lack of contextual information in the datasets used. A number of potential events from the COPDAB dataset are not included in these analyses because it was impossible to tell from the brief event summary whether the event concerned water specifically. Further research is required for these events, which would expand our coverage of the years 1948 to 1978.

Across Space

In terms of geographic distribution, the majority of events in our database are associated with basins in North Africa and the Middle East, Sub-Saharan Africa, and Eastern Europe – followed by Southeast and South Asia and South America (Figure 2.8). Figure 2.9, Average Bar Scale by Region, details the average BAR scale value (as an average of the average for each year, because the intensity of effort in obtaining event coverage is unequal across years), by country-region for the years 1948-1999. For each of these regions, the overall average BAR Scale is cooperative. The Middle East/North

Africa region shows the lowest level of cooperation, while Western Europe represents the highest. In terms of number of events, therefore, BAR's water event data is somewhat weighted toward the least cooperative region. Despite this bias, the majority of international relations over freshwater resources were found to be cooperative. Further detail is provided in Figure 2.10, which separates out the data by cooperative and conflictive events. Note that the regions are ordered most cooperative to least cooperative in both graphs and that the order changes slightly from Figure 2.9 to Figure 2.10.

Figure 2.6: Distribution of Cooperative, Conflictive, and Total Events By Year

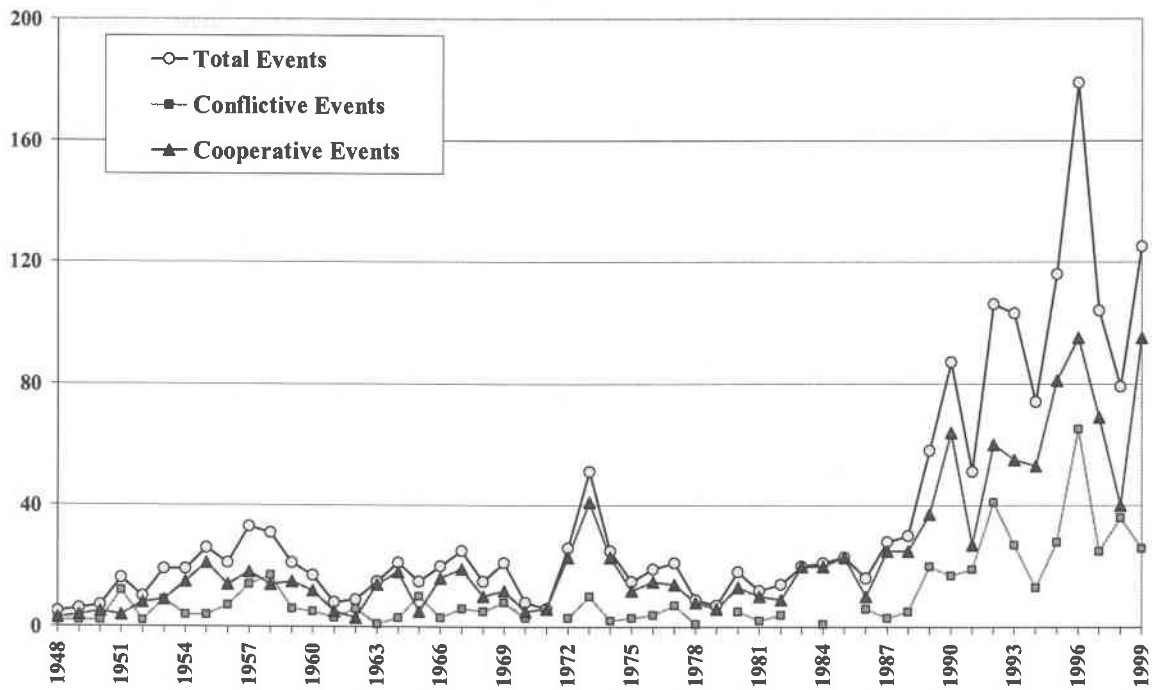


Figure 2.7: Cooperative Events as Percentage of Total Events By Year

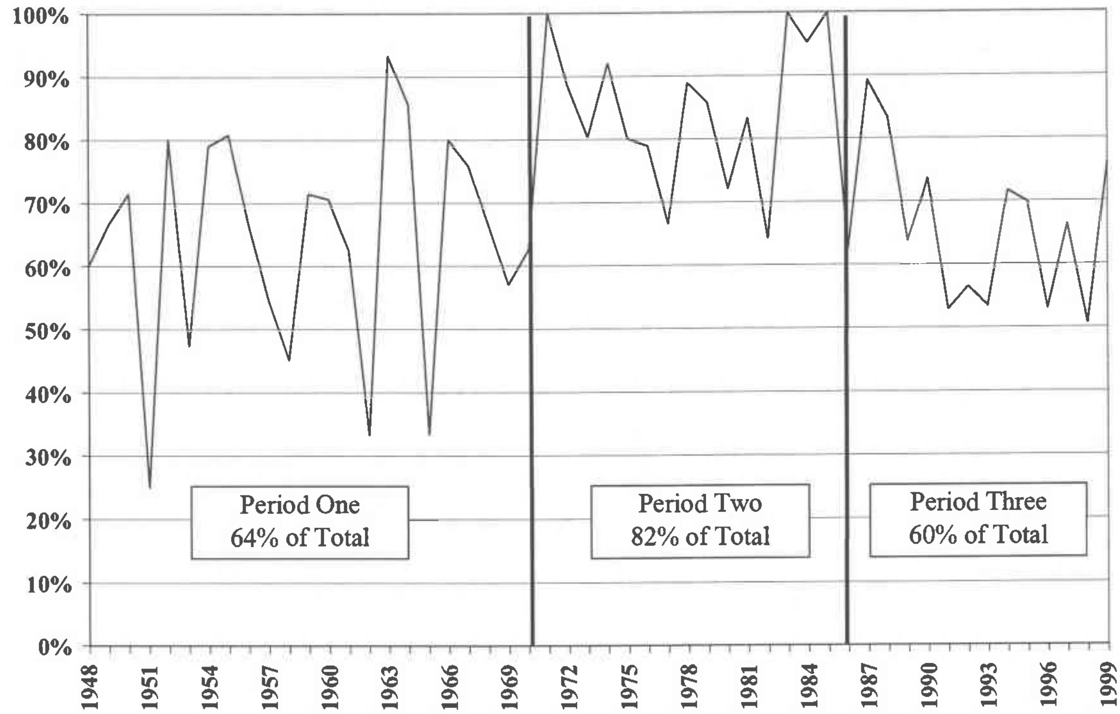


Figure 2.8: Number of Events Per Region

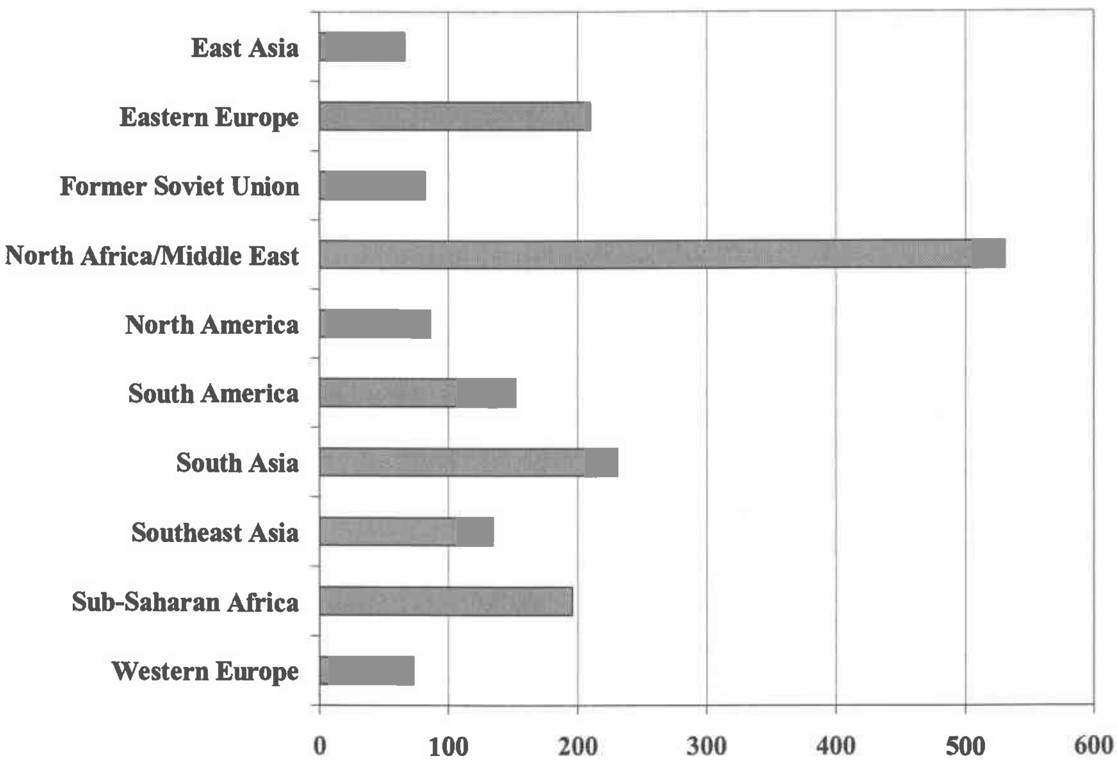


Figure 2.9: Average BAR Scale Values By Region

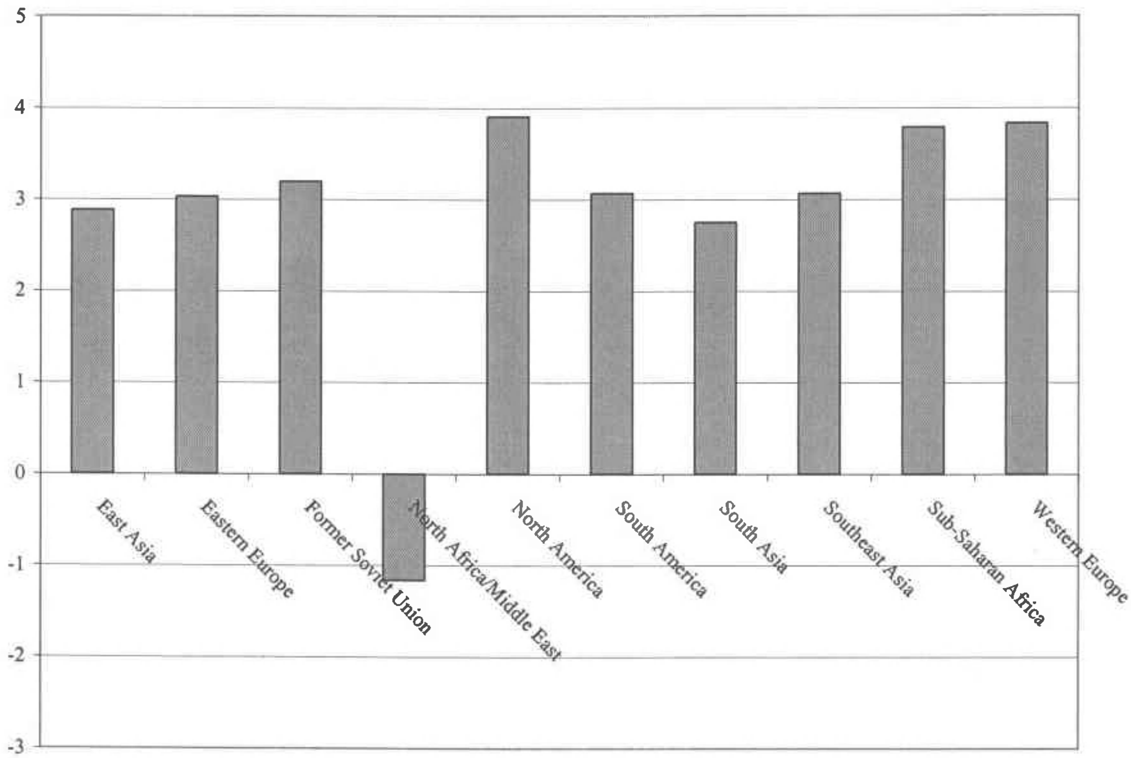
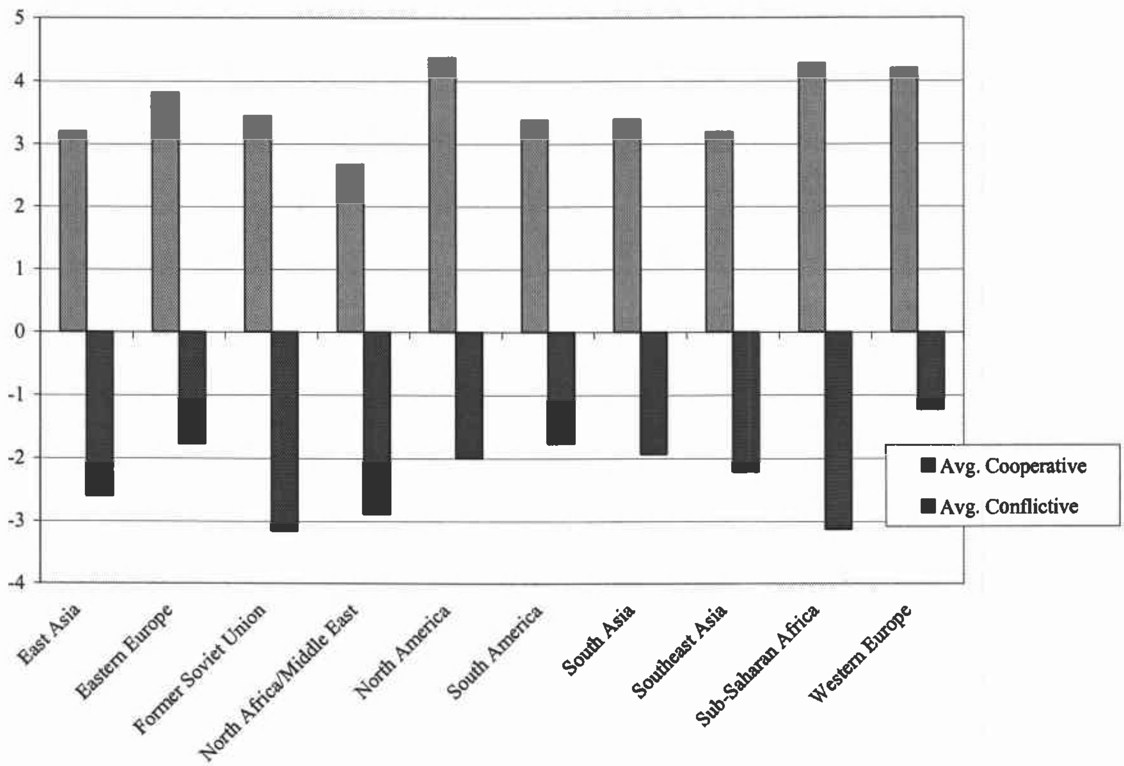


Figure 2.10: Average Cooperative and Conflictive BAR Scale Values By Region



CONCLUSION

The data above are just a sampling of the types of information that can be culled from the BAR event database. Gathered from a wide range of sources, this database represents a unique resource. It allows for analyses at multiple spatial (e.g., country, dyad, basin, region) and temporal (e.g., day, month, year, decade) scales, as well as by issue area and intensity of conflict or cooperation. When combined with other biophysical, socioeconomic, or political data, this water event database offers a powerful resource for both qualitative and quantitative, multi-scale exploration of international water issues, offering particular insights into possible drivers behind conflict or cooperation over international water. Chapter 4 discuss the results of some of this empirical research. The methodology used to create the event database could also be applied to other natural resource or other issues, especially if interest lies with more recent events (e.g., within the last 30 years). Future research plans include more specific regional or topical research projects, expansion of the database into intra-national water events and exploring events where water was involved, but not was necessarily a driver of conflict (e.g., water as a victim, target, or tool of warfare). The BAR Event Database will be publicly available through the Transboundary Freshwater Dispute Database website (http://www.transboundarywaters.orst.edu/).

ACKNOWLEDGEMENTS

Spanning more than two years, the BAR project involved the efforts of more than 10 faculty and student researchers at Oregon State University. The authors would like to thank those researchers for their efforts and enthusiasm, especially Case Bowman, Mark Giordano, Meredith Giordano, Kyoko Matsumoto, Marc Rothgery, and Daniel Wise. In addition, the authors would like to extend their thanks to Glenda Pearson, at University of Washington Library, *National Geographic*, and the National Science Foundation Fellowship in Landscape Studies.

CHAPTER 3 USE OF GIS FOR ANALYSIS OF INDICATORS OF CONFLICT AND COOPERATION OVER INTERNATIONAL FRESHWATER RESOURCES

Shira Yoffe and Greg Fiske

Submitted for publication, as part of set of three articles, to *Water Policy*, World Water Council, October 1, 2001, 28 pages, in review.

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 were produced as part of the Basins At Risk (BAR) project. To facilitate development of indicators to identify international river basins at potential risk for 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 advances 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 spatial distribution. In the 1993 *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 (Adams, Harlin et al. 1993). Since that time, GIS has become a 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 exercises detailed in this paper were conducted as part of the *Basins At Risk* (BAR) project, under the auspices of the *Transboundary Freshwater Dispute Database* (TFDD), which is directed by Dr. Aaron T. Wolf, Oregon State University. The purpose of the Basins At Risk project was to identify historical indicators of international freshwater conflict and cooperation and, from these indicators, create a framework to identify and further evaluate international river basins at potential risk for future freshwater conflict. The GIS component of the BAR project included the creation of historical basin and country polygon coverages for the period of the study and the mapping of environmental, political, and socioeconomic variables across international drainage basins, to allow for a global-scale analysis of possible patterns which might facilitate our understanding of water resource conflict and cooperation.

GIS as a tool in complex social science research is only just beginning to be explored, but the field is expanding rapidly. GIS offers powerful tools for compiling, visualizing and analyzing potential indicators of international water resource conflict, because it has the capability to incorporate biological, physical and socioeconomic data. While there has been substantial work in mapping the physical aspects of watershed systems, much less work has been done to incorporate these physical systems with socioeconomic data. Nevertheless, in many circles GIS technology has been praised for its potential to bring policy and science together and to facilitate integration, analysis, mapping and presentation of spatial and non-spatial information in the understanding and managing of natural resources. In this light, GIS offers a great deal to this project, enabling a much more complex analysis than would otherwise be attainable.

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 at least 261 international river basins, covering at least 45.5% of the total land area of the earth, excluding Antarctica (Wolf, Natharius et al. 1999).[12] Framing questions in terms of river basins offers a way to look at water issues that mitigates problems associated with the fact that most data is classified by country and fails to account for within-country variation. River basins are considered a natural framework for studies of geomorphic fluvial processes (Leopold, Wolman et al. 1964). River basins' focus on water resources makes them equally appropriate when considering the relationships between conflict, cooperation and freshwater resources.

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 been defined by national borders. Readily available water data are only at the country level (Brunner, Yumiko et al. 2000). This fact has limited studies exploring spatial aspects associated with international water conflict. 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 conflict and the spatial area defined by a particular international basin. 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 (Ohlsson 1999).

[12] Since the last publication of the TFDD basins, new basins have been "found." An updated version of the TFDD database of international rivers is now in process. The current basin total is 263.

All the Geographic Information System exercises depicted in this paper focus on the international river basin as the scale of reference.

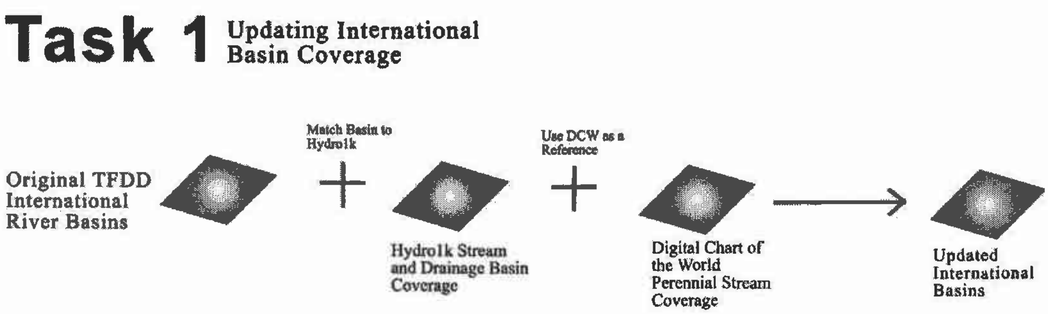
The following sections of this paper describe three separate GIS tasks. Each section contains a general description of the methods, data, and approach used as well as a brief summary of how the task contributed to goals of the BAR project.

RESTRUCTURING OF THE WATERSHED BOUNDARIES

The first task in this succession of methods was to update the TFDD delineation of international river basins to match new data and to better meet the needs of the BAR project. The basins of the TFDD project had their origin in a 1958 United Nations panel report entitled *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 (United Nations 1978). The most recent version of the international basin dataset, prior to this study, was Wolf (Wolf, Natharius et al. 1999) *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 by matching GTOPO30's simulated flow pattern. At the release of this document, the *Register* includes 261 international river basins.

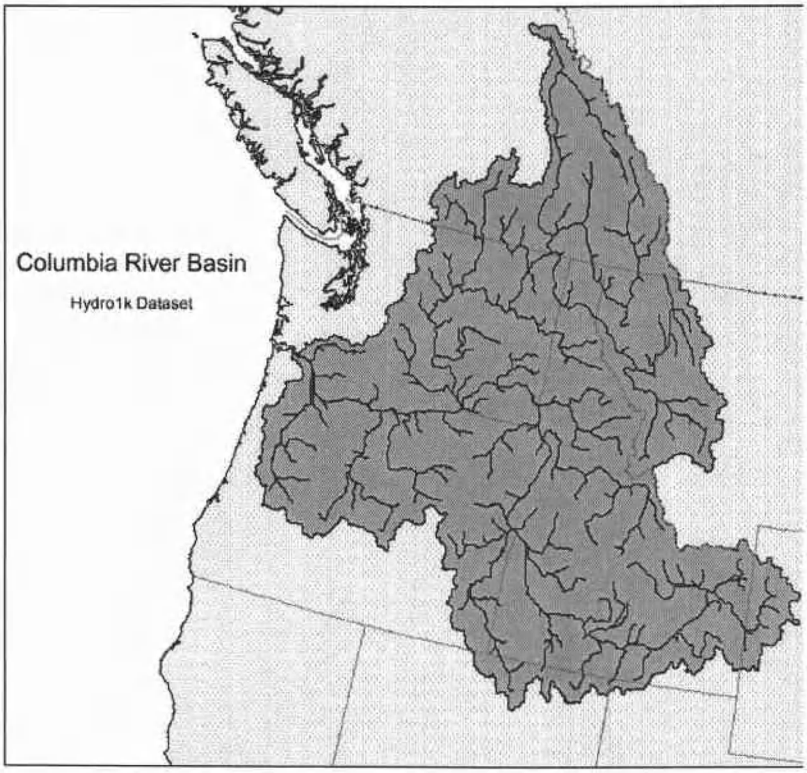
In task 1, the 261 basins depicted in the 1999 *Register* were manually matched, as accurately as possible, to the Hydro1k (USGS 2000) dataset, a global coverage of streams and drainage basins derived from digital elevation data (Figure 3.1). This on-screen exercise, completed one continent at a time, 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 3.1: Task 1. A basic model representing the steps taken to update the TFDD international basin coverage



In all, less that half of the basins required alteration. Where there were confounding issues or uncertainty in the exact location of a basin boundary, outside sources were consulted. One of these sources was the perennial stream coverage of the Digital Chart of the World (DCW). The DCW (Environmental Systems Research Institute 2000), 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 1993). This level of detail proved particularly useful in settling most questions regarding 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 3.2); 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 creation of a sound coverage for the further collection and derivation of information for the BAR project.

