FRIEND - a global perspective 2002-2006

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FRIEND – Flow Regimes from International Experimental and Network Data

FRIEND - a global perspective 2002-2006

Edited by Eric Servat and Siegfried Demuth

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IHP – International Hydrological Programme of UNESCO

HWRP – Hydrology and Water Resources Programme of WMO

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Foreword

The origin of FRIEND goes back to the International Hydrological Decade (IHD), which launched a large number of representative and experimental basins, underpinned mostly by national financial support. In retrospect, the IHD was a highly visionary programme, which now provides the longer-term data sets for assessing the hydrological impacts of climatic variability and land-use change. At the time the IHD was launched, neither climate change nor global change were commonly part of the scientific vocabulary.

With the launch of FRIEND as a contribution to UNESCO's Third International Hydrological Programme (IHP-III) from 1984-1988, the initial focus was on the data-rich basins of north-west Europe (Northern European FRIEND). Various techniques were established, ranging from statistical methods to conceptual and physical models, for assessing the regional hydrological behaviour of flow regimes. The end of this first phase was marked by the "FRIENDS in Hydrology" Conference in Bolkesjø, Norway in April 1989, the publication of Conference proceedings in the IAHS Series of Proceedings and Reports (Red Books) and a two-volume report on FRIEND. This started a long partnership between FRIEND and the International Association of Hydrological Sciences (IAHS), which continues today through sponsorship of conferences and publication of reports.

In its second phase (1989-1993), as project H-5-5 in IHP-IV, FRIEND expanded geographically. With the support of Cemagref (La recherche pour l'ingénierie de l'agriculture et de l'environnement) in France, FRIEND became established in the Alpine and Mediterranean (AMHY) region, and later in west and central Africa (AOC: Afrique de l'Ouest et Centrale) and in southern Africa in collaboration with SADC, the Southern African Development Community. At this stage, FRIEND scientific groups had made a unique contribution by their impact on the policy of national governments towards the international exchange of hydrological data. Until then political considerations had not encouraged such exchanges, but FRIEND now provided the means by which this could be achieved.

During the third (1994-1997) and fourth (1998-2001) phases, FRIEND has made a major contribution to the fifth International Hydrological Programme (1996-2001) as Project 1.1 and has progressively diffused into other regions. Asian Pacific FRIEND, Nile FRIEND, Hindu Kush/Himalayan (HKH) FRIEND and Latin America and Caribbean FRIEND AMIGO have all been established. The fourth phase was a contribution to IHP Phase VI of UNESCO during which the international network has been even expanded. 141 countries now participate in FRIEND within eight regional FRIEND groups.

In recognition of the expansion of this project, and its ever enlarging network, the 14th Session of the IHP Intergovernmental Council, in June 2000, approved the elevation of FRIEND to a stand-alone cross-cutting theme within IHP-VI (2002-2007) and at the 17th Session of the IHP Intergovernmental Council, in July 2006, it was approved to keep FRIEND as a cross-cutting programme within IHP-VII (2008-2013).

A significant feature of FRIEND is the impressive list of publications that have emerged in refereed scientific journals, and these are summarised in the current and previous FRIEND reports. FRIEND has been a 'flag-carrier' for the IHP in maintaining a high level of ‘cutting-edge’ science. The brief to maintain a core scientific focus will continue to answer concerns that the technical focus of FRIEND could be diluted by its new cross-cutting position within IHP-VI. As with the contiguous cross-cutting HELP (Hydrology for Environment, Life and Policy) Project in IHP-VI, the ability to undertake good science linked with practical land-water management issues is not a contradiction. FRIEND is now in a position whereby it should be encouraged to impact on the water policy of national governments through the conveyance of technical outputs where they are most needed. For example, poverty alleviation linked with the technical outputs of the Low Flow groups will secure a better understanding (and supply) of water during seasonal and inter-annual drought. Furthermore FRIEND has recently developed a very strong training and capacity building component to disseminate research results to students and water services. A textbook on hydrological droughts has been published.

Elsewhere FRIEND has established close links to WMO’s Commission for Hydrology programme on disaster mitigation on floods and droughts which will be a contribution towards the joint UNESCO-WMO-IAHS International Flood Initiative (IFI).

In the current phase FRIEND has gone beyond the scope of the UNESCO IHP, it has reached the political domain, for example within the framework of an initiative of EurAqua (an association of European Hydrological Services). A paper on European drought policy has been written. Furthermore a European Drought Centre has been established to facilitate the exchange of knowledge on drought issues. The results of such initiatives are aimed at contributing towards the European Water Framework Directive.

In IHP-VI, FRIEND is now sufficiently mature to begin interfacing with other IHP technical projects, notably groundwater and ecohydrology, as well as supporting selected HELP basins as part of the scientific assessment and inventory of water resources to define the appropriate experimental hydrology response. Steps have already being undertaken to establish an intra-scientific expert group to advise how best to interface between these various disciplines and projects during IHP-VI. One of the recent developments was the establishment of an expert group which will address the topic Climate variability and land cover change impact on flooding and low flows – at what scales? Work undertaken as part of the FRIEND AOC will be a major contributor towards the outputs from this expert group.

In conclusion, I would like to express my thanks to all the hydrologists, regional coordinators and national governments who have provided the necessary financial support to ensure the success of the FRIEND project. In particular, I thank Eric Servat (Global FRIEND co-ordinator) from IRD, Montpellier, France and Siegfried Demuth (Coordinator of NE FRIEND), German IHP/HWRP Secretariat, Koblenz, Germany who have compiled and edited this report on behalf of the FRIEND Regional Groups as a contribution towards the 5th FRIEND World Conference "Climate Variability and Changes – Hydrological Impacts" in Havana, Cuba, 27 November to 1 December 2006.

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Abbreviations

ABN	Authorité du Bassin du Niger (Niger Basin Authority)
ADB	Asian Development Bank
AHDR	Aswan High Dam Reservoir
AGRHYMET	Agricultural Hydrological Meteorological Training Centre, Niamey, Niger
AMIGO	Latin America and Caribbean FRIEND
AMHY	Alpine and Mediterranean Hydrology
AMMA	African Monsoon Multidisciplinary Analysis
AOC	West and Central Africa (Afrique de l'Ouest et Centrale)
ARIDA	Assessment of the Regional Impact of Drought in Africa
ARIDE	Assessment of the Regional Impact of Droughts in Europe
ASTHyDA	Analysis, Synthesis and Transfer of Knowledge and Tools on Hydrological Drought Assessment through a European Network
AUF	Agence Universitaire de la Francophonie (Francophone university agency)
BfG	Bundesanstalt für Gewässerkunde (Federal Institute for Hydrology), Koblenz, Germany
BFI	Base flow index
BOD	Biochemical oxygen demand
BOKU	Universität for Bodenkultur (University of Natural Resources and Applied Life Sciences), Vienna, Austria
CATHALAC	Water Centre for the Humid Tropics of Latin America and the Caribbean
CAZALAC	Water Centre in the Arid and Semi-arid Zones of Latin America and the Caribbean
CEH	Centre for Ecology and Hydrology, Wallingford, UK.
CENAREST	Centre National de la Recherche Scientifique et Technologique du Gabon (National Scientific and Technological Research Centre, Gabon)
CERGEC	Centre de Recherche Geographique et de Cartographie (Geographic and Cartographic Research Centre), Congo
CHy	Commission for Hydrology
CILSS	Comité Permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (Permanent Interstate Committee on Drought Control in the Sahel)
CORUS	Coopération pour la Recherche Universitaire et Scientifique (Cooperation for University and Scientific Research)
CRH	Centre de Recherches Hydrologiques (Hydrological Research Centre), Yaoundé, Cameroon
DEA	Diplôme d'études approfondies (Diploma of advanced studies)
DEM	Digital elevation model
DESS	Diplôme d'études supérieures spécialisées (Diploma of specialised studies)
DFID	Department for International Development, UK
DGRST	Direction Générale de la Recherche Scientifique et Technique (General Directorate of Scientific and Technical Research), Congo

