Bundesanstalt für Gewässerkunde

Report 37

GRDC Report Series

Hydrology of the World's International River Basins: Hydrological parameters for use in global studies of international water-relations

Kerstin Stahl
Oregon State University, Department of Geosciences, Corvallis, USA
now at: Universität Freiburg, Institut für Hydrologie, Freiburg, Germany

Global Runoff Data Centre

GRDC operates under the auspices of the World Meteorological Organization (WMO) with the support of the Federal Republic of Germany within the Federal Institute of Hydrology (BfG

Global Runoff Data Centre

in the
Federal Institute of Hydrology (BfG)

Am Mainzer Tor 1
56068 Koblenz, Germany

P.O.Box 20 02 53
56002 Koblenz, Germany

Phone: +49 261 1306-5224
Fax: +49 261 1306-5280
E-Mail: grdc@bafg.de
Internet: http://grdc.bafg.de

About the Global Runoff Data Centre (GRDC):

The GRDC is acting under the auspices of the World Meteorological Organization (WMO) and is supported by WMO Resolutions 21 (Cg XII, 1995) and 25 (Cg XIII, 1999). Its primary task is to maintain, extend and promote a global database on river discharge aimed at supporting international organizations and programs by serving essential data and products to the international hydrologic and climate research and assessment community in their endeavor to better understand the earth system. The GRDC was established at the Federal Institute of Hydrology in 1988. The National Hydrological and Meteorological Services of the 187 member states of WMO are the principal data providers for GRDC.

December 2007

Foreword

While human society has divided our planet into sovereign states and autonomous regions, there is a natural organization scheme of the land surface, namely the hierarchically nested structure of river basins. River systems are an integral part of the global climate system and as such feed back to many geophysical processes on local, regional and global scales.

Water is vital for life and should be managed as a common property. However, the use of water has a political dimension. In some regions of the world, water is considered as a strategic resource and tensions between countries can arise over water ownership and water rights. Competition over scarce or poorly allocated resources can lead to disputes and insecurity.

Approximately one third of 263 trans-boundary river basins are shared by more than two countries. The first World Water Development Report (WWDR) published by UNESCO in 2003 mentioned 1,831 interactions (both conflict-laden and cooperative) over the last fifty years: 7 disputes have involved violence, and 507 conflictive events have occurred. At the regional and international level, many river basin authorities are developing integrated, cooperative approaches to manage the shared resource. Approximately 200 treaties have been signed, with a total of 1,228 cooperative events.[1] This assessment bases on the largest empirical study of water conflict and cooperation, completed in 2001 at Oregon State University. With the *Transboundary Freshwater Dispute Database* the Department of Geosciences at Oregon State University, developed a database, which includes water related treaties between countries and all reported conflictive and cooperative events in the world's international river basins.[2] This comprehensive database provides the opportunity to study the link between hydrologic conditions and water-related political conflicts and cooperation.

The degree of dispute or cooperation over water from transboundary rivers is often attributed to unfavorable hydrologic conditions such as water scarcity or the occurrence of floods and droughts. In her study Kerstin Stahl identified and tested for the world's international river basins hydrological and hydro-climatic parameters suitable to indicate whether and if so how certain hydrologic conditions can trigger, exacerbate or enhance political conflict and cooperation between countries sharing a river. The parameters focus on rapid and gradual changes in the intra-annual and inter-annual discharge and precipitation variability and the occurrence of rare extremes (floods and droughts). To find whether, under which conditions, and in which direction a certain parameter influences water-related conflict and cooperation, a special test procedure was developed. The risk for conflict in the international river basins of the world under the effect of climate and other environmental change will be evaluated.

The GRDC is happy to have been able to support this study by an appropriate set of river discharge data. The GRDC likes to thank Kerstin Stahl for her work and the permission to publish the results in its report series. We believe that the geopolitical aspects of water scarcity and water allocation and the modeling of a 'risk for conflict in a basin' will attract wide interest.

GRDC invites scientists to assist the centre in the scientific exploitation of its database. A couple of valuable cooperation's and reports arose from these invitations in the past, at last this interesting report. Therefore, I would like to encourage others to follow this proved tradition.

Koblenz, Germany

I. Dornblut
GRDC

1 WWAP (2003): World water development report. Chapter 12: Sharing water: Defining a common interest.
2 http://www.transboundarywaters.orst.edu/

Contents

List of Tables included

List of Figures included

Summary

With the rising water demand worldwide, international cooperation in water resources management has become an important issue. Dispute between riparian nations over the water of transboundary rivers is often attributed to unfavorable hydrologic conditions such as water scarcity or the occurrence of floods and droughts. However, few systematic analyses on this relationship have been carried out. The Transboundary Freshwater Dispute Database at Oregon State University is a global GIS database merging the geography of the 263 transboundary rivers and their basins with historic treaties and intensity-coded political events of conflict or cooperation over water. It provides a unique opportunity to study the link between hydrologic conditions and water related political conflict and cooperation. The report presents a dataset of hydrologic parameters derived from Global Runoff Data Centre (GRDC) data and designed for integrated multidisciplinary studies addressing this link. The hydrologic parameters describe average conditions as well as the variability and extremes over time. They are available in tabular format, maps, and signature plots for each international basin. Three applications are presented to illustrate how the hydrologic parameters together with other variables can be used

- to test general theories on international relations over water,
- to model the global influence of the hydroclimate on conflict and cooperation, and
- to explore individual time series of climate, hydrology and international relations in selected international basins.

Such studies can help to shed light on the causality of conflict and cooperation over water. They highlight the importance of hydroclimatic variability both in time and space and demonstrate the need for a solid long-term global runoff database.

Introduction

Water is a natural resource considered to play a major role in countries' political stability. The role of water in international relations is particularly palpable in conflict and collaboration over transboundary rivers. Water ignores political boundaries and rivers are known to have been the source of tensions between the countries that share its water. Journalistic writing and reporting has elaborated widely on the notion of *water wars*. Yet, water can also bring nations together. The magnitude and global extent of the issue is given by the world's over 260 international river basins, which cover more than 45% of the land surface and affect more than 40% of the world's population (Wolf, et al. 1999).

Due to rising water demand, relative water scarcity is increasing worldwide (e.g. Alcamo *et al.*, 2000). Climate change research predicts an intensification of the hydrologic cycle with increasing hydrologic extremes (IPCC, 2007). Reflecting such changes and the resulting uncertainty in the availability of water, international river basin management has become an important topic in politics and international relations. The German Advisory Council on Global Change (1999) identified that one out of four aspects lending a global dimension to the degradation of freshwater was that regional water conflicts might escalate and cause destabilization at the global level.

Current concepts of environmental or human security have to consider complex interactions between environment and society. Since little empirical work has been done to elucidate these interactions most concepts are based on selected case studies in particularly conflictive regions (Wolf, et al. 2001). To overcome this drawback, researchers at Oregon State University have in an enormous effort assembled and analyzed the best possible data sample: all reported events of water-related conflict and co-operation in all international river basins of the world (Wolf et al., 2003a). This database, which is part of the Transboundary Freshwater Dispute Database (TFDD), provides a unique framework to test presumed relationships and shed light on the complex interactions between environment, socio-economics and conflict and cooperation over water. Political incidents such as conflicts over water issues between riparian countries of international rivers are often attributed to unfavorable hydrologic conditions, in particular to the occurrence of droughts and floods. Analyses with TFDD data within the Basins-at-Risk project, have used very limited hydrologic and climatologic data and had to conclude that the database was not sufficient to test such hypotheses (Yoffe et al., 2003).

This report describes the effort to establish and test an improved dataset of hydrologic and hydro-climatic parameters that were specifically derived for the world's international river basins in the TFDD. The following section briefly introduces the global TFDD datasets of international basins and political data. Section 3 then presents the new hydrologic dataset integrated into the TFDD framework. First, the criteria for selecting data and parameters will be framed then the data and derived parameters will be presented and finally their global distribution as well as specific examples discussed. With three applications, Section 4 of the report aims to illustrate potential uses of the dataset. All applications are concerned with the analysis and modeling of the link of hydrology and international relations over water.

1 The world's international river basins

The Transboundary Freshwater Dispute Database, an online database held at Oregon State University (TFDD, 2003), links a Geographical Information System (GIS) of the world's international basins with an international freshwater treaties dataset and a dataset of reported political events of water-related political conflict and cooperation. The combination of these datasets provides the most comprehensive database available in this field that is based on the geographic unit relevant for water resources issues, the international river basin (Yoffe *et al.*, 2004). TFDD data and reports are accessible at www.transboundarywaters.orst.edu.

1.1 Geography

On the basis of the Inventory of International River Basins of the World, Fiske and Yoffe (2001) set up a GIS of historic and current international river basins. Today there are 263 international basins worldwide (Figure 1). Overlaying the basins with political boundaries of the world's nation states allows to carry out analyses on the scale of the international basin as a whole, a country's territorial share of an international basin (referred to as basin-country-polygon or BCP), or on the scale of country pairs (dyad). The latter is the common unit of analysis in political sciences.

Besides geographic location, several biophysical, geopolitical and socio-economic indicators are available at the basin and country level. Some of these indicators relate to prevailing wisdom of factors relevant to international relations over water. They were integrated into the database for the 'Basins-at-Risk' (BAR) project in which Yoffe et al. (2003) tested a large number of indicator variables for their influence on the level of conflict over water between riparian countries of a transboundary river. Some of the indicator variables from the BAR project are also used in the Section 4 of this report and are therefore briefly described in the next paragraph along with the rationale for their consideration.

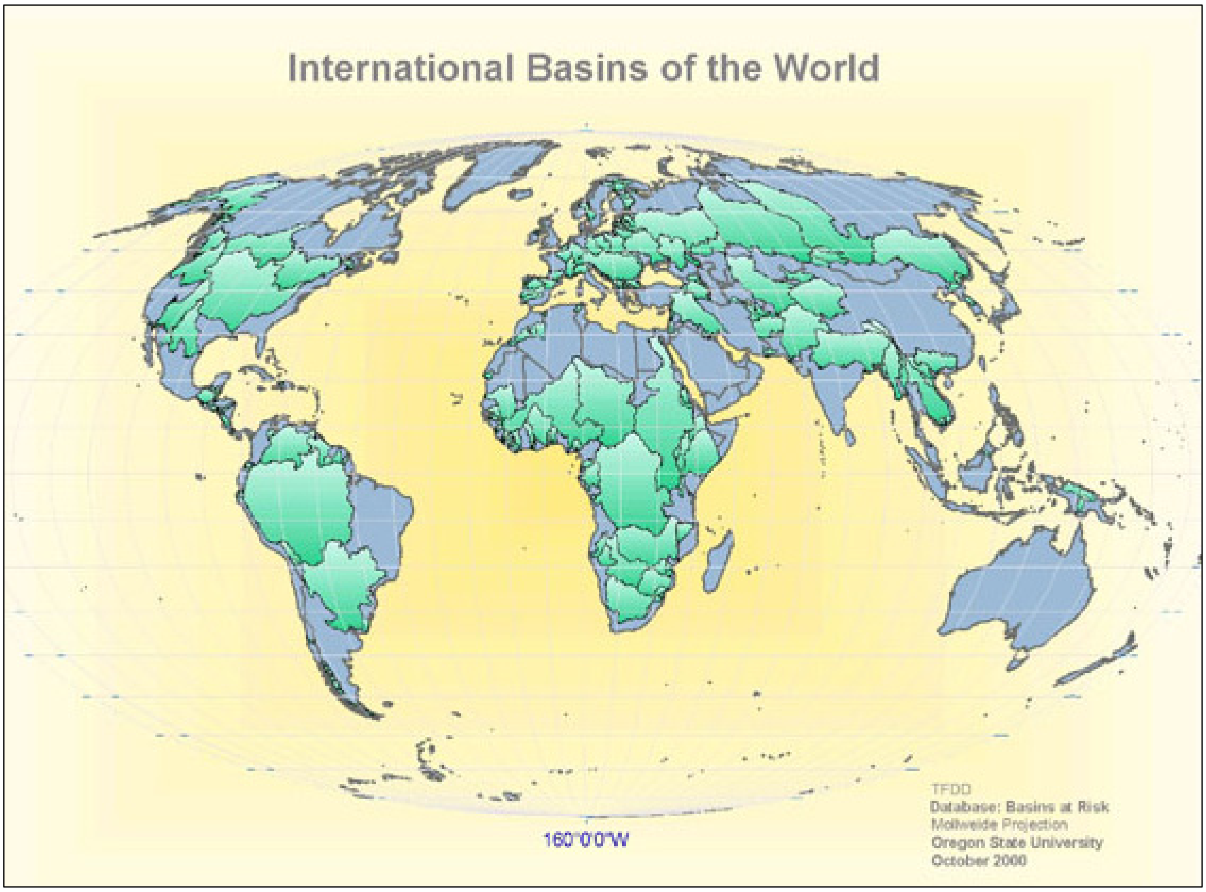


Figure 1: The world's international river basins (Wolf et al., 2003a)

The basin area or more precisely the percentage of a country's areal share of the international basin (*Area*) indicates the relative importance of that country within the international basin. The same applies to the country's relative location along the river (*Loc, B*). Upstream-downstream relationships and a river as a border are widely considered to increase the risk for conflict (Ashton, 2002; Toset, et al., 2000). Population Density (*Pop*), which is derived from the LandScan2000 coverage (Dobsen, et al., 2000), is a major social indicator and many studies have illustrated its significance for water issues. The water stress index (water availability/population) (Falkenmark, 1989) and its variants have become common variables in global environmental assessments. Scenario simulation experiments suggest that population growth outweighs climate change as a factor of increasing water stress (Vörösmarty *et al*., 2000). Economic and political variables are also commonly used indicators for a region's economic and institutional capacity to deal with environmental stress. Such numbers are only available at the country level. The World Bank (2003) regularly publishes Per Capita Gross Domestic Product (GDP) per country. For this study their annual data was averaged for the period available for each country (1960-2000). GDP data will help to test the hypothesis that cooperation is easier and hence works better between economically well-off countries that can afford technological solutions. Finally, one could hypothesize that democratic countries are more inclined to cooperate while autocratic countries where decisions are made by a small elite are prone to conflict. To describe the political regime characteristics, the 1950-2000 democracy/autocracy indices (*DA*) of the commonly used PolityIV Project (2000) were averaged for each country. The scale ranges from –10 (most autocratic) to +10 (most democratic). Most of the named variables are only available for a specific time or as a time-average characteristic. Details of the data availability are summarized in Appendix 1.

1.2 Conflict and Cooperation

Two political datasets in the TFDD are linked to the world's international basins: the international freshwater treaties dataset (published as an atlas by UNEP & OSU, 2002) and a dataset of reported political events of water-related political conflict and cooperation. The latter dataset covers the period from 1948 to 2000. All political events relate to water as a scarce or consumable resource and were coded on a scale of conflict and cooperation. From its introduction within the Basins-At-Risk project, this scale is now known as the BAR-scale and runs from –7 (most conflictive) over 0 (neutral interaction) to +7 (most cooperative) (Table 1). Treaties signed during that period are cooperative events on the scale that were coded with the number 6. Details on methodology and data sources can be found in (Yoffe and Larson, 2001).

BAR Scale	**Description of nature of the water-related political event between riparian countries** (COPDAP scale by Azar (1980) adapted to water events by Yoffe & Larson (2002))	**Conflict-Cooperation Level (CCL)**
6	International Freshwater Treaty; Major strategic alliance	most cooperative
5	Military economic or strategic support	
4	Non-military economic, technological or industrial agreement	cooperative
3	Cultural or scientific agreement or support (non-strategic)	
2	Official verbal support of goals, values, or regime	
1	Minor official exchanges, talks or policy expressions--mild verbal support	neutral
0	Neutral or non-significant acts for the inter-nation situation	
-1	Mild verbal expressions displaying discord in interaction	
-2	Strong verbal expressions displaying hostility in interaction	conflictive
-3	Diplomatic-economic hostile actions	
-4	Political-military hostile actions	
-5	Small scale military acts	most conflictive
-6	Extensive War Acts causing deaths, dislocation or high strategic costs	

Table 1: The Conflict-Cooperation Levels for water-related political events

The political events dataset can be and has been used in several ways (Yoffe et al., 2004). Global mapping illustrated where the conflictive 'hot spots' are; summary statistics revealed that cooperation outweighs conflict and that a wave of conflicts had emerged after the internationalization of river basins of the former Soviet Union (Wolf et al, 2003a). Also within the BAR project, Yoffe *et al*. (2003) calculated the mean of all events' BAR codes in each basin to describe a basin's general degree of 'conflictiveness/cooperativeness'. These values were then used as response variable in regression analysis that aimed at finding environmental indicators that can point to future conflict or cooperation. Refining the data scale in a follow-up study, Stahl (2005) included the variability of the events in the description of water-related political relations by classifying the basins by the distribution of their event levels. Finally, the individual events and their levels on the BAR scale can also be used to analyze the temporal development of political relations over water in a basin. The three applications in Section 4 of this report use the political data at various of these different resolutions.

2 The hydroclimatology of the world's international river basins

2.1 Parameterizing hydrology and climate

The Transboundary Freshwater Dispute Database is unique in terms of its worldwide coverage and systematic coding of information, which facilitates global hydro-political assessments. The hydrologic and climatic parameters presented in this report are derived to aid such assessments. They should therefore fulfill the same criteria of global coverage, global comparability, and comprehensiveness. They should be suitable for global integrated multidisciplinary analyses.

Hydroclimatic conditions that may influence a region's risk for conflict or its potential for cooperation over freshwater can be described by many different variables. Freshwater indicators in political and natural resources assessments as suggested by Gleick (1993) include estimates of supply to demand ratios, or combined indices such as the water stress index relating water availability to population and the human development index. Although demand is difficult to determine, long-term average estimates are derived and published routinely for most countries worldwide. The use of these common freshwater indices as explanatory variables in statistical analyses is problematic as it assumes that the variability of the individual factors in time and space is negligible. In times of rapid development and/or climate and environmental change, however, this can be problematic. Assessments of conflict and cooperation over transboundary rivers require consideration of spatial and temporal variability and change.

Spatial issues

Though the average water availability situation of a country may indicate potential water stress, the source itself (in this case the river) is the center of dispute or cooperation. Countries may cooperate well over one shared river, but not well over another or with another riparian country. Hence, the geographic unit of analysis must relate to the river basin.

Basically, two different types of data can be considered for use in global studies: original at-station data or grid-based data, which are produced by appropriate and well-tested interpolation strategies. Grid-based data is readily available for most climate variables. For surface hydrology, most existing grid datasets are derived from model output. Global hydrological models are often run at an annual time step and tend to have difficulties reproducing hydrological variability in time and space (e.g. Döll et al., 2003). At-station data can be expected to better reflect the real situation of discharge conditions as they are challenging river management; including data gaps, trends, human influences, etc. The Global Runoff Data Center (GRDC) holds discharge data from over 2000 stations that are within an international basin and have records of more than five years. Figure 2 shows the location and number of GRDC stations in the 263 current international basins.