Figure 3.2: Columbia River Basin, USGS Hydro1k dataset



This image indicates a close match between TFDD international river basins and 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 documenting historical incidents of international freshwater cooperation and conflict from 1948 to 1999. Using precise definitions of cooperation and conflict, these incidents are ranked by intensity and linked to the international basin and riparian countries with which they are associated. In order to explore correlations between events and other variables across both space and time, 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 which 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 historical 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 intra-national, rather than international waters and as not all basins were international across the entire time period of the study. More importantly, the historical 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.

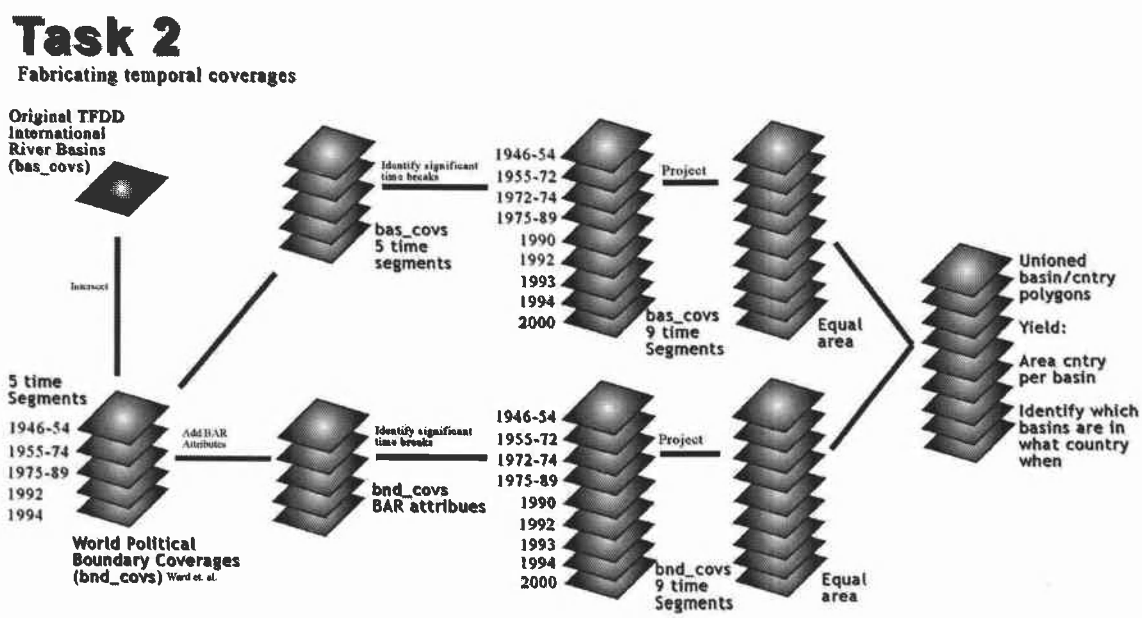
In short, the most recent GIS coverage of international river basins had to be modified to consider the status of international boundaries for each year of the BAR event database. The 1999 register of the *International Basins of the World* indicated that 47 basins became international, and were therefore added to the *Register*, due to the break-up of countries such as the former Soviet Union and the former Yugoslavia (Wolf, Natharius et al. 1999). 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 international boundary changes impacting the 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 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 shift, a better fit can be made between the spatial and non-spatial portions of the BAR database. Spatial analysis of an inventory of socioeconomic, political, 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 elements 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 (Langram 1993).

Indeed this concept was fully utilized when spurred by the recognition that incidents in the BAR event database would only be included in statistical analyses if they were associated with basins that were international at the time the event occurred. Moreover, the spatial data derived at the basin and country scale needed to be temporally matched to the event data in order to conduct time-sensitive 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.

Figure 3.3: Task 2. A basic model showing the steps taken in the creation of a temporal spatial database for the Basins At Risk Project.



The GIS coverages that comprise the temporal portion of this study are divided into nine time segments (Figure 3.3), which were chosen to capture periods of significant changes in international political boundaries, as well as polity changes. 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.[13] The GIS contains correct attributes for all the polity and boundary changes.

For each time segment, a complete coverage of the world's international boundaries and international river basins was created. These coverages most accurately represent the status, both through their spatial characteristics and their attributes, of the international political boundaries of the time period. Years were grouped into a common coverage for periods in which there were no major changes in the location of international boundaries. Otherwise, single-year coverages were created. This method resulted in nine temporal coverages, covering the period 1946-2000, for countries and their associated international basins.

The world international basin and international boundary coverages were constructed from a base map, which was graciously shared by Dr. Michael Ward, Professor of Political Science, University of Washington. This base map came in the form of Arc/Info coverages spanning five time segments, 1946-54, 1955-74, 1975-89, 1992, and 1994 (Figure 3.3). The coverages delineate national boundaries for each time segment from the early 1990's (which saw the break up of the Soviet Union and Yugoslavia) back to 1946 (Ward, Shin et al. 2000). These crude, yet fully viable, delineations of the international boundaries of each time period were particularly valuable in the success of Task 2. International boundaries and attribute labels showing political ownership of each polygon were comparable to BAR's year 2000 country coverage. From this starting point the compulsory manipulation of the country and basin coverage for each time segment could be built.[14]

A link was created between the polygon attribute data of the donated coverages and the BAR country coverage and data via BAR country codes and the Polity 3 dataset country codes (McLaughlin, Gates et al. 1998) used by Ward. Polity 3's country codes

---

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

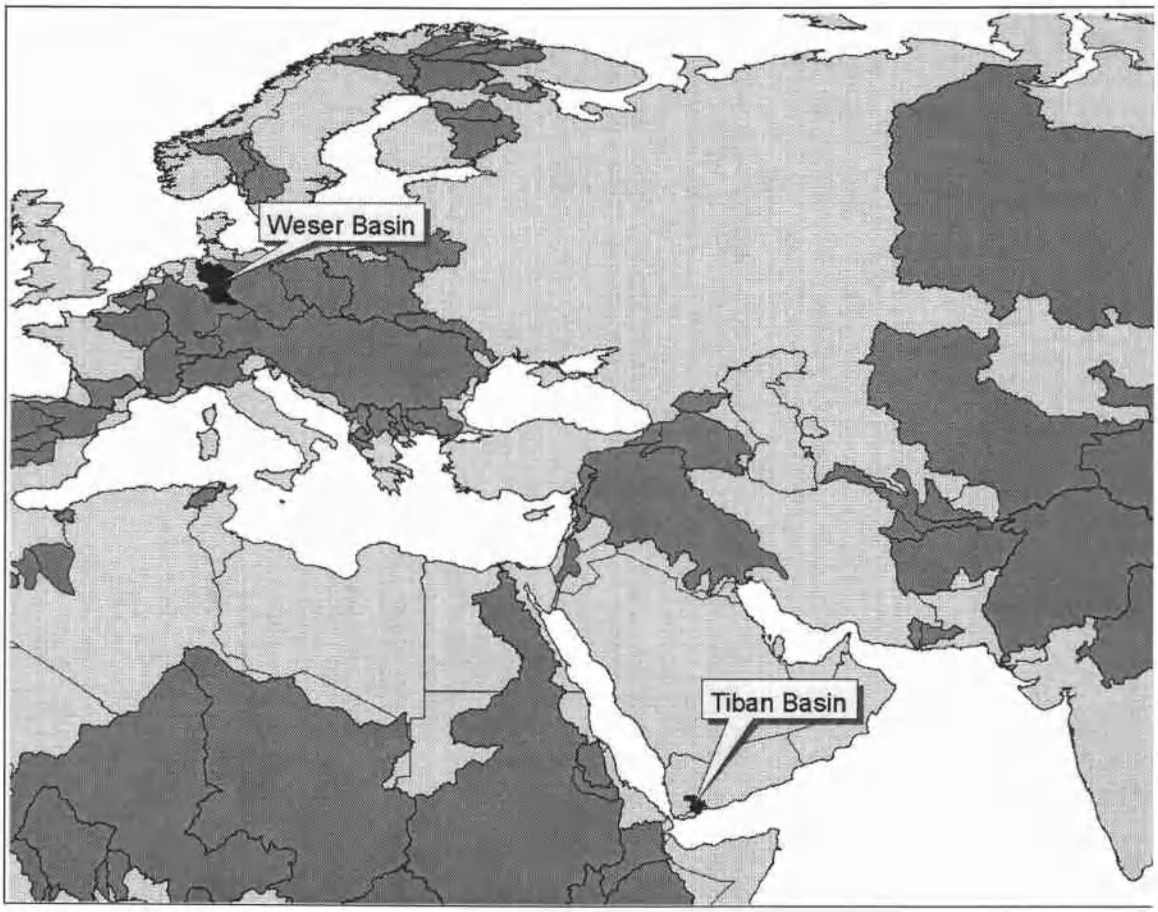
[14] Compared with other forms of GIS data, finding coverages of historically accurate international political boundaries represented a much more involved treasure hunt. Historic GIS coverages are rare. While there is a large body of work, especially in political science and political geography, involving analysis of political boundaries (e.g., Gleditsch and Ward 2001), these studies are rarely conducted using a GIS.

were converted to BAR's country codes in the final coverages, as BAR country codes link all country-scale spatial and tabular 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.

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 relationship with contemporary international boundaries. A union of the current basin coverage with the political coverage of each time segment yielded a list of basin 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. The emergence of new nations and shifts in international boundaries resulted in the addition of 30 international basins from 1946 to 2000. Only two international basins were removed – the Weser, shared between the former East and West Germany, and the Tiban, shared by the former North and South Yemen (Figure 3.4). Both the Weser and Tiban lost their international status in the 1990s, with the unification of their respective riparian countries.

The dataset provided by this representation of international river basins and their riparian countries for each year from 1946 to 2000 allows for a wide range of applications to BAR and other projects. These coverages allow interactions between pairs and groups of countries in shared river basins to be more accurately linked with other datasets. At the time of this report, utilization of these historical coverages included linking riparian countries to their associated basins for each year, calculating the area of each riparian nation's portion of current and historical international river basins, and aggregating some ancillary datasets to those basins that are no longer international. In the future, BAR plans to link the event data with the historical basin coverages, calculate climate and water availability variables for non-current international basins, and back-calculate other spatial data, such as historical population per basin and basin-country polygon for each year of the study. Much of this data will be made available on the TFDD website, to facilitate access for researchers and policy-makers.

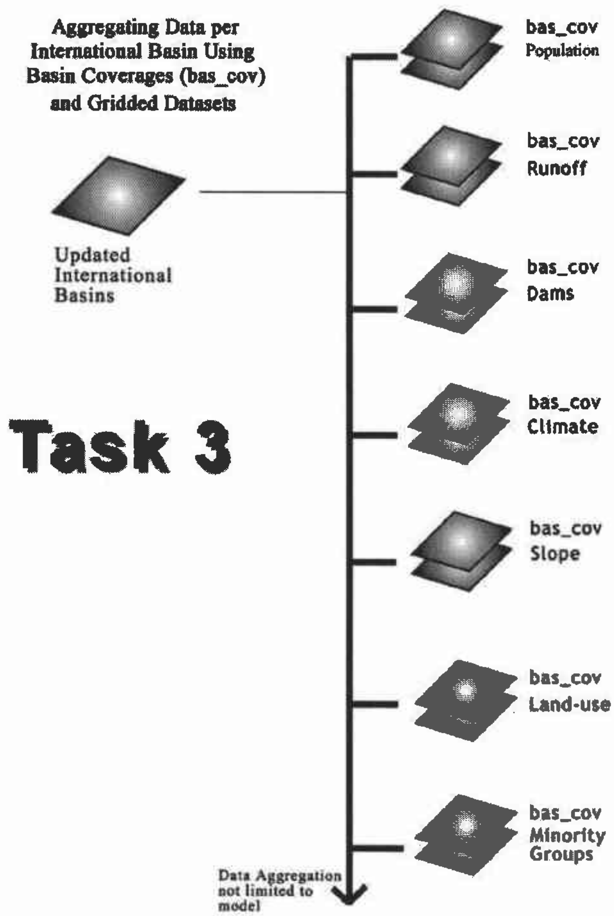
Figure 3.4: Historical International River Basins



AGGREGATING DATA PER BASIN

With the establishment of updated basin boundaries and a reasonable estimate of international basin status (past and present), accurate aggregation of various datasets to the basin boundaries was possible (Figure 3.5). Aggregation of data at the basin level include population, climate, runoff, number of dams, elevation, land use, and minority groups. As examples, population and runoff are described in further detail below.

Figure 3.5: Task 3



A basic model showing some of the datasets that were merged with the updated basin coverages to obtain data values at the basin scale.

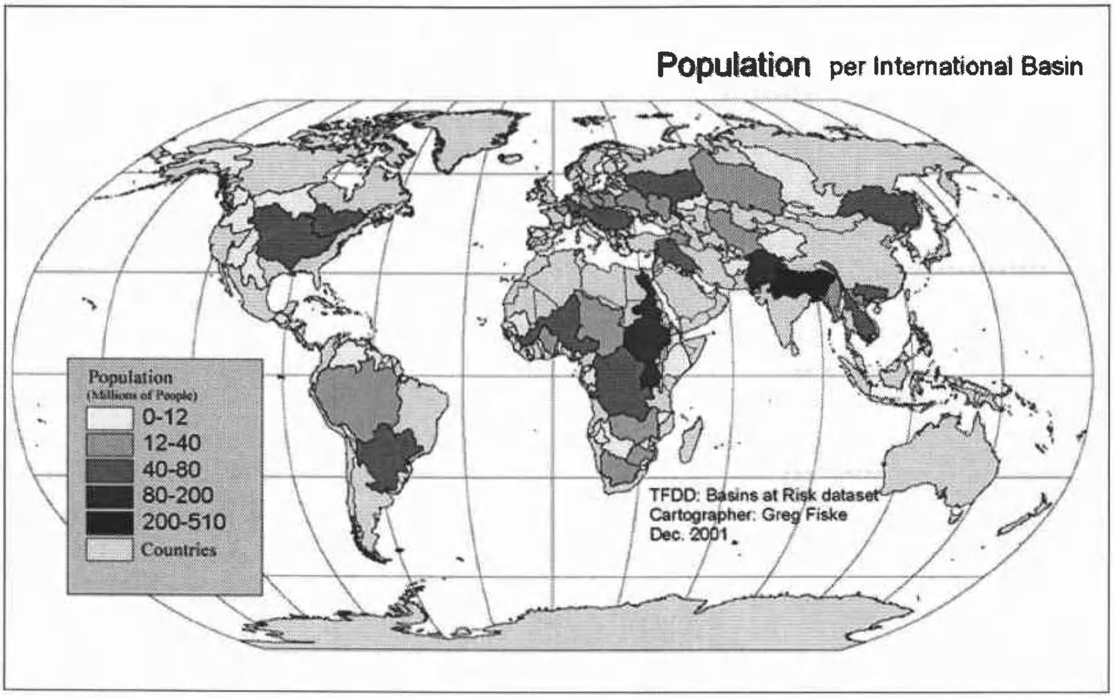
Population

Recent studies have shown that population growth is a key factor in assessing water scarcity (Brunner, Yumiko et al. 2000). Research conducted jointly by the World Resources Institute (WRI) and the University of New Hampshire (UNH) concluded that in evaluations of water scarcity, an investment in the monitoring of socioeconomic data should be as important as the hydrologic information gathered (Brunner, Yumiko et al. 2000). The location an assessment of regional water resources should therefore be coupled with information regarding regional population distribution. Population assessments traditionally have been conducted within the spatial boundaries of a political unit (e.g., the nation-state). The spatial variability of water resources, however, rarely matches the contours of political boundaries.

The population data produced by BAR surpasses previous measures of population at the basin scale 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 within a river basin, 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, led 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, Bright et al. 2000). 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 at the international river basin scale 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 (Figures 3.6 and 3.7).

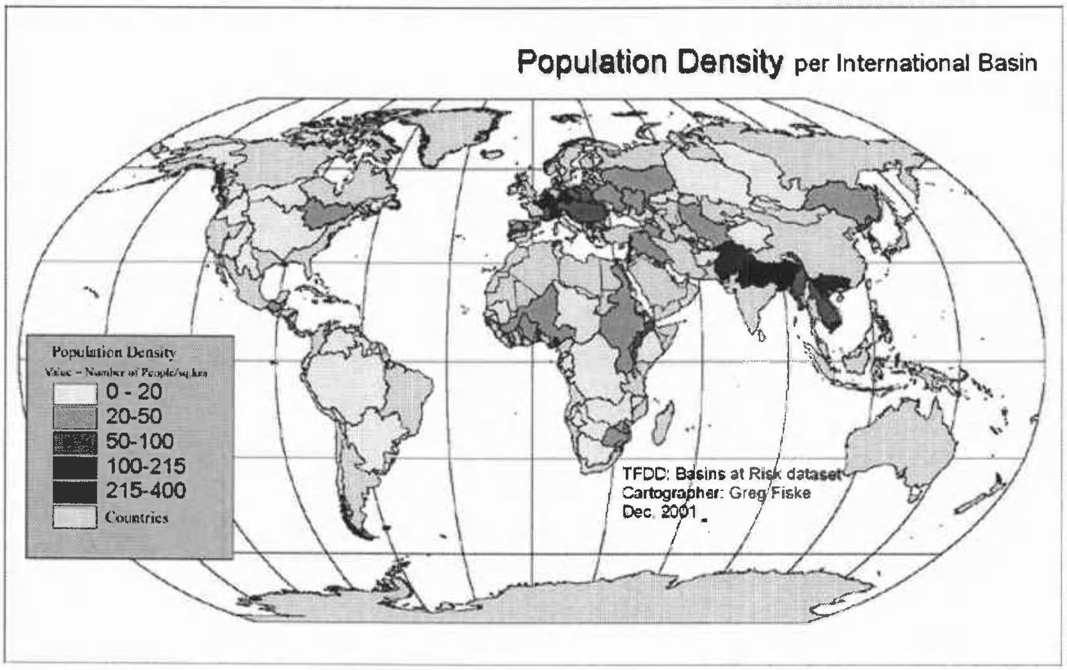
Figure 3.6: A map showing population per international basin



Runoff

Any assessment of a water resource related issue would be incomplete without some approximation of water availability within 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 produce an estimation of runoff amounts (Luker, Samson et al. 1993). 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 wide range of new opportunities for GIS analyses, including the correlation of water availability to conflict occurrence.

Figure 3.7: A map showing population density per international basin



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 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. (Fekete, Vorosmarty et al. 2000) were able to produce the composite runoff fields by accessing GRDC discharge data, selecting significant global gauging stations, and geo-registering the discharge information to locations on a simulated topological network. 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" (Fekete, Vorosmarty et al. 2000). The use of this gridded dataset was the most reasonable path to obtain 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) were multiplied by the area of the associated grid cell (sq. km) to produce a runoff volume grid (mm*km^2/yr). An estimate of annual 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 (Figure 3.8). 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, Vorosmarty et al. 2000). This confined our calculation of runoff per international river basin to approximately half the 263 watersheds. Furthermore, 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' lose a great deal of water volume at the end of their path due to natural and man-made withdrawals.[15]

With a reasonable estimate of population and discharge for each international basin (> 25,000 km^2), it was possible to manipulate the data one step further and calculate

[15] The discharge numbers calculated compared closely with discharge data from alternate sources, with larger and wetter basins matching most closely.

"water stress" within each basin (Figure 3.9). A commonly used index for water management, Malin Falkenmark's (Falkenmark 1989) Water Stress Index measures freshwater availability per capita within a country. Falkenmark's water stress index usually has been calculated by combining population by country with freshwater availability by country, thereby missing regional variability. By calculating this number by basin, a more accurate assessment of water quantity issues is possible. BAR used the calculated population per basin combined with the calculated discharge per basin to map Water Stress per basin. The thresholds of water stress (<1700 cu.m/person/year), chronic water scarcity (<1000 cu.m/person/year) and absolute scarcity (<500 cu.m./person/year) are represented in the results (Figure 3.9). These data, evaluated by basin using the most up to date world scale runoff and population datasets, represent the current, best known estimate of water availability per person per international river basin.

Figure 3.8: A Map showing estimated discharge per international basin in cu.km/yr.