DHI	Danish Hydraulic Institute (DHI Water and Environment, Denmark, is an amalgamation of the Danish Hydraulic Institute, the Danish Institute for the Water Environment and the Danish Toxicology Centre)
DHM	Department of Hydrology and Meteorology, Nepal
DLFA	Droughts and low flow analysis
DSF	Départment Soutien et Formation des communautés scientifiques du sud (Department for the support and development of scientific communities in southern countries)
DWAF	Department of Water Affairs and Forestry
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
ECQ	Extreme value analysis
ECTS	European Credit Transfer and accumulation System
EDC	European Drought Centre
EEA	European Environment Agency
EIER	École Inter-États d'Equipment Rural (Interstate School for Rural Equipment)
ENI	Ecole Nationale d'Ingenieur (National School of Engineering), University of Mali
ENSO	El Niño Southern Oscillation
ERA	European Research Area
ERB	European Research Basin
ESRI	Environmental Science Research Institute
EU	European Union
EurAqua	Network of European Freshwater Organisations
EUWI	European Union Water Initiative
EV	Extreme value
EWA	European Water Archive
FFA	Flood frequency analysis
FRIEND	Flow Regimes from International Experimental and Network Data
GAME	GEWEX Asian Monsoon Experiment
GCM	Global climate model
GEMS	Global and regional Earth-system (atmosphere) Monitoring using Satellite and in-situ data
GEV	Generalised Extreme Value
GEWEX	Global Energy and Water Cycle Experiment
GFFS	Galway Flood Forecasting System
GIS	Geographical Information Systems
GI-WRM	Geo-Information for Water Resources Management
GLOF	Glacial lake outburst flood
GLUE	Generalised Likelihood Uncertainty Estimation
GRAPES	Groundwater and River resources Action Programme on a European Scale
GRDC	Global Runoff Data Centre
GWAVA	Global Water Availability Assessment
GWP	Global Water Partnership
HEC	Hydrologic Engineering Center, California, USA
HELP	Hydrology for the Environment, Life and Policy
HKH	Hindu Kush-Himalayan
HMS	Hydrologic modelling system
HRC	Hydraulics Research Centre

HTC	Regional Humid Tropics Hydrology and Water Resources Centre, Kuala Lumpur, Malaysia
HWRP	Hydrology and Water Resources Programme, WMO
HYCOS	Hydrological Cycle Observing System
HYDATA	Hydrological Database and analysis system
IAHS	International Association of Hydrological Sciences
ICA	Integrated Catchment Approach
ICCE-BF	Impact du Changement Climatique sur les processus de dégradation de l'Environnement au Burkina Faso (Impact of climate change on the process of environmental degradation in Burkina Faso)
ICHARM	International Centre for Water Hazard and Risk Management
ICIMOD	International Centre for Integrated Mountain Development
ICSI	International Commission on Snow and Ice
ICSW	International Commission on Surface Water
IFD	Intensity-frequency-duration
IFM	Integrated flood management
IHP	International Hydrological Programme
IPO	Interdecadal Pacific Oscillation
IPR	Institut Polytechnique Rural, University of Mali
IRD	Institut de Recherche pour le Développement, Montpellier, France
IRSH	Institut de Recherche en Sciences Humaines (Research institute for human sciences)
IRTCES	International Research and Training Centre for Erosion and Sedimentation, Beijing, China
IWRM	Integrated water resources management
JEAI	Jeunes Equipes Associées à l'IRD (Young associated team)
LAC	Latin American and Caribbean
LF2000-SA	Low Flows 2000 Southern Africa
MALF	Mean annual low flow
MAPGEN	Mixed initiative Activity Plan Generation system
MDG	Millennium Development Goal
ML	Maximum likelihood
MOM	Moments
NCAR	National Center for Atmospheric Research, USA
NCEP	National Centers for Environmental Protection, USA
NE-FRIEND	Northern European FRIEND
NEPAD	New Partnership for Africa's Development
NHI	National Institute of Hydrology, Roorkee, India
NOAA	National Oceanic and Atmospheric Administration, US Dept of Commerce
NPI	North Pacific Index
PCN	Project concept note
PDO	Pacific Decadal Oscillation
PDOI	Pacific Decadal Oscillation Index
PNRH	Programme National de Recherche en Hydrologie (National programme of hydrological research), France
POT	Peaks over threshold (partial duration series)
PROECO	Projet de Conservation et de Protection des Ecosystèmes du Nord-Congo (Project for the conservation and protection of the ecosystems of North Congo)
PUB	Predictions in Ungauged Basins

PWM	Position weight maxtrix
RAS	River analysis system
RDC	Regional Data Centre
REFRESHA	Regional flow estimation for small-scale hydropower assessment
RFFA	Regional flood frequency analysis
RHDC	Regional Hydrological Data Centre
RRM	Rainfall-runoff modelling
RSC	Regional Steering Committee
RWG	Regional Working Group
SADC	Southern Africa Development Community
SAWAN	South Asian Water Analysis Network
SCA	Snow-covered area
SGMRM	Snow and glacier melt runoff model
SIMGRO	Simulation of groundwater flow and surface water levels
SMS	Surface water modelling system
SOI	Southern Oscillation Index
SOPAC	South Pacific Applied Geoscience Commission
SPATSIM	Spatial and time series information modelling
SST	Sea surface temperature
STWM	Sediment transport and watershed management
SWAT	Soil and water assessment tool
SWE	Snow water equivalent
TAC	Technical Advisory Committee
TCEV	Two components extreme value
TOSHKA	South Egypt Development Project
TWINBAS	Twinning European and third country basins for development of integrated water resources management methods
UCAD	Cheick Anta Diop University, Dakar, Senegal
UMR	Unité Mixte de Recherche (University research team), France
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
VRE	Variabilité des ressources en eau (Variability of water resources)
WCRP	World Climate Research Programme
WERRD	Water and Ecosystem Resources in Regional Development
WGHM	WaterGap Global Hydrological Model
WHYCOS	World Hydrological Cycle Observing System
WMO	World Meteorological Organization
WMS	Watershed modelling system
WOISYDES	Water Observation and Information System for Decision Support
WRI	Water Research Institute
WRRI	Water Resources Research Institute
WWAP	World Water Assessment Programme
Z	Parameter representing runoff in 4-layer tank model

1 Introduction

1.1 Introduction to FRIEND

Water is an integral part of the environment and is of vital importance to all socioeconomic sectors. Human and economic development is not possible without a safe, reliable water supply. With an increasing global population, the challenge of managing water resources grows. Conflicts between different water uses and users become more common, as increasing demands are placed on this limited resource. Misuse of water resources and poor water management practices have resulted in depleted supplies, falling water tables, shrinking inland lakes and stream flows diminished to ecologically unsustainable levels. In addition, water pollution, originating mostly from human activity, is occurring even more frequently, decreasing the amount of water suitable for many uses. There are added risks and uncertainties associated with climate change and the long-term impact on water availability is only now beginning to be understood.

Water stress, where the demand for freshwater water outstrips supply, is keenly felt all over the world. Europe, for example, has recently suffered a number of extensive and costly floods and droughts, problems of groundwater pollution, lake eutrophication, over-abstraction of groundwater and degradation of wetlands. In parts of the Middle East, South Africa and Asia water shortages are stifling economic growth, limiting food production and depriving many of adequate clean water for drinking, cooking and personal hygiene. The effects are hardest felt by the most vulnerable in society, particularly women and children of the poorest families, who lack the adaptive capacity to cope with such water shortages. The challenge for the international hydrological research community is considerable: to develop better methods and tools to ensure more effective and sustainable management of an increasingly scarce resource and, through this, contribute to improving the quality of life for the poorest people in our global society.