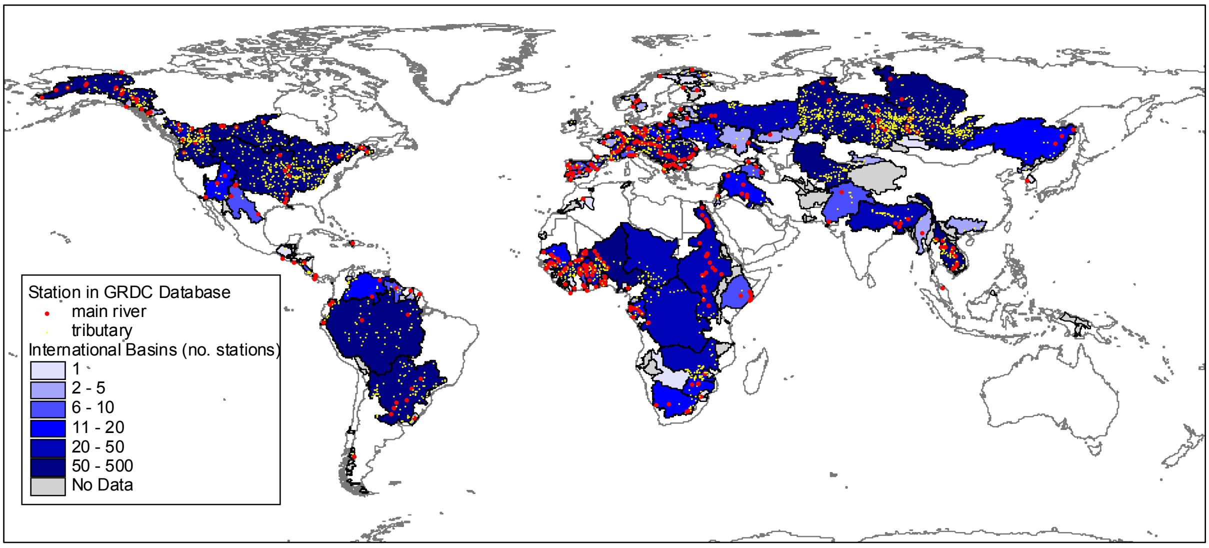


Figure 2: GRDC stations in the 263 current international basins (enlarged at GRDC Homepage)

The map shows great differences in the data availability and coverage for the basins. While hydrologic data is available in 138 of the 263 international basins, not for all of these basins hydrometric data is available from the main river. Some of records are from small tributaries which may have a very different hydrological regime. With no sufficiently detailed global river network available that includes names of all the tributaries, the distinction between main river and tributary was based on the name of the river. It is therefore difficult to derive and compare hydrological differences between upstream and downstream sections of international rivers and their basins and hence such differences can not be considered systematically.

Temporal variability

Surface water in particular is often characterized by high temporal variability with extremes such as floods and droughts, characteristic that has been fought for a long time through the building of dams and reservoirs. Such projects, however, have also caused much tension between countries that share a river especially when the development was carried out unilaterally. Ashton (2002) presents a map linking conflict to geographical regions of transition from perennial to ephemeral rivers in Africa. He suggests that conflicts occur where the high seasonality and inter-annual variability of water availability make an adequate preparation for dry spells difficult. Although the influence of spatial and temporal variability is increasingly recognized, many treaties between riparian countries of transboundary rivers to date do not include rules for extreme hydrological conditions such as floods and droughts. Some do, but there is still a risk that agreements were made during a wet climatic period and do not include enough flexibility to account for changed conditions. Mexico, for example, has not been able to deliver the agreed discharge in the Rio Grande after taking the drought year escape clause in the agreement with the US (Kelly and Chapman, 2002). Hence, knowledge of the role of hydrologic and climatic variability in political incidents over water is crucial for management and cooperation in international basins.

Besides the general climatic water balance, a dataset of hydrologic parameters for use in interdisciplinary studies should therefore also include parameters that describe variability and reliability of water availability, as well as information on extremes.

Time-aggregate vs. time-series data

Environmental stress may cause political incidents at different levels of temporal resolution. It may act as an underlying stressor or as a trigger (Homer-Dixon, 1994). The underlying stressor can be a constant property or a slow trend or change. Variables indicating underlying stressor may be useful to explain the general history or indicate the risk for conflict or potential for cooperation in a time-non-specific sense. A trigger on the other hand will have an immediate effect. In reality both likely act together. The hydrologic parameters should allow testing for both.

To be globally applicable and comparable, variability parameters and time-series parameters have to be defined in a relative way, i.e. as deviations from the normal (long-term) condition at the site. The first step is therefore to define what is 'normal'. Generally, this refers to the annual cycle and variability of water availability to which nature and human water use and management practice has adapted through history, including for example a dry summer season or floods during certain times of the year due to monsoon, snow melt, etc. The second step is to define the relevant level of deviation. Here, human perception of hydrologic variability becomes important such as the recurrence of hydrologic extremes within a short time, the duration of a situation, increasing stress, or abrupt changes, etc., rather than water volumes.

2.2 Parameters

Based on the considerations in the previous section as well as on data availability, parameters describing the hydrology of the world's international river basins were defined at three different resolutions:

- time-series (annual values)
- time-aggregated characteristic distributions
- and time-aggregated parameters expressed in a single value.

For each hydrometric station, the available streamflow record within the frame period of 1940 - 2000 was used. Unfortunately, the length of the available series differ greatly, and for many rivers records are short. The minimum length to be considered was five years. To calculate mean values of a specific month of the year, five years of data for that month had to be available. Parameters were first calculated for each individual station. Then, for each basin or basin-country share, the average was calculated from all stations within the unit. Most time-aggregated basin-averaged parameters are included in this report as a table in Appendix 2. Signature plots for the basins also include aggregated distributions and time-series parameters (Section 3.4; Appendix 4). They show the average, maximum and minimum of the parameters separately for the main transboundary river and for all tributaries.

Time-series parameters

The time frame is set by the political events dataset, which covers 1948-2000. As the hydrology of a few years prior to a political event may be relevant for international relations, the period 1940-2000 was chosen to derive the hydrologic dataset. All parameters are normalized and can therefore only considered relative to the mean or another characteristic of the available period of record.

The *normalized annual discharge* expresses the annual mean discharge as departure from the long-term mean. Anomaly series are frequently used in climatology. They facilitate the detection of periods of water deficit and surplus as well as trends and changes.

The *annual seasonality index* was calculated from each year's monthly mean discharge. This seasonal or intra-annual variability of discharge is an important aspect of hydrology. It defines the possibilities of water use for irrigation, hydropower, etc. Therefore, a Seasonality Index was derived from circular statistics of monthly mean values according to Markham (1970). The standard method/algorithm to calculate the parameter can be found in hydrology textbooks (e.g. Dingman, 2002). The seasonality index summarizes the runoff concentration during the year. An index of zero means that every month has the same average discharge, while an index of one means that all the annual discharge is concentrated within one month of the year. Seasonality time series allow to detect unusual years in which perhaps a certain seasonality feature was extremely pronounced or missing (e.g. monsoon, snowmelt). A shift in seasonality over time may indicate a change to the hydrology perhaps caused by the building of a dam or other human influence, or more gradually by climate change. All these factors may induce a change in water availability and hence exert stress that may affect the water-related international relations.

The *annual maximum flood* may indicate an unusual flood of cross-border impact. Flood events can provoke dispute and illustrate the need for agreements in international basins. Maximum monthly values of each year were normalized by the mean of all historic annual maxima.

A *drought index* was calculated as the proportion of the year during which the discharge was below the 10-percentile of a month's historic distribution (calendar month specific Q90). Compared to floods, a drought characteristic adversely affecting agriculture and water supply is persistence. Since the global dataset contains basins with different regimes in different climate zones around the world even including rivers that regularly fall dry, such a relative approach provides a suitable basis for comparison and detection of years with water shortage.

Time-aggregated parameters – characteristic distributions

Some classic distributions are useful to obtain a quick overview of a river's hydrology. They include the distribution of discharge throughout the year. Expressed as monthly mean discharge normalized by the mean annual discharge, this is also known as *hydrologic regime*. It describes the seasonality in more detail than the seasonality index.

The *flow duration curve* of annual mean discharge and monthly mean discharge values are cumulative frequency curves, which show the average percentage of time that specific flows are equaled or exceeded. The shape of the flow duration curve has links to climate and geology, which is why it is being used in many regional hydrologic analysis and estimation methods.

Time-aggregated parameters – single value

All values are derived from the available time-series within the 1940-2000 frame period. A table of basin averages is included in Appendix 3.

q: The specific discharge (mean annual discharge/basin area) is a measure for the runoff production in the basin. For some stations, basin area was not available.

CVQ: The coefficient of variation of annual mean discharge describes the overall inter-annual variability. Inter-annual variability is an important indicator of the reliability of water availability.

SQ: The seasonality was calculated the same way as the annual seasonality but from the long-term monthly mean discharge. It provides a measure of the seasonal availability of water. Comparing the seasonality of the discharge with that of precipitation furthermore may indicate that river flow is regulated, e.g. by a reservoir or naturally by a lake.

Qz: The fraction of time without discharge characterizes whether the river is perennial (less than 10%), intermittent (10% to 30%), or ephemeral (>30%).

Climate and precipitation

The applications presented in Section 4 of this report also use hydroclimatic parameters (Table 2). Precipitation was obtained from the Climate Research Unit's (CRU) 0.5-degree monthly mean precipitation grid (New et al., 2000). From this dataset it is possible to derive time-series as well as monthly mean or annual mean precipitation for the spatial units of the basin, country or basin-country-polygon (BCP). Another global 0.5-degree grid used to calculate a time-averaged parameter in this study is the mean annual potential evapotranspiration by Ahn & Tateishi (1994), which is available to the public from UNEP GRID (2003). It was used to calculate an Index of Aridity (A). This measure of the general climatic water balance is often used to classify arid, semi-arid and humid regions (UNESCO, 1997). Except for the spatial coefficient of variation, which describes the variability of the individual grid cells that compose a basin or BCP, averages were derived from the original values of the grid cells that make up the geographic unit before calculating the parameters.

Variable	Description	data source	available for no. of BCPs
A	Index of Aridity (mean annual precipitation/potential evapotranspiration)	Ahn-Tateishi (1994)	664
P	Mean annual precipitation	CRU	664
CVPs	Spatial variability: coefficient of variation of mean annual precipitation	CRU	664
CVPt	Inter-annual variability: coefficient of variation of annual precipitation 1948 to 1998	CRU	664
SP	Intra-annual variability: seasonality index of mean monthly precipitation	CRU	664

Table 2: Hydroclimatic parameters

2.3 Global Distribution

The hydrologic dataset provides many opportunities for analysis. A summary and a few exemplary characteristics with importance for integrated and international river basin management are pointed out here.

Discharge-based parameters are available for 136 of the 260 international basins. Summary statistics for the 136 basins show that they cover a wide range of hydrological regimes (Table

3). The mean annual runoff calculated for the respective portions of the gauged basin ranges less than 10 mm/year in hyper-arid regions to basins with more than 2000mm/year. Similarly, inter-annual and intra-annual variability of discharge ranges from almost constant flow to extremely variable conditions. The dataset of international basins includes perennial, intermittent, ephemeral, and episodic rivers.

Parameter	Mean	Median	Min	Max	Range
Q (mm/year)	580	372	8	2793	2785
CVQ	0.36	0.27	0.07	2.08	2.01
SQ	0.42	0.40	0.03	0.93	0.90
Qz (%)	6.06	0.02	0.00	93.05	93.05

Table 3: Summary statistics of discharge parameters for the international basins

How these characteristics are distributed spatially is shown by maps in Appendix 3. The color-coded maps illustrate the global spatial distribution of at-station values, basin-country-polygon averages and basin averages. A generally strong spatial association with climate zone can be noticed. However, the different levels of detail that are displayed also show the loss of information when aggregating from station to basin-country-polygon to basin.

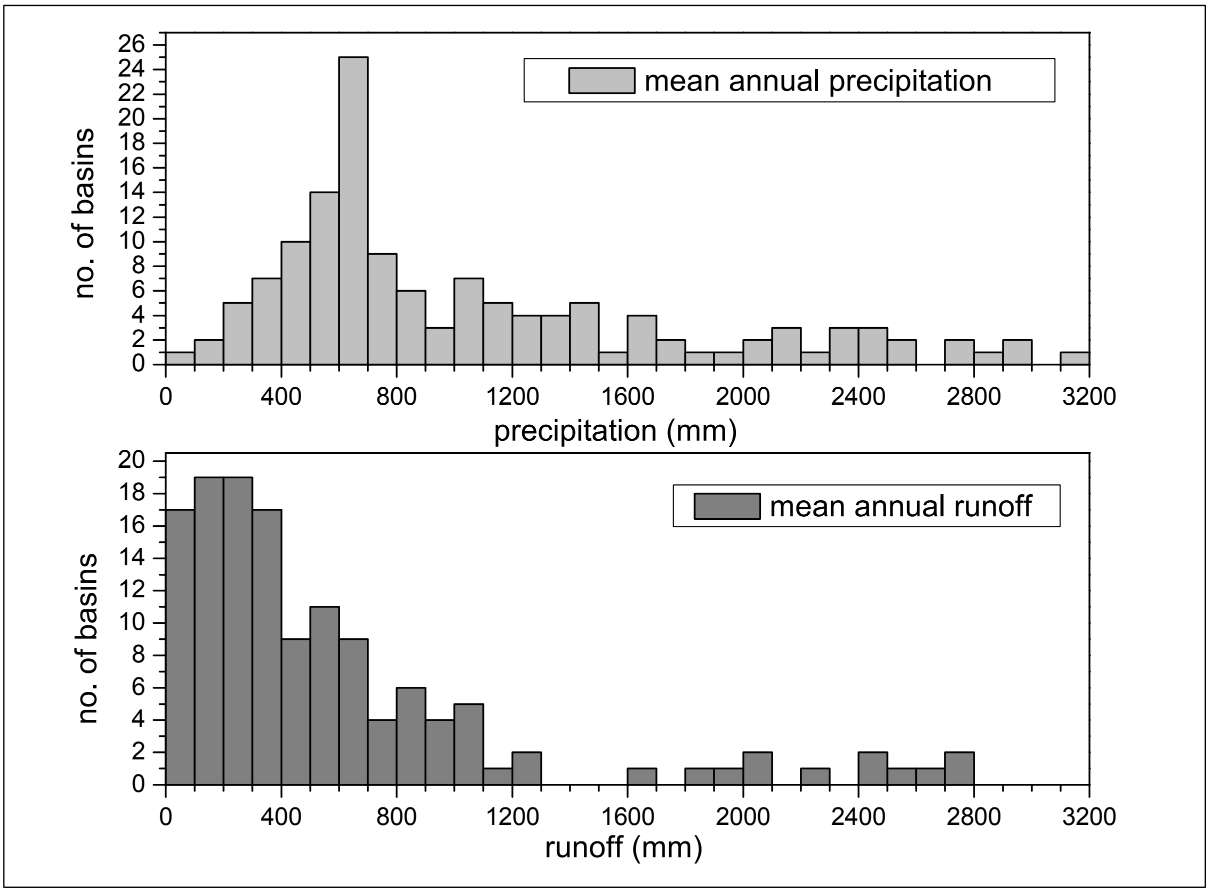


Figure 3: Distribution of basin-averaged mean annual precipitation and mean annual runoff (n=136 international basins)

A comparison of the distribution of annual runoff values with the annual precipitation values found in the global international basins (Figure 3) shows: the distribution of annual precipitation is almost normal with the majority of the basins around 700mm. The distribution of basin runoff is highly skewed. Low runoff values are calculated for the majority of international river basins and high runoff for only a few basins.

A map of regimes (Figure 4) provides an overview over the monthly variation of river flow and the timing of high flow and low flow periods. Despite the effort of mankind to dam the rivers and store the water across seasons and years, it can be seen that many international rivers in fact exhibit a high variability and seasonality of discharge. This characteristic challenges international cooperation and is therefore important to be considered in any comparative or global analysis.

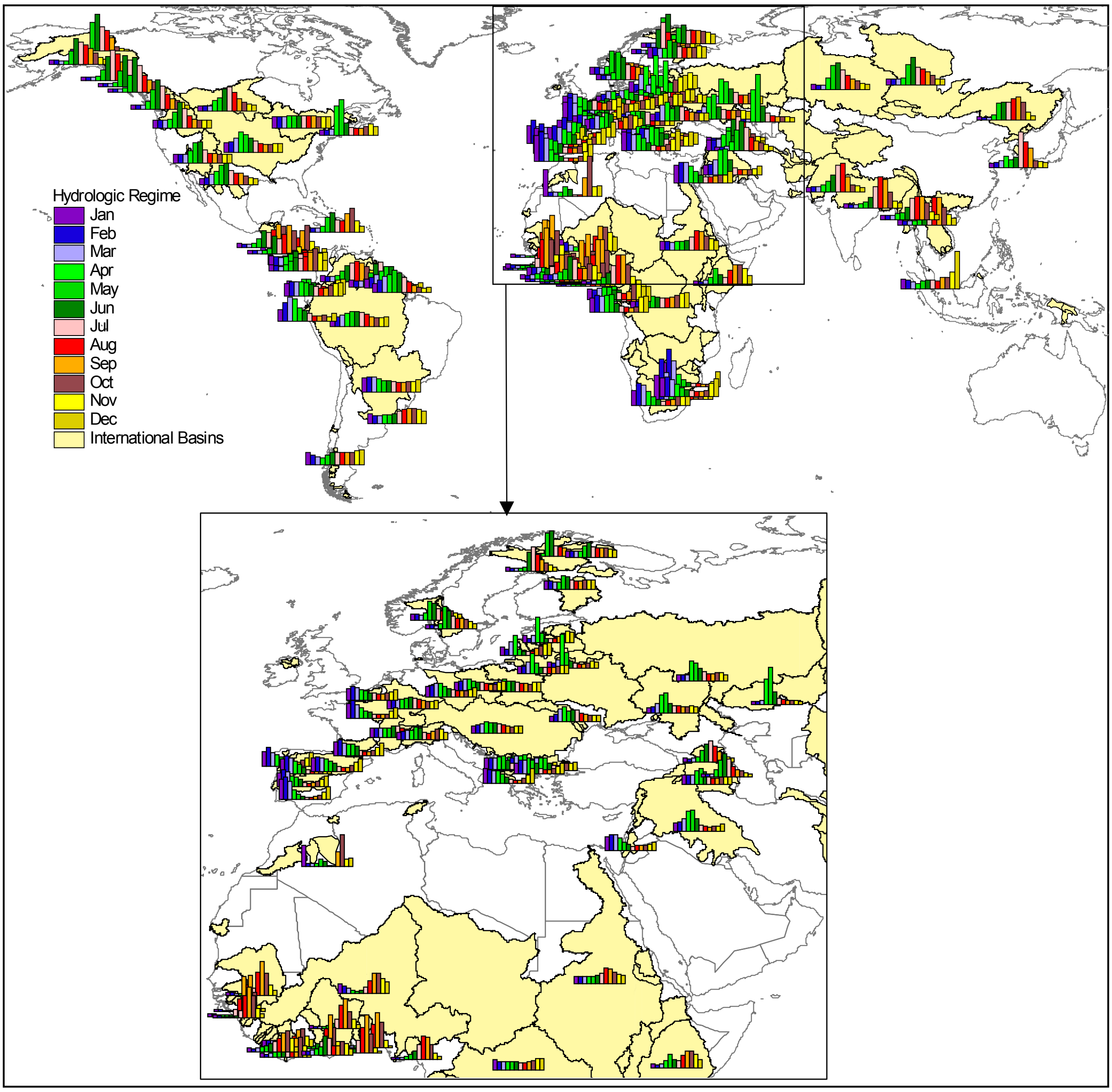


Figure 4: Hydrological Regimes in the transboundary rivers (enlarged at GRDC Homepage)

A plot of all the annual normalized flow duration curves (fdc) reveals a few outliers (Figure 5). These are rivers which experienced rare but particularly low and high flows. They are probably rivers where multi-year droughts and/or catastrophic flooding has occurred. Human influence may also have affected the flow. It can be noticed that many of these extreme fdcs are from the Southern African Region (i.e. Incomati, Limpopo, Orange, Sabie) where conflicts have occurred as South Africa has been developing their upstream sections of the rivers. However, the need for cooperation has also been recognized and the effort for international water course management has increased tremendously in recent years. Another example highlighted in Figure 5 is the Rio Guadiana, which is shared by Spain and Portugal, and is one the most disputed river in Europe.