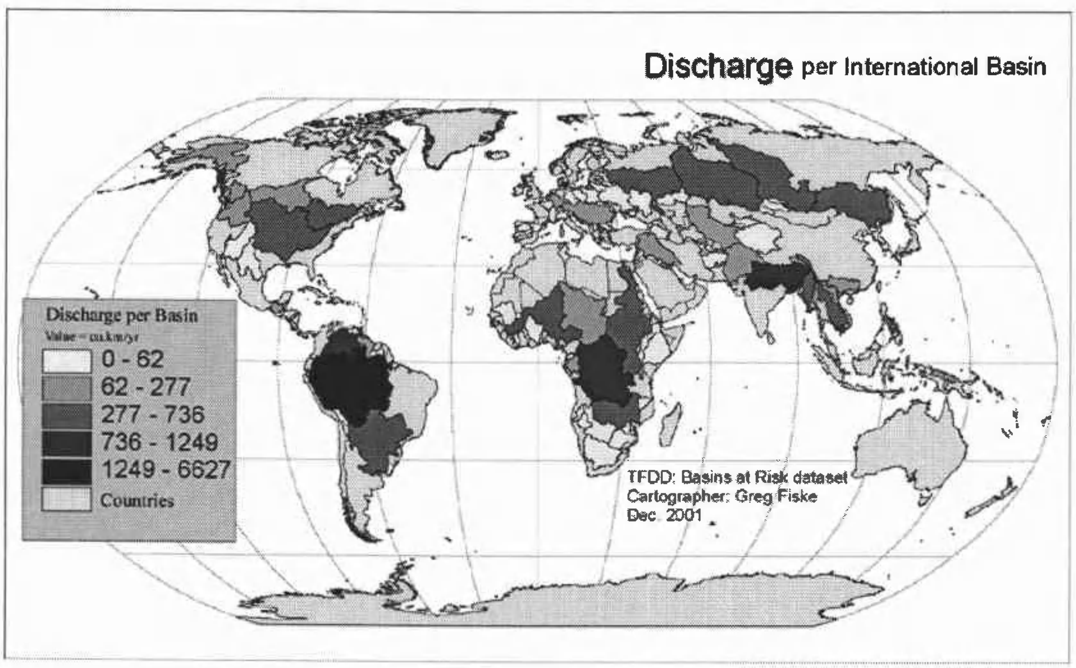
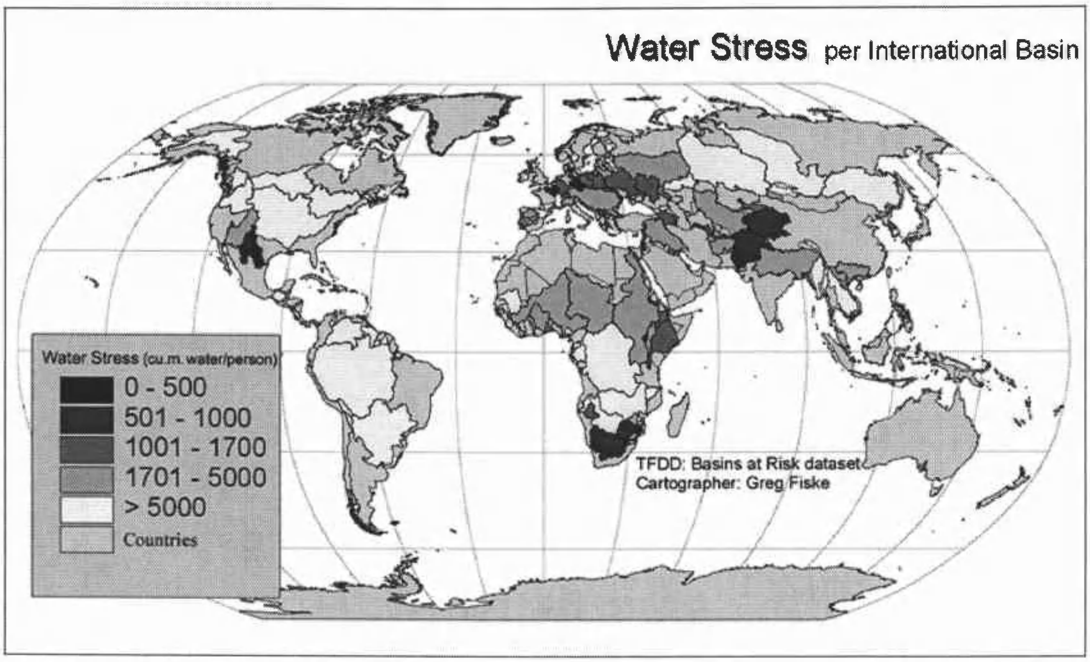


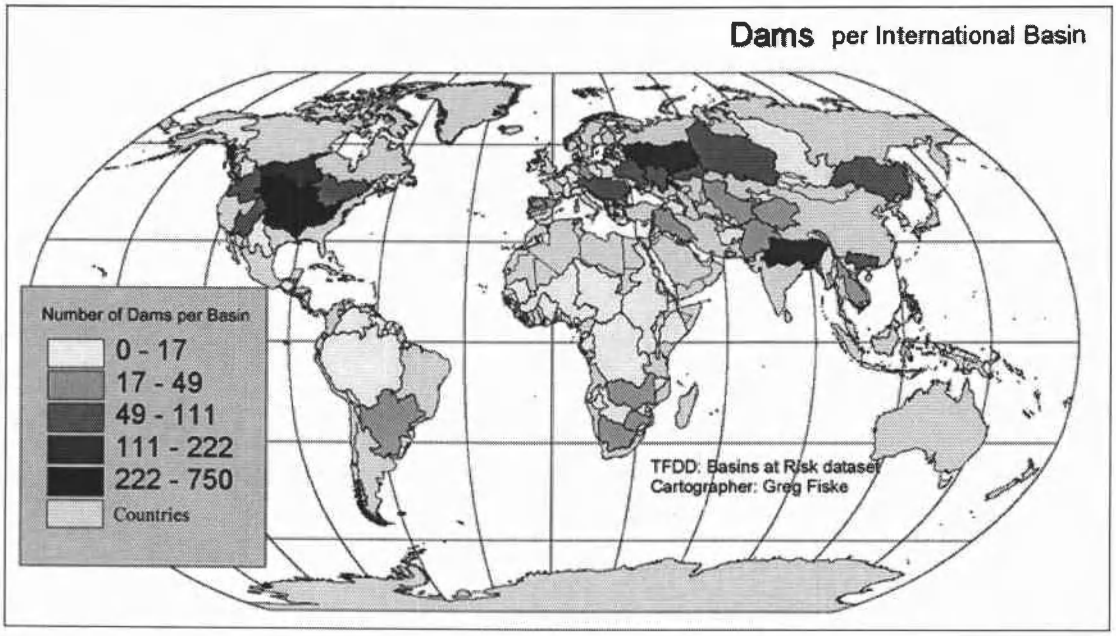
Figure 3.9: A Map showing estimated water quantity per person for each International River Basins (>25,000 sq. km.)



Other Datasets

Similar GIS techniques to those described above were used to derive data from other gridded and polygonal coverages. These data were gathered as part of the Basins At Risk project's analysis of potential indicators of conflict and cooperation over international freshwater resources (see Chapter 4 for project findings). 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 Agrometeorology Group 1997); 2) the number of dams and dam density per international basin, derived via Digital Chart of the World data (see Figure 3.10). In some cases, the derivation of these datasets was limited to international basins with an area of 25,000 km^2 or greater due to the resolution of the input data.

Figure 3.10: A map showing estimated dams per basin.



CONCLUSION

The GIS proved an invaluable tool in assessing global-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 global-scale, water-related research.

ACKNOWLEDGEMENTS

This research benefited from the support and teamwork of the many researchers participating in the Basins At Risk project, in particular the guidance and insights of Dr. Aaron Wolf. The project also benefited from the many individuals and institutions who contributed generously of their time and data. We extend our thanks to Jeff Danielson and Kent Lethcoe, EROS Data Center; Jerry Dobson, Oak Ridge National Laboratories; Balazs Fekete, Complex Systems Research Center, University of New Hampshire; and Kirsten Thompson, World Resources Institute. Furthermore, we would like to thank Dr. Dawn Wright, Oregon State University, for the use of her lab and its resources.

CHAPTER 4 CONFLICT AND COOPERATION OVER INTERNATIONAL FRESHWATER RESOURCES: INDICATORS AND FINDINGS OF THE BASINS AT RISK PROJECT

Shira Yoffe, Aaron T. Wolf, Mark Giordano

To be submitted for publication, with revisions, to the Journal of the American Water Resources Association

ABSTRACT

This paper seeks to identify historical indicators of international freshwater conflict and cooperation and create a framework to identify and evaluate international river basins at potential risk for future conflict. To accomplish this task, we derived biophysical, socioeconomic, and geopolitical variables at multiple spatial and temporal scales from a GIS of international river basins and associated countries, and tested these variables using a database of historical incidents of water-related cooperation and conflict across all international basins, 1948 to 1999. We found that international relations over freshwater resources are overwhelmingly cooperative and cover a wide range of issue areas, including water quantity, quality, joint management, and hydropower. Conflictive relations tend to center on quantity and infrastructure concerns. No single indicator explained conflict/cooperation over water, including climate, water stress, government type, and dependence on freshwater resources for agriculture or energy. Even those indicators that showed a significant correlation with water conflict, such as high population density, low per capita GDP, and overall unfriendly international relations, explained only a small percentage of the variability in the data. Overall, the most promising sets of indicators for water conflict were those associated with rapid or extreme changes in the institutional or physical systems within a basin (e.g., internationalization of a basin, large dams) and the key role of institutional mechanisms, such as international freshwater treaties, in mitigating such conflict.

KEYWORDS

water, international river basins, conflict, cooperation, event data, GIS, geography, indicators

INTRODUCTION

In the policy literature and popular press, issues of water and international conflict have been linked with increasing frequency (Westing 1986; Elliott 1991; Gleick 1993; Homer-Dixon 1994; Remans 1995; Butts 1997; Elhance 1999). This literature often stresses various indicators for conflict, including proximity, government type, aridity and rapid population growth. Yet despite the number of case studies analyzing and comparing water-related conflict in various international river basins, little global-scale or quantitative evidence has been compiled. Existing work often consists of case studies from the most volatile basins and excludes examination of cooperation, spatial variability and precise definitions of conflict.

In the Basins at Risk (BAR) project, we addressed the gaps in the literature on international freshwater resources by providing a quantitative, global scale exploration of the relationship between freshwater and conflict. We considered the full spectrum of interactions, using precise definitions of cooperation and conflict and our approach incorporates a spatial perspective. In essence, we asked whether the theories and claims are supported by historical evidence. We also considered another hypothesis, that the likelihood and intensity of conflict within a basin increases as the magnitude or amount of physical or institutional change exceeds the capacity within a basin to absorb that change.

The BAR project had three objectives:

- to identify historical indicators of international freshwater conflict and cooperation;
- to use these indicators to create a framework to identify and evaluate international river basins at potential risk for future freshwater conflict; and
- to enhance understanding of the driving forces that may cause water to become a focus of conflict or cooperation.

It is hoped such information can contribute to the development of international management approaches designed to enhance cooperation and mitigate the potential conflict over international freshwater resources.

METHODS

Our approach consisted of three main elements:

- creation of an event database documenting historical water relations, including a methodology for identifying and classifying events by their intensity of cooperation and conflict;
- construction of a Geographic Information System (GIS)[16] of countries and international basins, both current and historical, and creation of associated indicator variables (biophysical, socioeconomic, political); and
- formulation and testing of hypotheses about factors associated with water conflict.

The BAR Water Event Database[17]

In the BAR Water Event Database (http://www.transboundarywater.orst.edu), we compiled all reported instances of conflict or cooperation over international freshwater resources in the world from 1948-1999. For each event, we documented the international river basin in which it occurred, the countries involved in the event, the date, level of intensity of conflict or cooperation, and the main issue associated with each event. This information was compiled in a relational database to allow for analyses at an array of spatial and temporal scales (Table 4.1).

We defined water events as instances of conflict and cooperation that

- occur within an international river basin,
- involve the nations riparian to that basin,[18] and

---

[16] A GIS is a computerized system that enables storage, management, analysis, modeling, and display of spatial and associated data.

[17] For a more detailed discussion of the BAR Water Event Database, see Chapter 2, Yoffe and Larson (2001).

[18] In incidents involving a country that is a topographic, but not functional, riparian (i.e., the country's territorial share of a basin does not regularly contribute water to that basin), the country is not treated as riparian, and so that incident would not be considered an event. An exception to this rule are situations in which the country acts as a riparian, such as Egypt in the Jordan River basin during the course of the Huleh Swamp drainage dispute.

- concern freshwater as a scarce or consumable resource (e.g., water quantity, water quality) or as a quantity to be managed (e.g., flooding or flood control, managing water levels for navigational purposes).

Incidents that did not meet the above criteria were not included as events in the analyses.[19]

We chose the time period, 1948-1999, for its relevance to potential future instances of cooperation and conflict and for data manageability and availability. The spatial coverage is global and considers all international river basins.

We gathered event data from political science datasets (International Crisis Behavior Project (Brecher and Wilkenfeld 2000); the Conflict and Peace Databank (Azar 1980); Global Event Data System (Davies 1998); Transboundary Freshwater Dispute Database (Wolf 1999)), historical analyses, and case studies of international river basins. In addition, we conducted our own primary searches of several electronic news databases (Foreign Broadcast Information Service; World News Connection; Lexis-Nexis Academic Universe), from which we obtained about half of our event data.

Incidents of conflict and cooperation over freshwater were considered in two basic formats:

- **interactions**, in which incidents are broken out by the country-pairs (dyads) and basins involved, and
- **events**, in which one entry is provided for each incident in a basin, regardless of the number of country-pairs involved.

The BAR Water Event database contains approximately 1,800 events, which can be broken out into approximately 3,300 country-pair interactions. The data includes events for 124 countries and 122 out of 265 current and historical international basins.

---

[19] E.g., water as a weapon/victim/target of warfare; navigation or construction of ports; boundary or territorial disputes (e.g., control over river islands); purchasing and selling of hydroelectricity; third-party (i.e., non-basin country) involvement; issues internal to a country.

Table 4.1: Example of Events in BAR Water Event Database

DATE	BASIN	COUNTRIES INVOLVED	BAR SCALE	EVENT SUMMARY	ISSUE TYPE
12/5/73	LaPlata	Argentina-Paraguay	4	PRY and ARG agree to build 1B dam, hydroelectric project	Infrastructure
1/1/76	Ganges	Bangladesh-India-United Nations	-2	Bangladesh lodges formal protest against India with United Nations, which adopts consensus statement encouraging parties to meet urgently, at level of minister, to arrive at settlement.	Quantity
7/3/78	Amazon	Bolivia-Brazil-Colombia-Ecuador-Guyana-Peru-Suriname-Venezuela	6	Treaty for Amazonian Cooperation	Economic Development
4/7/95	Jordan	Israel-Jordan	4	Pipeline from Israel storage at Beit Zera to Abdullah Canal (East Ghor Canal) begins delivering water stipulated in Treaty (20 mcm summer, 10 mcm winter). The 10 mcm replaces the 10 mcm of desalinated water stipulated Annex II, Article 2d until desalinization plant complete.	Quantity
6/1/99	Senegal	Mali-Mauritania	-3	13 people died in communal clashes in 6/99 along Maur. & Mali border; conflict started when herdsmen in Missira-Samoura village in w. Mali, refused to allow Maur. horseman to use watering hole; horseman returned w/ clansmen, attacking village on 6/20/99, causing 2 deaths; in retaliation that followed, 11 more died.	Quantity

The Historical GIS

We created a Geographic Information System (GIS) to delineate all international basins, current and historical, and their riparian countries, from 1948-1999 (Chapter 3). The GIS allowed us to conduct analyses at a range of spatial scales, including country, region, and basin-country polygon.[20] The key unit of analysis, however, was the international river basin, which comprises all the land that drains through a given river and its tributaries into the ocean or an internal lake or sea and includes territory of more than one country.

BAR's GIS includes 263 current international basins and two historical basins. This historical GIS enabled incorporation of both temporal and spatial variability into our analyses. It allowed us to derive data, including population, climate, and water availability, at the basin level or other scales and to explore correlations between these variables and the event data. This ability to explore factors associated with events, in essence to ask why an event occurred, is a powerful feature of the BAR Event Database and directly addresses past criticisms concerning the utility of event datasets (Lanphier 1975; Andriole and Hopple 1984; Laurance 1990).

The BAR Scale of Intensity of Conflict and Cooperation

Each event was coded by its intensity of conflict or cooperation. We created a 15 point "BAR Scale", whose numbers range from +7, the most cooperative – voluntary unification into one nation over water, to -7, the most conflictive – formal declaration of war over water; 0 represents neutral or non-significant acts (Table 4.2). The BAR Scale, while based on the International Cooperation and Conflict Scale developed by Edward Azar (1980), incorporates water-specific terms and other changes, described in detail in Chapter 2.

Before conducting our statistical analyses, we applied an exponential transformation to the BAR Scale values (Table 4.2), in order to provide a numerical representation of the (in our view) greater significance of the extremes of the scale and the transition from, for example, extensive war acts and small scale military acts (categories -6 and -5) as compared to the transition from strong to mild verbal hostility (-2 to -1). Other transformations besides the exponential are possible. Having chosen our

[20] A basin-country polygon refers to a country's territorial share of an international basin. It is the smallest spatial grain used in the BAR study.

transformation, we calculated conflict/cooperation at a range of spatial and temporal scales (e.g. basin, country, year, etc.).[21] We then averaged these values for our response variable. In analyses comparing data by year, the response variable was the average value of conflict/cooperation for all events in that year (AABS). In analyses spanning the entire time period of our study, the response variable was the average of the annual averages (ABS). The graphs accompanying this paper show the results of analyses back-transformed to the 15-point (+7 to -7) BAR Scale.

[21] For example, the formula for calculating event intensity for a basin, j, over the entire time period is:

$$\sum_{i=1}^{n} a_{ij}/n$$

where a_i is an event and n is the number of events associated with basin j. This formula can be modified to calculate event intensity by year, by dyad, etc.

Table 4.2: Water Event Intensity Scale

COPDAB SCALE	RE-CENTERED BAR SCALE	ANTI-LOGGED, RE-CENTERED SCALE	EVENT DESCRIPTION
15	-7	-198.3	*Formal Declaration of War*
14	-6	-130.4	Extensive War Acts causing deaths, dislocation or high strategic cost
13	-5	-79.4	Small scale military acts
12	-4	-43.3	Political-military hostile actions
11	-3	-19.8	Diplomatic-economic hostile actions. *Unilateral construction of water projects against another country's protests; reducing flow of water to another country, abrogation of a water agreement.*
10	-2	-6.6	Strong verbal expressions displaying hostility in interaction. *Official interactions only.*
9	-1	-1.0	Mild verbal expressions displaying discord in interaction. *Both unofficial and official, including diplomatic notes of protest.*
8	0	0.0	Neutral or non-significant acts for the inter-nation situation
7	1	1.0	Minor official exchanges, talks or policy expressions--mild verbal support
6	2	6.6	Official verbal support of goals, values, or regime
5	3	19.8	Cultural or scientific agreement or support (non-strategic). *Agreements to set up cooperative working groups.*
4	4	43.3	Non-military economic, technological or industrial agreement. *Legal, cooperative actions between nations that are not treaties; cooperative projects for watershed management, irrigation, poverty-alleviation.*
3	5	79.4	Military economic or strategic support
2	6	130.4	Major strategic alliance (regional or international). *International Freshwater Treaty*
1	7	198.3	Voluntary unification into one nation

RESULTS AND DISCUSSION

Are the theories and claims linking water to international conflict supported by historical evidence? If not, what is water's role in international relations? What basins are at potential risk for future conflict over international freshwater resources? The following sections describe historical patterns in international conflict and cooperation over freshwater resources and the hypotheses and statistical analyses from which we derive our framework for identifying basins at risk.

Overall Patterns

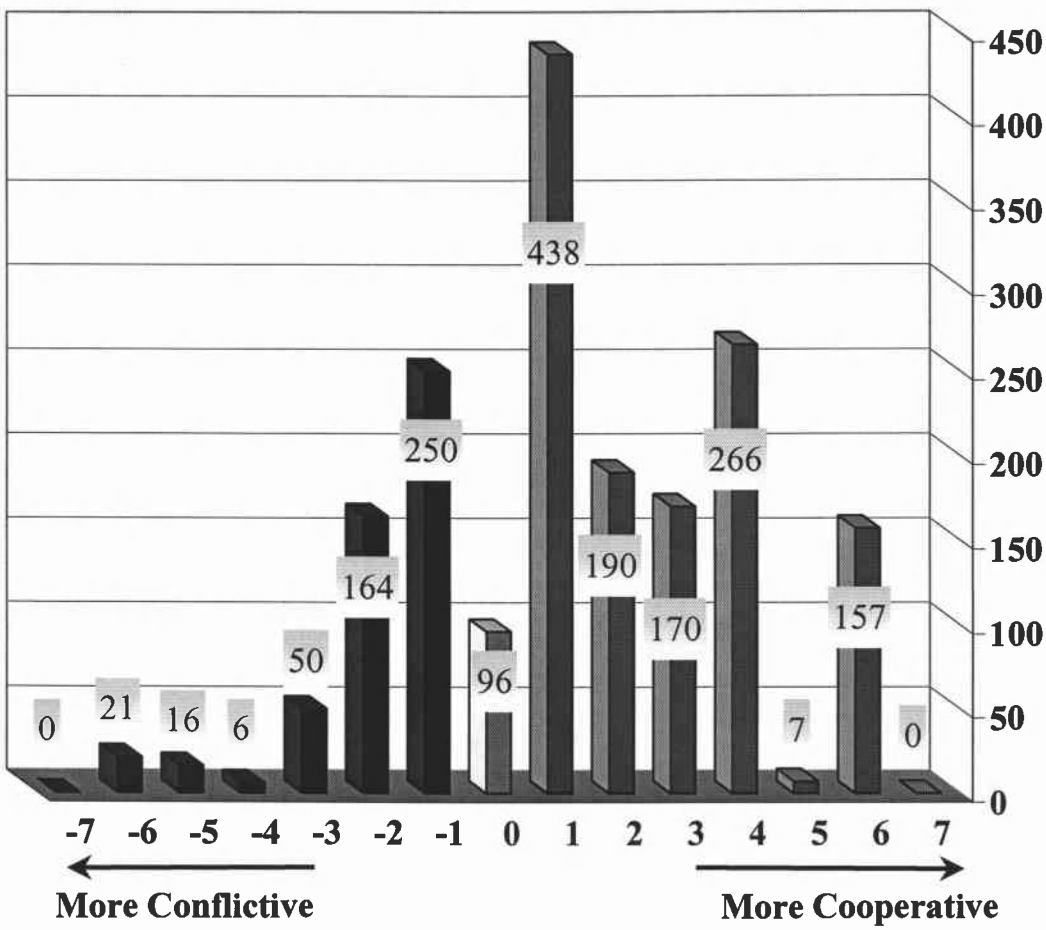
We found no events at the extremes of the intensity scale – no formal declaration of war over water and no countries voluntarily unifying into one nation over water. For the years 1948-1999, cooperation over water, including the signing of treaties, far outweighed overall conflict over water and violent conflict in particular (Fig. 4.1). Out of 1,831 events, 28% were conflictive (507 events), 67% were cooperative (1,228), and the remaining 5% were neutral or non-significant. Of the total events, more than half (57%) represented verbal exchanges, either mildly conflictive or cooperative. Interactions follow the same pattern.[22]

Six issues, water quantity, infrastructure, joint management and hydropower, dominated the events. Cooperative events concerned a slightly wider range of issues than conflictive events, with a more dramatic difference at the extremes of the scale. International freshwater treaties, the most cooperative event in our dataset, covered a wide range of issue areas, with emphasis on water quality and quantity, hydropower, joint management and economic development. The most extremely conflictive events in our database, extensive military acts, concerned quantity and infrastructure exclusively, two issue areas closely tied together (Table 4.3).