FRIEND (Flow Regimes from International Experimental and Network Data) is one of the initiatives being undertaken by hydrologists to meet this challenge. FRIEND is a contribution to the International Hydrology Programme (IHP) of the United Nations' Educational, Scientific and Cultural Organization (UNESCO) and aims to develop better understanding of hydrological variability and similarity across time and space, through mutual exchange of data, knowledge and techniques at a regional level. The project was founded in 1985 by a small international team of European scientists, who sought to realise operational benefits from the vast amount of information gathered from representative and experimental basins across northern Europe during the 1960s and 1970s. The outcome of their work attracted considerable attention and its merits ensured that FRIEND evolved through several successive phases to become the worldwide, regionally based study outlined in this report. The growth of FRIEND has been significant, with some 141 countries now participating in the eight established regional FRIEND projects of Northern Europe (NE), the Alpine and Mediterranean region (AMHY), Southern Africa, the Nile Basin, West and Central Africa (AOC), the Hindu Kush-Himalayan region (HKH), the Asian Pacific region and the Latin America and Caribbean region (AMIGO) (Figure 1.1; Table 1.1). Meanwhile, interest in FRIEND continues to grow, with new projects which could be considered in a near future.

Figure 1.1 Location of FRIEND projects worldwide

FRIEND research covers a diverse range of topics including low flows, floods, variability of regimes, rainfall/runoff modelling, processes of streamflow generation, sediment transport, snow and glacier melt, climate-change and land-use impacts. As a result FRIEND has been elevated to the position of a cross-cutting theme in the sixth phase of the IHP (IHP-VI) from 2002 to 2007, with links to such themes as global changes and water resources, integrated watershed and aquifer dynamics, land habitat hydrology, water and society, and water education and training. The FRIEND programme also complements the other cross-cutting initiative HELP (Hydrology for the Environment, Life and Policy), which aims to integrate hydrological science with social issues and provide the scientific basis for improved land and water management through a global network of experimental basins.

Activities within each regional FRIEND project are determined by local project participants, who are drawn from operational agencies, universities and research institutes, and are therefore in the best position to identify the research priorities in their region. The FRIEND project tends, therefore, to have a problem-solving approach in most of its regions, with its scientific output being applied practically towards hazard mitigation and poverty alleviation. As floods and droughts are not necessarily confined by political boundaries, the major efforts of regional FRIEND projects towards the sharing of data between countries and the establishment of regional hydrological databases, used for FRIEND research, have made a real and lasting step towards international cooperation.

Several FRIEND projects, seeking to build the capacity of local hydrologists and water practitioners to assess and manage their own national water resources, have identified as a priority a need for training and skills transfer. Training and capacity building has become an important part of the FRIEND Programme and is conducted through training courses, technical workshops, conferences, symposia, the subsidised distribution of technical literature and support to postgraduate students. The transfer of skills, knowledge and experience between regional projects at different stages of development is one of the key achievements of FRIEND.

1.2 Links with other international projects

The status of the FRIEND project within the international hydrological community is reflected in its many links to other international programmes and projects. The project has a particularly effective relationship with the World Meteorological Organisation (WMO), through elements of the Hydrology and Water Resources Programme (HRWP) and the World Climate Research Programme (WCRP). It was specifically praised for its close cooperation with WMO programmes at the Fifth UNESCO/WMO International Conference on Hydrology (UNESCO/WMO, 1999). The Northern European FRIEND project has had a good relationship for many years with the Global Runoff Data Centre (GRDC), one of four sub-regional data centres of the FRIEND European Water Archive. There is also synergy between FRIEND and the WMO WHYCOS (World Hydrological Cycle Observing System) programme. Several of the ongoing or future WHYCOS projects coincide geographically with a regional FRIEND project and involve organisations that are also active within FRIEND.

There are also collaborative links with WCRP’s GEWEX (Global Energy and Water Cycle Experiment) and several of its regional declensions.

FRIEND works closely with the International Association of Hydrological Sciences (IAHS) in organising conferences and workshops and publishing conference proceedings. An example of this collaboration is the FRIEND 2006 conference in Cuba, the proceedings of which are published in the IAHS Red Book Series.

Table 1.1 Countries participating in the FRIEND project

FRIEND Group	**Participating countries**			
Northern Europe	Austria	Belarus	Belgium	Czech Republic
(24 countries,	Denmark	Estonia	Finland	France
established 1985)	Germany	Hungary	Iceland	Ireland
	Latvia	Lithuania	Luxembourg	The Netherlands
	Norway	Poland	Russia	Slovakia
	Sweden	Switzerland	Ukraine	UK
AMHY	Albania	Algeria	Bulgaria	France
(20 countries,	Greece	Hungary	Italy	Lebanon
established 1991)	Malta	Moldavia	Morocco	Palestine
	Portugal	Romania	Serbia	Slovenia
	Spain	Switzerland	Tunisia	Turkey
Southern Africa	Angola	Botswana	Lesotho	Malawi
(12 countries,	Mauritius	Mozambique	Namibia	South Africa
established 1991)	Swaziland	Tanzania	Zambia	Zimbabwe
Asian Pacific (14 countries,	Australia	Cambodia	China	Dem. People's Rep. of Korea
established 1997)	Indonesia	Japan	Lao People's Dem. Rep.	Malaysia
	New Zealand	Papua New Guinea	Philippines	Rep. of Korea
	Thailand	Vietnam		
West & Central Africa (AOC)	Benin	Burkina Faso	Cameroon	Central African Republic
(17 countries,	Chad	Congo	Côte d'Ivoire	Ghana
established 1992)	Guinea	Liberia	Mali	Mauritania
	Niger	Nigeria	Senegal	Sierra Leone
	Togo			
Hindu Kush-Himalayan	Afghanistan	Bangladesh	Bhutan	China
(8 countries, established 1996)	India	Myanmar	Nepal	Pakistan
Nile	Egypt	Ethiopia	Kenya	Sudan
(5 countries, established 1996)	Tanzania			
Latin America and Caribbean (AMIGO)	Anguilla	Antigua and Barbuda	Argentina	Aruba
(42 countries &	Bahamas	Barbados	Bermuda	Bolivia
administrative dependencies,	Brazil	British Virgin Islands	Cayman Islands	Chile
established 1999)	Colombia	Costa Rica	Cuba	Dominica
	Dominican Republic	Ecuador	Federal dependencies of Venezuela	French Guiana
	French West Indies	Grenada	Guyana	Haiti
	Honduras	Jamaica	Mexico	Montserrat
	Netherlands Antilles	Panama	Paraguay	Peru
	Puerto Rico	Saint Kitts and Nevis	Saint Lucia	Saint Vincent & the Grenadines
	Suriname	Trinidad and Tobago	Turks and Caicos Islands	United States Virgin Islands
	Uruguay	Venezuela		

FRIEND has been developing links with the Global Water Partnership (GWP), which it joined formally in October 2000. The GWP is an independent global network that seeks to offer new and innovative ways of networking between stakeholders and to support countries in the sustainable management of their resources by bringing together research needs and donors. The GWP operates through a number of regional Technical Advisory Committees (TACs) and is working in many regions where FRIEND is already established. For instance, the research focus of the Southern Africa FRIEND project has been guided by the regional TAC and many of the active FRIEND participants are also involved in the GWP.