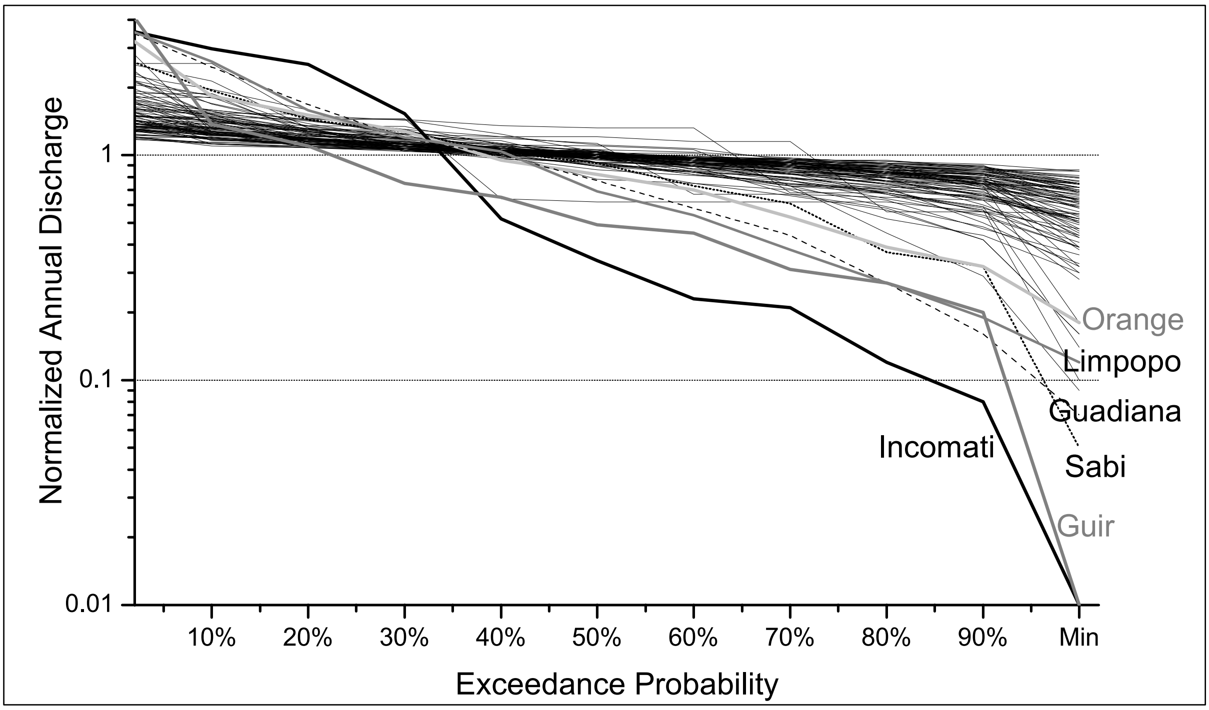


Figure 5: Mean flow duration curves for the international river basins

The aggregated distributions are possibly most helpful if one is interested in a particular river. Their use for global comparison is limited due to the complexity of the information.

2.4 Basin-Signature plots

With the hydrologic parameters at hand, so-called “signature plots" have been created for all basins (and BCPs – not shown). These assembled values and graphs are designed to illustrate the characteristic climatology and hydrology for each international basin together with the reported political events from the TFDD. Technically, the plots of the individual parameters for each basin were automatically generated and saved as .png files. Using hypertext markup language (html), they are then automatically assembled by basin on html pages. This will allow future inclusion in any on-line database (e. g the TFDD).

Senegal

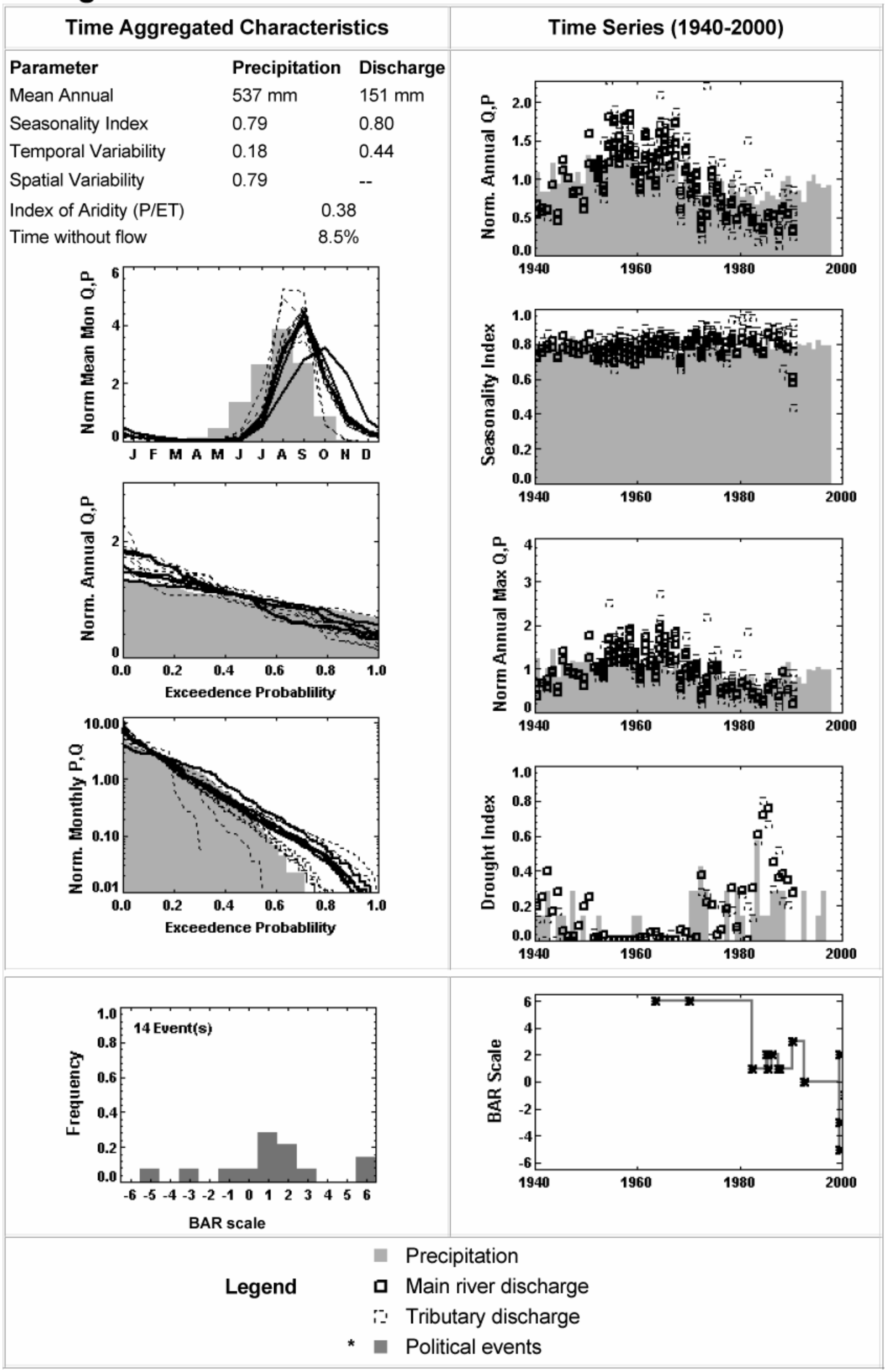


Figure 6: Example of a basin signature plot: The Senegal River Basin (shared by Guinea, Mali, Mauritania and Senegal)

Figure 6 shows an example for the Senegal River basin. The values for the time-aggregated single-value parameters are placed in the upper left hand corner, graphs of the aggregated distributions are on the left hand side, and time series are on the right hand side. For the discharge-based variables, the average (thick line) as well as the maximum and minimum (thin line) of all gauges at the main river are plotted as solid lines. The same values for tributaries are plotted as dashed lines. Finally, for comparison with the international relations data in the basin, the distribution of conflictive and cooperative political events is plotted below the distributions of hydrologic parameters (see also Stahl, 2005), and the time series of political events on the conflict-cooperation scale is plotted below the hydrologic time series. The graphs give an overview of the situation in the basin. The example of the Senegal River illustrates the strong seasonality of the river that features a long dry period. The inter-annual variability of precipitation and discharge is high and since the 1970s the well-known reduction of precipitation in the Sahel region can be seen. This is even more pronounced in the drought index. Two treaties between riparian countries that were closed in the 1960s seem to not have been able to absorb the stress imposed by the reduction of available water: cooperation became less concrete in the 1980s and conflictive events were reported at the end of the 1990s.

More signature plots for selected basins for which political events and sufficient hydrological data were available are included in Appendix 4. They are included to illustrate various issues, including extreme hydroclimatic conditions, data problems as well as links between hydroclimate and water-related international relations. A few interesting aspects are briefly discussed in the following paragraphs and the specific issue of hydrologic events as stress and trigger for conflict and cooperation is dealt with in Section 4.3.

Signature plots from North America

The Colorado River basin receives and average of 323 mm of precipitation. Yet, the specific discharge is only 48 mm. This low value is likely a combination of the exotic nature of the river (flows through different climate zones) and over-exploitation. Seasonality and inter-annual variability are high. The drop in seasonality in the 1960s which is visible in the data from the main river is likely the results of the building of Glen Canyon dam.

The Columbia River in southwestern Canada/ Northwestern USA has a snow-melt dominated hydrological regime. The development of the Columbia River by Canada and the USA can be seen in the signature plots. After agreements between two countries were signed and several dams were built in the 1960s, the hydrological regime changed. The seasonality of the discharge at a station in the lower Columbia River is lowered from pre-development 0.4 to a value of 0.2 indicating this ‘flattening’ of the regime. A slight reduction in the magnitude of the maximum annual floods is also visible. Periods of low flow are longer in the second half of the time-series, even though precipitation indicates minor drought conditions at the most.

Signature plots from Southern Europe

The Rio Guadiana, which is shared by Spain and Portugal, flows through some of the driest parts of the Iberian Peninsula. At the same time it is heavily regulated and heavily used, mainly for irrigation. The low specific discharge as well as the high seasonality and temporal variability, especially compared to more moderate values for precipitation are indicators for such water stress. Multi-year reservoirs are common in both countries and the flow is almost entirely regulated. Spain and Portugal signed treaties regulating use and development of the water resources of the international reaches of the Miño, Limia, Tajo, Guadiana and Chanza rivers and of their tributaries in the 1968 and 1976. With increasing pollution, demand and water use these agreements have proven insufficient and renegotiations which started in the mid 1990s are still ongoing.

Signature plots from Central Europe

The signature plots of the Oder/Odra River (Czech Republik, Slovakia, Poland and Germany) present a fairly quiet basin both hydrologically and politically. The two major floods in 1997 and 1999 were clearly exceptional in recent history. All political events recorded in the TFDD are cooperative.

Signature plots from the Southern African Region

The signature plots of the Incomati River show some limits to the adopted methodology. The data shown is from the station Hooggenoeg on the Komati River in South Africa. The Nooitgedacht dam, which was commissioned in 1962 (Carmo Vas and van der Zaag, 2003) completely changed the flow of the Komati River in 1965. The plots help detect the influence, however, with such a change the derived parameters cannot be interpreted easily. Despite the hydrologic regime change, however, some of the extreme events mentioned by Carmo Vas and van der Zaag (2003), such as the extreme low flow and drought events in 1982/83 and 1992 as well as the flood in 2000 can still be distinguished as extremes in the post-dam streamflow series.

Signature plots from the Middle East

The signature plots for the Jordan and for the Tigris-Euphrates River Basins, the political 'hot spots' in the Middle East, are included. Though both are in dry regions, the Jordan River clearly has the less fortunate hydroclimatic regime with a longer dry season and high temporal variability. As the discharge values indicate, both rivers are heavily regulated. The data availability from the region is poor and the available data don't fully overlap with the political data. The reasons are most likely a mix of general unavailability as well as data being kept secret due to unilateral developments common in the region. This particularly concerns Turkey's past and current dam building activities.

3 Applications

3.1 Influence of hydroclimate on water-related international relations

Background and Objective

Hydrology and climate is believed to play a major role in the level of conflict and cooperation over water and in the difficulty for riparian countries to agree over transboundary water management issues. Studies on the topic are generally site-specific and look at one or perhaps a few selected basins. The only large-*n* study, the Basins-at-Risk (BAR) project by Yoffe et al. (2003), found no significant difference between most climate types and dispute levels and no consistent pattern in the relationship with precipitation. The BAR analysis utilized the international river basin as the primary spatial unit of analysis. The dependent variable, a conflict level for the basins, was derived by averaging BAR scale values of all historic political events (cooperative and conflictive) that were reported within the period of the study.

Using the new improved hydroclimatic dataset we investigated the influence of hydrology, climate and hydrologic variability on the international relations in international basins. On a global scale, the specific objective was to test whether riparian states of transboundary rivers with higher/lower hydro-climatic variability, arid/humid conditions, etc. conflict and cooperate more/less over water.

Method

For this purpose, a finer spatial resolution, the geographic unit of the basin-country-polygon (BCP) was chosen for the analysis. The BCP is the portion of an individual country within an international river basin. As the averaging of all political events' conflict level strongly reduced the variability in the data in the BAR study, another approach was chosen for the representation of the political relations. The relative frequencies of events in five aggregated conflict-cooperation (CCL) levels were used. The five levels represent most conflictive, conflictive, neutral, cooperative and most cooperative political events. Only units with more than five events in their record were included in the analysis.

As the response is now a frequency distribution with five discrete classes, bivariate correlation and regression analysis cannot be used. Instead, the hydrologic and climatic parameters for the basin-country-polygons were used to test if BCP subsets with particular hydro-climatic conditions (e.g. arid climate, high discharge variability, a certain river type, etc.) have a different distribution of conflictive and cooperative political events than randomly chosen subsets of BCPs. As each hydro-climatic subset contains a different number of BCPs, we adopted an approach which compares the observed average relative frequency distribution of the political events for a given hydro-climatic subset of n BCPs with the average frequency distributions of the political events re-sampled from 10 000 subsets of *n* BCPs randomly drawn from the available dataset. The ranking of the political events' frequencies of the hydro-climatic subset within the 10000 random samples indicates whether a certain hydro-climatologic region is associated with relatively high or low frequency of a certain conflict level.

Nine parameters describe the BCPs' hydro-climatology: aridity, annual precipitation, specific discharge, spatial variability of precipitation, temporal variability and seasonality of precipitation and discharge, and river type. The relationship of mean annual precipitation to mean annual potential evapotranspiration is often used as an index of aridity (A) with the climate characterized by $A< 0.2$ (arid), $A< 0.5$ (semi-arid), $0.5<A<1.33$ (sub-humid) and $A>1.33$ (humid). Finally we defined the prevailing river type by the time with zero flow (Qz in %) with $Qz<10\%$ (perennial) and $Qz>10\%$ (intermittent or ephemeral), averaged for the data from stations with more than 5 years of record in a basin-country-polygon. The three relative classes of the other parameters were based on the distribution in the sample.

Results

Table 4 summarizes the parameters, the sample size of available BCPs, and some results. Here, we concentrate on the hydroclimatic classes for which the subsets of BCPs show an increased probability of most conflictive or most cooperative events. An increased probability for conflict was found for arid and semi-arid regions, dry and high-variability precipitation

Hydroclimatic Variable	Parameter	Number of BCPs for test sample	Exceedance Probability > 75%	
			most conflictive (BAR –7 to –5)	most co-operative (BAR 5-7)
Precipitation and Evapotranspiration	Index of Aridity	134	arid semi-arid	arid
Precipitation	Annual Precipitation	134	dry	wet
	Spatial Variability	134	high	
	Temporal Variability	134	high	
	Seasonality Index	134	high	low
Discharge	Specific Discharge	77	low	low
	Temporal Variability	79		high
	Seasonality	79		high
	River Type	79	ephemeral	ephemeral

Table 4: Hydroclimatic parameters and test results

conditions, and ephemeral rivers. An increased probability of most cooperative events was also determined for arid regions, for regions with high precipitation and low seasonality, as well as for rivers with little and variable discharge. Graphs with the probabilities for the four discharge-based parameters are shown in Appendix 5.These results suggest that extreme conflicts but also strong cooperation are relatively frequent in regions with extreme climatic conditions characterized by high hydrologic variability. A high relative frequency of events on both sides of the conflict-cooperation intensity scale makes the basin appear moderate when averaging the scale of all events (as done in the BAR study mentioned earlier), thus concealing the more complex relationship with geographical indicators shown here.

Conclusion

Despite a net dominance of cooperation over water between riparian countries worldwide, our analysis demonstrates that historically, extreme events of conflict were more frequent in basins in marginal climates with highly variable hydrologic conditions. However, these climatic regions are also places where strong cooperation and treaties have been worked out. Extreme hydroclimatic conditions seem to leave only the choice of violent conflict or strong cooperation (particularly visible for river flow parameters). The riparian states of rivers with less extreme natural conditions have been more moderate in their conflict/cooperation relationship. The entire causal relationship between hydrology and water-related political relations is certainly complex and strongly dependent on socio-economic conditions and institutional capacity as well as the timing and occurrence of changes and extremes in a country and basin. Therefore it can be concluded that further work with the global database should focus on multivariate approaches (Section 4.2) and consider temporal aspects (Section 4.3).

3.2 Multivariate modeling of the risk of conflict

Background and Objective

The Basins-At-Risk Analysis by Wolf et al. (2003) as well as the analysis with improved hydroclimatic data presented in the previous section show that

a) not one single factor combinations of several influences are related to conflict and cooperation and

b) the relations between hydroclimatic factors and political events along the conflict scale are not linear.

This application therefore attempts to model the likelihood of the occurrence of conflict in a basin with a given combination of hydroclimatic and socioeconomic factors.

Method

For the multivariate modeling of the risk for conflict in a basin, a classification and regression tree (CART) approach was chosen and carried out using the CART-software of Salford Systems, San Diego. CART models allow the inclusion of numeric as well as categorical variables. These do not have to be normally distributed, and can be interrelated. The method further accounts for the multiple conjunctional causality known to govern international relations, meaning that different combinations of factors can lead to the same outcome, and the same factor can have a different effect under different circumstances (Chan, 2002).