---

[22] Out of approximately 3,200 interactions (events by dyad), 17% are conflictive (568 interactions), 78% are cooperative (2,544), 5% are neutral, and verbal exchanges account for 54% of total interactions.

Figure 4.1: Total Number of Events by BAR Intensity Scale



In comparing events to interactions, we found that events involving high levels of conflict (BAR Scale –3 to –7) occurred for the most part between individual dyads (i.e., involve only one country-pair). In contrast, highly cooperative events (BAR Scale +3 to +7) often involved multiple dyads. For example, the 157 international freshwater treaties (BAR Scale +6) involved 490 dyadic interactions (an average of approximately 3 country pairs per treaty), while all of the 21 events categorized as Extensive War Acts (BAR Scale –6) were bilateral conflicts. A large portion of the multilateral freshwater treaties emphasized economic development, joint management, and water quality, whereas bilateral agreements tended to concern water quantity and hydropower. Overall, joint management, water quality, and economic development were more prevalent and infrastructure concerns less so in events involving multiple country-pairs. It may be that countries find more difficulty in reaching multilateral agreements on water quantity, while economic development, joint management and water quality offer more opportunities for mutual benefit. Such differences point to areas where one approach, multilateral vs. bilateral, may be more appropriate than the other, in attempting to develop institutional mechanisms to facilitate negotiation and management of international freshwater resources.

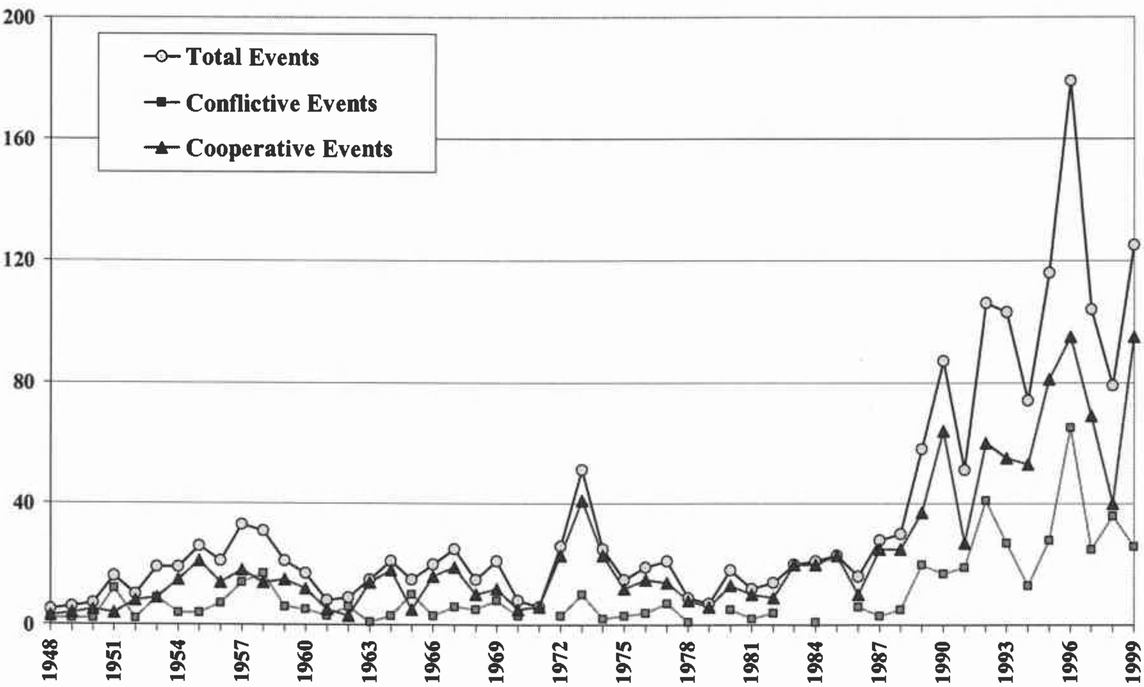
Table 4.3: Percentage of Events by Issue Area and Level of Conflict/Cooperation

Issue	All Events		All Cooperative		All Neutral		All Conflictive		Extreme Cooperative		Extreme Conflictive	
	#	%	#	%	#	%	#	%	#	%	#	%
Water quantity	857	46	450	36	68	71	309	61	44	28	19	90
Infrastructure	351	19	203	17	19	20	129	25	4	3	2	10
Joint Management	225	12	208	17	4	4	13	3	21	13	0	0
Hydropower	175	10	163	13	3	3	9	2	46	29	0	0
Water Quality	102	6	78	6	0	0	24	5	18	11	0	0
Technical Cooperation	42	2	41	3	0	0	1	0	0	0	0	0
Flood Control/Relief	38	2	31	3	1	1	6	1	8	5	0	0
Irrigation	30	2	24	2	1	1	5	1	1	1	0	0
Border Issues	25	1	14	1	0	0	11	2	4	3	0	0
Economic Development	9	0	9	1	0	0	0	0	7	4	0	0
Navigation	7	0	7	1	0	0	0	0	4	3	0	0

Temporal and Spatial Coverage of the Event Data

Although we used a wide range of data sources in order to achieve as broad a temporal and spatial coverage as possible, event data coverage was not consistent for all countries or for all years. Despite appearances in Figure 4.2, which shows the number of cooperative, conflictive and total events by year, conflict or cooperation over water has not necessarily been increasing over time. Rather, identification of water events for earlier periods is less comprehensive, because the relative lack of contextual information in the datasets used made positive identification of water-specific events difficult. The skew towards later years in the temporal distribution also reflects intensity of effort, in large part because of the availability of electronic news databases, with searchable text or summaries, for the latter period of our study. The pattern of temporal distribution may also reflect a growing importance of water, and environmental issues in general, in international news reporting.

Figure 4.2: Distribution of Cooperative, Conflictive, and Total Events By Year



From a regional perspective, the majority of events in the BAR Water Event Database are associated with basins in North Africa and the Middle East, Sub-Saharan Africa, and Eastern Europe – followed by Southeast and South Asia and South America (Fig. 4.3; Appendix 10 lists the basins included in each regional grouping). For all but one of these regions, the average BAR Scale is cooperative (Fig. 4.4). Overall, the Middle East/North Africa region shows the lowest, while Western Europe represents the highest, level of cooperation. In terms of number of events therefore, BAR's water event data is somewhat weighted toward the least cooperative region. Despite this bias, we found that the majority of international relations over freshwater resources were cooperative. Moreover, the most conflictive basins were also among the most cooperative (Appendix 4, Table A4.4). The same does not hold true for dyads. Country-pairs with highly conflictive events also have highly cooperative events, but not necessarily the reverse (Appendix 5). The basins for which we had the highest number of events were: Danube, Ganges-Brahmaputra-Meghna, Jordan, La Plata, Tigris-Euphrates, Mekong. A comparison of the number of events per basin region with the number of interactions reveals that multilateral relations were most prevalent in Eastern Europe, Southeast Asia, Soviet Union/FSU, and East Asia, as compared with other study regions (Fig. 4.3, Table 4.4).

Figure 4.3: Number of Events and Interactions Per Basin-Region

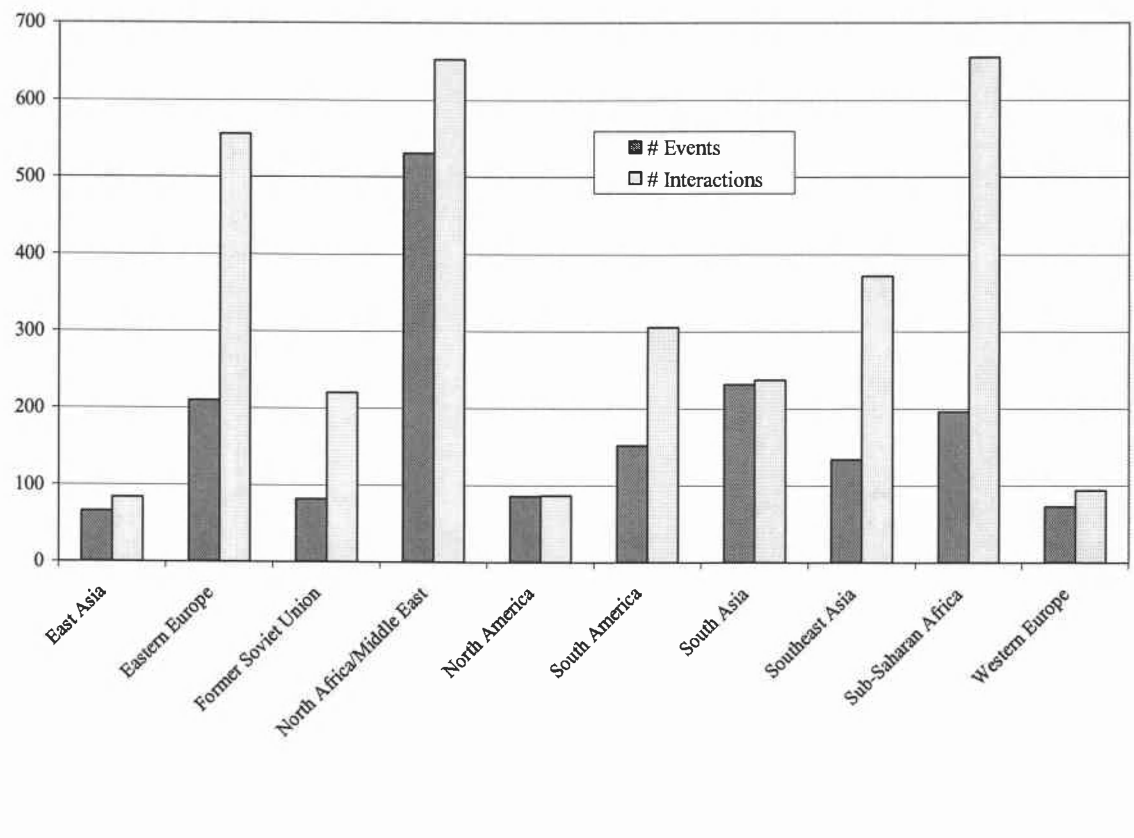
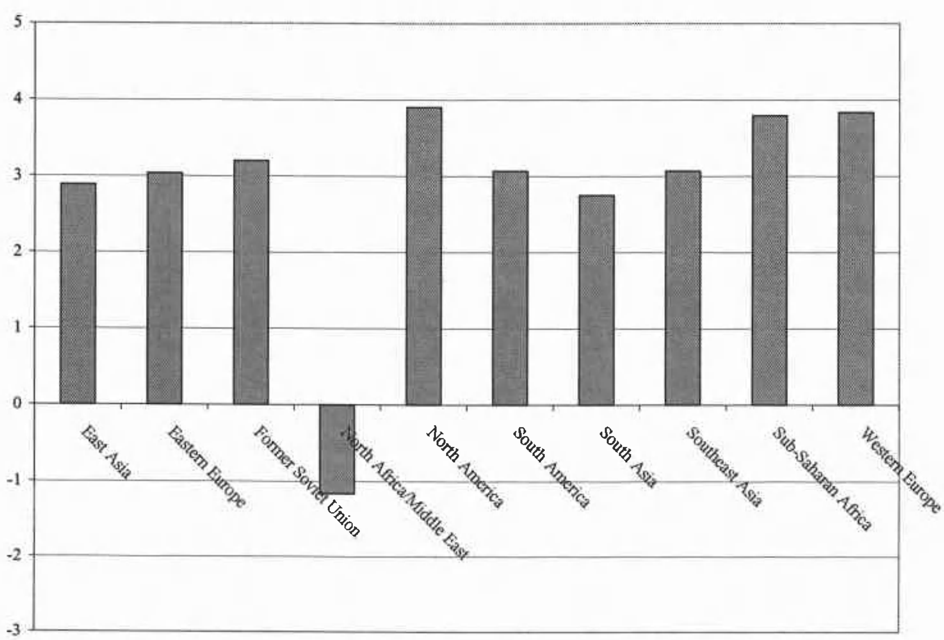


Table 4.4: Numbers and Percentages Behind Figure 4.4

Basin Region	# Events	# Interactions	Total Difference	# of Basins per Region	% Increase of Interactions Relative to Events	% Increase Weighted by # of Basins
East Asia	66	84	18	11	21.43	1.95
Eastern Europe	210	556	346	14	62.23	4.45
Soviet Union/FSU	82	220	138	30	62.73	2.09
N. Africa/Mid. East	531	652	121	21	18.56	0.88
North America	86	87	1	40	1.15	0.03
South America	152	305	153	38	50.16	1.32
South Asia	231	237	6	5	2.53	0.51
Southeast Asia	134	372	238	18	63.98	3.55
Sub-Saharan Africa	196	655	459	54	70.08	1.30
Western Europe	73	94	21	34	22.34	0.66

Figure 4.4: Average BAR Scale Values By Basin-Region



Hypotheses and Analyses for Developing Framework to Identify Basins at Risk

We tested a set of hypotheses relating the level of international conflict/cooperation over water to a set of quantifiable independent variables cited in the literature, or formulated by our research group. For the majority of our analyses, we chose to use linear regression as our main statistical tool because it offered a concise summary of the mean of the response variable as a function of an explanatory variable. Linear regression models were compared to assess the relative strength of various independent variables in explaining the variability in the event data. Other univariate statistical analyses employed two-sample t-tests. We also considered indicators based on qualitative assessments of the empirical data (graphical comparison of average BAR Scale values), where statistical analyses were not feasible/appropriate. Table 4.5 lists the majority of hypotheses considered. The results of the hypotheses are discussed below. Further detail regarding the hypotheses and datasets used may be found in the Appendix.

Table 4.5: Hypotheses Considered and Results

Indicator	Relationship of Interest	Result			
Linear regression		**n**	**R^2**	**Coeff.**	**P-value***
GDP	GDP vs. country ABS	115	0.01	0.00	0.43
GDP/capita	GDP/capita vs. country ABS	114	0.05	5.11	0.01
Population density (# people/km^2)	Population density vs. country ABS	123	0.03	-0.02	0.04
	Population density vs. basin ABS	121	0.04	-0.30	0.04
	Population density vs. basin-country polygon ABS	344	0.02	-0.19	0.00
Overall Relations	Friendship/Hostility vs. country ABS	130	0.12	1.74	0.00
Relative Power	Ratio of GDP/capita vs. dyad ABS	304	0.02	-1.78	0.03
	Ratio of population densities vs. dyad ABS	490	0.02	6.70	0.00
Rate of Population Growth	National pop. growth rate (1950-1999) vs. country ABS	126	0.02	-11.77	0.08
	National pop. growth rate (1950-1999) vs. average country Friendship/Hostility	169	0.07	-3.24	0.00
# of Dams	# of dams vs. basin ABS	82	0.00	-1.57	0.58
	# of dams vs. basin-country polygon ABS	155	0.02	0.00	0.12
Dam Density (# dams/km^2)	Dam density vs. basin ABS	82	0.02	-3.93	0.16
	Dam density vs. basin-country polygon ABS	155	0.01	-0.00	0.16
Basin Area	Basin area in km^2 vs. basin ABS	122	0.03	3.47	0.04
# Basin Countries	# of countries sharing a basin vs. basin ABS	122	0.01	1.39	0.38
Water Stress	Freshwater availability/capita vs. basin ABS	86	0.01	6.56	0.51
Social Water Stress	Capacity adjusted water/capita vs. basin ABS	85	0.04	5.66	0.06
Human Dev. Index (HDI)	Country HDI vs. country ABS	119	0.01	19.39	0.29
	Average of riparian country HDI's vs. basin ABS	121	0.01	-24.87	0.37
Agric. as % GDP	% GDP in agriculture vs. country ABS	63	0.01	-0.22	0.35
% labor force	% country labor force in agriculture vs. country ABS	126	0.00	-0.08	0.47
Hydropower	Hydropower as % electricity production vs. country ABS	98	0.04	-0.06	0.06

Table 4.5: Hypotheses Considered and Results (cont.)

Indicator	Relationship of Interest	Result		
Two-Sample T-test		**n**		**P-value***
Freshwater Treaties	ABS of non-treaty dyads (2.6) vs. ABS of dyads with treaties for years before first treaty signed (2.5)	388		0.34
Adjacency	ABS of basin dyads sharing a border (3.8) vs. ABS of basin dyads not sharing border (3.3)	3,332		0.00
Riverine Contiguity	ABS of riparian countries with river as border (4.0) vs. ABS or riparian countries w/out river as border (3.9)	390		0.31
No statistical test conducted due to structure of data		**Graphical comparison of ABS**		
Dam density and freshwater treaties	Series of comparisons of high dam density and low dam density basins with and without treaties	High dam density basins more conflictive than low dam density basins except in presence of freshwater treaties.		
Freshwater Treaties	Basin AABS in 3 years before a treaty was signed vs. three years after treaty signature	3 years preceding treaty, ABS no different than in normal years. 3 years following treaty, ABS higher than in normal years.		
Climate	Basin % primary climate zone (based on % area) vs. basin ABS	ABS of arid basins similar to that of basin in most other climate zones.		
Precipitation	Annual basin precipitation vs. basin AABS	Most cooperative years were those in which rainfall close to avg. basin precipitation. Very dry years marginally more cooperative than wet/very wet years.		

*p-value considered significant at < .05

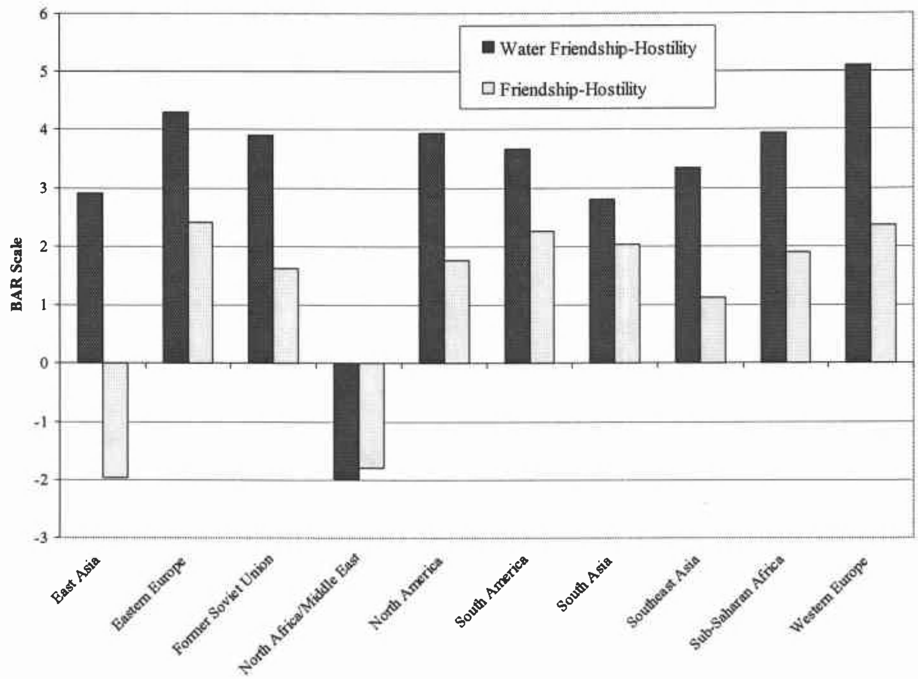
GDP and Population

We considered Gross Domestic Product (GDP) and GDP per capita at the country scale and population and population density (# people/km^2) at the basin and country scales. Only GDP per capita and population density showed an association with conflict over water. We found that rich countries and those with lower population densities tended to be more cooperative over water than poorer, more densely populated countries. Despite their statistical significance, however, these factors explain only a small percentage of the variability in the data (r-squared values < .10).

Overall Relations

The overall level of friendship-hostility among riparian countries was significantly associated with conflict/cooperation over water. Countries that cooperate in general also cooperate over water, and countries with overall unfriendly relations also are unfriendly over water issues. We also considered whether this correlation held true at the regional scale. While we did not see a correlation between relations over water and overall friendship-hostility at the region-scale, we did find that, from a regional perspective, countries appear to have friendlier relations over water than they do overall (Fig. 4.5). This result may indicate that other, non-water, issues provide a greater source of regional tensions. Although the Middle East/North Africa region presents an exception, it should be noted that the water event data is based on public reports of interactions and therefore under-represents non-public cooperation, such as the secret "picnic table talks" between Israel and Jordan on the Jordan river. At the country level, the relationship is much less clear, perhaps because freshwater resources are largely dealt with as a bilateral concern.

Figure 4.5: Comparison of BAR Scale vs. Friendship-Hostility Index, by Region



We also considered population growth rates and conflict over water, as well as conflict overall. Countries with more rapidly growing populations tended to be more internationally conflictive overall, but not more conflictive over water resources. These findings suggest that the drivers of water conflict and cooperation are not the same as for overall conflict and cooperation.

Relative Power

A general indicator of international conflict cited in the political science/geography literature is "relative power." Theorists exploring geography as a source of conflict consider distribution of power (e.g., Mandel 1980) or the change in the relative power of states (e.g., Prescott 1965; Garnham 1976) as indicators of the frequency or likelihood of territorial disputes. Authors have offered various ways to measure relative power. Garnham (1976), for example, measured power parity using four indicators of national power: geographical area, population size, fuel consumption, and steel production. These indicators are assumed to correlate with a nation's capability to create and mobilize military forces. Garnham found that international war was more likely to occur between nation-states of relatively equal national power, in terms of population parity.

We tested a series of possible measures of relative power between countries, including the ratio of GDP per capita between basin-dyads and the ratio of their population densities. We found that dyads with greater differences in their per capita GDP's were associated with greater conflict over water. In contrast, basin-dyads with greater differences in their population densities were associated with greater cooperation over their shared freshwater resources. As with the other statistical analyses above, however, these indicators explain only a small percentage of the variability in the data.

Infrastructural Development and Institutional Mechanisms

The majority of indicators discussed in this paper relate to existing theoretical claims regarding causes of international conflict or, more specifically, geography or water's relationship to international conflict. We also considered our own hypothesis:

> that the likelihood and intensity of conflict within a basin increases as the magnitude or amount of change in physical or institutional systems exceeds the capacity to absorb that change.