In Europe, FRIEND has been supported by, and has contributed to, the EU Framework Programmes for Research, Technological Development and Demonstration, with projects such as ARIDE (Assessment of the Regional Impact of Droughts in Europe), GRAPES (Groundwater and River Resources Action Programme on a European Scale) and ASTHyDA (Analysis, Synthesis and Transfer of Knowledge and Tools on Hydrological Drought Assessment through a European Network).

1.3 FRIEND Report

This volume is the fifth in a series of FRIEND Reports (Gustard *et al.*, 1989; Gustard, 1993; Oberlin and Desbos, 1997; Gustard and Cole, 2002), which have been produced to mark the end of successive phases of FRIEND and to coincide with major international FRIEND Conferences held in Bolkesjø, Norway, in 1989, Braunschweig, Germany, in 1993, Postøjna, Slovenia, in 1997 and Cape Town, South Africa, in 2002 (Roald *et al.*, 1989; Seuna *et al.*, 1994; Gustard *et al.*, 1997; Van Lanen and Demuth, 2002). This report presents research conducted during the fifth phase of FRIEND from 2002 to 2006 and coincides with the Fifth FRIEND World Conference, Climate Variability and Change – Hydrological Impacts, in Havana, Cuba, 26 November – 1 December 2006.

The report presents a synthesis of global FRIEND research, giving the reader a flavour of the wide range of research activities addressed and the different problems faced by each regional FRIEND group. Following this introduction, a chapter is devoted to each of the eight established regional FRIEND projects. Each chapter was prepared by the regional FRIEND coordinator and project leaders, based on contributions from regional participants. They typically describe the hydrological challenges faced by the regional FRIEND group, its organisation and project development, an outline of the activities undertaken and selected examples of its research output. Chapter 10 gives an overview of FRIEND education and training programmes and Chapter 11 provides a general conclusion, summarises the overall achievements of FRIEND and outlines future plans.

Annexes give background information on the FRIEND project: contact details for the eight regional coordinators, FRIEND research participants, FRIEND meetings, and publications by FRIEND participants. Although it is impossible to provide a fully comprehensive picture of all regional groups, these annexes show clearly the vigour, high productivity and wide-ranging nature of FRIEND research and collaboration, and the wide dissemination of research results in scientific journals, conference proceedings, books and reports.

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2 Northern Europe – NE-FRIEND

2.1 Introduction

2.1.1 Regional characteristics

In Europe the demand for water resources has increased in recent years due to the increase of population and the economic development. Therefore conflicts between human requirements and changes in human water use, which may contribute to future alterations in water resources and river flows, and ecological needs, are likely to increase. The conflicts are most critical and intensify during water stress situations. Water stress situations and the impact of climate variability on the water resources are the key factors currently affecting Europe's water bodies. The projected changes may lead to changes in the spatial and temporal distribution of regional and at site water resources. Therefore mitigation strategies are needed which will provide tools for the society to prepare and adjust to, for example, varying water levels and water supply. There are many studies outlining the present and future trends for the

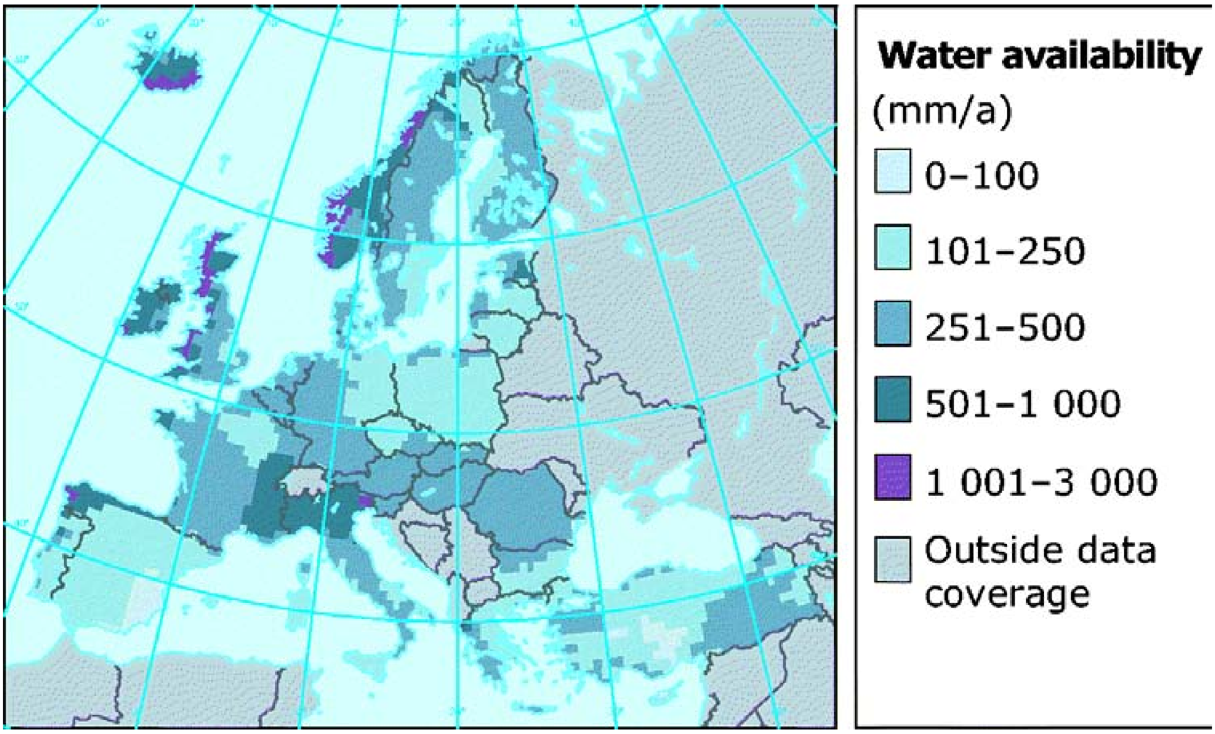

Figure 2.1 Current water availability in European rivers (EEA, 2005)

European and global environment including various aspects of water resources and hydrology (IPCC, 1992, 2001a, 2001b; EC 2005).

Across Europe about 300 billion m³ of water are currently withdrawn every year – about equal to the combined annual water discharge at the mouths of the three major European rivers, Danube, Rhine and Loire. This amounts to roughly a tenth of Europe's annual available freshwater resources. Most of this water is used in agriculture (37%) and the energy sector (32%), households (24%) and manufacture (13%). The EU's water framework directive and the 6th environment action programme stress the need for close international cooperation at river basin level and call for individual river basin management plans for all European waters. They promote sustainable water use, improved protection of aquatic ecosystems, reduced pollution of surface and ground waters, and the mitigation of the effects of floods and droughts (EEA, 2005).