A classification tree predicts a single categorical response variable (here: conflict = 1 and no conflict = 0) by the values of a set of predictor (explanatory) variables. Constructed by recursive partitioning of a learning sample of class values (response variable) and predictors, the tree finally represents a collection of many decision rules displayed in the form of a binary tree. Each point in the tree where a decision has to be made is called a "node" with true or false leading either to the next decision rule or to a "terminal node", where a classification is assigned. In our case the rules take the form of: "if Index of Aridity $A \geq 1.5$ and population density $Pop \geq 100$ people/km2 and the river is ephemeral and …, then basin x is most likely in Class 1 (conflict)". For cases with missing data in the predictor values alternative rules using available predictors (surrogate splitters) are found.

In this study the response variable was based on the political events from 1950 -2000 and describes whether there has ever been a conflict (events with a negative BAR code) or never been a conflict (no events with a negative BAR code) in a basin. The predictor variables consist of all time-aggregated hydroclimatic variables for the basins as well as the number of riparian countries (*ncountries*), the number of major dams (*dams*), the basin area (*Barea*), the population density (*Pop*), the average GDP per capita (GDP_{avg}) and the average index of democracy (DA_{avg}) of the countries involved. In a standard procedure, first a maximum classification tree was fitted to the learning sample of 123 basins which have records of political events. The tree was then pruned to a cost-complexity optimized tree and subjected to a 20-fold cross-validation. Finally, the optimum tree rules were applied to the basins without political data to predict their risk for conflict.

Results

The CART analysis produced a classification tree with 14 nodes (Figure 7). It can be read in the same manner as a decision tree: if the spatial variability of precipitation (PCVS) in a basin is lower than 0.47 then further classification follows the rule at node 2, else it follows the one at node 12, etc. The figure also shows the distribution of classes at each terminal node and the number of basins classified at each terminal node. The tree correctly classifies 90.2% of all basins with no conflict (65 of 72) and 94% of all basins with conflict (47 of 50) in the learning sample. In the 20-fold cross-validation procedure, on average 64% of basins with no conflict and 70% of basins with conflict are classified correctly.

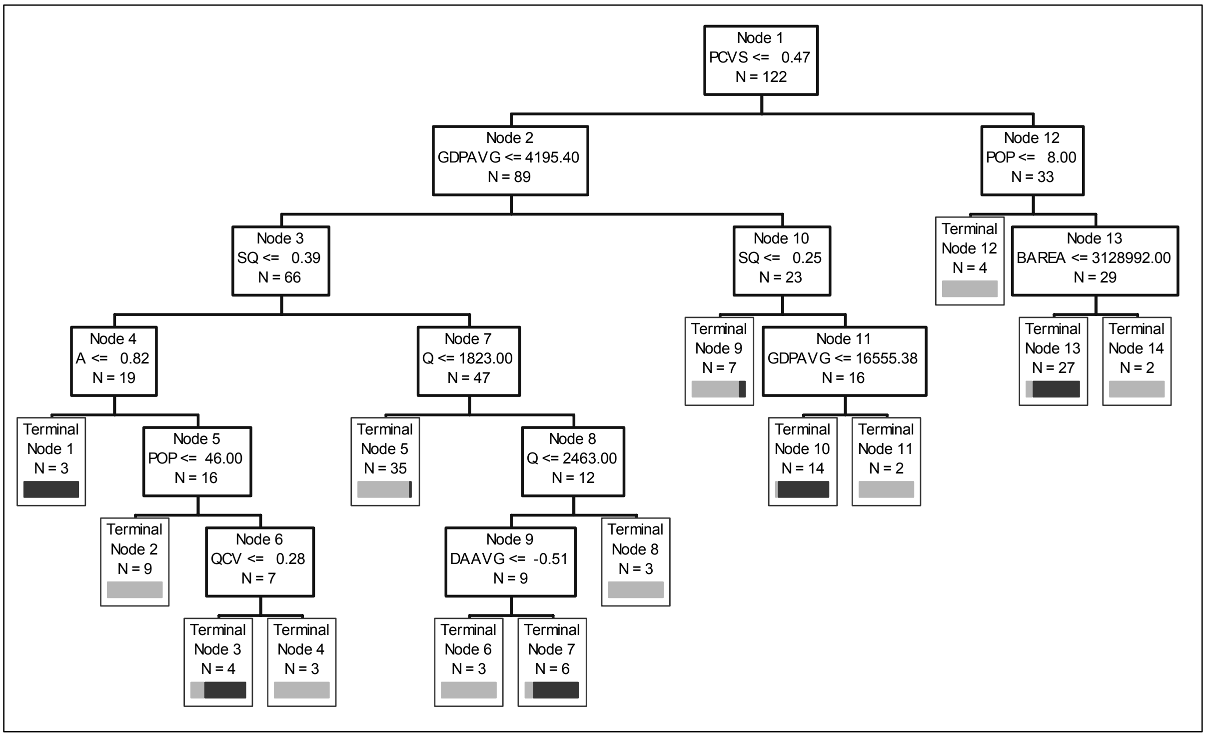


Figure 7: Optimum classification tree with class distribution at the terminal nodes (dark grey = basins with conflict, light grey = basins with no conflict)

The most important splitters are seasonality of discharge, spatial variability of precipitation, GDP, and population density. Many of the well-known conflictive basins (e.g. Jordan, Tigris) were classified by a high variability of precipitation and a moderate (not very low) population

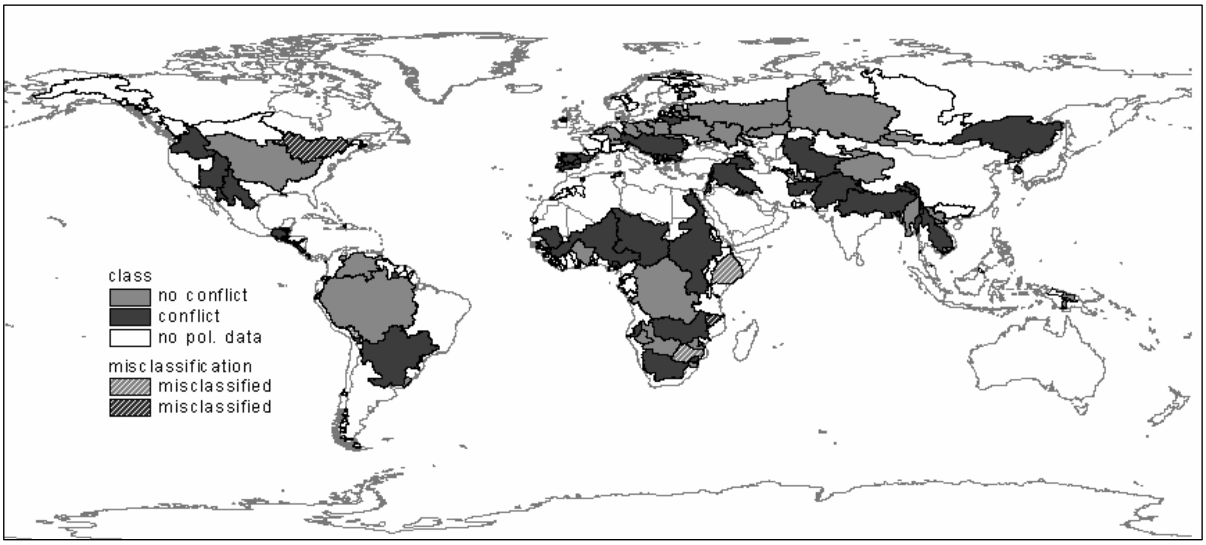


Figure 8: Classification tree result for the learning sample of 123 basins with political data records

density. The map in Figure 8 shows the classification result. It confirms the strong relevance of the hydroclimate, in particular that of its variability and climatic transition locations. Figure 9 shows the result of the application of the derived classification rules to all basins, including those for which no political data was available. For the latter basins, the result from this application could be interpreted as prediction of the risk for conflict or potential for cooperation.

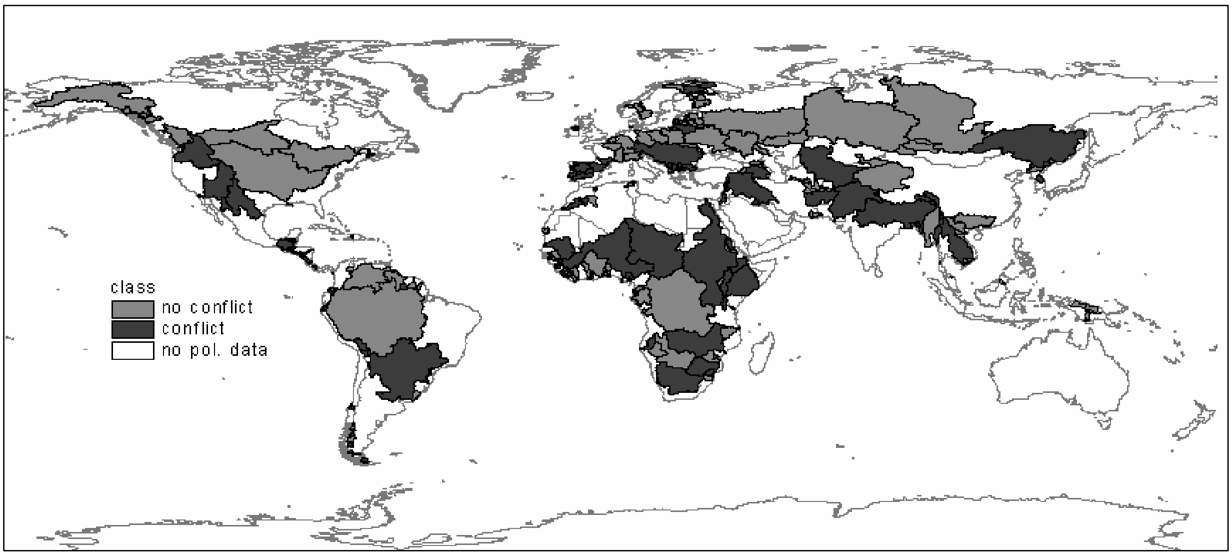


Figure 9: Classification tree model application to all global international basins

Conclusion

A classification model such as the one shown in this application is relatively easy to establish. It could be improved any time with new and additional data, both political data for the response and new and additional predictor variables, including qualitative categorical data. This is an important aspect as political scientists have made considerable progress for example in explaining institutional influences. The model has potential for risk assessment and in principle it can serve for the evaluation of scenarios elucidating potential impact of climate change or political and economic developments.

3.3 Investigating hydrology as potential stress and trigger

Introduction

While the previous applications, and in fact most global studies on causes for conflict and cooperation in international basins, rely on time-averaged indicator data, there are strong indications that temporal changes of these are even more influential. Homer-Dixon (1995) distinguishes environmental scarcity's causal role in political conflict as underlying stressor, aggravator, or trigger – i.e. by its temporal effect. Using a similar concept, Alcamo et al. (2001) present a modeling strategy for global environmental security based on freshwater and crop production. They distinguish "slow" and "fast" changes for crisis determination. With respect to conflict in the world's international river basins, Wolf et al., (2003) concluded from their global analysis, that if rapid change cannot be absorbed by institution, conflict is likely. As an example they cite the overall increase in the conflictive fraction of water related political events after the break up of the Soviet Union and former Yugoslavia, which reduced institutional capacity in the regions.

Analyses with TFDD data have identified factors such as high population density and low GDP (Wolf et al. 2003; Yoffe et al., 2003) as well as climate and hydroclimatic variability (Stahl, 2005) as underlying stressors for water-related international relations. Using the available information from the signature plots (Appendix 4), the aim of this section is to explore examples of hydrology acting as stress or trigger for political events. The different periods covered and varying data availability between basins at this stage only allows visual inspection and interpretation of hydroclimatic time-series together with the political events from the TFDD for individual basins.

Examples of stress and trigger time series visualization

Table 5 provides a selection of hydrological events from basins around the world which are found or suspected to be linked to subsequent political events.

Region	Basin	Hydrological Event	Possibly linked political event
North America (US-Mexico)	Colorado	Drought in the 1960s	Dispute over salinity (1972)
		Drought in the early 90s, low annual floods	Dispute over renegotiation of treaty because of pollution and over allocation
Southern Europe	Guadiana	Drought in the early 1990s	Dispute over renegotiation of treaty because of pollution and over allocation
Central Europe	Odra	Flood 1997	Cooperation on flood protection and other issues
Southern African Region	Incomati	Drought 1982	Trilateral negotiations on water sharing
West Africa	Senegal	Trend and multi-year droughts	Conflict over projects and water rights in the 1990s
Middle East	Jordan	1994 moderate drought 1999 drought	Raising the need for treaty amendments conflict, particularly between Israel and Jordan
Southeast Asia	Mekong	Negative trend of annual q and increase in drought in early 1990s	Increased political activity; drought of 1994 is the context for negotiations on river diversions for irrigation in Thailand

Table 5: Hydrological changes and events linked to conflict and cooperation

In North America, the USA and Mexico share the Colorado and the Rio Grande Rivers. Both have been the issue of considerable dispute, negotiation, and cooperation. In the signature plot of the Colorado River (Appendix 4), it can be seen that drought in the 60s as well as drought in the early 1990s were followed by political events. In the Rio Grande basin (not shown), consecutive years of drought in the late 1990s and early 2000s were and still are the cause for dispute, because Mexico has not delivered the negotiated discharge (after taking the drought escape clause included in the treaty).The water-related international relations between Spain and Portugal have been strained by consecutive drought years in the 1990s. Recent discharge data was unavailable for any of the transboundary rivers in the region (Guadiana, Duoro and Minho). However, the drought is visible in the precipitation data of the signature plots for the Guadiana (Appendix 4). The current drought (2005) has further soured the relations.

The disastrous flood of the Oder/Odra River (Czech Republik, Slovakia, Poland and Germany) in 1997 has triggered a series of talks and negotiations among the riparian countries concerning cooperation on flood protection but also on other issues of integrated river basin management.

Carmo Vas and van der Zaag (2003) describe in detail the chronology of water-related conflict and cooperation over the Incomati River. Floods and droughts have started and greatly influenced negotiations. After the 1982/83 drought, when the Incomati had fallen dry in Mozambique, South Africa agreed to guarantee a minimum flow. Future droughts have challenged this agreement, which was not always met. Floods have also triggered cooperation and data sharing among riparian states.

The time series of the hydroclimatic and hydrologic variables for the previously discussed Senegal River show a strong seasonality with frequent droughts of the Senegal und its tributaries. Since the 1970s, annual precipitation and runoff have decreased continuously. This drought that affected the whole Sahel region is also visible in the drought index and the decreasing annual floods (Figure 6). At the same time, the political relations between the riparian countries seem to have deteriorated. After having closed several treaties in the 1960s (Level 6 on the BAR Scale) several incidents of verbal and violent dispute (negative levels on the BAR scale) have been reported. Though they were mainly concerned with engineering projects and water rights, the increasing water scarcity is likely to have played the role of a stressor on the water-related international relations.

Much has been written on water disputes over the Jordan river and its tributaries and political motivation and relative water scarcity are clearly main drivers for most of the water-related interactions between Israel and its neighbors. In the many political events about the Jordan river in the political event database of the TFDD, drought is mentioned several times as a concern and issue pressing for cooperation. The first mentioning can be found in 1991 and then in 1994, right after years with low flow according to the discharge data available (Appendix 4). The database entry is a record of public concern that drought conditions should be considered and included in any future treaties over water sharing. The next mentioning of drought can be found in 1998/99, when Israel announced that due to drought it can only provide 40% of the annual allocation of the Yarmuk water. Jordan initially rejects any change in the terms of the treaty and a long process of negotiations starts to solve the crisis.

In the records for the Mekong basin, finally, it can be found that the drought of 1994 was the context for negotiations on river diversions for irrigation in Thailand. Droughts in the early 1990s are visible in the signature plots.

Discussion

In all examples one can find mentioning of both, increasing stress and specific hydrologic events which then triggered political incidents. Drought seems to have been the major hydrological event to influence international relations. Often smaller droughts occurred, then a more severe one (likely exacerbated by increased demand due to accelerated development) followed and triggered interaction between the riparian countries of the transboundary river. Finally, in most of the aforementioned examples, drought has not only caused conflict but also initiated cooperation. However, it seems that too often the need is recognized to consider the occurrence of drought in treaties and agreements but then it is not successfully implemented before a more severe event occurs.

Floods are more sudden events that seem to lead almost exclusively to increased cooperation between countries. Reasons probably include that the destruction from floods is often more visible and hence leaves a strong impression on people. Also, knowledge on technical flood protection measures is more advanced than drought mitigation measures. The sample of floods considered here, however, maybe biased towards financially privileged countries.

4 Concluding Remarks

This report presented a set of hydrologic parameters derived from Global Runoff Data Centre (GRDC) data which were merged with a global political database on water-related international relations. The parameters describe average conditions as well as hydroclimatic variability and extremes over time in the world transboundary rivers and their tributaries. Three applications illustrated how the parameters together with other variables can be used for interdisciplinary analyses such as testing general theories on international relations over water, modeling influences of hydroclimate on conflict and cooperation, and exploring simultaneous occurrence of climatic and hydrologic events and conflicts or treaty negotiations.

Though somewhat limited by availability and quality of hydrologic as well as political data, the set of variables does provide a basis for interesting global analyses. Studies as the ones suggested can help to shed light on the causality of conflict and cooperation over water. They demonstrated the importance of hydroclimatic variability both in time and space and hence highlighted the need for a solid long-term global runoff database. Since the project's completion more data has become available and future applications could in more detail study the causal effect of hydrology on international relations by looking at the year to year variability of these indicators.

Acknowledgements

The author is particularly grateful for Shira Yoffe's introduction to the political event data and Aaron Wolf's support and advice. The research was funded by a scholarship from the German Research Foundation (DFG) and carried out at the Department of Geosciences at Oregon State University. Data and support from the Department and the Transboundary Freshwater Dispute Database are gratefully acknowledged. The CRU kindly provided the precipitation data used in the applications.

5 References

Ahn, C.-H. and R. Tateishi. 1994. Development of a Global 30-minute grid Potential Evapotranspiration Data Set. Journal of the Japan Soc. Photogrammetry and Remote Sensing, 33(2): 12-21.

Alcamo, J., Henrichs, T. and Rösch, T. 2000. World Water in 2025 - Global modeling and scenario analysis for the World Commission on Water for the 21st Century. Report A0002. Center for Environmental Systems Research, University of Kassel, Germany.

Alcamo, J., Endejahn, M.B., Kaspar, F., and Rösch, T. 2001. The GLASS model: a strategy for quantifying global environmental security. Environmental Science and Policy, 4:1-12.

Ashton, P.J. 2002. Avoiding Conflicts over Africa's Water Resources. Ambio, 31 (3): 236-242.

Azar, E.E. 1980. The Conflict and Peace Data Base (COPDAB). Journal of Conflict Resolution, 24(1): 143-152.

Carmo Vas, A. and van der Zaag, P. (2003). Sharing the Incomati Waters. Cooperation and Competition in the Balance. UNESCO, IHP, WWAP. Technical Documents in Hydrology. PC-CP series. No. 14. 102p.

Chan, S. 2002. On different types of international relations scholarship. Journal of Peace Research, 39 (6): 747-756.

Dingman, L.S. 2002. Physical Hydrology. Prentice-Hall.

Dobson, J.E., E.A. Bright, P.R. Coleman, R.C. Durfee, and B.A. Worley. 2000. LandScan: a global population database for estimating populations and risk. Photogrammetric Engineering & Remote Sensing, 66 (7): 849–857.