An extreme change in the physical systems of a basin might be the construction of a large dam or water development project. We tested number of dams and density of dams (number of dams/1000 km^2) against the BAR scale and neither proved significant. In and of themselves, dams did not appear to provide a useful indicator for conflict over water, yet many of the conflictive events in the database concerned infrastructure development issues. We then considered the relationship of dams to freshwater treaties. We divided basins into two groups, those with a high density of dams and those with a low density of dams. We also identified basins with and without treaties. We then did a series of comparisons (Table 4.6) and found that overall and in basins without treaties, lower dam density basins tended to exhibit slightly less conflict. In basins with treaties, the relationship was reversed and lower dam density basins exhibited slightly more cooperation. In all these instances, however, the relationship was not significant. We then compared high dam density basins with treaties to those without. In high dam density basins, treaties mitigate conflict. High dam density basins with treaties showed significantly higher levels of cooperation than in non-treaty basins (41% difference; average BAR Scale of +4.2 in treaty basins vs. +2.5 in non-treaty basins). Moreover, this difference was not because pairs of countries with treaties started out as inherently more cooperative than pairs of countries without treaties. In fact, average water relations between dyads in the three years before a treaty was signed were somewhat more conflictive than in general. Nonetheless, once a freshwater treaty was signed, cooperation increased and, over time, often additional treaties were signed.

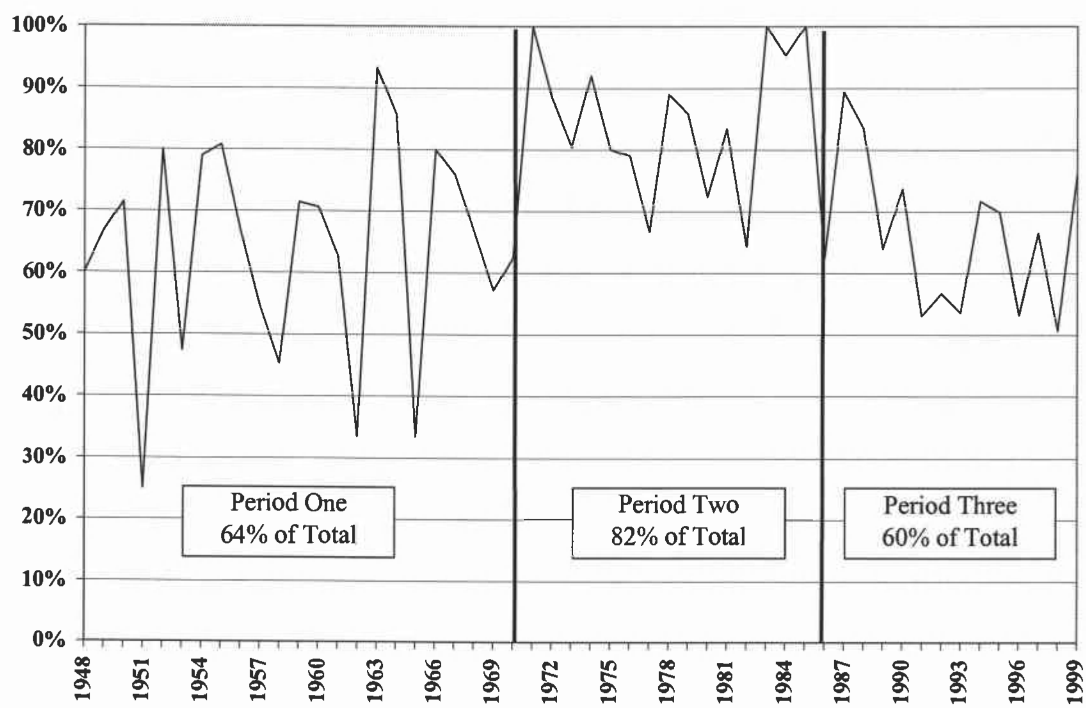
Table 4.6: Dam Density and Freshwater Treaties

Basin Setting	*BAR Scale*	*% Difference*
Basins With Low Dam Density	**4.2**	
Basins With High Dam Density	**3.7**	**-12%**
Basins Without Treaties and Low Dam Density	**2.8**	
Basins Without Treaties and High Dam Density	**2.5**	**-12%**
Basins W/Treaties (value of first treaty excluded) and Low Dam Density	**3.8**	
Basins W/Treaties (value of first treaty excluded) and High Dam Density	**4.2**	**11%**
Basins W/Treaties (value of first treaty excluded) and High Dam Density	**4.2**	
Basins Without Treaties and High Dam Density	**2.5**	**-41%**

In terms of rapid change on the institutional side, we considered internationalization of basins. Internationalized basins refer to basins whose management institutions were developed under a single jurisdiction, which was then fragmented when that jurisdiction suddenly became divided among two or more nations. Basins in regions experiencing internationalization, such as during the break up of the British Empire or the fall of the Soviet Union, showed much higher levels of conflict compared to other parts of the world.

Figure 4.6 indicates three distinct periods of cooperation over international freshwater resources.[23] Although we found many more cooperative events toward the latter years of the study, there was no significant increase in terms of cooperative events as a percent of total events recorded. In periods one and three (1948-1970 and 1987-1999), cooperation over water was relatively low compared to the middle period (1971-1986). We speculated that the difference in levels of cooperation was related to shifts in the international system during those time periods. We explored whether regions undergoing internationalization of river basins, due to either the disintegration of the British Empire or the breakup of the Soviet Union, accounted for the differences in overall cooperation.

Figure 4.6: Cooperative Events as Percentage of Total Events By Year



[23] Cooperative events represent 64% of total events for both 1948-1970 and 1987-1999 time periods and 84% from 1971-1986.

We found that periods of internationalization were associated with higher levels of conflict. Figure 4.7 depicts the average BAR Scale value for the Middle East and South Asia, regions of British control, for three time periods under consideration. Figure 4.8 depicts the same for Eastern Europe and the (former) Soviet Union. The graph for the Middle East/North Africa and South Asia indicates that while cooperation over water for the world as a whole decreased slightly from 1948 to 1999, the Middle East/North Africa and South Asia show very low levels of cooperation from 1948-1970, an increase from 1971-1986 – a period of the relative stability during the Cold War, and then a slight drop from 1987-1999. This drop in later years is worth further exploration. It may reflect, for example, active nationalist movements within a basin (e.g., Kurds and the Tigris-Euphrates, Palestinians in the Jordan basin), the decline of Cold War influence on regional stability, or infrastructure development plans in the Nile basin. The graph for Eastern Europe and the former Soviet Union illustrates that, while the rest of the world shows a decrease in cooperation in the latter period, 1990-1999, the regions of Eastern Europe and the former Soviet Union show a much more marked drop in cooperation. Both these graphs show low levels of cooperation during periods when the regions of interest were experiencing the emergence of new nations and, with that, the internationalization of river basins.

Adjacency/Spatial Proximity

Pairs of countries within an international river basin that also shared a border cooperated more over water than pairs of countries that shared a basin, but not border. This result contrasts with theories of geography and war. States are expected to exhibit more conflict with neighboring states than with others, because 1) it is less difficult to wage war against closer countries than against more distant nations) (Garnham 1976; Most and Starr 1989 in Vasquez 1995; Russett 1967); 2) multiple shared borders create uncertainty, which contributes to conflict (Richardson 1960; Midlarsky 1975; both in Diehl 1991); and, 3) countries closer together are more likely to have conflicting interests because of their proximity to each other (Bremer 1992).

Figure 4.7: Average BAR Scale by Time Period for Middle East and South Asia

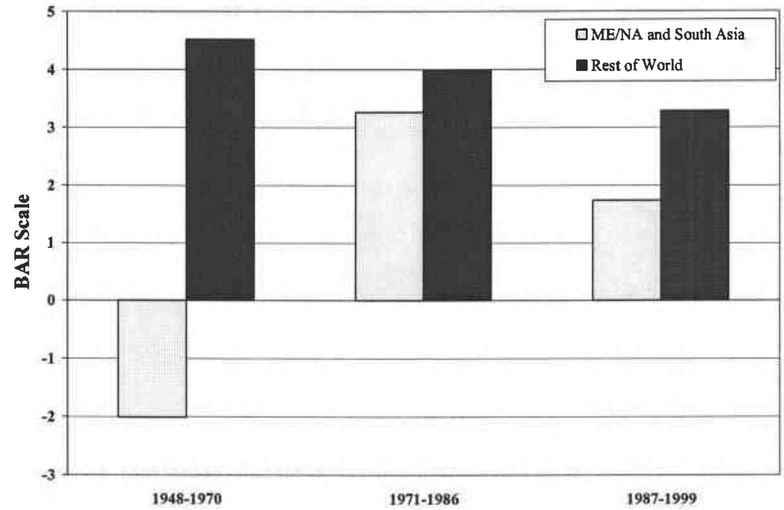
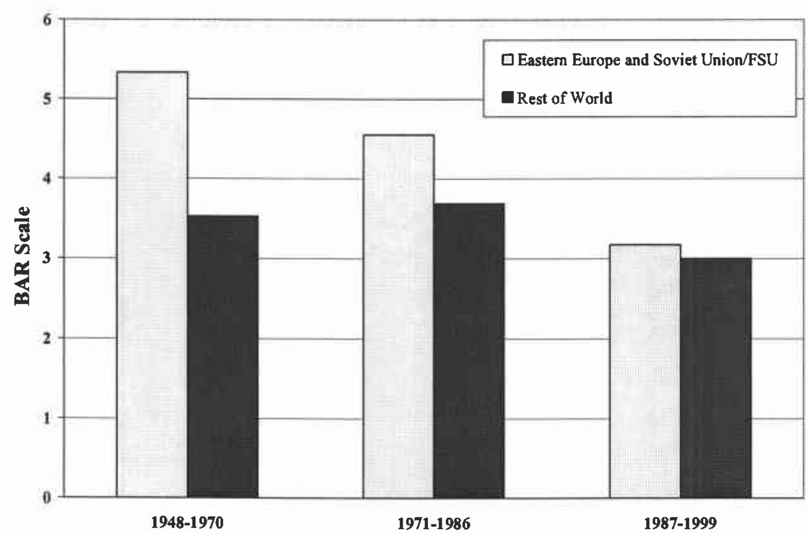


Figure 4.8: Average BAR Scale by Time Period for Eastern Europe and Soviet Union/FSU



Several studies have found a relationship between proximity and violent international conflict, war in particular (Gleditsch and Singer 1975; Garnham 1976; Gochman 1991; Gleditsch 1995; Bremer 1992). These studies, however, focused on wars or militarized international disputes, rather than a spectrum of conflict types, and did not consider the specific issue under dispute. Vasquez (1995) contends that the reason proximity is associated with international conflict is that war arises "from specific territorial disputes that have been unable to be resolved by other means. ... Wars are clustered among neighbors because neighbors have territorial disputes" (p.281). Many of the quantitative studies linking proximity in war concern territory or fail to distinguish the issues over which the war is fought. Toset and Gleditsch (2000) consider the relationship between militarized interstate disputes and water scarcity, as well as proximity, shared rivers, and other factors. Their study found contiguity to be significant, but not freshwater availability per capita.[24] Toset and Gleditsch explored militarized interstate disputes only and they note that it may be unreasonable to expect disputes over water to escalate to armed conflict. Even their study, however, does not distinguish the issues over which the conflicts were fought; in particular, whether the conflicts concerned shared rivers or freshwater as a resource.

Since the BAR water events specifically exclude issues where the concern is over territory or rivers as borders, we did not expect to find a correlation between proximity and conflict over international freshwater resources. In the political geography literature, the importance of shared borders has lain in interaction opportunities and the role of uncertainty. Our finding highlights that shared borders in and of themselves represent opportunities for cooperation, as well as conflict. This finding fits with more recent literature, which speculates that the effects of geography on the likelihood of war are not uniform and considers coexistence and cooperation, rather than conflict, across international boundaries (e.g., Barnard 1994; Blake 1994; Gradus 1994).

We infer that for water issues, shared borders in shared basins offer opportunities for trade-offs and cooperative interactions between states, because of the geographic proximity and other, non-water, relations the states may share. In situations where states share a river, but not a border, there may be fewer opportunities for such cooperative interactions. If uncertainty associated with multiple borders increases the potential for international conflict, then perhaps shared river systems, which serve to expand a

[24] In addition, their data sources differ from those we used. Shared rivers were defined using the 1978 UN Register of International Rivers, with supplemental sources, freshwater resources per capita was defined at the country level, and contiguity data was obtained from the Correlates of War Project (Toset and Gleditsch 2000).

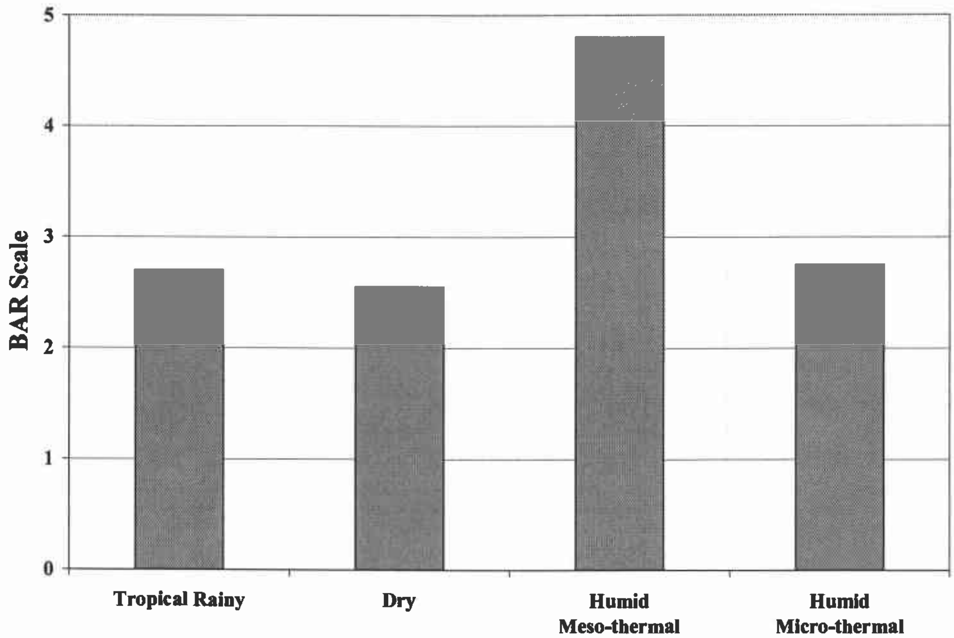
country's physical connections beyond its immediate neighbors, contribute to such conflict when other opportunities for cooperative interactions, such as with a shared border, are lacking.

Climate, Precipitation, Water Availability

Two factors often cited as indicators of water conflict are climate and water availability. In a modified form of environmental determinism, authors cite such factors as aridity and population growth as key contributors to potential 'water wars,' because scarcity of water is seen as contributing to instability and conflict (e.g., Gurr 1985; Lipschutz 1989; Homer-Dixon 1991; Elliott 1991; Westing 1986). Such thinking is prevalent in environmental security literature, which links environment and natural resource issues with violent conflict and national security concerns (e.g., Ullman 1983; Westing 1986; Gleick 1989; Myers 1989; Tuchman Mathews 1989; Homer-Dixon 1991).

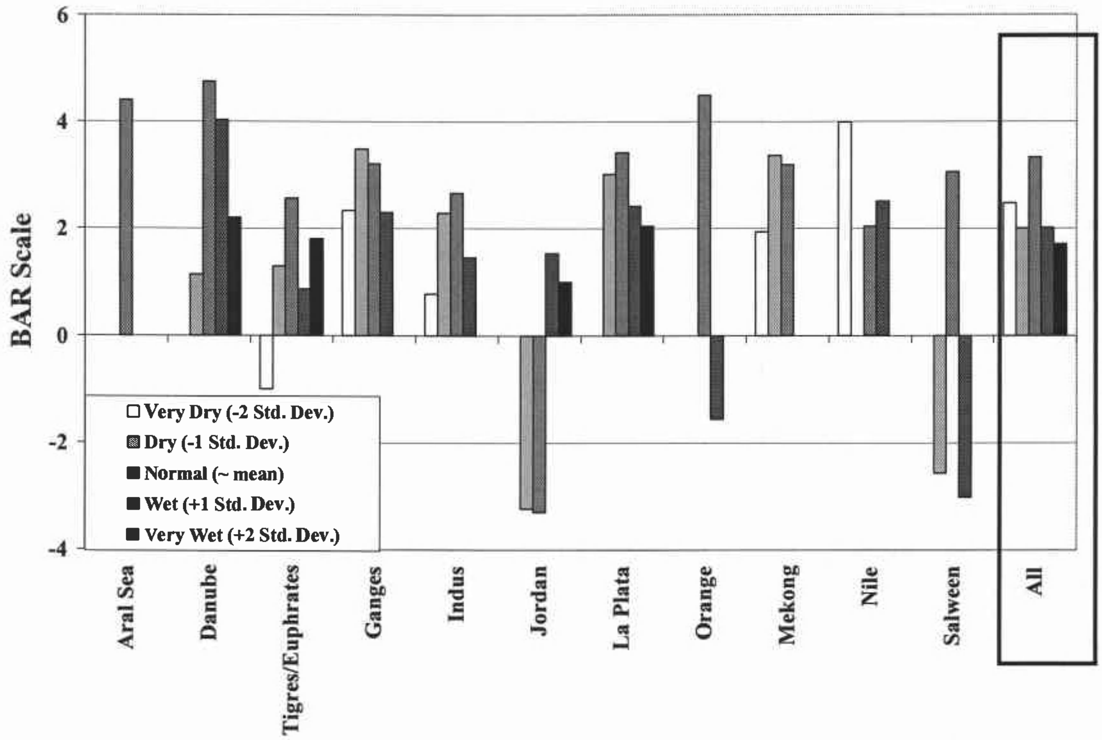
We found no relationship between climate and water conflict/cooperation in a basin. Arid regions were not found to be substantially less cooperative than other climate zones, excepting humid mesothermal regions. This latter climate zone includes the basins of Western Europe, in which other factors (e.g., overall friendly relations, relatively high GDP) may facilitate cooperation (Fig. 4.9).

Figure 4.9: Primary Climate Type vs. BAR Scale by Basin



In addition to overall climate, we considered precipitation as an explanatory factor. For the 11 basins for which annual precipitation data were available (for the years 1948-1999), we found that the most cooperative years were those in which rainfall was close to average basin precipitation, and that very dry years were marginally more cooperative than wet or very wet years (Fig. 4.10). Although 11 basins do not provide enough data for a broad assessment, Figure 4.10 does illustrate the wide range of variation in precipitation patterns from basin to basin. It may be that it is not the overall climate or average precipitation levels that provide an indicator of conflict, but the occurrence of extremes or the level of uncertainty concerning available water resources in a basin.

Figure 4.10: Annual Precipitation in Select Basins vs. BAR Scale



Although environmental security literature identifies few numerical measures of water as a potential indicator of international conflict, Falkenmark's (1989) Water Stress Index (WSI) offers a measure widely cited in water resources management. This index divides the volume of available water resources for each country by its population. We also considered Ohlsson's (1999) "Social Water Stress Index" (SWSI), basically Falkenmark's WSI weighted by a measure of a country's adaptive capacity (the UNDP's Human Development Index). Both the WSI and SWSI are usually derived and applied at the country-level. We considered these measures at the basin scale. Water availability by basin, both with and without an adjustment for institutional capacity, failed to show significant association with cooperation/conflict over freshwater resources.

Although the Social Water Stress Index incorporates the Human Development Index (HDI), for our purposes it provided only a partial picture of water-related institutional capacity because it is not water specific. The HDI itself is not significantly associated with conflict/cooperation over water. We considered testing percent of population with access to freshwater or sanitation services, incidence of water related disease, water quality/water pollution trends, and/or efficiency of existing water uses and water delivery systems. Currently available, global-scale data for these variables, however, were either unavailable or did not allow for cross-country comparisons.

Resource Dependence for Agricultural and Energy Needs

We also considered other indicators that might provide measures of a country's dependence upon freshwater resources, such as hydropower, potential irrigation, and the proportion of the economy in agriculture. We found that dependence upon water in terms of agricultural or energy needs was not associated with conflict/cooperation over water. Our findings differ from Gleick (1993), who identifies indices of vulnerability which might suggest "regions at risk" for international water conflicts. Gleick's indices are: 1) ratio of water demand to supply; 2) water availability per person (Falkenmark's water stress index); 3) fraction of water supply originating outside a nation's borders; and 4) dependence on hydroelectricity as a fraction of total electrical supply. Gleick's indicators concern the nation as the unit of analysis and focus on the physical components of energy and water needs. He did not quantitatively test these indicators. We also attempted to test water supply originating in other countries and potential irrigation as a measure of water demand, but the scale of available data was too coarse to be useful. Our findings indicate that, at the global scale, no one indicator of water resource availability is likely to provide a useful measure of the potential for conflict over freshwater resources within a basin.

Government Type

In addition to relative power, discussed above, political geography and political science theory consider the role of government type in overall international conflict. In general, these theories do not directly address resource-related issues, but they do deal specifically with indicators of international conflict. Our findings suggest that government regime type is not a useful indicator for international conflict over freshwater resources. The current political science wisdom concerning regime type and international conflict is that democracies are not more peaceful than other regime types, although they tend not to fight other democracies (e.g., Gleditsch 1995). Also, societies in uneven transition between democracy and autocracy are considered more likely to be involved in international conflict, as are highly undemocratic countries (Gleditsch and Ward 2000).

We found that governments under disruption or in transition (i.e., regimes with a mix of autocratic and democratic tendencies) were no more bellicose over water than other regime types and that countries at the democratic end of the spectrum tended to exhibit less cooperation over water than other regime types (Fig. 4.11), with the exception of countries at the democratic extreme. In comparing levels of water conflict between country pairs by their type of government regime, we found little discernible trend, except that the few sets of neighbors with the highest possible heterogeneity (greatest difference in type of government regime) seemed to have the worst relations (Fig. 4.12).[25] These differences between our findings and current political science theory may reflect the fact that the theories are based on research concerned specifically with international war, not a spectrum of conflict. Moreover, these studies rarely incorporate what the conflicts are about (e.g., territory, ideology, control of resources). Since over water, historically countries have exhibited greater cooperation than violent conflict, political science theories that hold true for war in general, might not hold true where water is concerned.

---

[25] Fig. 4.12 shows the difference between government types within a basin and the average BAR scale for each possible mix of governments. The Democracy-Autocracy variable, taken from the Polity IIID Project (McLaughlin, Gates et al. 1998), includes ten degrees of government type, so that there are 20 possible mixes within a basin (i.e., a strong democracy neighboring a strong autocracy would have a difference of 20).