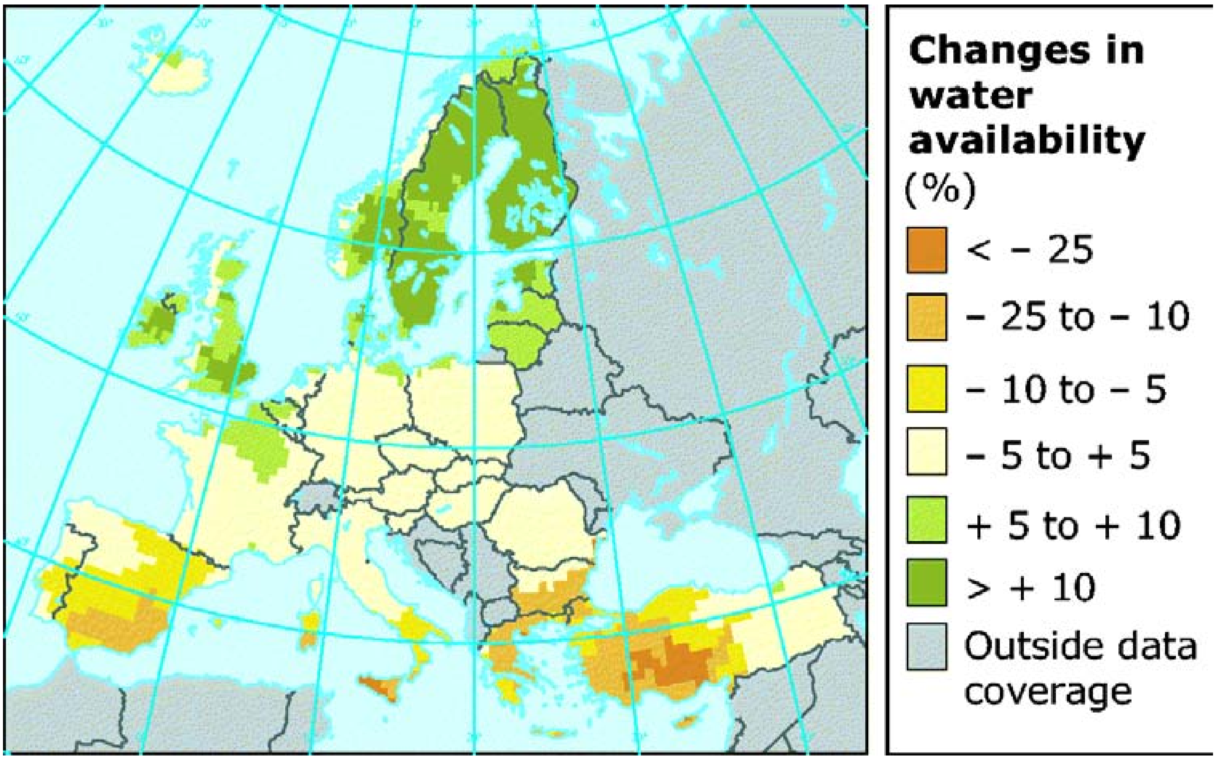

Figure 2.2 Changes in average annual water availability by 2030 (EEA, 2005)

Changes in the average water availability in most European river basins are estimated to be relatively small over the next 30 years. Increases in annual runoff are expected for several river basins in northern Europe as average precipitation increases. However, changes in the intra-annual water availability are expected, as are changes in the frequency and intensity of droughts, in particular in southern and parts of central Europe (Figures 2.1 and 2.2). In contrast, average runoff in south European rivers will decrease. Some river basins in the Mediterranean region will see decreases of 10% or more below today's level by 2030 (EEA, 2005).

Projections of extreme weather events, e.g. floods and droughts, are characterised by a high level of uncertainty. While the annual number of such events has increased in recent decades, the extent to which they are linked to changing climate and what patterns might lead to them is uncertain. During the reporting period large areas in central Europe, western and southern Europe, have experienced a rapid alternation of flood and drought events. Those particularly affected by the 2003 drought included France, Spain, Portugal, Italy, Germany, Switzerland, Austria, England, the Benelux countries, Poland, Slovakia, Romania and Hungary. The area affected by drought was in the region of several million square kilometres. As a consequence a document has been produced for politicians entitled "Towards a European Drought Policy". Between 1998 and 2005 Europe suffered about 100 damaging floods, the economic losses were high and about 1.5% of the population was affected.

A central feature of the Northern European FRIEND programme is the European Water Archive, a database available exclusively to project participants, that underpins much of the research undertaken. Since its establishment in the mid-1980s the database has been continuously updated by the project members. Today, the European Water Archive (EWA) comprises spatial data and time-series data for ca 4000 river gauging stations in 30 countries and provides FRIEND scientists with access to one of the most comprehensive hydrological datasets in Europe.

2.1.2 Northern European FRIEND project

The FRIEND project was initiated in 1985 by a handful of scientists from Germany, the Netherlands, Norway and the United Kingdom working together at the Centre for Ecology and Hydrology (former Institute of Hydrology). It is an international research programme within the framework of IHP. In the current phase VI of IHP (2002-2007) FRIEND, as a so-called cross-cutting programme, plays an important role. Its objective is to study the spatial and temporal variability of hydrological regimes on a European scale and in other regions outside Europe. Today FRIEND has developed into a worldwide network of similarly structured projects. About 141 countries in different parts of the world participate in this programme.

The Northern European FRIEND Group comprises five project groups covering four research themes and the further development of a hydrological database, the European Water Archive. The four themes are: low flow with emphasis on investigating the natural variability of low flow for water resources management applications and human impact studies, hydrological droughts and their climatic drivers; large-scale variations in hydrological characteristics focusing, for example, on detecting hydrological variability and change through regionalisation, interpolation and mapping, predicting and forecasting of hydrological variability, including floods and droughts; techniques for extreme rainfall and flood runoff estimation, e.g. studying uncertainty in flood inundation models, flood frequency computation within the uncertainty framework and spatial responses of hydrological models; and catchment hydrological and biogeochemical processes in a changing environment which concentrates their activities in small catchments with a research focus on runoff generation, assessment of the water quality components in streams and the impacts of projected climate and land use changes.

Each project group is led by a single individual who is responsible for coordinating group activities, such as technical workshops, training courses and meetings, directing the scientific direction of the group’s research and representing the group at Northern European FRIEND Steering Committee meetings. The individual groups comprise more then 20 researchers from different countries in Europe who meet regularly either at side meetings during conferences or at their own venues to report about ongoing research work and to exchange knowledge, experience and ideas. Some of the groups have created smaller units to work on particular topics. The researchers in the NE-FRIEND programme have developed a very strong international research network which reaches far beyond the boundaries of Europe. That enables the various groups to interact with other regional FRIEND groups on specific topics and opens up research to be conducted at various geographical and climatic regions. This helps to test and exchange methodologies at a global scale.

The activities of all five research groups are overseen by the Northern European FRIEND Steering Committee. The Committee, which meets every two years, consists of representatives from each participating country's national IHP committee, together with representatives from UNESCO, WMO, the European Research Basin network (ERB) and the European Environment Agency (EEA). As well as reviewing the scientific aspects of the project, the Steering Committee discusses options for the dissemination of FRIEND research (e.g. conferences, journals), the relationship with other FRIEND groups around the world and possibilities for improved cooperation between FRIEND and other international programmes and organisations, for example, WMO-HWRP-CHy (Commission for Hydrology), IAHS-PUB, WWAP, UN Water and EU. Furthermore, there is a strong link between the NE-FRIEND group and the various commissions of IAHS, and IAHS benefits from the scientific output of FRIEND. The NE-FRIEND chairmanship has been transferred from the Centre for Ecology and Hydrology UK to the IHP/HWRP Secretariat at the Federal Institute of Hydrology, Germany.

2.2 The European Water Archive

A central feature of the Northern European FRIEND project is the European Water Archive (EWA). Such a database is a fundamental prerequisite for developing a better understanding of the temporal and spatial variability of hydrological regimes in Europe. To characterise the variability of hydrological regimes on a regional scale, it is necessary to have access to spatially extensive long-term river flow data from predominantly natural catchments. In return for being able to access the data held on the Archive, FRIEND project participants are encouraged to identify and obtain data for those gauging stations within their own countries that would be suitable for regional analyses.

In October 2004 the EWA was transferred from the Centre for Ecology and Hydrology (CEH) in Wallingford, UK, to the Global Runoff Data Centre (GRDC) located at the Federal Institute of Hydrology (BfG) in Koblenz, Germany. The relational database management system is ORACLE. EWA remains entirely separate from the GRDC database (which focuses on larger rivers at global scale). The conditions for data release remain unchanged and the five Regional Data Centres (RDC) continue to share the responsibility for updating the EWA (Gustard and Cole, 2002). GRDC has created a new webpage providing several maps, e.g. gauging stations classified by times series, record length, etc. (http://ewa.bafg.de; Figure 2.3).