Falkenmark, M. 1989. The massive water scarcity now threatening Africa—why isn't it being addressed? Ambio, 18(2): 112–118,

Fiske, G. and S.B. Yoffe. 2001. Use of GIS for Analysis of Indicators of Conflict and Cooperation over International Freshwater Resources. http://transboundarywaters.orst.edu/documents/fiske-yoffe.pdf.

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

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

IPCC. 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability. A report of the working group II of the Intergovernmental Panel on Climate change.

Kelly, M. and K. Chapman. 2002. Sharing the Waters, Americas Program Investigative Article, Silver City, NM: Interhemispheric Resource Center.

Markham, C.G. 1970. Seasonality of precipitation in the United States. Annals of the Association of American Geographers, 60: 593-597.

New, M.G., M. Hulme and P. D. Jones, 2000. Representing twentieth-century space-time climate variability. Part II: Development of 1901-1996 monthly grids of terrestrial surface climate. J. Climate, 13: 2217-2238.

PolityIV Project. 2000. Polity IV Dataset. [Computer file; version p4v2000] College Park, MD: Center for International Development and Conflict Management, University of Maryland. http://www.cidcm.umd.edu/inscr/polity/ [last accessed 5-8-2003]

Stahl, K. 2005. Influence of hydroclimatology and socio-economic conditions on water-related international relations. Water International. 30 (3), 270-282.

The German Advisory Council on Global Change. 1999. World in transition: ways towards sustainable management of freshwater resources. Annual Report, 1997. Springer Verlag. Berlin Heidelberg.

Toset, H.P.W., N.P. Gleditsch and H. Håvard. 2000. Shared Rivers and Interstate Conflict. Political Geography, 19(8): 971-996,

UNEP and OSU. 2002. Atlas of International Freshwater Agreements. UNEP. Nairobi.

UNEP GRID. 2003. http://www.grid.unep.ch/data/grid/climate.php [last accessed: 3 Sep 2003]

UNESCO. 1997. Map of the world distribution of arid regions. Accompanied by explanatory note. MAB Technical Notes No. 7., Paris, UNESCO, 54 p.

Vörösmarty, C.J., P. Green, J. Salisbury, and R.B. Lammers. 2000. Global Water Resources: Vulnerability from Global Climate Change and Population Growth. Science, 289: 284-288.

Wolf, A.T., J. Natharius, J. Danielson, B. Ward, and J. Pender. 1999. International River Basins of the World. International Journal of Water Resources Development 15(4), 387-427.

Wolf, A., S.B. Yoffe, and M. Giordano. 2003a. International Waters: Identifying Basins at Risk. Water Policy, 5: 29-60.

World Bank. 2003. Online databases: GDP data. http://www.worldbank.org/data/ [last accessed: 29 Aug 2005]

Yoffe, S.B. and K. Larson. 2001. Basins at Risk: water event database methodology. http://www.transboundarywaters.orst.edu/projects/bar/index.html [last accessed: 29 Aug 2005].

Yoffe, S.B., A.T. Wolf, M. Giordano. 2003. Conflict and Cooperation over International Freshwater Resources: Indicators of Basins at Risk, Journal of American Water Resources Association, 39(5):1109-1126.

Yoffe, S., Giordano, M., Giordano M.A., Larson, K., Stahl, K., Wolf, A.T. 2004. Geography of international water conflict and cooperation: Data sets and applications, Water Resour. Res., 40, W05S04, doi:10.1029/2003WR002530.

Appendices

Appendix 1: TFDD Indicator Variables

Variable	Description	Data source	Available for no. of BCPs
Area	Percentage of the basin area within the country	BAR/TFDD	654
Loc	Indicator of country being upstream, middle or downstream	BAR	656
B	River is the border for a substantial part of the country	BAR	656
Pop	Population Density	LandScan 2000	644
GDP	Per Capita Gross Domestic Product in 1995-US$ per year and person	World Bank (2003)	654
DA	Democracy/Autocracy Level	PolityIV (2000)	644

Appendix 2: Single-value Time-aggregated Hydrologic Parameters

Bcode	Basin name	Area (km^2)	Political Events	Aridity Index	q (mm)	CVQ	SQ	Qz (%)
ALSK	Alsek	28365	0	2.49	648	0.18	0.59	0
AMUR	Amur	2085864	21	1.17	194	0.31	0.52	7
AMZN	Amazon	5883357	3	1.45	1034	0.15	0.28	0
ARAL	Aral Sea (internal drainage)	1231389	32	0.37	397	0.27	0.5	3.38
ASIX	Asi	37900	16	0.59	291	0.37	0.29	0
ATBN	Artibonite	8830	0	1.06	644	0.47	0.34	0
BENT	Benito_Ntem	45115	0	1.36	403	0.2	0.23	0
BUZI	Buzi	27681	2	0.89	58	1.48	0.87	80.16
CGNL	Changuinola	3204	0	2.02	2793	0.11	0.15	0
CHIR	Chira	15705	2	0.4	395	0.76	0.43	0
CHRQ	Chiriqui	1735	0	2.28	2484	0.18	0.35	0
CLDO	Colorado	655030	16	0.38	48	0.45	0.33	1.91
CLMB	Columbia	668433	9	0.86	484	0.22	0.45	0.18
CNGO	Congo	3691027	6	1.06	349	0.15	0.25	1.06
COCO	Coco (Segovia)	25389	0	1.37	262	0.48	0.49	0.36
CRBL	Corubal	24004	0	1.31	403	0.15	0.75	0
CROS	Cross	52756	1	1.53	2423	0.2	0.62	0
CRUH	Coruh	22066	0	1.65	985	0.09	0.38	0
CTTB	Catatumbo	30970	1	1.17	819	0.43	0.07	6.18
CVLY	Cavally	30580	0	1.52	538	0.29	0.42	0
DANU	Danube	790119	170	1.59	451	0.25	0.21	0.63
DAUR	Daoura	34479	0	0.06	34	0.96	0.27	48.33
DNPR	Dnieper	516281	1	1.39	120	0.33	0.35	10.89
DNSR	Dniester	62000	2	1.31	155	0.31	0.2	0
DONX	Don	425551	1	1.19	63	0.48	0.57	16.78
DRIN	Drin	17917	2	1.95	573	0.25	0.23	0
DUGV	Daugava	58742	1	1.98	216	0.24	0.34	0.97
DURO	Douro (Duero)	98856	10	1.03	292	0.44	0.47	2.73
EBRO	Ebro	85787	7	0.97	283	0.44	0.31	14.56
ELBE	Elbe	132245	3	1.82	461?	0.29	0.22	0.03
ESQB	Essequibo	239480	0	1.35	906	0.27	0.4	0.06
FOYL	Foyle	2917	0	5.33	809	0.16	0.34	0
FRSR	Fraser	239735	0	1.21	648	0.17	0.51	0
FRTH	Firth	6046	0	1.41	201	0.25	0.75	35.82
GAMB	Gambia	69932	5	0.81	186	0.47	0.84	22.08
GANG	Ganges-Brahmaputra-Meghna	1634936	148	1.21	1063	0.17	0.61	0.07
GEBA	Geba	12784	0	0.99	13	0.67	0.82	29.71
GJLV	Grijalva	126790	3	1.39	1269	0.15	0.36	0
GLAM	Glama	43002	0	2.91	594	0.17	0.4	0
GLOK	Golok	1842	0	1.51	2042	0.28	0.36	0
GRON	Garonne	55783	0	1.48	440	0.33	0.39	1.67
GUDN	Guadiana	67925	11	0.65	70	0.87	0.58	25.21
GUIR	Guir	78913	0	0.12	8	1.51	0.45	93.05
GUJA	Gauja	11553	0	1.96	370	0.28	0.2	13.09
HANX	Han	35266	11	1.77	634	0.35	0.52	0
HRUN	Har Us Nur	185252	2	0.53	74	0.23	0.71	0

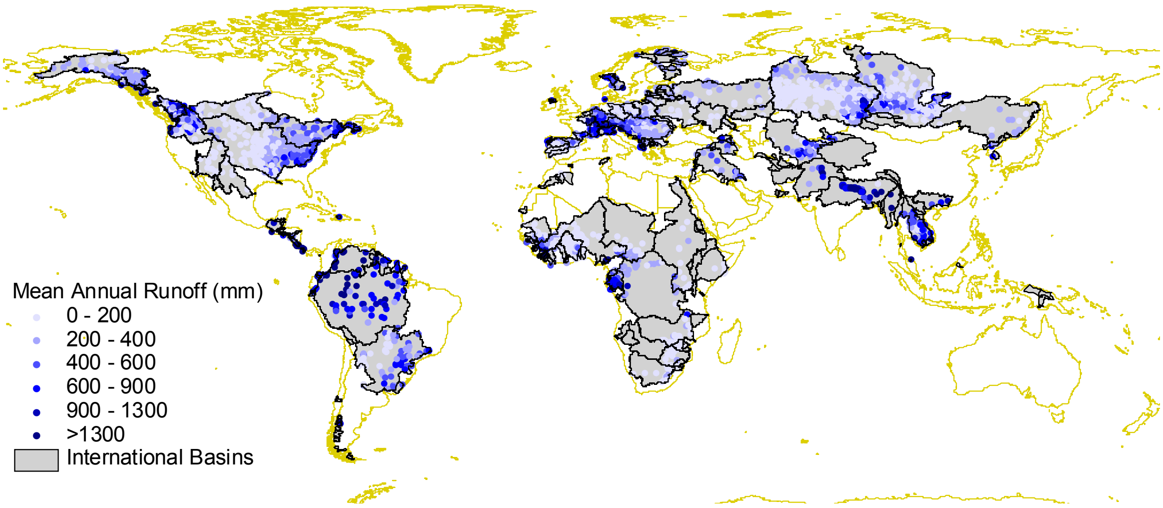
Bcode	Basin name	Area (km^2)	Political Events	Aridity Index	q (mm)	CVQ	SQ	Qz (%)
HSIX	Hsi	417755	0	1.34	733	0.25	0.49	0
ICMT	Incomati	46729	12	0.6	52	0.94	0.38	0.09
ILIX	Ili (Kunes He)	161221	8	0.52	431	0.18	0.43	0
INDU	Indus	1138805	58	0.36	528	0.38	0.54	0
IRWD	Irrawaddy	404189	3	1.5	2503	0.14	0.58	0
ISNZ	Isonzo	3021	0	2.08	1859	0.19	0.03	0
JORD	Jordan	34016	246	0.27	204	0.47	0.43	14.38
JUBA	Juba-Shibeli	803543	1	0.3	11	0.28	0.37	0.65
KEMI	Kemi	55732	0	3.07	349	0.2	0.29	0
KMOE	Komoe	78123	0	0.86	99	0.59	0.76	22.08
KRLV	Klaralven	50960	0	2.28	495	0.51	0.25	3.28
KURA	Kura-Araks	193197	16	0.84	367	0.26	0.32	0.06
LKCH	Lake Chad	2388687	5	0.28	200	0.32	0.67	8.11
LKPP	L_Prespa	9035	0	1.29	633	0.28	0.4	0
LKUN	Lake Ubsa-Nur	62784	0	0.78	176	0.18	0.5	0
LMPA	Lempa	18040	1	1.12	723	0.38	0.55	0
LMPO	Limpopo	414798	6	0.13	44	1.14	0.73	40.53
LMRM	Lagoon Mirim	54957	3	1.33	571	0.46	0.27	5.07
LPTA	La Plata	2954460	122	1.02	372	0.28	0.23	1.08
MBEX	Mbe	6981	0	1.62	1161	0.07	0.14	0
MEKO	Mekong	787776	88	1.18	607	0.26	0.58	1.36
MINO	Mino	15089	9	2.15	665	0.34	0.44	0
MIRA	Mira	12096	0	1.75	922	0.18	0.14	0
MISS	Mississippi	3226293	1	1.02	234	0.41	0.32	0.85
MONO	Mono	23430	0	0.88	949	0.53	0.83	19.98
MPUT	Maputo	30656	5	0.63	46	0.74	0.53	0
MRNI	Maroni	64999	0	1.52	742	0.34	0.45	0
MRSA	Maritsa	49643	11	1	166	0.43	0.48	13.64
NEGR	Negro	5766	0	1.15	376	0.71	0.56	0.81
NELS	Nelson-Saskatchewan	1109407	0	1.01	204	0.37	0.47	2.51
NGER	Niger	2113244	5	0.47	235	0.37	0.68	10.87
NILE	Nile	3031691	78	0.47	137	0.27	0.3	6.42
NMAN	Neman	90310	3	1.74	196	0.17	0.24	4.61
NRVA	Narva	52955	1	1.94	266	0.19	0.18	0
NSTO	Nestos	10190	5	1.05	320	0.26	0.36	0
NYGA	Nyanga	12340	0	1.23	840	0.19	0.33	0
OBXX	Ob	2950834	6	1.47	222	0.3	0.52	0.34
ODER	Oder (Odra)	122425	5	1.7	197	0.31	0.17	0.02
OGOO	Ogooue	222987	0	1.31	814	0.15	0.18	0
OKVG	Okavango	706879	4	0.24	21	2.08	0.93	87.22
OLNG	Olanga	18831	0	2.5	339	0.27	0.26	0
ORAL	Oral	311001	1	0.81	108	0.53	0.69	3.8
ORAN	Orange	945475	18	0.09	95	0.84	0.43	19.71
ORIN	Orinoco	927430	1	1.48	1671	0.16	0.37	0.65
OUEM	Oueme	59517	0	0.86	118	0.66	0.76	21.27
OULU	Oulu	28681	0	3.09	322	0.25	0.23	1.21
OYPK	Oyupock (Oiapoque)	23251	0	1.79	1044	0.25	0.41	0
POXX	Po	87076	0	1.9	811	0.23	0.16	0
PRNU	Parnu	5842	0	2.1	286	0.32	0.18	0
PSVK	Pasvik	16015	2	4.25	554	0.22	0.21	0
PTIA	Patia	21289	0	1.88	546	0.29	0.16	1.02
RGNA	Rio Grande	656109	8	0.33	13	0.75	0.38	3.25

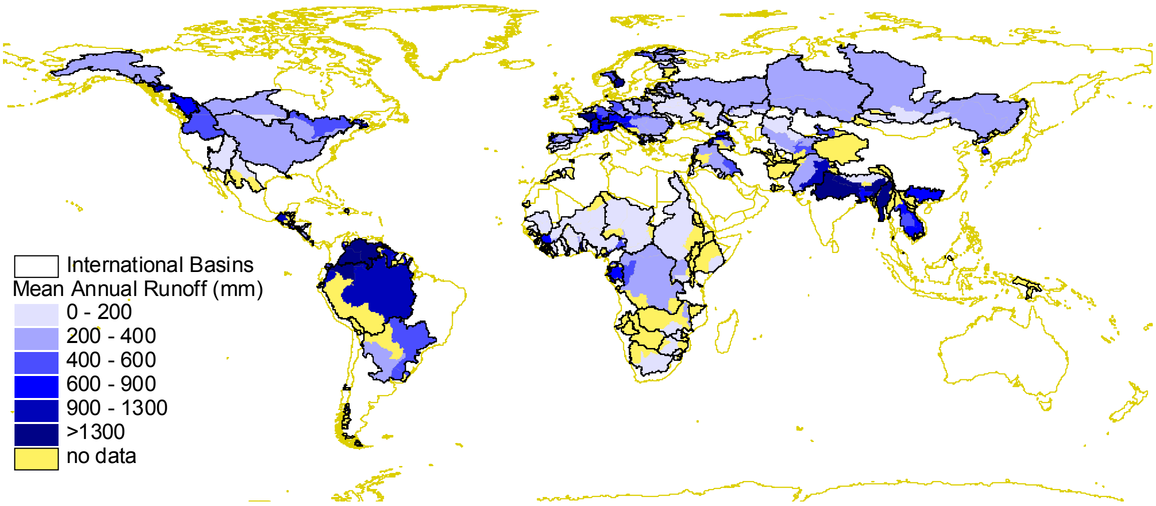
Bcode	Basin name	Area (km^2)	Political Events	Aridity Index	q (mm)	CVQ	SQ	Qz (%)
RHIN	Rhine	172945	9	2.3	582	0.24	0.23	0
RHON	Rhone	100219	0	1.82	822	0.26	0.26	0.2
SABI	Sabi	115695	2	0.53	124	0.76	0.7	22.71
SAMR	Samur	6772	1	0.7	539	0.19	0.52	0
SASS	Sassandra	68177	0	1.17	157	0.34	0.28	0
SCRO	St. Croix	4639	0	2.35	754	0.24	0.31	0
SEIN	Seine	85749	0	1.66	193	0.46	0.42	1.98
SENG	Senegal	435979	14	0.38	152	0.43	0.79	8.52
SHLD	Schelde	17107	1	1.93	130	0.32	0.22	0
SIOL	Sixaola	2873	0	2.01	2657	0.11	0.14	0
SJAF	St. John	15563	0	1.7	-	0.36	0.47	0
SJUA	San Juan	42166	2	1.52	2732	0.25	0.28	0.33
SKAG	Skagit	8021	1	2.26	2003	0.13	0.41	0
SLAW	St. Lawrence	1055163	22	1.58	351	0.17	0.19	0.06
STKN	Stikine	50868	0	3.1	1096	0.11	0.59	0
STUM	Struma	14982	1	0.98	186	0.28	0.32	0
SUCT	Suchiate	1554	0	1.64	2230	0.22	0.45	0
SULK	Sulak	15075	1	0.94	229	0.17	0.57	0
TAGU	Tagus (Tejo)	77871	9	0.93	158	0.58	0.39	0.17
TAKU	Taku	18145	0	3.3	539	0.14	0.6	0
TANO	Tano	15571	0	1.04	287	0.24	0.31	0
TERK	Terek	38741	1	1.44	657	0.15	0.49	0
TIGR	Tigris_Euphrates	789017	202	0.39	340	0.28	0.44	0
TORN	Torne	37316	0	2.88	593	0.18	0.52	0
TULM	Tuloma	25772	0	3.12	355	0.26	0.3	3.56
TUMB	Tumbes	4969	1	0.53	1223	0.25	0.53	2.08
VENT	Venta	9526	0	1.98	329	0.21	0.22	0
VJSE	Vijose	7169	1	1.45	1004	0.22	0.4	0
VOLG	Volga	1554883	1	1.65	226	0.27	0.4	4.3
VOLT	Volta	412799	3	0.72	88	0.48	0.76	22.5
VRDR	Vardar	32373	6	1.01	388	0.3	0.28	0
VSTL	Vistula	194010	4	1.56	230	0.36	0.17	0.01
WIED	Wiedau	1126	0	2.46	617	0.24	0.32	0
YALU	Yalu	50865	13	1.4	417	0.27	0.54	0
YELC	Yelcho	11139	0	1.75	1963	0.15	0.09	0
YNSY	Yenisey (Jenisej)	2557825	0	1.45	272	0.2	0.49	0.45
YUKN	Yukon	829732	0	1.43	304	0.17	0.56	2.36
ZAMB	Zambezi	1385275	18	0.72	122	0.91	0.75	44.26