Figure 4.11: Grouped Regime Type vs. BAR Scale, 1948-1999

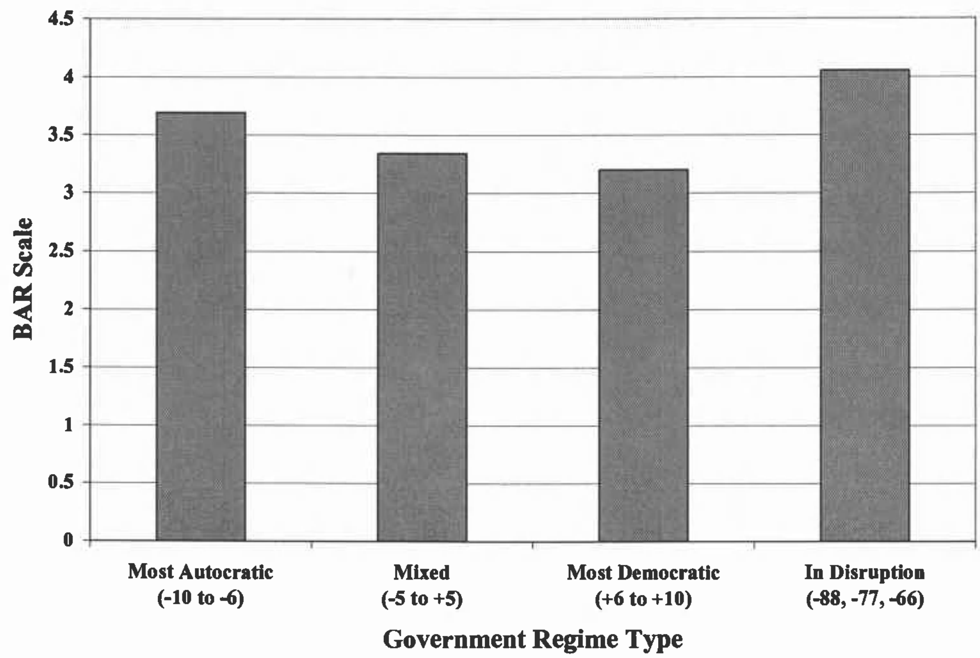
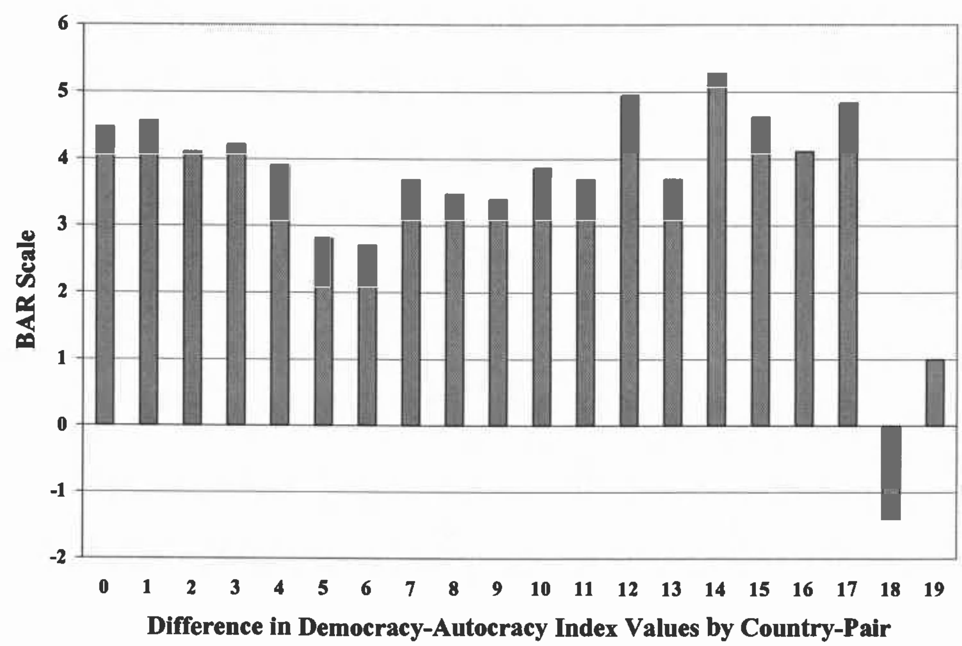


Figure 4.12: Difference in Regime Type by Country-Pair vs. BAR Scale, 1948-1999



Basins At Risk

Based on an assessment of our global-scale analyses, discussed in following sections, we created a framework to identify basins at risk for future conflict over freshwater resources. We systematically pulled out those basins that had a confluence of what we identified as indicators, based on the results of our statistical and empirical analyses and our own qualitative judgment – basins with:

- high population density (>100/sq.km);
- low per capita GDP (< $765/person – 1998 World Bank lowest income country definition);
- overall unfriendly relations (BAR Scale < -1.0);
- politically active minority groups that may lead to internationalization;
- proposed large dams or other water development projects; and,
- no or only limited freshwater treaties.

In addition, we also pulled out basins with ongoing international water conflicts.

Basins experiencing both high population density and average low per capita GDP include the Ca (Laos and Vietnam), Cross (Cameroon and Nigeria), Drin (Albania, Macedonia, and Serbia & Montenegro), Fenney (India, Bangladesh), Ganges-Brahmaputra-Meghna (India, Bangladesh, Bhutan, Nepal, Burma, and China), Han (North and South Korea), Indus (India, Pakistan, China, Afghanistan), Irrawaddy (India, Burma and China), Karnaphuli (Bangladesh, India), Red (China, Laos, Vietnam), Saigon (Cambodia, Vietnam), Song Vam Co Dong (Cambodia, Vietnam), and Yalu (China and North Korea). Of these, only the Ganges, Indus, and Song Vam Co Dong have international freshwater agreements and only the latter includes all the riparians. Appendix 13 contains tables listing basins and countries by the above factors, as well as the historically (1948-1994) most overall conflictive pairs of countries (BAR Scale ≤ -1.0) and the basins they share.

Regarding the potential for internationalization, we have information on current international basins that might experience further internationalization because of the presence of politically active minority groups with assertive nationalist aspirations (see Appendix 11). These basins include the Salween (Shan, Karen and other groups), Tigris-

Euphrates (Kurds), Jordan (Palestinians); Indus (Kashmiri), Ganges (Chittagong Hill peoples), Kura (Nagorno-Karabahk), Ili and Tarim (Uighers in northwest China that want separate East Turkestan State), Chiloango (Cabindans in Angola), Nile (Nuba in Sudan), Awash, Juba-Shibeli and/or Nile (Oromos in Ethiopia), and Ebro and Bidasoa (Basques in Spain).[26]

In term of physical change, basins in which large development projects are planned include, but are not limited to, the Amazon, Asi-Orontes, Ganges, Incomati, Indus, Irrawady, Kunene, La Plata, Mekong, Niger, Nile, Okavango, Orinoco-Caronni, Po, Salween, Senegal, Song Vam Co Dong, Tigris, Volta, and Zambezi.[27]

Of the above basins, only the Amazon, Incomati, Kunene, Niger, Okavango, Orinoco-Caroni, and Song Vam Co Dong have freshwater treaties that involve all the riparian parties. The provisions and strength of these treaties varies greatly, however. For example, the Okavango basin agreements that include all the basin riparians are general, multi-country SADC protocols regarding shared watercourse systems, rather than specific agreements on the quantity, quality or infrastructure issues unique to the Okavango. And although minutes on cooperation in water conservancy were signed between Cambodia and Vietnam on the Song Vam Co Dong, these minutes do not necessarily address development project concerns. Such realizations speak to the need to explore basins individually, in order to determine the propensity for conflict.

When all the various factors described above are pulled together, the following basins are worth further investigation as to the potential for future conflict over freshwater resources.[28] We divide these 'Basins at Risk' into three categories (Fig. 4.13, Table 4.7). The first category, basins negotiating current conflicts, includes the Aral Sea, Jordan, Nile, and Tigris-Euphrates. While each of these basins has a treaty associated with it, none of those treaties include all of the basin riparians. These basins are well known "hot spots", where the potential for continued disputes, at least into the immediate future, is therefore considered likely. The second category is basins in which factors

[26] The conflicts involving the Abkhaz in Georgia, Chechens in Russia, Moros in Philippines, and East Timorese in Indonesia fall outside of existing international basins.

[27] Data on future development projects were obtained from multiple sources, including news reports and websites on tender requests and construction bids. Data compiled by Kyoko Matsumoto.

[28] See also Wolf, Yoffe, Giordano (2001) for an earlier discussion and listing of basins at risk.

point to the potential for future conflict and in which up-coming development projects or other stresses upon the water system have raised protests among the riparians. The third category is similar to the second in that there is a confluence of factors which indicate the potential for future conflict. Unlike category 2 basins, however, there is no evidence of existing tensions in public policy or news fora. When viewing all the categories together, what stands out is that the majority of basins at risk fall in southern Asia and central and southern Africa.

In this section, we have discussed a series of possible indicators, derived from a broad and highly variable set of data, which concern basins that show a high degree of individuality. Categorizing a basin as "at risk" does not presume to identify basins in which acute conflict *will* occur, but to point to basins worth more detailed investigation. In such investigations, particular attention should be paid to the indicators discussed above, as well as more detailed assessment of the:

- existence, strength and provisions of existing international water treaties or other relevant, basin-level institutional mechanisms, as well as the level of development of water institutions within individual riparian countries;[29]
- quality of governance within the basin and conditions, such as high population density and low per capita GDP, that may hamper a government's ability to cope with change; and
- uncertainties associated with the basin's water regime (i.e., climatic variability and institutional adaptability to extreme fluctuations in water availability).

The above frameworks represent an intermediate step between the specific comparisons associated with case studies and the broad quantitative assessments that base

[29] There are as many definitions of institutions as there are theorists to describe them. O'Riordan, Cooper, et al. (1998 348) provide a listing of interrelated concepts at the heart of the meaning of institutions. "Institutions *regulate* behavior via socially approved mechanisms such as the rule of law and the accountable exercise of power. Institutions have a degree of *permanence* and are relatively stable. … Institutions are *patterns of routinized behavior*. Institutions are continually being *renegotiated* … Institutions are *cognitive* and *normative structures* that stabilize perceptions, interpretation, and justifications. Institutions determine what is *appropriate, legitimate*, and *proper*; they define obligations, self restraints, rights and immunities, as well as sanctions for unacceptable behavior. Institutions *structure* the channels through which new ideas are translated into policy and new challenges receive a government response. …"

predictive indicators solely on statistical results. Although some indicators proved statistically significant, individually they explained only a small percent of the variability in the event data. Moreover, no formal multivariate analyses were conducted (as the data sets lie at different spatial scales). The frameworks represent a qualitative assessment of the relative importance of our statistical and empirical findings, given our knowledge transboundary freshwater resources and the constraints of the data sources used.

Figure 4.13: Basins At Risk – Categories 1, 2, and 3

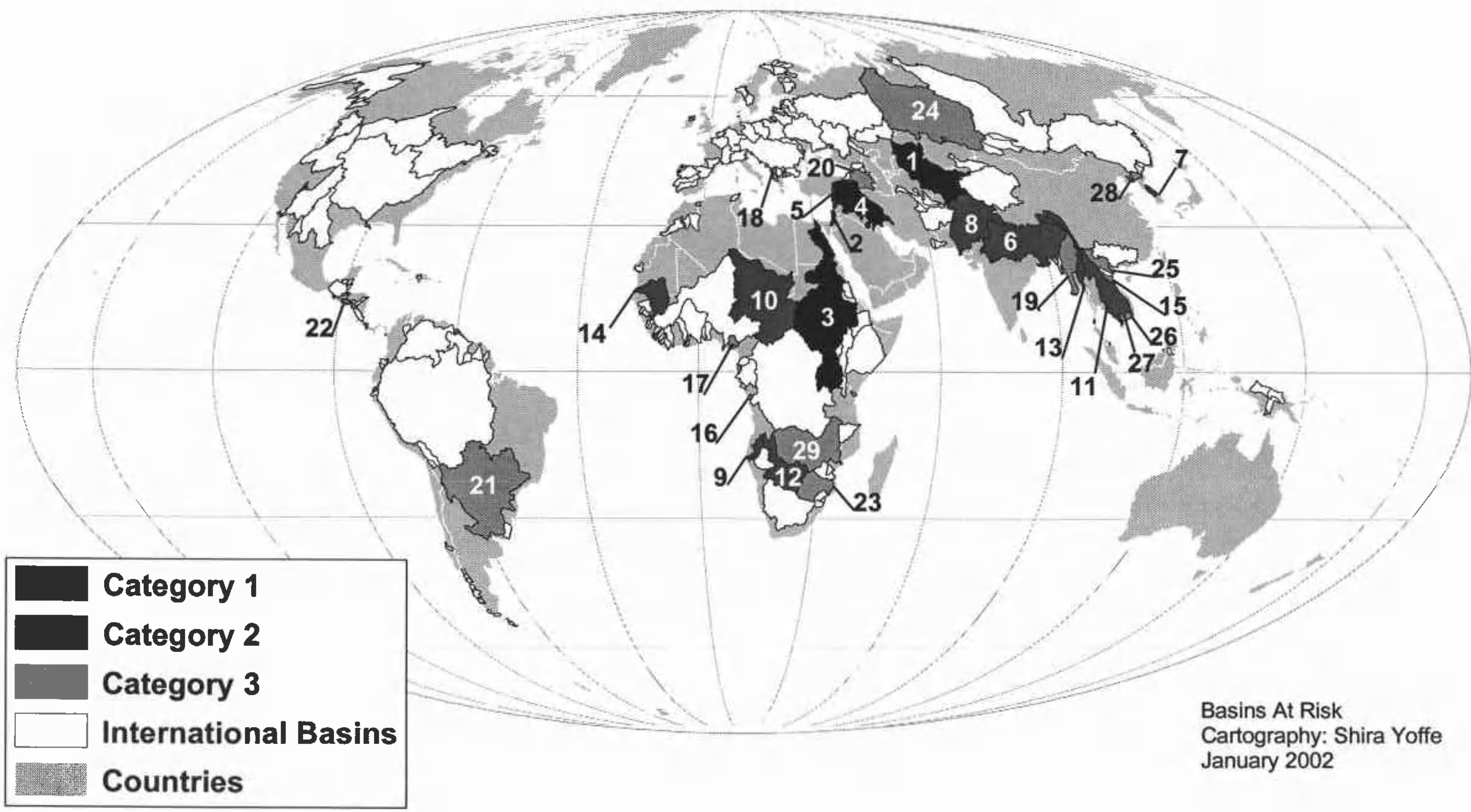


Table 4.7: Basins At Risk – Basin Map Number and Basin Riparians

#	Basin Name	Basin Riparians
CATEGORY 1 – Negotiating Current Conflicts		
1	Aral Sea	Afghanistan, China, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan
2	Jordan	Israel, Jordan, Lebanon, Palestinians, Syria
3	Nile	Burundi, Congo (Kinshasa), Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, Uganda
4	Tigris-Euphrates	Iran, Iraq, Jordan, Saudi Arabia, Syria, Turkey
CATEGORY 2 – Indicators and Protests Over Water		
5	Asi/Orontes	Lebanon, Syria, Turkey
6	Ganges-Brahmaputra-Meghna	Bangladesh, Bhutan, Burma, China, India, Nepal
7	Han	North and South Korea
8	Indus	Afghanistan, China, India, Pakistan
9	Kune	Angola, Namibia
10	Lake Chad	Algeria, Cameroon, Central African Republic, Chad, Libya, Niger, Nigeria, Sudan
11	Mekong	Burma, Cambodia, China, Laos, Thailand, Vietnam
12	Okavango	Angola, Botswana, Namibia, Zimbabwe
13	Salween	China, Burma, Thailand
14	Senegal	Guinea, Mali, Mauritania, Senegal
CATEGORY 3 – Indicators Only		
15	Ca	Laos and Vietnam
16	Chiloango	Angola, Congo (Kinshasa), Congo (Brazzaville)
17	Cross	Cameroon, Nigeria
18	Drin	Albania, Macedonia, Serbia & Montenegro
19	Irrawaddy	Burma, China, India
20	Kura-Araks	Armenia, Azerbaijan, Georgia, Iran, Turkey
21	La Plata	Argentina, Bolivia, Brazil, Paraguay, Uruguay
22	Lempa	El Salvador, Guatemala, Honduras
23	Limpopo	Botswana, Mozambique, South Africa, Zimbabwe
24	Ob	China, Kazakhstan, Russia
25	Red	China, Laos, Vietnam
26	Saigon	Cambodia, Vietnam
27	Song Vam Co Dong	Cambodia, Vietnam
28	Yalu	China, North Korea
29	Zambezi	Angola, Botswana, Congo (Kinshasa), Malawi, Mozambique, Namibia, Tanzania, Zambia, Zimbabwe

CONCLUSION

Historically, international cooperation over freshwater resources as a resource far outweighs international conflict. There have been no formal declarations of war over water. Where acute conflict over water has occurred, it concerned quantity and infrastructure, two issues closely related. These instances of acute conflict involve bilateral interactions, while cooperation is much more likely to be multilateral in nature. Multilateral interactions are also more likely to involve joint management, water quality, and economic development issues, rather than water quantity and infrastructure, which are more often bilateral concerns. Such differences highlight issues that may be appropriate for development of multilateral (as opposed to bilateral) institutional mechanisms to facilitate negotiation and management of freshwater resources. Regionally, and for many at the bilateral level as well, countries exhibit greater cooperation over water than overall, indicating that countries in conflict over other concerns may still find common interest in cooperation with regard to their shared water resources.

Most of the commonly cited indicators linking freshwater to conflict proved unsupported by the data. Neither spatial proximity, government type, climate, basin water stress, dams or development, nor dependence on freshwater resources in terms of agricultural or energy needs showed a significant association with conflict over freshwater resources. In fact, no one indicator proved a relevant, in and of itself. Even those factors that showed a statistically significant association with conflict or cooperation over freshwater resources explained only a small percent of the variability in the data.

The relevant indicators appear to be rapid or extreme changes in physical or institutional settings within a basin -- internationalization, large dams -- and the presence of institutional mechanisms that mitigate uncertainty, international freshwater treaties in particular. Broadly defined, institutions and institutional infrastructure matter, perhaps because institutions provide a mechanism for mitigating or managing the uncertainty that theorists associate with a propensity towards international conflict. Institutions are also important because they reflect a country's ability to understand and cope with stresses upon water resource systems.

Although no one indicator was sufficient to identify a basin at potential risk, in and of itself, we took those indicators that showed some association and qualitatively created a framework to identify basins at potential risk for future conflict. The majority of these basins fall in southern Asia and central and southern Africa. Identifying a basin at risk does not presume that conflict will occur in that basin, but to point to regions worth more detailed investigation in terms of water resource institutions, water resource needs and the ability of riparians to work together and to cope with changes or stresses upon a basin's water institutions and hydrological systems.

In the future, there will be international conflicts over water, and it may be that such conflicts will increase given increasing populations or other possible stresses upon the resource. The question is how and at what level of intensity such conflicts will be dealt with by the parties concerned.

Our framework to identify and evaluate basins at risk was based on historical indicators. There are a number of possible future trends, however, that may also influence the potential for international conflict or cooperation over water. There may be technological, economic, or management innovations in the obtaining, delivery, use, and overall management of water resources (e.g., cheap desalinization, transglobal water shipments, water sector privatization trends, Star Trek-like water replicators, etc.). There may also be new challenges to water management, such as changes in water-borne disease vectors, environmental and health impacts associated with wastewater reuse, and increased urbanization of populations. Intra-national water issues and their relationship to violent conflict, not explored in this study, may influence international water concerns. Climatic changes associated with global warming, especially if the presence of uncertainty contributes to conflict, may lead to higher incidences of conflict over international freshwater resources, assuming that there are no basin-level, institutional mechanisms in place to mitigate such conflict.

This study is a first step in what is hoped to be continued exploration of conflict and cooperation over freshwater resources, using the database we have created. Other issues that may play a role and which are worth further analysis include:

- intra-national water conflict and its possible relationship to water conflict at the international level;
- other indicators of intra-national government instability (e.g., civil unrest; number of regime changes from 1948-1999);
- spatial associations and the development of cooperative relationships (e.g., the role of border rivers in enhancing cooperation or conflict);
- multilateral vs. bilateral interactions (e.g., an exploration of why countries might find more difficulty in reaching multilateral agreements on water quantity, while treaties on economic development, joint management and water quality are more common);
- the influence of non-riparian countries or entities (e.g., World Bank) on water conflict and cooperation within a basin;
- whether basins with greater annual or inter-annual variability in precipitation show higher propensity for conflict than basins with more predictable climatic patterns.

This latter question also plays into analyses regarding institutions and infrastructure, since both provide mechanisms for managing variability in water supply and demand. Overall, it may not be the trends, such as population growth or average climate, but the discontinuities, such as extreme climatic events or sudden institutional change, which provide relevant indicators of international water conflict or cooperation.[30]

[30] The Basins At Risk project offers a wealth of data and resources for further research and comparative analyses. We hope that others will make use of the data we have gathered. The statistical analyses and numerical data developed through the BAR project are available through the Transboundary Freshwater Dispute Database website at: http://www.transboundarywaters.orst.edu.

APPENDIX –HYPOTHESES AND STATISTICAL RESULTS

Some definitions

- Average BAR Scale (ABS) refers to an average of the average for each year
- Average Annual BAR Scale (AABS) refers to an average for each year
- The term dyad refers to a pair of countries.
- Riparian country refers to a country associated with an international basin.
- Basin-country polygon refers to a spatial unit – a country's territorial share of a particular international basin.

GDP and Population

Hypothesis 1: Lower GDP (gross domestic product) was associated with higher levels of conflict over water.

Measure: GDP vs. ABS by country.

Test: Linear regression. n = 115, R-square = 0.01, Coeff. = 0.00, p-value = 0.43

Outcome: Not significant.

Data Sources and Caveats: WRI (1998).

Hypothesis 2: Higher GDP per capita was associated with greater cooperation.

Measure: 1995 GDP per capita data vs. ABS by country.

Test: Linear regression, n = 114, R-square = 0.05, Coeff. = 5.11, p-value = 0.01

Outcome: Higher GPD/capita was associated with greater cooperation over water.

Data Source and Caveats: WRI (1998).

Hypothesis 3A, 3B, 3C: Greater population density was associated with higher levels of conflict.

Measure: Population density (current data; ln of number of people/km^2) vs. ABS, at country, basin, and basin-country polygon scales

Test: Linear regression. By country: n = 123, R-square = 0.03, Coeff. = -.02, p-value = 0.04; by basin: n = 121, R-square = 0.04, Coeff. = -0.30, p-value = 0.04; by basin-country polygon: n = 344, R-square = 0.02, Coeff. = -0.19, p-value = 0.00

Outcome: Greater population density was associated with higher levels of conflict over freshwater resources at all scales.

Data Sources and Caveats: BAR. See Chapter 3 for a description of derivation of population data, as well as population density maps by basin. Population data was in persons/km^2 from Landscan 30 by 30 second resolution data (Dobson, Bright et al. 2000).

Relative Power (Ratios of GDP and population)

Hypothesis 4: Dyads with larger differences (measured as a ratio) in their respective per capita GDP's showed a greater association with conflict.