The EWA is now one of the most comprehensive hydrological archives in Europe. Since the inception of the FRIEND project in 1985, the Archive has grown steadily as more and more scientists from different countries become participants. The European Water Archive presently contains around 116 000 station years of daily flow records and station metadata for 3999 river gauging stations in 30 countries across Europe. The distribution of the stations is shown in Figure 2.3. Most of the stations are still clustered in the centre of Europe where the database originated. A fairly good coverage is found in the Mediterranean areas where water is under stress. Table 2.1 shows a summary of the current flow records archived in the European Water Archive. Record lengths are generally very long, with an average of 29 years per station. There are a few stations with over 100 years of data.

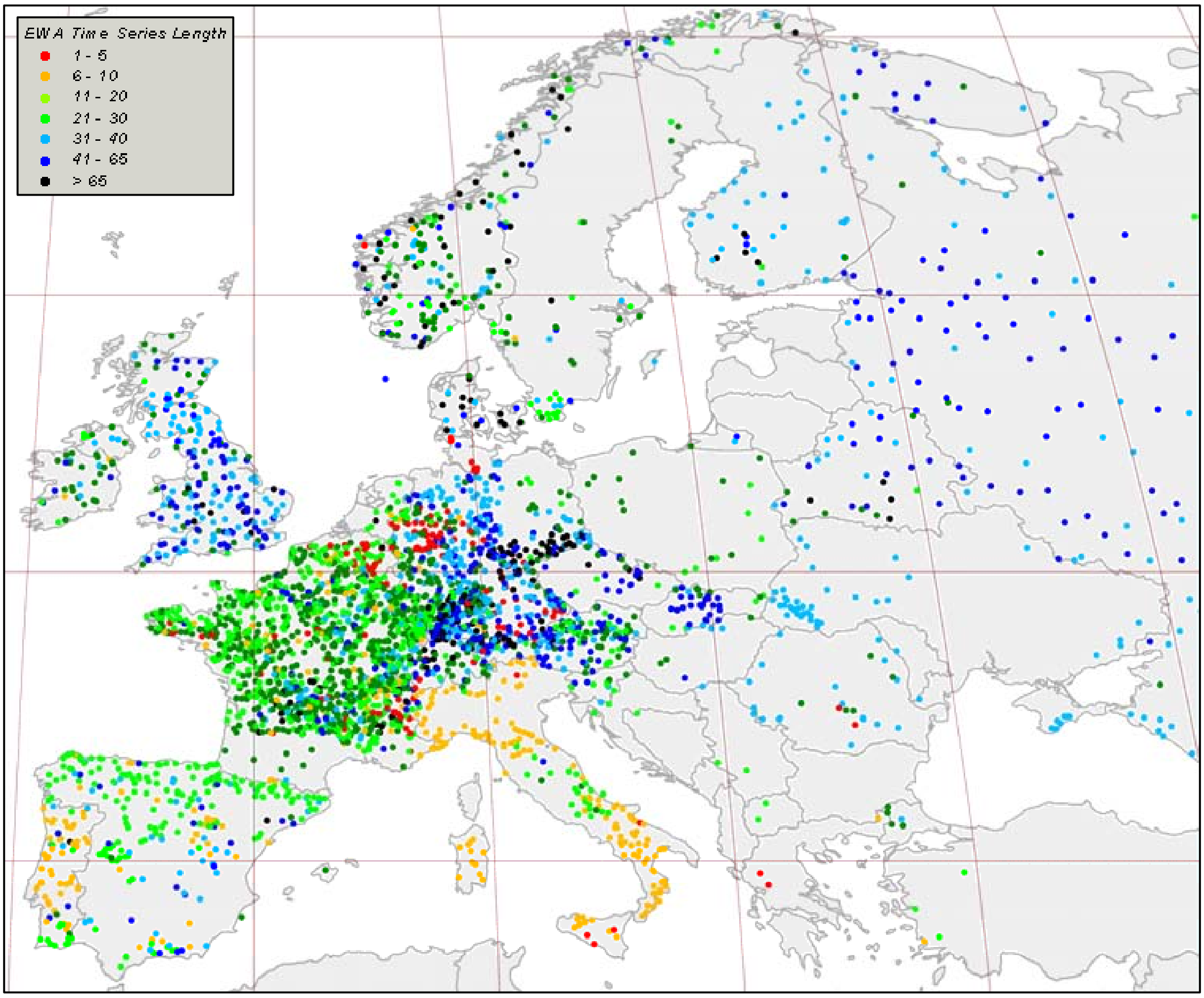

Figure 2.3 Location of FRIEND gauging stations across Europe

The Data Base Group is responsible for the development and maintenance of the EWA. The group coordinates data acquisition, applies quality control procedures and disseminates data to FRIEND researchers. Data is supplied to the archive on a voluntary basis, free of charge, and made freely available to FRIEND researchers on condition that these data are used exclusively for FRIEND research.

To sum up, the European Water Archive remains a valuable resource and a prime example of what can be achieved by international cooperation. NE-FRIEND participants from all over Europe have expended considerable time and effort to make the European Water Archive the high quality dataset for regional hydrological analysis it is today. Many scientists have already benefited from its existence by using the data for their research. The EWA will become even more relevant as we aim to understand the impacts of climate and other changes to water resources and threats from hydrological extremes, such as floods and droughts.

Table 2.1 Summary of gauged daily flow data on the FRIEND European Water Archive

Country	Country code ISO 3166	Total no. of stations	Station years	Earliest record	Latest record	Record length (yrs) Av.	Min.	Max.
AUSTRIA	AT	139	4520	1922	1996	32.5	4	75
BELARUS	BY	33	1383	1919	1995	41.9	18	77
BELGIUM	BE	75	837	1929	1997	11.2	2	54
BOSNIA AND HERZEGOVINA	BA	1	13	1978	1990	13.0	13	13
BULGARIA	BG	3	27	1978	1986	9.0	9	9
CZECH REPUBLIC	CZ	27	1468	1887	1993	54.4	11	104
DENMARK	DK	30	1873	1917	1997	62.4	23	81
FINLAND	FI	43	1722	1911	1997	40.0	20	87
FRANCE	FR	1314	29459	1863	1992	22.4	1	128
GERMANY	DE	736	27766	1884	1998	37.7	1	113
GREECE	GR	2	6	1978	1980	3.0	3	3
HUNGARY	HU	25	825	1935	1996	33.0	15	62
ICELAND	IS	8	386	1932	1994	48.3	43	61
IRELAND	IE	77	1908	1940	1997	24.8	7	57
ITALY	IT	252	3969	1925	1990	15.8	3	66
MACEDONIA	MK	1	13	1978	1990	13.0	13	13
NETHERLANDS	NL	32	694	1901	1994	21.7	3	93
NORWAY	NO	175	7148	1871	1999	40.8	4	127
POLAND	PL	29	738	1955	1992	25.4	11	36
PORTUGAL	PT	73	1092	1920	1994	15.0	9	71
ROMANIA	RO	31	982	1952	1990	31.7	2	39
RUSSIAN FEDERATION	RU	199	8674	1928	1995	43.6	11	63
SERBIA AND MONTENEGRO	CS	2	24	1978	1990	12.0	11	13
SLOVAKIA	SK	23	1441	1930	1992	62.7	61	63
SLOVENIA	SI	13	313	1945	1990	24.1	13	45
SPAIN	ES	258	4418	1912	1995	17.1	6	74
SWEDEN	SE	50	1366	1924	1992	27.3	8	68
SWITZERLAND	CH	75	2775	1904	1992	37.0	5	82
TURKEY	TR	12	201	1958	1991	16.8	8	33
UKRAINE	UA	58	1798	1960	1990	31.0	31	31
UNITED KINGDOM	GB	203	8068	1879	2003	39.7	20	123
Summary		3999	115907	1863	2003	29.0	1	128