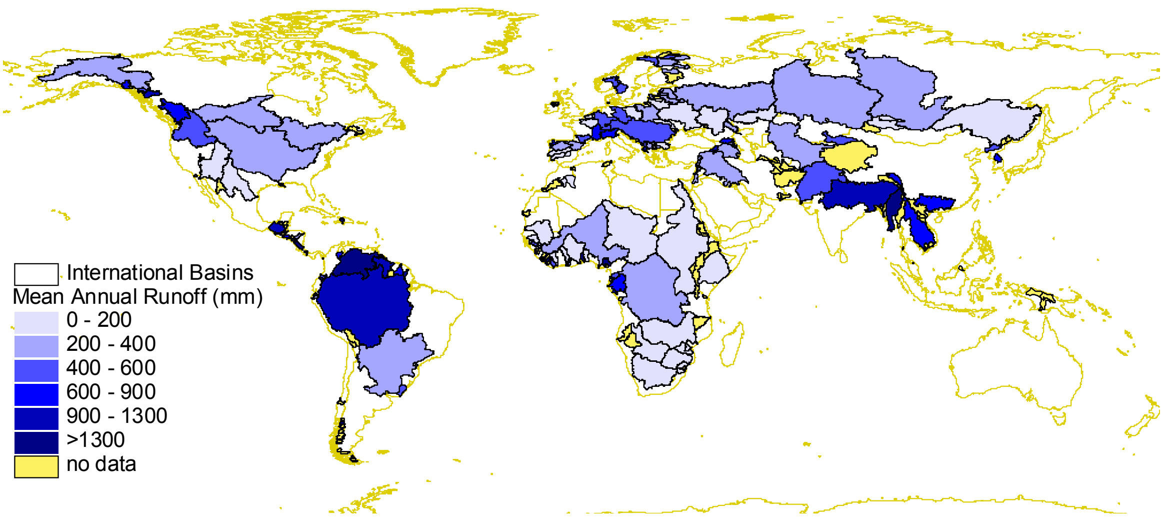
Appendix 3: Maps of Single-value Time-aggregated Hydrologic Parameters

(CTRL+click on the picture to enlarged figures at GRDC Homepage)

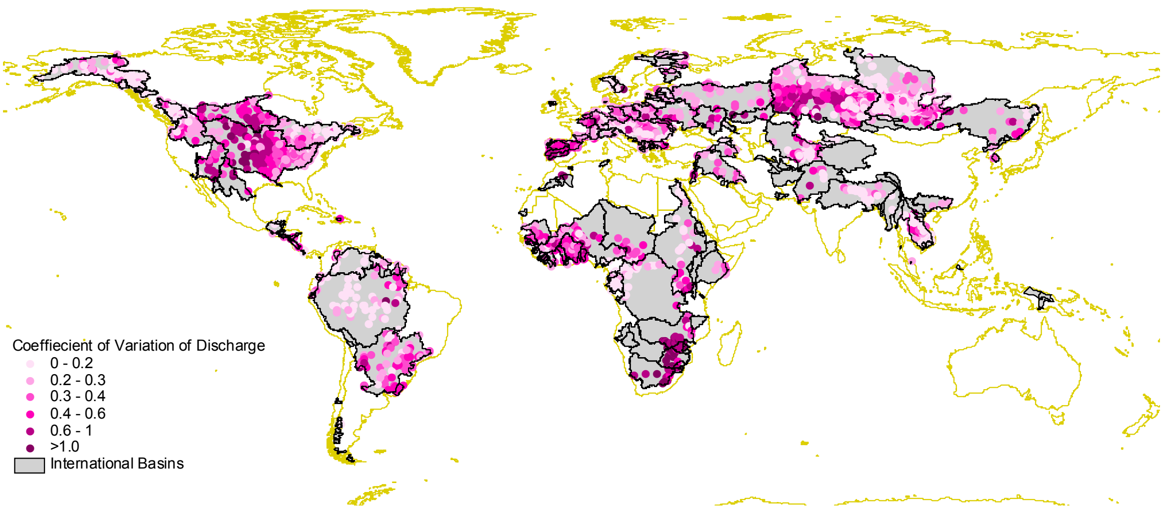
Mean Annual Runoff

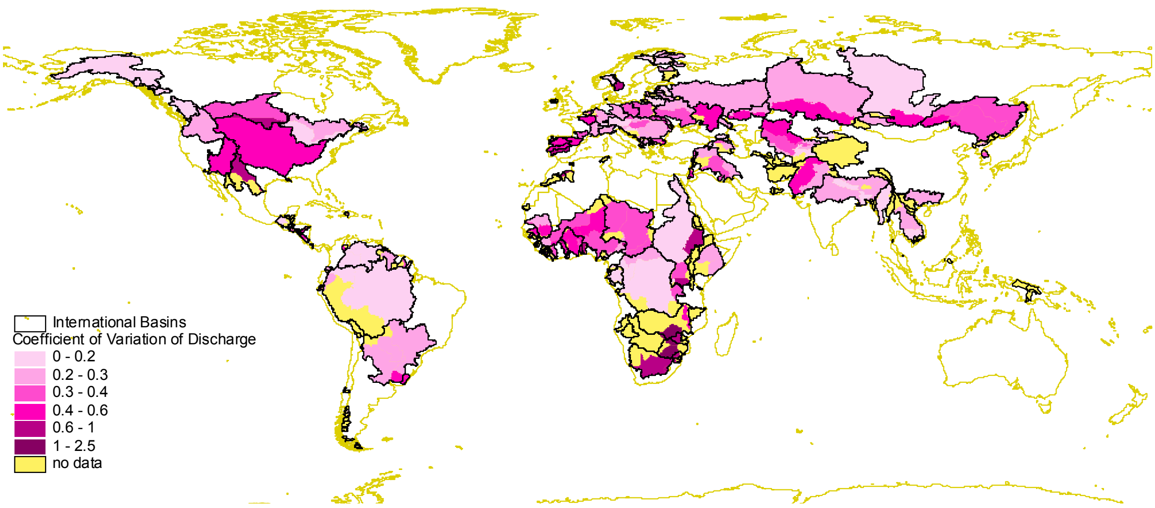


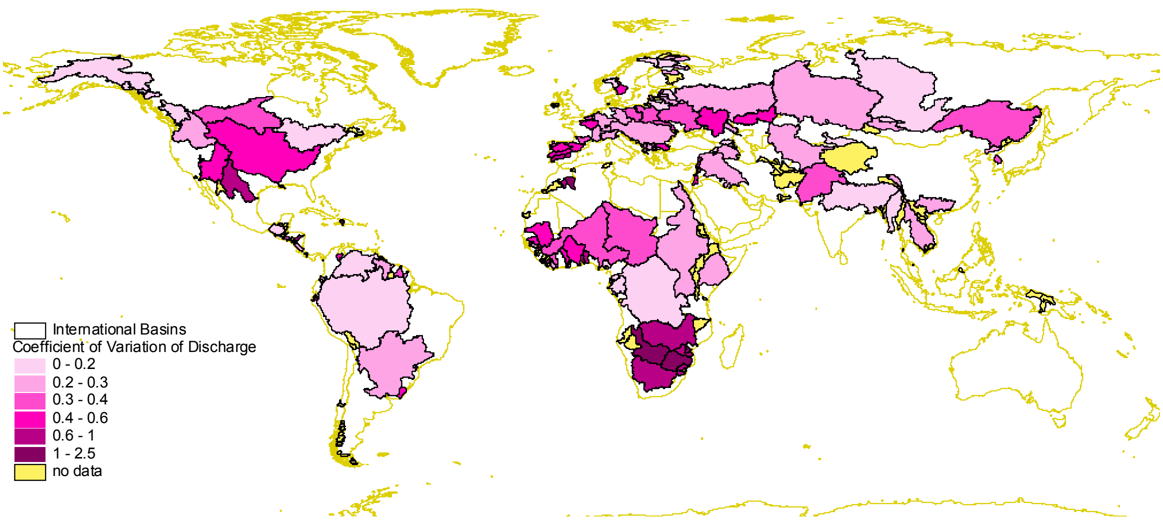




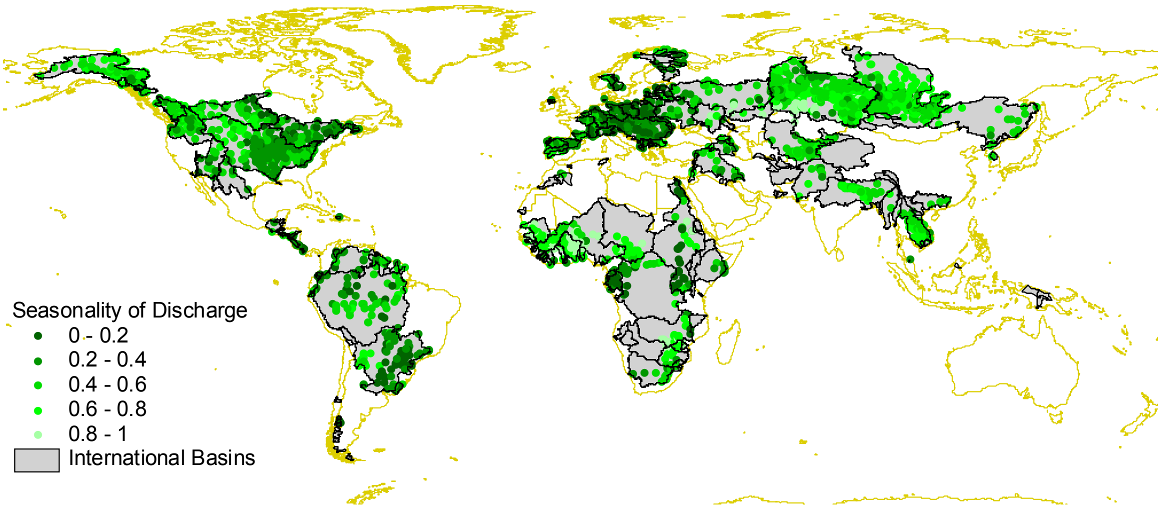
Coefficient of Variation of annual mean discharge

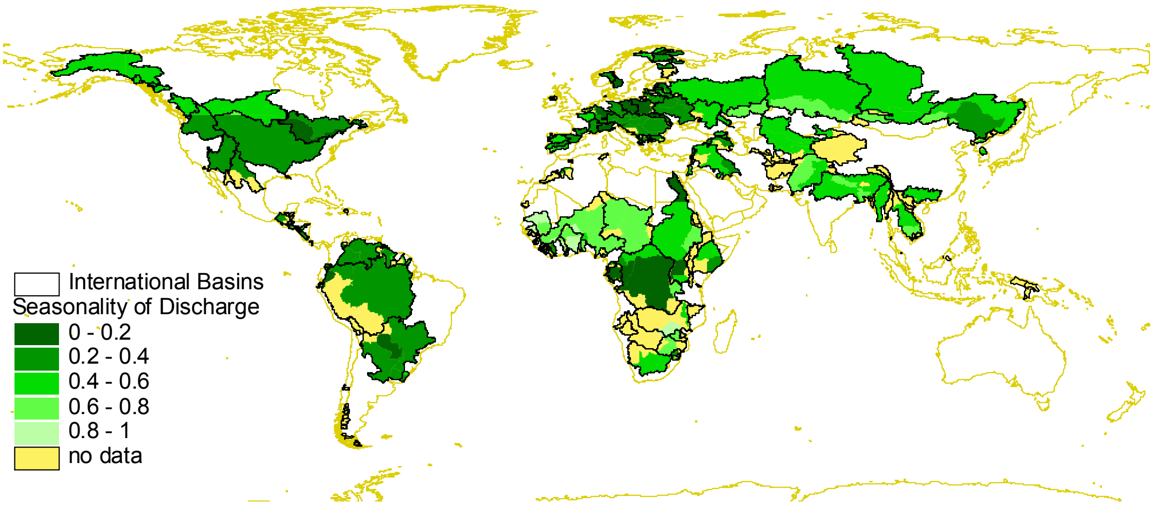


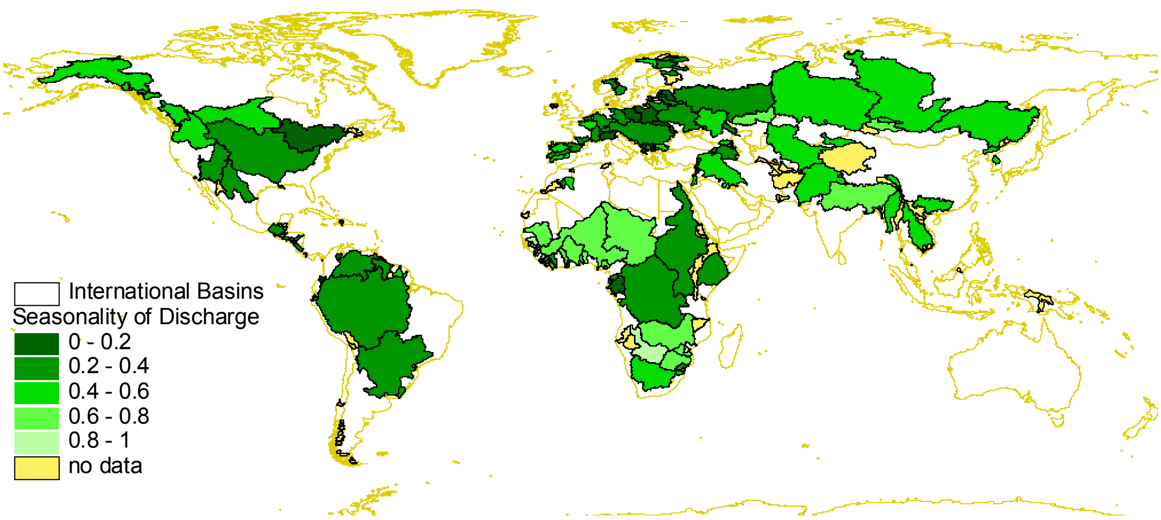




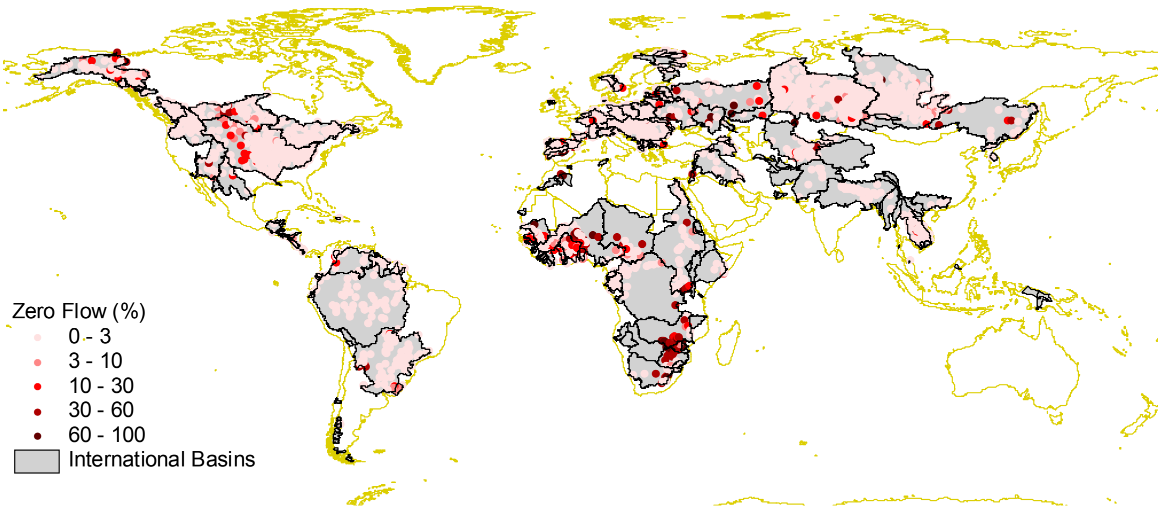
Seasonality of monthly discharge

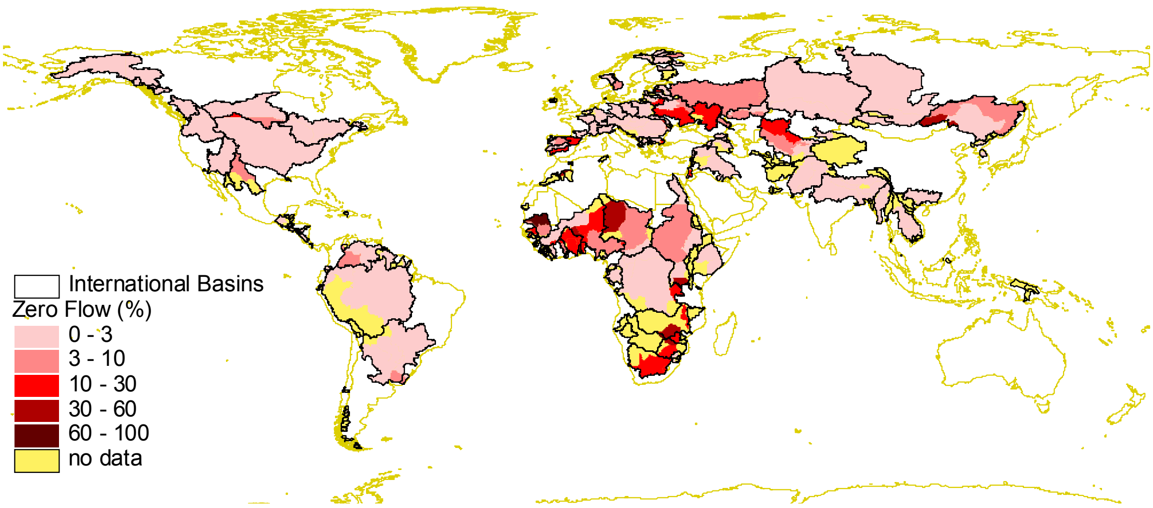


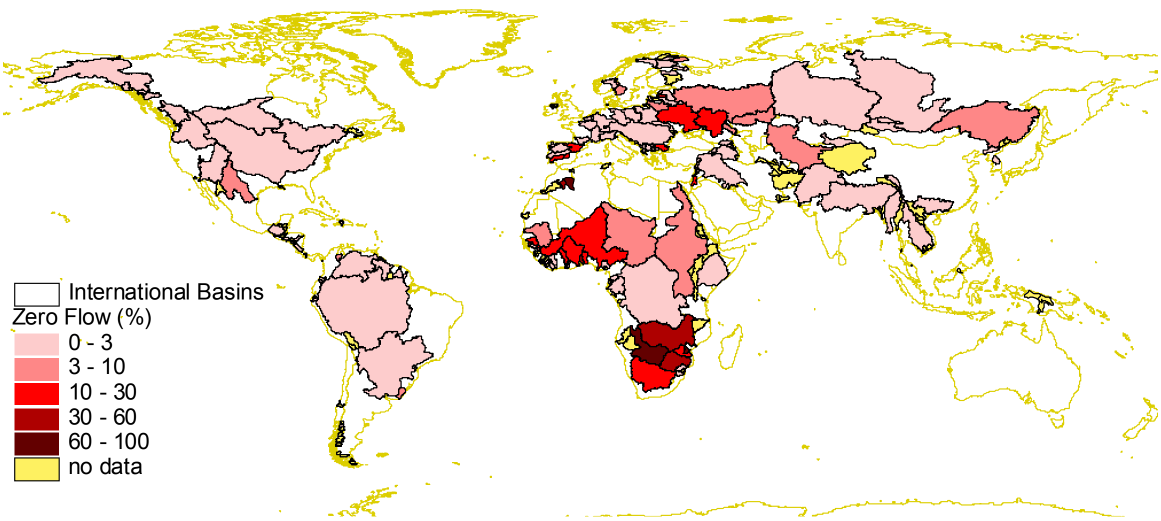




Mean Annual Time with no flow





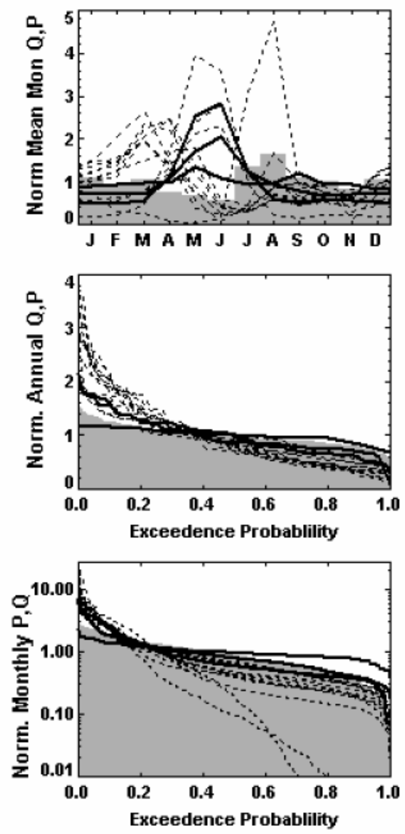


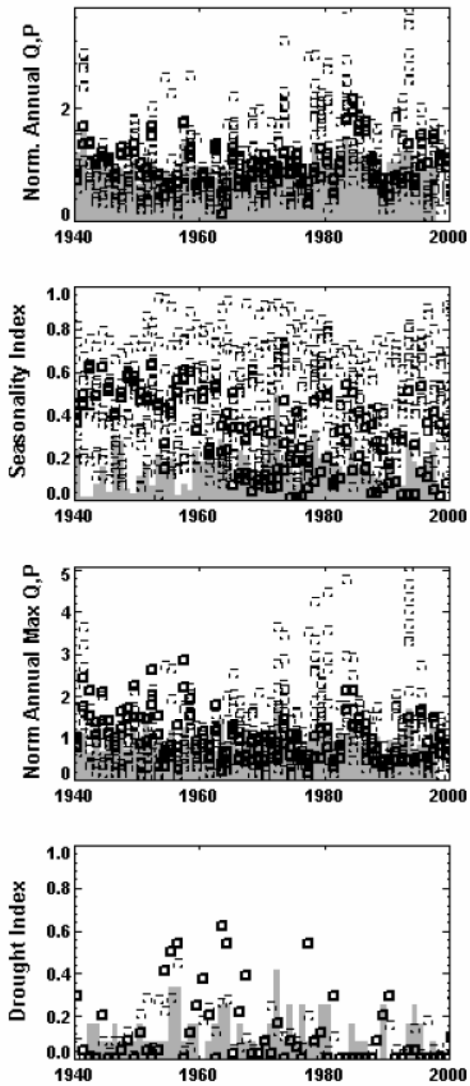
Appendix 4: Signature plots for selected international river basins