Measure: Ratio of GDP per capita (1995 data, ln) vs. ABS, by dyad

Test: Linear regression, n = 304, R-square = 0.02, Coeff. = -1.78, p-value = .03

Outcome: Dyads with greater differences in per capita GDP were associated with conflict.

Data Source and Caveats: WRI (1998).

Hypothesis 5: Pairs of basin-country polygons with larger differences in their respective population densities were associated with greater conflict.

Measure: Ratio of population densities (current data; ln of number of people/km^2) vs. ABS by dyad

Test: Linear regression, n = 490, R-square = 0.02, Coeff. = 6.70, p-value = 0.00

Outcome: High differences in population density between basin-country polygon pairs within a basin (based on the ratio of their population densities) were associated with greater levels of cooperation between those two countries.

Data Source and Caveats: BAR. See hypothesis 3.

Overall Relations

Hypothesis 6: A country's overall Friendship/Hostility was associated with its conflict/cooperation over water.
Measure: Friendship/Hostility vs. ABS by country
Test: Linear regression, n = 130, R-square = 0.12, Coeff. = 1.74, p-value = .00
Outcome: Friendship/Hostility showed a significant association with ABS.
Data Sources and Caveats: We created the Friendship/Hostility (F/H) variable using a combined COPDAB and GEDS database containing more than 330,000 event records, spanning the years 1948 to 1994. For each country in the COPDAB/GEDS database, we calculated the average friendship or hostility values associated with that country, by the same method used to calculate average BAR Scale (Yoffe and Giordano 2001). To avoid double-counting when comparing F/H with friendship/hostility over water, we removed all events from the F/H variable that were also included in the calculation of the BAR Scale.

Hypothesis 7: Countries with more rapidly growing populations exhibited greater conflict over water than countries with more stable or declining populations.
Measure: National population growth rate (1950-1999) vs. ABS, by country
Test: Linear regression, n = 126, R-square = 0.02, Coeff. = -11.77, p-value = 0.08
Outcome: No correlation between national population growth rates and ABS.
Data Sources and Caveats: WRI (1998).

Hypothesis 8: Countries with more rapidly growing populations exhibited more overall conflict than countries with more stable or declining populations.
Measure: National population growth rate (1950-1999) vs. average Friendship/Hostility Index, by country
Test: Linear regression, n= 169, R-square = 0.07, Coeff. = -3.24, p-value = 0.00

Outcome: Countries with more rapidly growing populations were significantly associated with higher levels of overall conflict.

Data Sources and Caveats: WRI (1998).

Number of Dams and Dam Density

Hypothesis 9A, 9B: Greater numbers of dams were associated with higher levels of conflict.

Measure: Number of dams (current data) vs. ABS, by basin and basin-country polygon.

Test: Linear regression. By basin - n = 82, R-square = 0.00, Coeff. = -1.57, p-value = 0.58; By basin-country polygon - n = 155, R-square = 0.02, Coeff. = 0.00, p-value = 0.12.

Outcome: Number of dams showed no correlation with ABS at either the basin or basin-country polygon level.

Data Sources and Caveats: We derived number of dams and dam density from Digital Chart of the World (DCW) data. The DCW is an extensive group of coverages developed under contract by Environmental Systems Research Institute (ESRI) and available through the US Defense Mapping Agency, and is considered to have a minimum resolution of 500 meters (Kemp 1993 369). Included in the DCW is a geo-referenced coverage of all the world's dams. The dam data does not account for the impact of the dam. Neither dam height, reservoir capacity, nor effect on downstream water uses are incorporated into the above analysis.

Hypothesis 10A, 10B: Greater dam density (number of dams/1000 km^2) was associated with higher levels of conflict.

Measure: Dam density (current data) vs. ABS, by basin and basin-country polygon

Test: Linear regression. By basin - n = 82, R-square = 0.02, Coeff. = -3.93, p-value = 0.16; by basin-country polygon - n = 152, R-square = 0.01, Coeff. = -0.00, p-value = 0.16

Outcome: Dam density showed no correlation with ABS at either scale.

Data Sources and Caveats: See hypothesis 9.

Freshwater Treaties

Hypothesis 11: In the three years preceding the signing of a treaty, conflict levels were higher than in other years and in the three years following treaty signature, conflict levels were lower than other years.

Measure:

Test: No statistical test conducted.

Outcome: In the three year period following freshwater treaty signature, average levels of cooperation were higher (3.0 on the BAR Scale) than in "normal" years (2.2). In the three year period preceding treaty signature, the average level of conflict/cooperation was no different (2.3) than in all other "normal" years.

Data Sources and Caveats: BAR. "Normal years" refer to all years except three years before, three years after, and the year in which a treaty was signed for those dyads that share freshwater treaties. The comparison of ABS by dyad before and after the signing of a treaty excludes the scale value for the first treaty event in the calculation of ABS. Only dyads which share an international basin were considered.

Hypothesis 12: Dyads that sign freshwater treaties were inherently more cooperative over water before the signing of their first treaty than dyads without freshwater treaties

Measure: ABS of non-treaty dyads vs. ABS of dyads with treaty for the years before the first treaty was signed

Test: Two-sample t-test, n = 388, ABS non-treaty dyads = 2.6 out of n = 291, ABS dyads with treaties for years before first treaty was signed = 2.5 our of n= 97, p-value = 0.34

Outcome: No significant difference in ABS between treaty dyads for the years before a first treaty was signed and the ABS of non-treaty dyads.

Data Sources and Caveats: BAR. A dyad was considered without a treaty up to the year the first treaty was signed between that dyad, if such an event occurred. A dyad was considered a 'treaty dyad' from the year in which the first treaty was signed. Dyads with treaties signed before 1948 were classified as treaty dyads from 1948 on, the start of our study period. Only dyads that share an international basin were included.

Hypothesis 13: The signing of a first freshwater treaty contributed to increased future cooperation over water in a basin.

Measure: A comparison of the difference in ABS by basin before a treaty was signed and after a treaty was signed, with all treaty values excluded, vs. the same comparison with only the first treaty value excluded.

Test: No test for difference in means conducted. See Table 4.8.

Outcome: With all treaty values excluded, the difference in ABS was 11%. With the value of the first treaty excluded, the difference in ABS in basins before a treaty was signed as compared with the ABS for the years after a first treaty was signed was 51%.

Data Sources and Caveats: BAR. A basin was considered without a treaty up to the year the first treaty was signed in that basin, if such an event occurred. A basin was considered a 'treaty basin' from the year in which the first treaty was signed. Basins with treaties signed before 1948 were classified as treaty basins from 1948 on, the start of our study period. We calculated ABS for treaty basins in two ways: 1) with the scale value of the first treaty excluded from the average; and, 2) with the values for all treaty events excluded.

Table 4.8: Basin ABS Before and After Signing of 1st Freshwater Treaty – Treaties Are Followed by More Treaties

Basin Setting	*BAR Scale*	*% Difference*
Basins Prior to Treaties	**2.6**	
Basins After Treaties (treaty values excluded)	**2.7**	**11%**
Basins Prior to Treaties	**2.6**	
Basins After Treaties (value of first treaty excluded)	**4.0**	**51%**

Dams and Freshwater Treaties

Hypothesis 14: The presence of freshwater treaties mitigated the conflict that would otherwise have been associated with high dam density in a basin.

Measure: A series of comparisons of high dam density basins and low dam density basins with and without treaties.

Test: No test for difference in means conducted. See Table 4.6.

Outcome: Overall, high dam density basins are slightly more conflictive than low dam density basins (~12% difference), except when comparing basins with treaties, in which the relationship is reversed and the higher density basins show slightly greater cooperation (again ~12% difference). A substantive difference occurs, however, when comparing high dam density basins with treaties to high dam density basins without treaties (~41%), with those basins without treaties showing much higher levels of conflict.

Data Sources and Caveats: See hypothesis 9 for source and caveats regarding dam density data. High and low dam density basins were divided into two groups by splitting basins at the median dam density value. See hypothesis 13 for definitions of treaty and non-treaty basins. A caveat concerning this analysis was that the dam data is not temporally linked to the event data, so there was no distinction made between when a dam was constructed and the signing of a treaty.

Adjacency

Hypothesis 15: Adjacent dyads within a basin were more likely to have instances of conflict than dyads that shared a basin, but not a boundary (e.g., in the Nile basin, Egypt and Sudan vs. Egypt and Ethiopia).

Measure: Average BAR Scale (ABS) among dyads within a basin that are adjacent against ABS among non-adjacent dyads within a basin

Test: 2-sample t-test, n = 3,332, mean of adjacent = 37.06 out of 2114 n, mean of non-adjacent = 24.62 out of 1218 n, p-value = 0.00

Outcome: Adjacent basin-dyads were significantly associated with a higher level of cooperation than non-adjacent basin-dyads.

Data Source and Caveats: BAR

Hypothesis 16: Countries that shared a river boundary with another country were more prone to conflict over international freshwater resources than basin countries that did not have a river as part of their border.

Measure: ABS of riparian countries with a river as a border against ABS of riparian countries without a river border

Test: 2-sample t-test assuming unequal variance, n = 390, 2-sided p-value = 0.31

Outcome: No significant association. Countries with rivers as borders were slightly more cooperative than countries without river borders (ABS 4.03 and 3.86, respectively).

Data Source and Caveats: BAR. For each riparian country, we coded whether a river formed a portion of its border as a yes/no variable, based on data from our GIS. This variable did not measure the average BAR Scale value between dyads that share a river as a border as compared to dyads that do not share a river as a border. We did not weight the contiguity variable to incorporate the length of the river border or the importance of the river, as the former does not necessarily provide a good measure of the latter and as the latter is a highly subjective measurement for which global data was not available.

Geographic Size

Hypothesis 17: Larger basins, in terms of area, were associated with greater conflict over freshwater resources.

Measure: Basin area in km^2 vs. ABS by basin

Test: Linear regression, n = 122, R-square = 0.03, Coeff. = 3.47, p-value = 0.04

Outcome: Larger basins were significantly more cooperative than smaller basins.

Data Source and Caveats: BAR. Although this finding appears relevant to other analyses in which the coarse scale of the data excludes basins < 25,000 km^2 in area, it explains such a small percentage of the variability in the data that we consider its impact on relevant analyses negligible.

Hypothesis 18: Basins with a greater number of riparian countries were associated with higher levels of conflict.

Measure: Number of countries sharing a basin vs. ABS of that basin

Test: Linear regression, n = 122, R-square = 0.01, Coeff. = 1.39, p-value = 0.38

Outcome: The number of countries sharing a basin showed no significant association with ABS by basin.

Data Source and Caveats: BAR

Riparian Position

Hypothesis 19A, 19B: *19A.* The riparian position of a country (i.e., upstream, downstream, mid-basin) was associated with its conflict/cooperation over water.
19B. A country's vote on the 1997 UN Convention on the Non-Navigational Uses of International Watercourses was associated with its riparian position.

Measure:

Test:

Outcome: We were unable to adequately test these hypotheses.

Data Source and Caveats: BAR. Riparian position of countries in each basin was derived by examining by hand stream network coverages overlaid on basin and country polygon coverages. Precise definition of riparian position proved difficult, as countries often represented multiple positions within a single basin or across a series of basins. Moreover, by definition, countries with a particular position will interact with countries with a different position (i.e. upstream countries interact with downstream countries), and therefore it makes little sense to wonder if upstream countries are more conflictive than downstream countries, since they are interacting with each other. For future research, the last concern might be addressed by including a variable delineating whether a country was the initiator or recipient of a particular conflictive or cooperative action. Although other studies have considered riverine contiguity or upstream-downstream as a factor in the likelihood of military conflict (Toset and Gleditsch 2000), it does not appear that these studies considered the river network in its entirety.

Climate and Precipitation

Hypothesis 20: Basins with largely arid climates were more prone to conflict over water than basins of other climate types.

Measure: Percent primary climate zone of a basin (based on largest percent area) vs. ABS

Test: Bar graph. Figure 4.9. No statistical test for difference in means conducted.

Outcome: Arid regions were not found to be substantialy more conflictive than other climate zones, excepting humid mesothermal regions.

Data Source and Caveats: Climate zones were derived from a United Nations Food and Agricultural Organization map of world climate zones (FAO-SDRN Agrometeorology Group 1997), which was collapsed into five primary climate types: Tropical Rainy, Dry, Humid Mesothermal, Humid Microthermal, and Polar. Only one basin was defined as Polar, so it was not considered in this comparison. The FAO map, while digital, required a series of transformations in order to convert it to a format suitable for analysis purposes. Appendix 9 describes the derivation of the climate zone by basin data. The scale of the climate data limits calculations to basins with area > 25,000 km^2.

Hypothesis 21: Basins with lower annual levels of precipitation were associated with higher levels of conflict over water.

Measure: Precipitation data by basin for each year from 1948-1999 were compared with the AABS for that basin and year. Years in which rainfall were normal were defined as within one standard deviation of mean basin precipitation. Dry and very dry years were defined as precipitation between 1 and 2 standard deviations below mean and more than 2 standard deviations below mean, respectively. Wet and very wet years were defined as precipitation between 1 and 2 standard deviations above mean and greater than 2 standard deviations above mean, respectively.

Test: Bar graph. Figure 4.10. No statistical test conducted.

Outcome: Data were available for only 11 basins, making broad assessments difficult. Preliminary findings indicate that very dry years were marginally more cooperative than wet or very wet years and that the most cooperative years were those in which rainfall was close to average basin precipitation.

Data Source and Caveats: Precipitation data were derived from the Global Historical Climatology Network (GHCN) data set produced by the National Climatic Data Center (NCDC) in cooperation with the World Meteorological Organization (Vose, Schmoyer et al. 1992). The data were downloaded from NCDC's web site at www.ncdc.noaa.gov. Appendix 8 details how BAR derived the basin level precipitation data.

Water Availability (water stress, social water stress)

Hypothesis 22A, 22B: More severe water stress (lower water available/per capita) was associated with higher levels of conflict.

Measure: Freshwater available per capita vs. ABS at country and basin scales

Test: Linear regression. By country, n = 113, R-square = 0.04, Coeff. = 4.19, p-value = 0.03; By basin, n = 86, R-square = 0.01, Coeff. = 6.56, p-value = 0.51

Outcome: By country, lower freshwater available per capita was significantly associated with higher levels of conflict. By basin, the trend ran in the same direction as by country, but the association was not significant.

Data Source and Caveats: Freshwater availability per capita by country was obtained from the World Resources Institute (WRI 1998). This data source was used, rather than that derived by BAR, because in enabled inclusion of countries smaller than 25,000 km^2, necessary to insure a large enough sample size for statistical analysis. At the basin scale, freshwater availability per capita ("water stress") was calculated by combining BAR-derived discharge data with BAR-derived population data (see Chapter 3). Population data was in persons per km^2 from Landscan 30 by 30 second resolution data (Dobson, Bright et al. 2000). Discharge data was in km^3 of water per year, derived from runoff data produced by the Complex Systems Research Center at the University of New Hampshire (UNH) and the Global Runoff Data Center (GRDC) in Koblenz, Germany (Fekete, Vorosmarty et al. 2000).

Caution should be used in interpreting results from the water stress data. WRI water availability data are measured as total renewable surface and groundwater and typically include flows from other countries that may be committed to downstream users. The data also mask large seasonal, inter-annual and long-term variations. It is not as accurate as the discharge data derived by BAR. At the basin-scale, the discharge data does not account for natural (e.g., evapo-transpiration) or anthropocentric (e.g., irrigation) extractions of water from the river system and may therefore overestimate water available downstream. This caveat is especially relevant for exotic, or allogenic, basins, in which the lower portion of the river system derives its water solely from upstream sources (e.g., Colorado, Nile). Our calculated discharge numbers did compare closely with discharge data from alternate sources, with larger and wetter basins matching most closely. The scale of the discharge data limits calculations to areas greater than 25,000 sq. km., constraining analysis to 86 of the 123 basins for which we had event data.

Hypothesis 23A, 23B: More severe social water stress (lower capacity-adjusted water available/per capita) was associated with higher levels of conflict.

Measure: Capacity Adjusted Water per Capita vs. ABS, by country and basin

Test: Linear regression. By country, n = 109, R-square = 0.05, Coeff. = 4.43, p-value = 0.02; by basin, n = 85, R-square = 0.04, Coeff. = 5.66, p-value = 0.06

Outcome: Countries with lower capacity adjusted water per capita were significantly associated with higher levels of conflict. By basin, the trend ran in the same direction as by country, but the association was not significant.

Data Source and Caveats: See hypothesis 22 for the sources of data on freshwater availability at the country and basin scale. Our Capacity Adjusted Water Per Capita variable is based on methodology used by Ohlsson (1999) in the construction of his Social Water Stress Index. Ohlsson's index begins with the awkward accounting unit of 100 people/km^3 of water/year (basically the Water Stress Index), which he then divides by the Human Development Index (HDI). The results of this quotient are then divided by an arbitrary value of 2 in order "to make the two indices (Water Stress Index and Social Water Stress Index) directly comparable" (Ohlsson 1999 248). Our variable starts with the more intuitive accounting unit of m^3 of water/per capita/year (basically the inverse of Ohlsson's unit). We then multiply, rather than divide, this value by a normalized HDI. The HDI is normalized such that the median country value equals 1 in a base year of

1997, in order to ease interpretation. Thus countries with higher than average HDI's have their per capita water availability number adjusted upwards and those with lower than average HDI's have their number adjusted downwards. If a country has an HDI higher than the original value of the median HDI, its "water per capita" increases. If a country's HDI value is lower than the median, that country's "water per capita" decreases and it is considered to suffer from more severe water stress.

Because the UNDP Human Development Index (HDI) is classified by country, we averaged the HDI of each basin's riparian countries to calculate capacity-adjusted water availability per basin. This averaging masks within-basin variation in government institutional capacity and should therefore be considered with caution. Analysis was limited to those countries that have HDI values.

Hypothesis 24A, 24B: Countries with a higher Human Development Index (i.e., higher level of institutional capacity) showed a stronger association with cooperation.

Measure: Most recent available HDI (by country) vs. ABS, by country and basin

Test: Linear regression. By country, n = 120, R-square = 0.01, p-value = 0.29; by basin, n = 121, R-square = 0.01, p-value = 0.37

Outcome: Not significant at either the country or basin scale.

Data Source and Caveats: United Nations Development Programme (UNDP) HDI data was obtained from the World Resources Institute (1998). The HDI is comprised of life expectancy, literacy and educational enrollment, and GDP per capita (in purchasing power parity dollars), per country. Although often used as a measure of the institutional capacity of a country, for our purposes, HDI provided only a partial picture of institutional capacity. It does not, for example, include measures of percent of population with access to freshwater or sanitation services, incidence of water related disease, water quality/water pollution trends, and/or efficiency of existing water uses and water delivery systems. A number of BAR countries drop out of this analysis because they lack HDI values, which may impact more conflictive events. To obtain an HDI value at the basin-scale, we averaged the HDI of each basin's riparian countries. This averaging masks within-basin variation in government institutional capacity and should therefore be considered with caution.

Resource Dependence (potential irrigation, economy in agriculture, hydropower)

Hypothesis 25: Countries with greater potential irrigable area were associated with greater conflict over water.

Measure:

Test:

Outcome: We were unable to derive appropriate scale data to test this hypothesis.

Data Source and Caveats: We used a GIS to calculate an estimate of the arable and irrigable land within each international river basin, based on climate, land cover, slope, elevation, soil degradation, soil type, and existing irrigated area data layers. This estimate was compared with an existing global GIS coverage of currently irrigated area, to calculate the amount of potential future irrigated land per international river basin. While the methodology was sound, the analysis was limited to the scale of the coarsest dataset used, one degree resolution (equivalent to approximately 110,000 meters in the Lambert equal area world projection), and the resulting variable proved too coarse to provide a meaningful numerical estimate. It will be worth exploring, however, as finer scale datasets become available. For a detailed description, see Wiess (2001).

Hypothesis 26: Countries with agriculture as a larger percent of their GDP were associated with greater levels of conflict over water.

Measure: % GDP vs. ABS, by country

Test: Linear regression, n = 63, R-square = 0.01, Coeff. = -0.22, p-value = 0.35

Outcome: Not significant.

Data Source and Caveats: WRI (1998).

Hypothesis 27: Countries with a larger percent of their labor force in agriculture were associated with greater conflict.

Measure: % labor force in agriculture vs. ABS, by country

Test: Linear regression, n = 126, R-square = 0.00, Coeff. = -0.08, p-value = 0.47

Outcome: Not significant.

Data Source and Caveats: WRI (1998).

Hypothesis 28: Countries more heavily dependent upon hydropower were associated with greater conflict over water.

Measure: Hydropower as a percent of total electricity production for 1995 (or most recent year available for that country) vs. ABS, by country

Test: Linear regression. n = 98, R-square = 0.04, Coeff. = -0.06, p-value 0.06

Outcome: Not significant.

Data Sources and Caveats: WRI (1998).

Hypothesis 29: Countries whose surface or ground water supply depends upon sources originating outside their borders were more prone to conflict over water than countries lacking such dependence.

Measure:

Test:

Outcome: Unable to test this hypothesis.

Data Sources and Caveats: The scale of available, spatially explicit global level data for discharge (Fekete, Vorosmarty et al. 2000) is too coarse to calculate meaningful values for the size of the areas of interest.

Government Type

Hypothesis 30: Autocracies showed greater tendency toward conflict over water than other government regime types.

Measure: Democracy-Autocracy Index values vs. AABS, by country and year

Test: No statistical test for difference in means conducted.

Outcome: Autocracies did not exhibit greater tendency toward conflict. Countries at the democratic end of the spectrum tended to exhibit slightly greater conflict over water than other regime types, with the exception of countries at the democratic extreme (a value of +10 on the DEM-AUT Index, see hyp. 31).

Data Source and Caveats: The Democracy-Autocracy variable is taken from the Polity IIID Project (McLaughlin, Gates et al. 1998), which codes structural characteristics of regimes, including the direction of change in terms of democracy or autocracy, for approximately 152 countries from 1800 to 1994. Coding is done for states when they are independent only. The DEM-AUT value is the Democracy Index minus the Autocracy Index, with each index consisting of an additive 10-point scale. In the DEM-AUT Index, therefore, a negative value indicates autocratic tendencies and a positive value indicates democratic tendencies. The further a value from 0, the stronger the tendency. Countries with values close to 0 indicate a mix of autocratic and democratic tendencies. In addition, PolityIIID also accounts for values outside the scale, such as a period of interruption (DEM-AUT value of "66"; e.g., occupation of a country by foreign powers during wartime, where the previous polity is re-established after the occupation ends); a period of interregnum in which central political authority has collapsed completely (DEM-AUT of "77"; e.g., during a period of civil war); and, periods of transition (DEM-AUT of "88").