2.3 Research projects

2.3.1 Low flow

Drought, which is often associated with low streamflow, is a complex phenomenon with wide-ranging social, environmental and economic impacts. It is a relative and worldwide phenomenon relating a water shortage to what would normally be available in a region at a particular time. Drought as compared to flood differs in many ways. It develops slowly in time and space and will normally cover a larger area and extend for a longer time period than a flood event, e.g. the severe drought that hit Europe in 2003 which had adverse effects on sectors like water supply, agriculture, power production, transport and forestry (Figure 2.4). Drought analysis thus often requires the availability of transboundary data and the NE-FRIEND database, the European Water Archive (EWA), has in this respect offered the Low Flow Group a unique dataset of daily streamflow series across Europe. Important aspects of a drought include the spatial extent of the event (climate control), the variability within the affected area (catchment control), the dynamics of the event (growth and decay) and possible recurrent patterns in space.

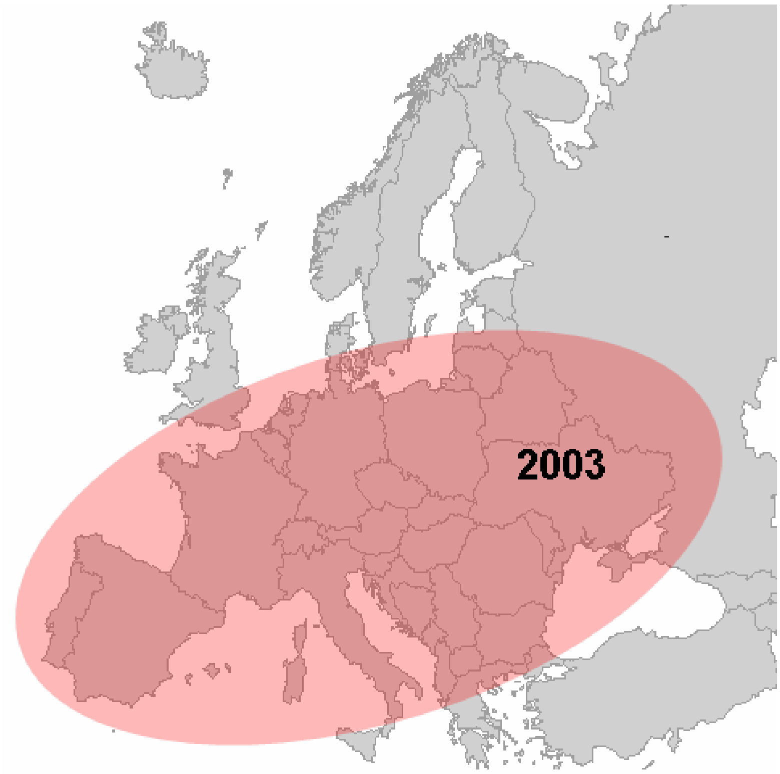

Figure 2.4 The approximate spatial extent of the 2003 drought in Europe

The NE-FRIEND Low Flow Group consists of 25 members from 10 countries. Within the Low Flow Group co-operation has in recent years evolved around smaller research groups, such as the Eastern European group and the European Union supported projects ARIDE (Demuth and Stahl, 2001) and ASTHyDA (Tallaksen and van Lanen, 2005). Considerable work has been invested in proposal writing for funding, in particular EC framework programmes, and although not always successful, it has contributed to the further development of research ideas, innovations and scientific networks.

The primary objective of the NE-FRIEND Low Flow Group has been to characterise the regional behaviour of low flow and drought and to identify the main governing factors at different scales. Comparative analyses have been carried out using a consistent set of definitions and analysing tools, focusing on drought characteristics obtained from observed or simulated time series of precipitation, streamflow and groundwater variables. The diversity in hydroclimatological and hydrogeological regimes found across Europe implies that a wide range of features have to be taken into account, including catchments that experience seasonality (e.g. frost represented by snow, ice and glaciers, or wet and dry seasons), intermittent rivers, mixed regimes and different hydrogeological properties (e.g. groundwater catchments). A first comprehensive description and definition of the temporal and spatial aspects of streamflow and groundwater drought has been presented. In addition, the characterisation of human activities disturbing the natural regime and of climate change effects on water resources and droughts in particular, have been investigated. This includes the response of the physical habitat to hydroclimatological variability and change (ecohydrology).

The research has covered a range of topics, including definitions, extreme characteristics, process understanding, anthropogenic impacts (including climate change), regionalisation and mapping, estimation at the ungauged site, variability in time and space, hydroclimatological drivers and synoptic behaviour across Europe. The studies comprise exploratory data analyses, reviews (historical events and drought studies), advanced statistical techniques (e.g. extreme value analysis, time series analysis and regional approaches) and finally, conceptual and physical based hydrological modelling. The work has been directed towards basic research as well as operational practice. Common to many of the studies, which encompass large-scale pan-European, regional and process based studies, is the use of the threshold level method to define drought events from time series of hydrological variables.

A significant contribution to the research is achieved through the involvement of PhD students. During the last FRIEND period, four of its members completed their PhD theses covering process-based regionalisation of low flows (Laaha, 2003), western European climate and river flow regimes (Bower, 2004), regional aspects of drought (Hisdal, 2002) and propagation of drought through the groundwater system (Peters, 2003). In addition, master students have contributed to the group (e.g. Fleig, 2004; Verwij, 2005). The main scientific achievements as well as dissemination and training activities over the last two FRIEND periods are summarised in Tallaksen *et al.* (2005), along with references to research results published in international journals and conference proceedings.

The Low Flow Group responded in the reporting period to the need for a concise review and dissemination of knowledge on hydrological drought. This activity has been supported by the ASTHyDA (http://www.geo.uio.no/drought) project, an accompanying measure in EC’s 5th framework programme. Hydrological data, drought processes, estimation methods, impact of environmental change and operational management practice under drought conditions were reviewed. The main focus was Europe, although the diversity in the world's hydroclimatology was considered and streamflow series from around the world were used to evaluate the applicability of a particular model or estimation procedure. Recently, the production of a manual on the estimation and prediction of low flows for operational agencies has been initiated as a joint WMO/UNESCO (FRIEND) project.

2.3.2 Large-scale variations in hydrological characteristics

Given heightened concerns about climate change and human impacts upon water resources, it is critical to provide information about current and future variations in hydrological characteristics. By elucidating patterns and drivers of hydrological response, it is possible to assess those regions and time-periods most susceptible to climate change/variability and anthropogenic influences and thus inform decision-makers so that water hazards and stress (e.g. floods and droughts) may be mitigated. NE-FRIEND Project 3 aims to identify and understand variations in hydrological behaviour at a range of spatial (within basin to global) and temporal (event to multi-decadal) scales, so much of the research effort is targeted toward regional hydrology. Research themes include:

1) methods for detection of hydrological variability and change: regionalisation/ interpolation, mapping hydrological characteristics, time-series analysis, classification, assessing climatic sensitivity of flows, hydrostochastics, etc.
2) multi-scale hydrological systems/scale issues
3) large scale climate-hydrology interactions, including teleconnections
4) modelling hydrological fluxes/budgets and water use
5) prediction and forecasting of hydrological variability, including floods and droughts.