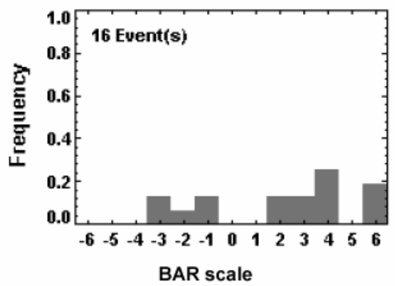
Colorado

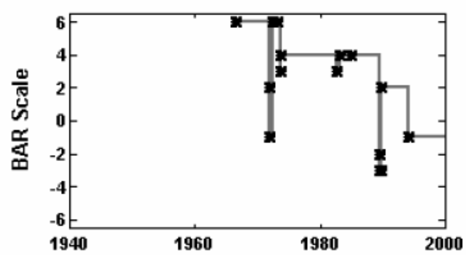
Time Aggregated Characteristics			Time Series (1940-2000)

Parameter	Precipitation	Discharge
Mean Annual	323 mm	48 mm
Seasonality Index	0.17	0.42
Temporal Variability	0.20	0.59
Spatial Variability	0.08	--
Index of Aridity (P/ET)	0.38	
Time without flow	1.9%	









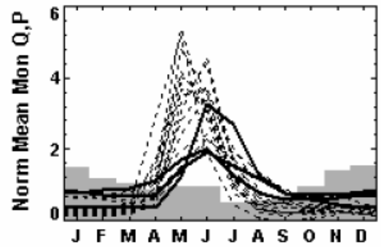
Legend

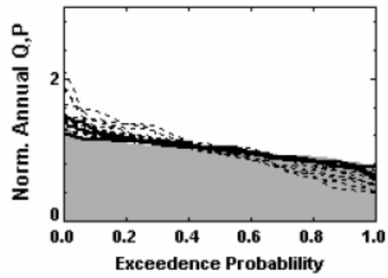
- Precipitation
- Main river discharge
- Tributary discharge
- * Political events

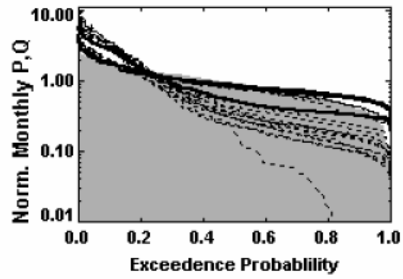
Columbia

Time Aggregated Characteristics

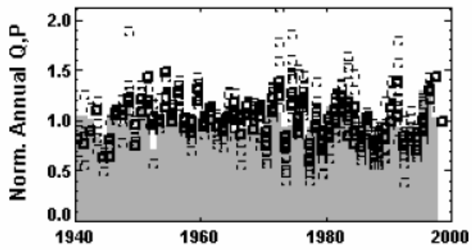
Parameter	Precipitation	Discharge
Mean Annual	633 mm	483 mm
Seasonality Index	0.23	0.52
Temporal Variability	0.13	0.23
Spatial Variability	0.22	--
Index of Aridity (P/ET)	0.86	
Time without flow	0.2%	

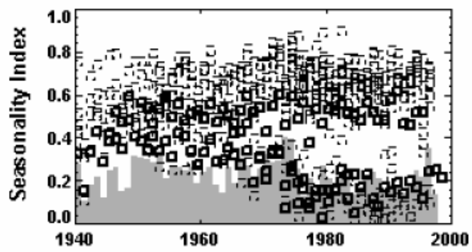


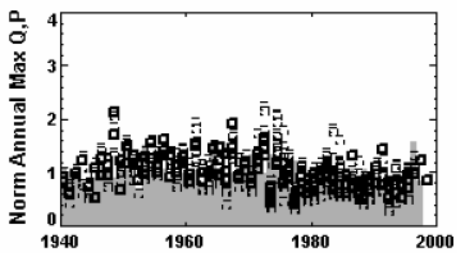


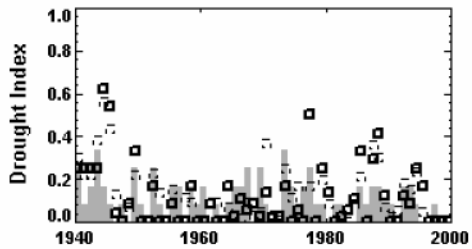


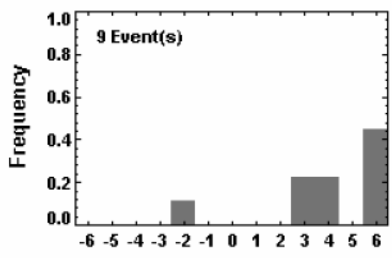
Time Series (1940-2000)

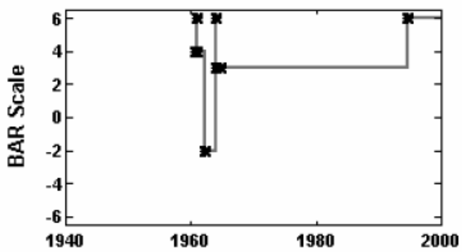












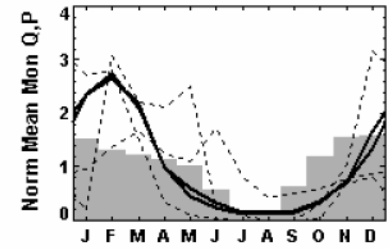
Legend

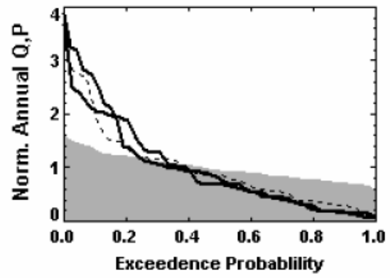
- Precipitation
- Main river discharge
- Tributary discharge
- * Political events

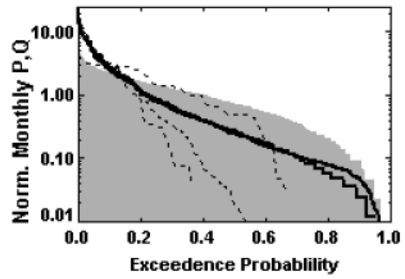
Guadiana

Time Aggregated Characteristics

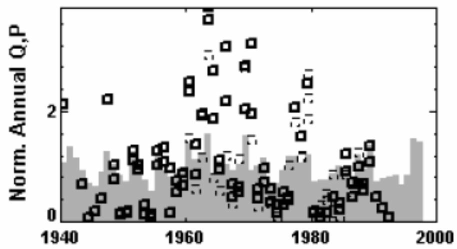
Parameter	Precipitation	Discharge
Mean Annual	518 mm	69 mm
Seasonality Index	0.36	0.66
Temporal Variability	0.25	0.86
Spatial Variability	0.31	--
Index of Aridity (P/ET)	0.65	
Time without flow	25.2%	

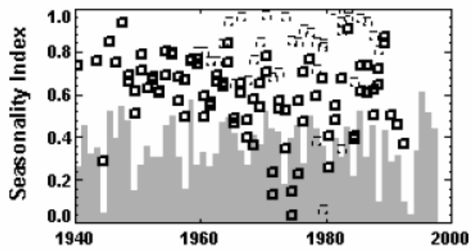


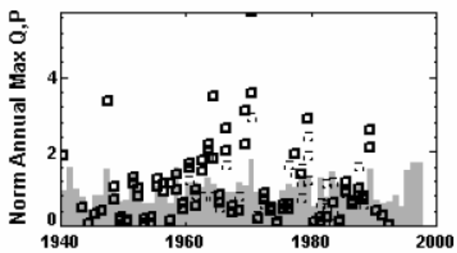


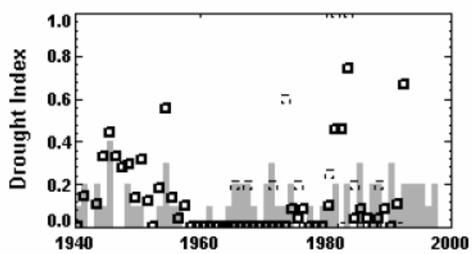


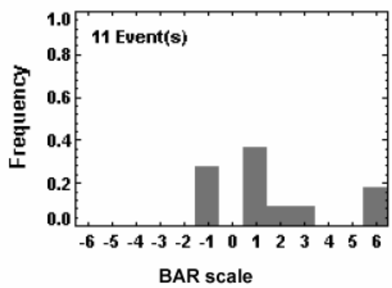
Time Series (1940-2000)

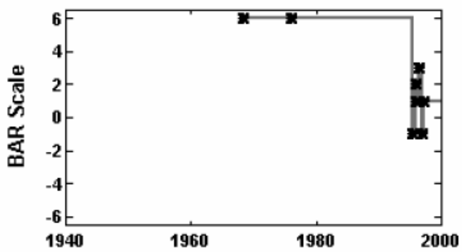












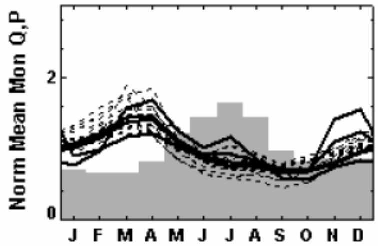
Legend

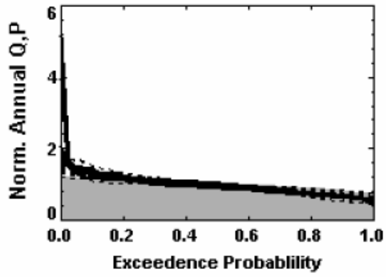
- Precipitation
- Main river discharge
- Tributary discharge
- * Political events

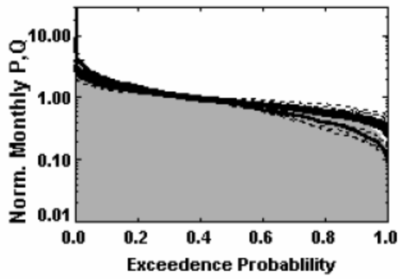
Oder (Odra)

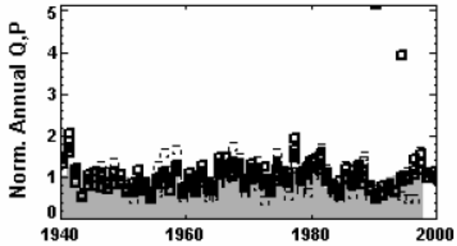
Time Aggregated Characteristics			Time Series (1940-2000)

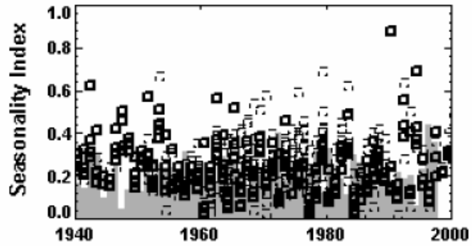
Parameter	Precipitation	Discharge
Mean Annual	608 mm	197 mm
Seasonality Index	0.22	0.24
Temporal Variability	0.12	0.33
Spatial Variability	0.19	--
Index of Aridity (P/ET)	1.70	
Time without flow	0.0%	

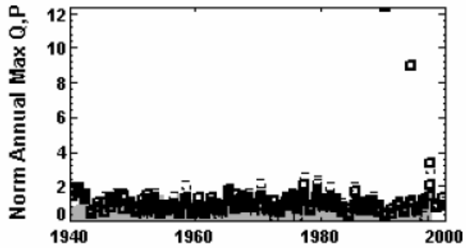


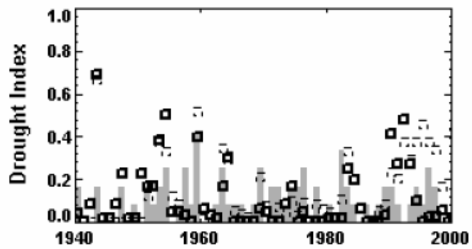


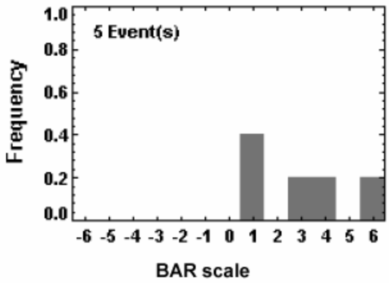


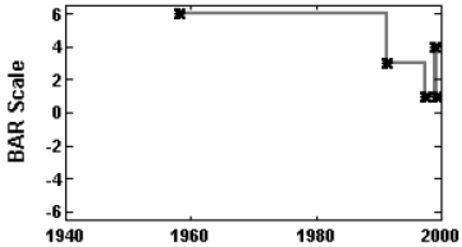












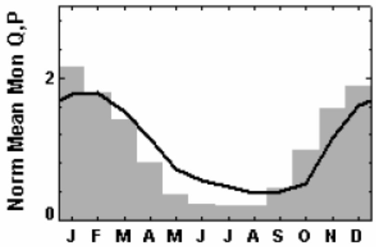
Legend

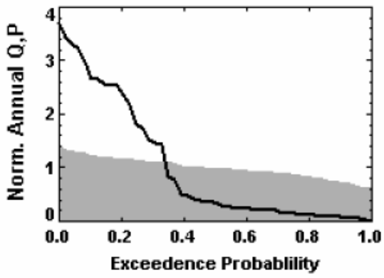
- Precipitation
- Main river discharge
- Tributary discharge
- * Political events

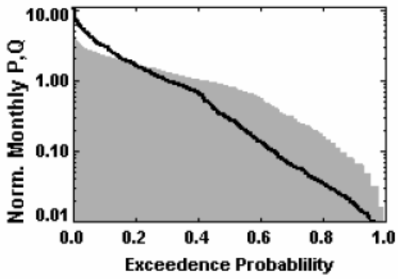
Incomati

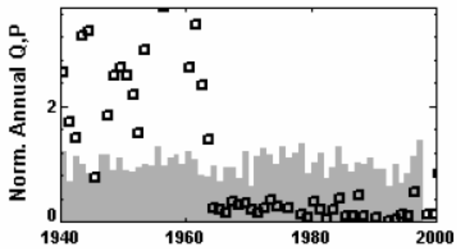
Time Aggregated Characteristics			Time Series (1940-2000)

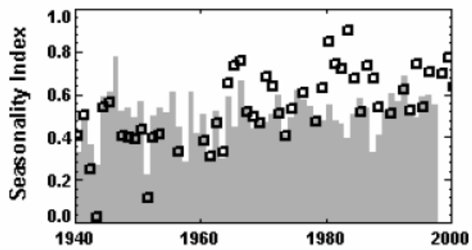
Parameter	Precipitation	Discharge
Mean Annual	746 mm	51 mm
Seasonality Index	0.50	0.54
Temporal Variability	0.19	1.16
Spatial Variability	0.50	--
Index of Aridity (P/ET)	0.60	
Time without flow	0.1%	

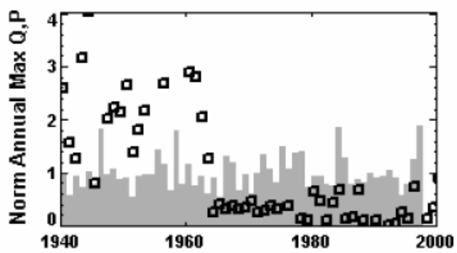


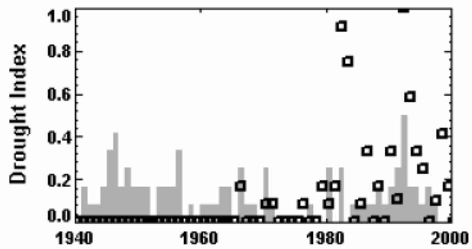


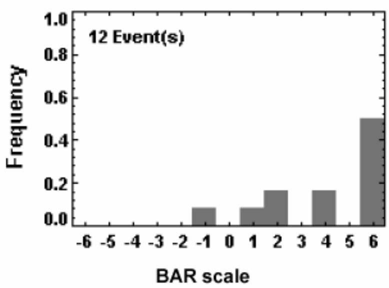


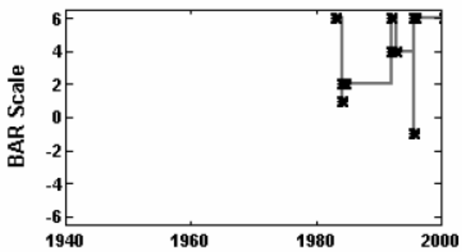












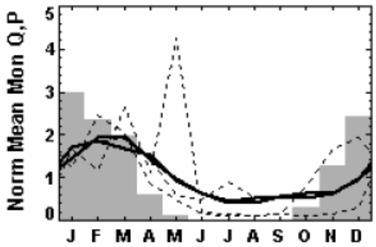
Legend

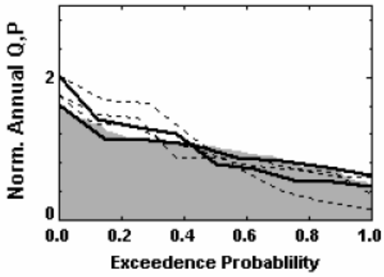
- Precipitation
- Main river discharge
- Tributary discharge
- * Political events