Hypothesis 31: Governments under disruption or in transition showed greater tendency toward conflict over water than more stable government regimes.
Measure: Democracy-Autocracy Index values in three groups – Autocracies, Democracies, and Mixed vs. AABS, by country and year
Test: Bar graph. Figure 4.11. No statistical test for difference in means conducted.
Outcome: Governments under disruption (DEM-AUT score of 66, 77, 88) or in transition (i.e., regimes with a mix of autocratic and democratic tendencies) did not exhibit greater tendencies towards water-related conflict than other regime types. Countries at the democratic end of the spectrum tended to exhibit greater conflict over water than other regime types.
Data Source and Caveats: The Democracy-Autocracy variable is taken from the Polity IIID Project (McLaughlin, Gates et al. 1998). See Hypothesis 30. Also included in the mixed column were countries with DEM-AUT values of 66, 77, and 88.

Hypothesis 32: Certain pairings of government types were more prone to conflict over freshwater resources than others.

Measure: Difference in DEM-AUT values between dyads vs. ABS by dyad, plotted for each possible mix of government types

Test: Bar graph. Figure 4.12. No statistical test conducted.

Outcome: The graph indicated little discernible trend, except that neighbors with the highest possible heterogeneity (greatest difference in type of government regime) seemed to have the worst relations.

Data Source and Caveats: See hypothesis 30. Only basin dyads were considered. The Democracy-Autocracy variable (McLaughlin, Gates et al. 1998), includes ten degrees of government type, so that there are 20 possible mixes within a basin (i.e., a strong democracy neighboring a strong autocracy would have a difference of 20).

ACKNOWLEDGEMENTS

Spanning three years, the Basins At Risk project involved the efforts of more than 10 faculty and student researchers at Oregon State University. The authors would like to acknowledge the insights, assistance and support of Dr. Julia Jones, Dr. Jon Kimerling, Dr. Phil Jackson, Dr. Chuck Rosenfeld, Dr. Dawn Wright, Case Bowman, Kuuipo Burleigh, Becci Dale, Meredith Giordano, Greg Fiske, Jeanne Hoadley, Kelli Larson, Kyoko Matsumoto, Marc Rothgery, Brian Ward, and Daniel Wise. In addition, the authors would like to extend their thanks to George Taylor, Oregon State Climatologist, and his assistants Nathaniel De Young and Melanie Mitchell; Mark Levy, CIESIN; Jake Brunner and Kirsten Thompson,WRI; Petra Doell, University of Kassel, Germany; Glenda Pearson, University of Washington Library; David B. Kynoch, President, Pacific Northwest GIS Consulting, Inc.; Dr. Michael D. Ward, Department of Political Science, University of Washington (Seattle); Balazs Fekete, Complex Systems Research Center, University of New Hampshire; Dr. Jerome E. Dobson, Oak Ridge National Laboratory; Joe Toth and Carrie Ottow, OSU Valley Library; Brian Smith; Jeff Danielson and Kent Lethcoe, EROS Data Center; Global Event Data System, University of Maryland; *National Geographic*; and, the National Science Foundation Graduate Research Traineeship (GRT) Fellowship in Landscape Studies.

CHAPTER 5 CONCLUSION

In the policy literature and the popular press, the issues of water and conflict are being raised together with increasing frequency. Geographic, international relations, and environmental security theories speculate on the linkages between geographic features, natural resources, spatial relationships, and war or acute conflict. This literature often stresses various indicators for conflict, including aridity and rapid population growth. Little quantitative or global-scale research exists, however to test these theories regarding the relationship of water to international conflict. Moreover current literature often lacks consideration of water cooperation or spatial variability.

My dissertation research addressed a series of overarching gaps in research on freshwater resources and international conflict by providing a quantitative, global scale exploration of the relationship between freshwater resources and conflict. In essence, we asked whether the existing theories and claims regarding water's relationship to conflict held true. We also incorporated a spatial perspective and considered the full spectrum of interactions, using precise definitions of conflict and cooperation. The specific purpose of my dissertation research was threefold:

- To identify historical indicators of international freshwater conflict and cooperation;
- To use these indicators to create a framework to identify and evaluate international river basins at potential risk for future freshwater conflict;
- To enhance understanding of the driving forces that may cause water to become a focus of conflict or cooperation.

To accomplish these goals required three main elements: creation of an event database documenting historical water relations, including a methodology for identifying and classifying events by their intensity of cooperation and conflict; construction of a geographic information system (GIS) of countries and international basins, both current and historical; and the collection or creation of indicator variables (biophysical, socioeconomic, and geopolitical) for testing of hypotheses about factors associated with water conflict. Each of these elements is described in detail in the preceding chapters.

International relations over shared freshwater resources were overwhelmingly cooperative. Although conflicts over water occurred, violent conflict was rare and far outweighed by the number of international water agreements. International cooperation over water resources covered a wide range of concerns, including quantity, quality, hydropower, and infrastructure development. Conflict, especially acute conflict, centered on issues of quantity and infrastructure (e.g., dams, reservoirs).

Many of the factors traditionally considered to be relevant indicators of international conflict, and of water conflict in particular, showed no statistically significant association with international water conflict or cooperation. Neither spatial proximity, climate, basin water stress, government type, relative power, dams, nor dependence on freshwater resources for agriculture or energy showed a significant association with conflict over international freshwater resources. Geographic theories relating proximity to conflict were unsupported by empirical evidence; quite the contrary, when considering co-riparian countries with adjacent territories. What comes to light in exploring such theoretical claims is that the issue over which the international conflict occurs is a key consideration in identifying relevant indicators. Indicators of territorial disputes differ, for example, from disputes over freshwater resources, which in turn differ from other resource issues such as oil. An environmental determinist approach that emphasizes physical aspects, such as climate and water availability, proved unsupported by the data.

The factors that did show a slight association with conflict over freshwater resources included high population density, low per capita GDP, and overall unfriendly relations between countries. None of these indicators, however, explained more than a small percentage of the variability in the data. The relevant indicators appear to be rapid or extreme changes in physical or institutional settings within a basin (e.g., the building of large dams or the internationalization of a basin) and the presence of institutional mechanisms that mitigate uncertainty, international freshwater treaties in particular.

Broadly defined, institutions and institutional infrastructure matter, perhaps because institutions provide a mechanism for mitigating or managing the uncertainty that theorists associate with a propensity towards international conflict. It would be worth exploring freshwater treaties and other institutional mechanisms in more detail, especially the nature of articles regarding water quantity, quality and management, the opportunities for flexibility in the face of changing physical circumstances, and the evolution of water treaties over time. Institutions are also important because they reflect the ability of a country to understand and cope with stresses upon water resource systems. From the results of our analyses, we identified three categories of basins at risk:

- basins negotiating current conflicts – well known "hot spots", where the potential for continued dispute is therefore considered likely.
- basins in which factors point to the potential for future conflict and in which up-coming development projects or other stresses upon the water system have raised protests among the riparians.
- basins in which factors point to the potential for future conflict, however there is no evidence of existing tensions in public policy or media fora.

When viewing all the categories together, what stands out is that the majority of basins at risk fall in southern Asia and central and southern Africa.

We also presented a framework for further evaluation of the potential for international water conflict in these basins. Our indicators are derived from a broad and highly variable set of data, which concern basins that show a high degree of individuality. Categorizing a basin as "at risk" does not presume to identify basins in which acute conflict *will* occur, but to point to basins worth more detailed investigation. Assessing basins at risk is as much art as science and requires a mix of quantitative and qualitative research approaches, in which particular attention should be paid to:

- the existence, strength and provisions of existing international water treaties or other relevant, basin-level institutional mechanisms;
- overall relations among the riparian countries;
- the likelihood and potential impact of large-scale water infrastructure projects;
- uncertainties associated with the basin's water regime (i.e., climatic variability and institutional adaptability to extreme fluctuations in water availability);
- the presence of minority groups that might contribute to further internationalization of a basin; and,

- the quality of governance within the basin and conditions such as high population density and low per capita GDP that may hamper a government's ability to cope with change.

In the future, there will be international conflicts over water and it may be that such conflicts will increase given increasing populations or other possible stresses upon the resource. The question is how and at what level of intensity such conflicts will be dealt with by the parties concerned.

What we set out to do in the Basins at Risk project was an extensive undertaking involving the creation of multiple, linked spatial and tabular databases encompassing an array of disciplines, and the development of new data variables and accompanying methodologies. It now comes as no surprise as to why quantitative, global-scale evidence to support or disprove claims associating water with violent conflict had not been gathered before. In addition to the difficulty of the task, the quality and coverage of many of the data variables left something to be desired.

As with any project involving socio-economic and other data at global scales, the analyses are as much an art as a science. We did not expect to produce exact numbers but to provide a picture of the world, certainly in more detail than has heretofore been available, and to allow for relative comparisons at various spatial and temporal scales. And in these aspects, we succeeded.

It is hoped that the results of this research will provide a framework for policy makers interested in conflict or cooperation over water and regional stability. Concern about the potential for violent conflict over transboundary freshwater resources has been prevalent in academic literature and the popular press. Conflict over water is also of concern to national policy-makers, from both a perspective of intra-state and inter-state instability and conflict. We provide a framework that policy-makers and others concerned with international water resources may use to identify and evaluate basins at potential risk for future conflicts over water. In addition, the research provides an empirically based understanding of the driving forces that may cause water to become a focus of conflict or cooperation. This knowledge can contribute to the development of international management approaches and programs based on region- or basin-specific information and designed to mitigate the potential for international water conflict. An enhanced understanding of the driving forces behind international water resource conflicts also may facilitate policy-makers' ability to contribute to the peaceful resolution of existing water conflicts.

BIBLIOGRAPHY

Adams, B. D., J. M. Harlin, et al. (1993). "Symposium on Geographic Information Systems and Water Resources." American Water Resources Association Technical Publication Series.

Andriole, S. J. and G. W. Hopple (1984). "The Rise and Fall of Event Data: From Basic Research to Applied Use in the U.S. Department of Defense." International Interactions **10**(3-4): 239-309.

Azar, E. E. (1980). "The Conflict and Peace Data Base (COPDAB)." Journal of Conflict Resolution **24**(1): 143-152. Data obtained from Inter-university Consortium for Political and Social Research [distributor], (http://www.icpsr.umich.edu/).

Barnard, W. S. (1994). From obscurity to resurrection: the lower Orange River as international boundary. Political Boundaries and Coexistence: Proceedings of the IGU-Symposium in Basle, Switzerland, 24-27 of May. W. A. Galluser and e. al. New York, Peter Lang.

Blake, G. (1994). International transboundary collaborative ventures. Political Boundaries and Coexistence: Proceedings of the IGU-Symposium in Basle, Switzerland, 24-27 of May. W. A. Galluser and e. al. New York, Peter Lang.

Brecher, Michael & Wilkenfeld, John. (2000). *A Study of Crisis*. Ann Arbor, MI, University of Michigan Press.

Brunner, J., K. Yumiko, et al. (2000). Water Scarcity, Water Resources Management, and Hydrological Monitoring. Second World Water Forum, The Hague, March.

Butts, K. (1997). "The strategic importance of water." Parameters **Spring**: 65-83.

Central Intelligence Agency. 2000. *World Factbook 2000*. USA: U.S. Central Intelligence Agency, http://www.odci.gov/cia/publications/factbook/index.html.

Dartmouth Flood Observatory: Dartmouth Flood Observatory – NASA supported. http://www.dartmouth.edu/artsci/geog/floods/.

Davies, John L. (1998). *The Global Event-Data System: Coders' Manual*, Center for International Development and Conflict Management and Department of Government and Politics, University of Maryland, College Park MD, August Revision, http://geds.umd.edu/geds/.

Diehl, P. F. (1991). "Geography and war: a review and assessment of the empirical literature." International Interactions 17(1): 11-27.

Dobson, J. E., E. A. Bright, et al. (2000). "Landscan: A Global Population Database for Estimating Populations at Risk." Photogrammetric Engineering and Remote Sensing 66(7): 849-857.

Döll, P. and Siebert, S. (1999): A Digital Global Map of Irrigated Areas. Report A9901, Center for Environmental Systems Research, University of Kassel, 23 pp. + appendix.

Elhance, A. P. (1999). Hydro-Politics in the Third World: Conflict and Cooperation in International River Basins. Washington, DC, United States Institute of Peace of Press.

Elliott, M. (1991). "Water wars." Geographical Magazine(May): 28-30.

Environmental Systems Research Institute, E. (2000). The Digital Chart of the World (DCW), ESRI. Available on-line at: http://www.maproom.psu.edu/dcw/.

Falkenmark, M. (1989). "The Massive Water Scarcity Now Threatening Africa-Why Isn't It Being Addressed?" Ambio 18(2): 112-118.

FAO-SDRN Agrometeorology Group (1997). FAO's Environment and Natural Resources Service (SDRN) global climate maps series, United Nations Food and Agricultural Organization SDRN Agrometeorology Group, http://www.fao.org/sd/eidirect/CLIMATE/EIsp0001.htm.

Fekete, B. M., C. J. Vorosmarty, et al. (2000). Global, Composite Runoff Fields Based on Observed River Discharge and Simulated Water Balances, http://www.grdc.sr.unh.edu/ February 4.

Foreign Broadcast Information Service, US Central Intelligence Agency.

Garnham, D. (1976). "Dyadic international war 1816-1965: the role of power parity and geographical proximity." Western Political Quarterly 29: 231-242.

Gleditsch, K. S. and M. D. Ward (2000). "War and peace in space and time: the role of democratization." International Studies Quarterly 44(1): 1-30.

Gleditsch, K. S. and M. D. Ward (2001). "Measuring Space: A Minimum Distance Database and Applications to International Studies." Journal of Peace Research forthcoming.

Gleditsch, N. P. (1995). "Geography, democracy, and peace." International Interactions 20(4): 297-323.

Gleditsch, N. P. and J. D. Singer (1975). Distance and international war, 1816-1965. Proceedings of the International Peace Research Association Fifth General Conference, Oslo, International Peace Research Association.

Gleick, P. (1989). "The implications of global climatic changes for international security." Climatic Change 15(1/2, October).

Gleick, P. (1993). "Water and conflict: fresh water resources and international security." International Security 18(1): 79-112.

Gleick, Peter. *The World's Water*, 1998: The World's Water: The Biennial Report on Freshwater Resources, Peter H. Gleick (Island Press, Washington, D.C., 1998).

Gurr, T.R. *Armed Self-Determination Conflicts in 2000*. Minorities at Risk Project, University of Maryland Center for International Development and Conflict Management. http://www.bsos.umd.edu/cidcm/mar/autonomy.htm.

Gochman, C. S. (1991). "Interstate metrics: conceptualizing, operationalizing, and measuring the geographic proximity of states since the Congress of Vienna." International Interactions 17: 93-112.

Gradus, Y. (1994). The Israel-Jordan Rift Valley: a border of cooperation and productive coexistence. Political Boundaries and Coexistence: Proceedings of the IGU-Symposium in Basle, Switzerland, 24-27 of May. W. A. Galluser and e. al. New York, Peter Lang.

Homer-Dixon, T. F. (1991). "On the threshold: environmental changes as causes of acute conflict." International Security 16(2): 76-116.

Homer-Dixon, T. F. (1994). "Environmental scarcities and violent conflict: evidence from cases." International Security 19: 5-40.

International Commission on Large Dams, *World Register of Dams,* 1998.

Kasule, Samuel. 1998. *The History Atlas of Africa*. USA: Macmillan.

Kemp, K. K. (1993). Spatial databases: sources and issues. Environmental Modeling with GIS. M. Goodchild and e. al. New York, Oxford University Press: 361-371.

Langram, G. (1993). Time in geographic information systems. Washington, DC, Taylor & Francis.

Lanphier, V. A. (1975). Foreign relations indicator project (FRIP). Theory and Practice of Events Research: Studies in Inter-Nation Actions and Interaction. E. Azar and J. D. Ben-Dak. New York, Gordon and Breach: 161-174.

Laurance, E. J. (1990). "Events data and policy analysis: improving the potential for applying academic research to foreign and defense policy problems." Policy Sciences **23**: 111-132.

Leopold, L. B., M. G. Wolman, et al. (1964). Fluvial Processes in Geomorphology. San Francisco, W.H. Freeman and Company.

Luker, S., S. A. Samson, et al. (1993). Development of a GIS based Hydrologic Model for Predicting Direct Runoff Volumes. Symposium on Geographic Information Systems and Water Resources, American Water Resources Association: American Water Resources Association Technical Publication Series.

Mandel, R. (1980). "Roots of modern interstate border disputes." Journal of Conflict Resolution 24: 427-454.

NcEvedy, Colin. 1980. *Atlas of African History*. NY: Facts on File.

McLaughlin, S., S. Gates, et al. (1998). "Timing the changes in political structures: a new polity database." Journal of Conflict Resolution 42(2): 231.

Merritt, Richard L., Robert G. Muncaster, & Zinnes, Dina A., eds. (1993) *International Event-Data Developments: DDIR Phase II.* Ann Arbor, MI: University of Michigan Press.

Midlarsky, M. (1975). On war. New York, Free Press.

Most, B. A. and H. Starr (1989). Inquiry, logic, and international politics. Columbia, University of South Carolina Press.

Myers, N. (1989). "Environment and security." Foreign Policy 74(Spring): 23-41.

Ohlsson, L. (1999). Environment, scarcity, and conflict: a study of Malthusian concerns. Goteborg, Switzerland, Department of Peace and Development Research, Goteborg University.

O'Riordan, T., C. L. Cooper, et al. (1998). Institutional frameworks for political action. Human choice and climate change, vol. 1: the societal framework. S. Rayner and E. Malone. Columbus, OH, Battelle Press. 1: 352-364.

Prescott, J. R. V. (1965). The geography of frontiers and boundaries. Chicago, Aldine.

Remans, W. (1995). "Water and war." Humantäres Völkerrecht 8(1).

Richardson, L. (1960). Statistics of deadly quarrels. Pittsburgh, Boxwood.

Russett (1967). International regimes and the international system. Chicago, Rand McNally.

Schrodt, Philip A. (1993). "Event Data in Foreign Policy Analysis" Prepared for Laura Neack, Patrick J. Haney& Jeanne A.K. Hey, eds. *Foreign Policy Analysis: Continuity and Change in Its Second Generation*, October.

Toset, H. W. and N. Gleditsch (2000). "Conflict and Shared Rivers." Journal of Political Geography 19(8): 971-927.

Tuchman Mathews, J. (1989). "Redefining security." Foreign Affairs 68(2): 162-77.

Ullman, R. H. (1983). "Redefining security." International Security 8(1): 129-153.

United Nations (1978). Register of International Rivers. New York, Pergamon Press.

United Nations Development Programme, *Human Development Report*, http://www.undp.org/hdro/indicators.html#developing.

United Nations Environment Programme/Global Environment Monitoring System; Fraser, A. S., M. Meybeck, and E. D. Ongley. 1996. Annotated Digital Atlas of Global Water Quality (computerized). UNEP GEMS/Water Collaborating Centre, Canada. Global Environment Monitoring System (GEMS/Water); http://www.cciw.ca/gems/intro.html.

United Nations Environment Programme /GRID – EROS: http://grid2.cr.usgs.gov/; http://edcwww.cr.usgs.gov/.

United Nations Food and Agriculture Programme; FAO's Environment and Natural Resources Service (SDRN) global climate maps series. - FAO-SDRN Agrometeorology Group - 1997. http://www.fao.org/sd/eidirect/CLIMATE/EIsp0001.htm.

United States Agency for International Development, Office of US Foreign Disaster Assistance (OFDA) & the WHO Collaborative Center for Research on the Epidemiology of Disasters (CRED); EM-DAT: The OFDA/CRED International Disaster Database - www.md.ucl.ac.be/cred - Université Catholique de Louvain - Brussels – Belgium.

United States Geolgocial Service (2000). United States Geological Survey Hydro1k dataset, GIS coverage. http://edcdaac.usgs.gov/gtopo30/hydro/.

United States Geological Service, GTOPO30, EROS Data Center, http://edcdaac.usgs.gov/gtopo30/gtopo30.html

Unrepresented Nations and Peoples Organisation (UNPO). *List of Members*. http://www.unpo.org.

Vasquez, J. A. (1995). "Why do neighbors fight? Proximity, interaction, or territoriality." Journal of Peace Research 32(3): 277-293.

Vörösmarty, C.J., B. Fekete, and B.A. Tucker. 1998. River Discharge Database, Version 1.1 (RivDIS v1.0 supplement). Available through the Institute for the Study of Earth, Oceans, and Space / University of New Hampshire, Durham NH (USA) at http://pyramid.unh.edu/csrc/hydro/. Vörösmarty, C.J., B. Fekete, and B.A. Tucker. 1996. River Discharge Database, Version 1.0 (RivDIS v1.0), Volumes 0 through 6. A contribution to IHP-V Theme 1. Technical Documents in Hydrology Series. UNESCO, Paris.

Vose, R. S., R. L. Schmoyer, et al. (1992). The Global Historical Climatology Network: long-term monthly temperature, precipitation, sea level pressure, and station pressure data. ORNL/CDIAC-53, NDP-041. Oak Ridge, Tennessee, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory.

Ward, M. D., M. E. Shin, et al. (2000). Post-1945 International Boundaries, GIS coverages, University of Washington, mdw@u.washington.edu.

Westing, A., Ed. (1986). Global resources and international conflict: environmental factors in strategic policy and action. New York, Oxford University Press.

Wiess, D. (2001). Estimation of Arable and Irrigable Land in the World. Corvallis, Oregon, Department of Geosciences, Oregon State University.

Wolf, Aaron T. (1998). "Conflict and Cooperation Along International Waterways" *Water Policy.* 1(2), 251-265.

Wolf, A. T. (1999). "The Transboundary Freshwater Dispute Database Project." Water International 24(2, June): 160-163.

Wolf, Aaron T., Jeffrey Natharius, Jeffrey Danielson, Brian S. Ward, and Jan K. Pender. 1999. "International River Basins of the World" *International Journal of Water Resources Development.* 15(4), 387-427.

Wolf, A. T., S. Yoffe, et al. (2001). "International waters: identifying basins at risk." Water Policy in review.

World News Connection, US Central Intelligence Agency.

WRI (1998). World Resources 1998-1999 Database, World Resources Institute.

Yoffe, S. and M. Giordano (2001). "Measuring friendship hostility between nation-states: a variable for quantitative analysis." Journal of Peace Research submitted.

Yoffe, S. and K. Larson (2001). "Basins at Risk: water event database methodology." Water Policy in review.