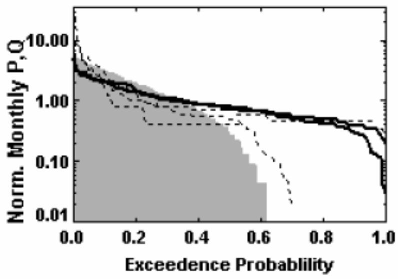
Jordan

Time Aggregated Characteristics

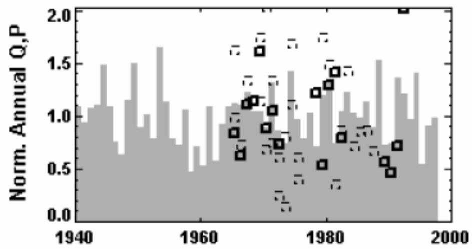
Parameter	Precipitation	Discharge
Mean Annual	270 mm	204 mm
Seasonality Index	0.75	0.49
Temporal Variability	0.27	1.47
Spatial Variability	0.74	--
Index of Aridity (P/ET)	0.26	
Time without flow	14.4%	

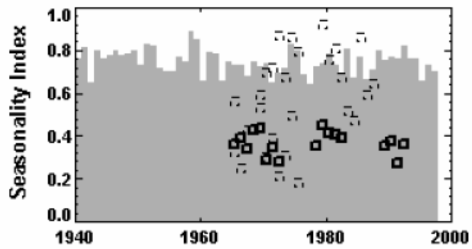


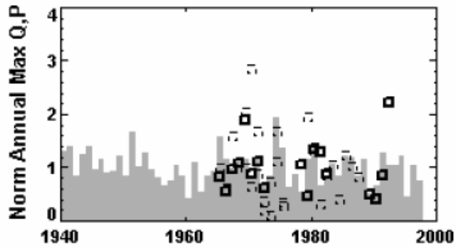


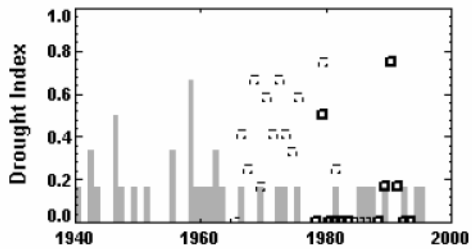


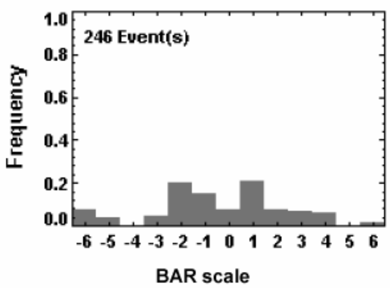
Time Series (1940-2000)

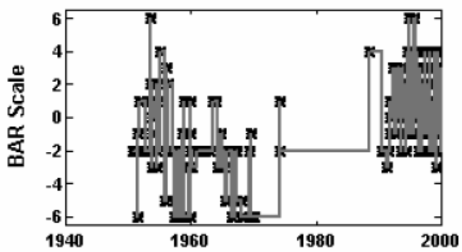












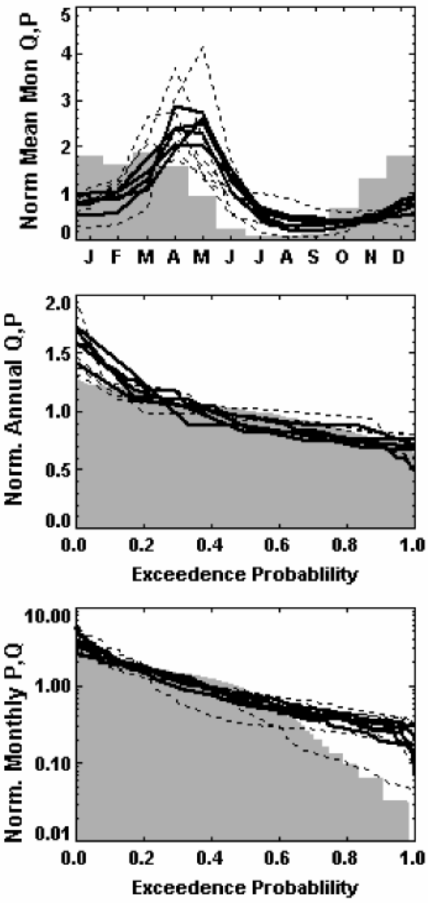
Legend

- Precipitation
- Main river discharge
- Tributary discharge
- * Political events

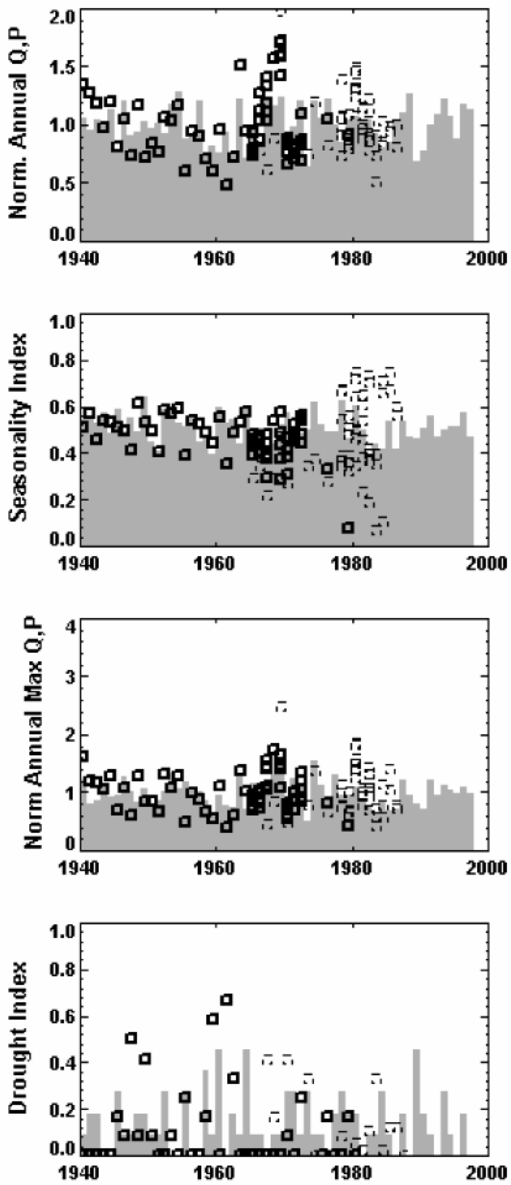
Tigris-Euphrates

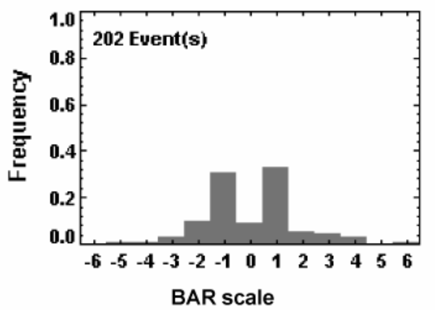
Time Aggregated Characteristics

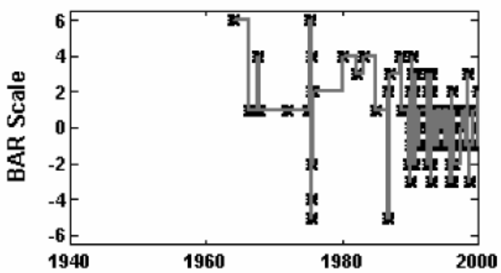
Parameter	Precipitation	Discharge
Mean Annual	366 mm	340 mm
Seasonality Index	0.51	0.46
Temporal Variability	0.17	0.27
Spatial Variability	0.49	--
Index of Aridity (P/ET)	0.39	
Time without flow	0.0%	



Time Series (1940-2000)





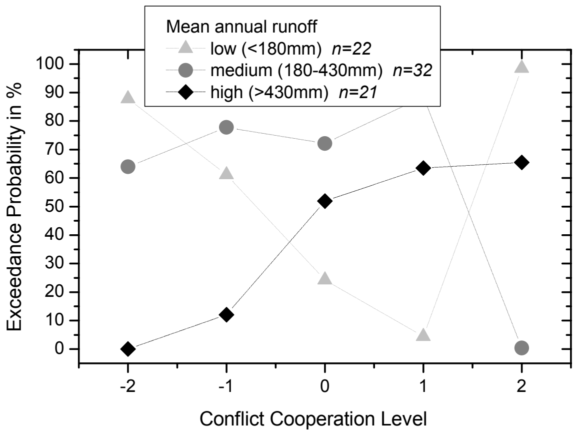


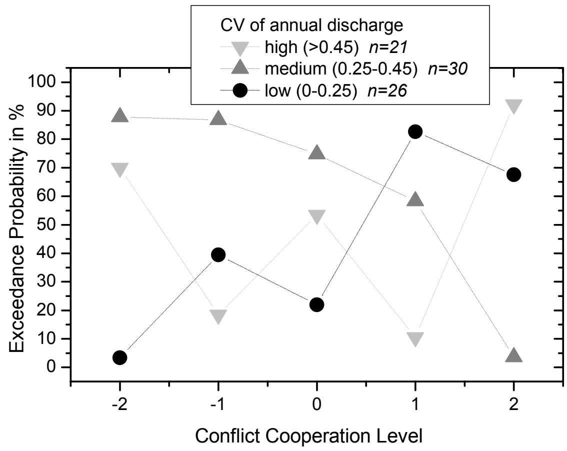
Legend

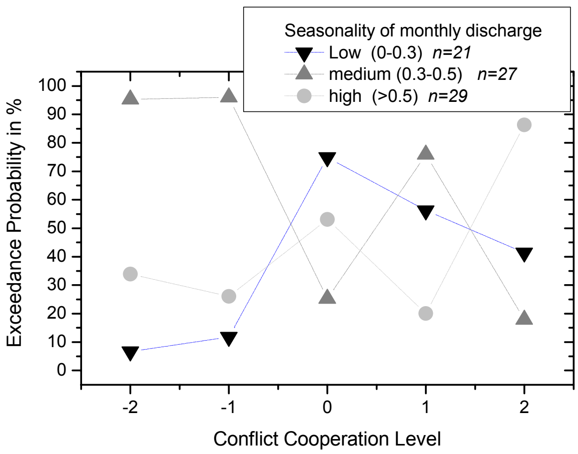
- Precipitation
- Main river discharge
- Tributary discharge
- * Political events

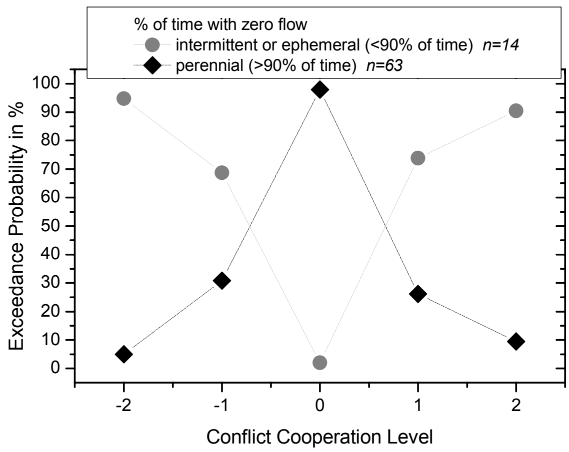
Appendix 5: Detailed Results for the discharge-based BCP Parameters (Application 1, Section 4.1)

It was tested, whether the relative frequencies of the events on the CCL scale in Basin-County-Polygons (BCPs) with a particular hydro-climatology are different from 10000 randomly chosen subsets of the same sample size *n*. The figures show the mean observed frequency of a certain conflict-cooperation level expressed as exceedance probability.









Report No. 1 (May 1993)	Second Workshop on the Global Runoff Data Centre, Koblenz, Germany, 15 - 17 June, 1992.
	(17 pp, annex 73 pp)
Report No. 2 (May 1993)	Dokumentation bestehender Algorithmen zur Übertragung von Abflußwerten auf Gitternetze. (incl. an English abstract in English by the GRDC: Documentation of existing algorithms for transformation of runoff data to grid cells) / G.C. Wollenweber.
	(71 pp)
Report No. 3 (Jun 1993)	GRDC - Status Report 1992.
	(5 pp, annex 5 pp)
Report No. 4 (Jun 1994)	GRDC - Status Report 1993.
	(16 pp, annex 34 pp)
Report No. 5 (Nov 1994)	Hydrological Regimes of the Largest Rivers in the World - A Compilation of the GRDC Database.
	(275 pp)
Report No. 6 (Dec 1994)	Report of the First Meeting of the GRDC Steering Committee, Koblenz, Germany, June 20 - 21, 1994.
	(10 pp, annex 38 pp)
Report No. 7 (Jun 1995)	GRDC - Status Report 1994.
	(12 pp, annex 20 pp)
Report No. 8 (Jul 1995)	First Interim Report on the Arctic River Database for the Arctic Climate System Study (ACSYS).
	(34 pp)
Report No. 9 (Aug 1995)	Report of the Second Meeting of the GRDC Steering Committee, Koblenz, Germany, June 27 - 28.
	(17 pp, annex 34 pp)
Report No. 10 (Mar 1996)	Freshwater Fluxes from Continents into the World Oceans based on Data of the Global Runoff Data Base / W. Grabs, Th. de Couet, J. Pauler
	(49 pp, annex 179 pp)

Global Runoff Data Centre (GRDC)
Am Mainzer Tor 1, 56068 Koblenz, Germany
phone +49 261 1306-5224
fax +49 261 1306-5280
email grdc@bafg.de
web http://grdc.bafg.de

Report No. 11 (Apr 1996)	GRDC - Status Report 1995.
	(16 pp, annex 45 pp)
Report No. 12 (Jun 1996)	Second Interim Report on the Arctic River Database for the Arctic Climate System Study (ACSYS).
	(39 pp, annex 8 pp)
Report No. 13 (Feb 1997)	GRDC Status Report 1996
	(25 pp, annex 36 pp)
Report No. 14 (Feb 1997)	The use of GRDC - information. Review of data use 1993/1994. Status: January 1997
	(18 pp, annex 34 pp)
Report No. 15 (Jun 1997)	Third Interim Report on the Arctic River Data Base (ARDB) for the Arctic Climate System Study (ACSYS): Plausibility Control and Data Corrections (Technical Report)
	(3 pp, annex 20 pp)
Report No. 16 (Aug 1997)	The GRDC Database. Concept and Implementation / J. Pauler, Th. de Couet
	(38 pp, annex 4 pp)
Report No. 17 (Sep 1997)	Report on the Third Meeting of the GRDC Steering Committee, Koblenz, Germany June 25-27, 1997
	(30 pp, annex 137)
Report No. 18 (Jul 1998)	GRDC Status Report 1997
	(13 pp, annex 37 pp)
Report No. 19 (Aug 1998)	Evaluation of Statistical Properties of Discharge Data of Stations Discharging Into the Oceans - Europe and Selected World-Wide Stations / F. Portmann
	(80 pp)
Report No. 20 (Jul 1998)	Water Resources Development and the Availability of Discharge Data in WMO Region II (Asia) and V (South-West Pacific) W. Grabs, J. Pauler, Th. de Couet
	(51 pp, annex 68 pp)

Report No. 21 (Sep 1998)	Analysis of long runoff series of selected rivers of the Asia-Pacific region in relation with climate change and El Niño effects / D. Cluis
	(23 pp, annex 58 pp)
Report No. 22 (April 1999)	Global, Composite Runoff Fields Based on Observed River Discharge and Simulated Water Balances / B. M. Fekete, C. Vörösmarty, W. Grabs
	(36 pp, annex 77 pp)
Report No. 23 (Oct 1999)	Report of the fourth Meeting of the GRDC Steering Committee, Koblenz, Germany, 23-25 June 1999
	(29 pp, annex 140 pp)
Report No. 24 (Nov 1999)	Use of the GRDC Data 1993-1999: A Comprehensive Summary
	(48 pp)
Report No. 25 (Jun 2000)	GIS-related monthly Balance of Water Availability and Demand in Large River Basins - case study for the River Danube / I. Dornblut
	(27 pp, annex 46 pp)
Report No. 26 (Nov 2000)	Modelling raster-based monthly water balance components for Europe / Carmen Ulmen
	(133 pp)
Report No. 27 (Jul 2002)	Water Resources Management Country Profile Germany. A contribution to the Global Water Information Network WWW.GLOBWINET.ORG / R. Winnegge and T. Maurer
	(32 pp)
Report No. 28 (Nov 2002)	Report of the Fifth Meeting of the GRDC Steering Committee, Koblenz, Germany, 25-28 June 2001
	(36 pp, annex 300 pp)
Report No. 29 (Feb 2003)	GRDC Status Report 2002
	(28 pp, annex 32 pp)
Report No. 30 (Dec 2003)	Development of an Operational Internet-based Near Real Time Monitoring Tool for Global River Discharge Data / T. Maurer
	(23 pp, annex 5 pp)

Global Runoff Data Centre (GRDC)
Am Mainzer Tor 1, 56068 Koblenz, Germany
phone +49 261 1306-5224
fax +49 261 1306-5280
email grdc@bafg.de
web http://grdc.bafg.de

Report No. 31 (Oct 2004)	Globally agreed standards for metadata and data on variables describing geophysical processes. A fundamental prerequisite to improve the management of the Earth System for our all future / T. Maurer
	(43 pp, annex 28 pp)
Report No. 32 (Nov 2004)	Detection of change in world-wide hydrological time series of maximum annual flow / Z.W. Kundzewicz, D. Graczyk, T. Maurer, I. Przymusinska, M. Radziejewski, C. Svensson, M. Szwed
	(36 pp, annex 52 pp)
Report No. 33 (Nov 2004)	Trends in flood and low flow series / C. Svensson, Z.W. Kundzewicz, T. Maurer
	(26 pp, annex 18 pp)
Report No. 34 (Mar 2005)	Report of the Sixth Meeting of the GRDC Steering Committee, Koblenz, Germany, 11-13 June 2003
	(27 pp, annex 85 pp)
Report No. 35 (Nov 2006)	Report of the Seventh Meeting of the GRDC Steering Committee, Koblenz, Germany, 6 - 8 July 2005
	(36 pp, annex 80 pp)
Report No. 36 (Aug 2007)	The Global Terrestrial Network for River Discharge (GTN-R) : Real-time Access to River Discharge Data on a Global Scale. 1st Interim Report / U. Looser, I. Dornblut, T. de Couet
	(24 pp, annex 42 pp)
Report No. 37 (Dec 2007)	Hydrology of the World's International River Basins: Hydrological parameters for use in global studies of international water-relations / K. Stahl (Oregon State University, Department of Geosciences, Corvallis, USA)
	(36 pp, annex 16 pp)

Global Runoff Data Centre (GRDC)
Am Mainzer Tor 1, 56068 Koblenz, Germany
phone +49 261 1306-5224
fax +49 261 1306-5280
email grdc@bafg.de
web http://grdc.bafg.de