The research philosophy of the group is holistic. Research spans the spectrum of hydrological descriptors (average, minimum (drought), maximum (floods), annual regimes, duration curves, moments, etc.) rather than focusing upon certain aspects of the hydrological regime. Both inductive (data mining) and deductive (hypothesis-driven) approaches are adopted. Many of the group’s innovative techniques for hydrological analysis have been developed to be adaptable to a range of hydrological descriptors to increase applicability. Moreover, several participants work on the atmosphere-surface water (including snow and ice)-groundwater process cascade and, thus, bridge traditional (sub-)discipline boundaries. Although a range of research themes and approaches exist within the group, participants are united by a common goal: to share expertise, methods, findings and data. The benefit and unique aspect of NE-FRIEND Project 3 is the cross-cutting nature of research activities, which allow the group and participants to collaborate with AMIGO (Latin America and Caribbean), AMHY (Alpine and Mediterranean) and HKH (Hindu Kush-Himalayan) FRIEND programmes, as well as other NE-FRIEND groups (e.g. Project 2: Low Flow).

The ability to ‘think beyond the drainage basin’ and identify, understand and predict drivers of hydrological variability are fundamental to assessment of the impact of global environmental change (both climate and human-induced) upon water resources. In addition, the regionalisation and interpolation of hydrological characteristics coupled with the investigation of multi-scale hydrological systems are important in two contexts: (1) addressing the ‘ungauged basin problem’ (e.g. the IAHS-PUB initiative) and (2) upscaling finer-scale process-based understanding to the large scale (and *vice versa* downscaling). These scientifically and practically important issues are being addressed by NE-FRIEND Project 3, as demonstrated by the following key achievements. To organise information, projects are grouped under the above research themes; however, it should be noted that these research strands are interwoven rather than mutually exclusive.

Methodological advances and scale issues

Several participants have worked on advancing regionalisation/interpolation and time-series analysis methods (theme 1 and theme 2). This research includes:

- quantification and explanation of regional hydrological variations and evaluation of competing time-series analysis methodologies for studying hydrological records in Wales and the English Midlands
- regional frequency analysis to examine changes in extreme rainfall causing flooding in the UK (1961-2000) and assessing the ability of regional climate models to reproduce extreme rainfall patterns and assessing future changes
- new statistical methods for interpolation of runoff at different space and time scales, termed 'hydrostochastics'; these techniques allow consistent regionalisation of all river flow characteristics (from mean runoff and coefficient of variation to low flow and floods) and they respect 'contextual rules', that is, all parts of the basin and river network are interrelated.
- evaluation of flood risk in Slovakia, including computation of design discharges in small mountain basins, regional flood frequency analysis, flood risk analysis, rainfall-runoff modelling and assessing climate change impacts on flooding
- development of a national low flow regionalisation method for Austria, including seasonality indices classification, comparison of various approaches for grouping hydrologically similar basins and mapping schemes, investigation of the value of short records for regionalisation and the Consensus Modelling Approach
- analyses of the spatial and temporal distribution of floods within Britain over the last 1000 years, including methods for the incorporation of historical hydrological information into flood frequency analysis
- regionalisation, using basin properties, of hydrological parameters for lumped models and river flow prediction at ungauged sites
- explicit consideration of scale issues (within a geostatistical framework) to interpolate runoff, regionalise catchment parameters and flood frequency, and model regional water availability
- identification of a regional variability in hydrological/basin characteristics and flood frequency for small basins in Slovakia as a basis for assessing flood risk (Figure 2.5).

Climate-hydrology interactions (theme 3)

Both empirically based and modelling (also see theme 4 below) approaches have been adopted to investigate large-scale hydroclimatological patterns and interactions. At the Western European scale, empirical research has focused upon identifying and understanding spatial and temporal variability in climate and river flow regimes, and the impact of climate variability/change upon river flow regimes. This work has included:

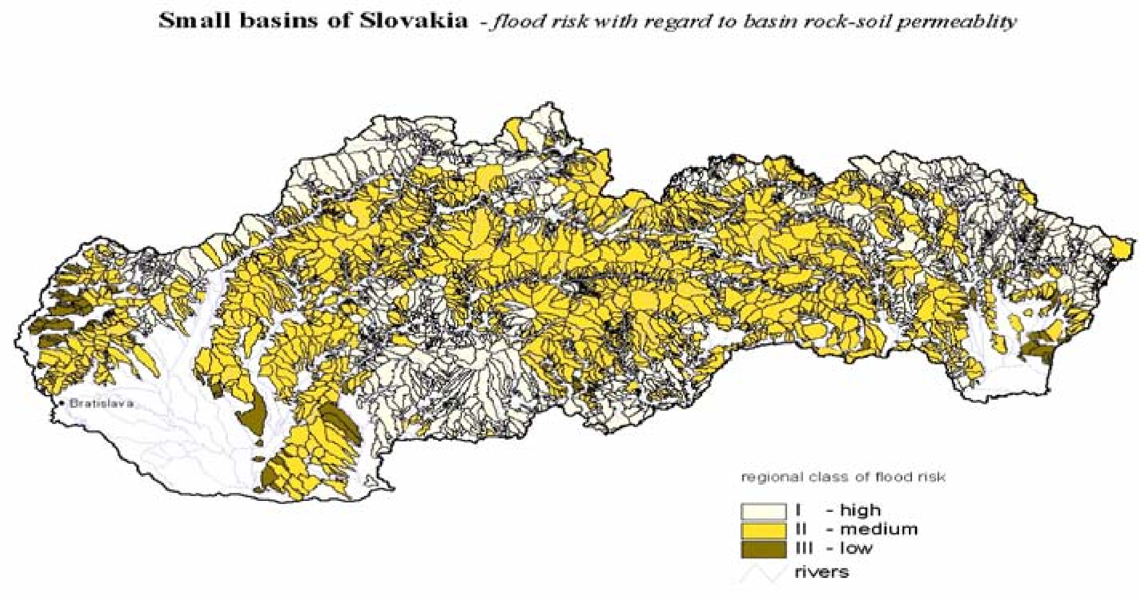

Figure 2.5 Flood risk for small basins in Slovakia, based upon evaluation of rock-soil complex permeability (source: Solín) [Note: I = basins with no permeable and very poorly permeable soils having high variability of mean daily discharge values (Cv = 100-160%) and low percentage of baseflow (30-50%); II = basins with permeable soil having medium variability of mean daily discharge values (Cv = 50-100%) and medium percentage of baseflow (50-75%); III = basins with highly permeable soils with very low variability of mean daily discharge values (Cv < 50%) and very high percentage of baseflow (over 75%)]

- developing a methodology for classification of river flow regimes (i.e. annual hydrographs) at the continental scale to aid characterisation of spatial and temporal variability in Western European river flows (Figure 2.6)
- deriving a new air-mass climatology for Western Europe
- developing a transferable Sensitivity Index to assess the impact of climatic variability upon flow regimes
- investigating linkages between Western European air-mass types and their frequencies, and river flow regimes
- developing methodologies for detecting changes in river flow regimes in space and time, e.g. for Scandinavia and France.

In addition, these methodologies (or derivatives) have been applied to characterise large-scale precipitation and runoff patterns and to assess the potential impact of climate variability/change upon river flows for Himalayan river basins of Nepal. Similar techniques have also been used to examine climate-hydrology links in the Upper Indus Basin (Hindu Kush Himalaya) to assess recent climatic trends and associations between atmospheric circulation patterns and hydrology response.

For the northern North Atlantic region, ocean-atmosphere (including the North Atlantic Oscillation) controls upon river flow have been investigated to identify the key climatological drivers of both high and low flows. Scenario-based modelling has been undertaken across

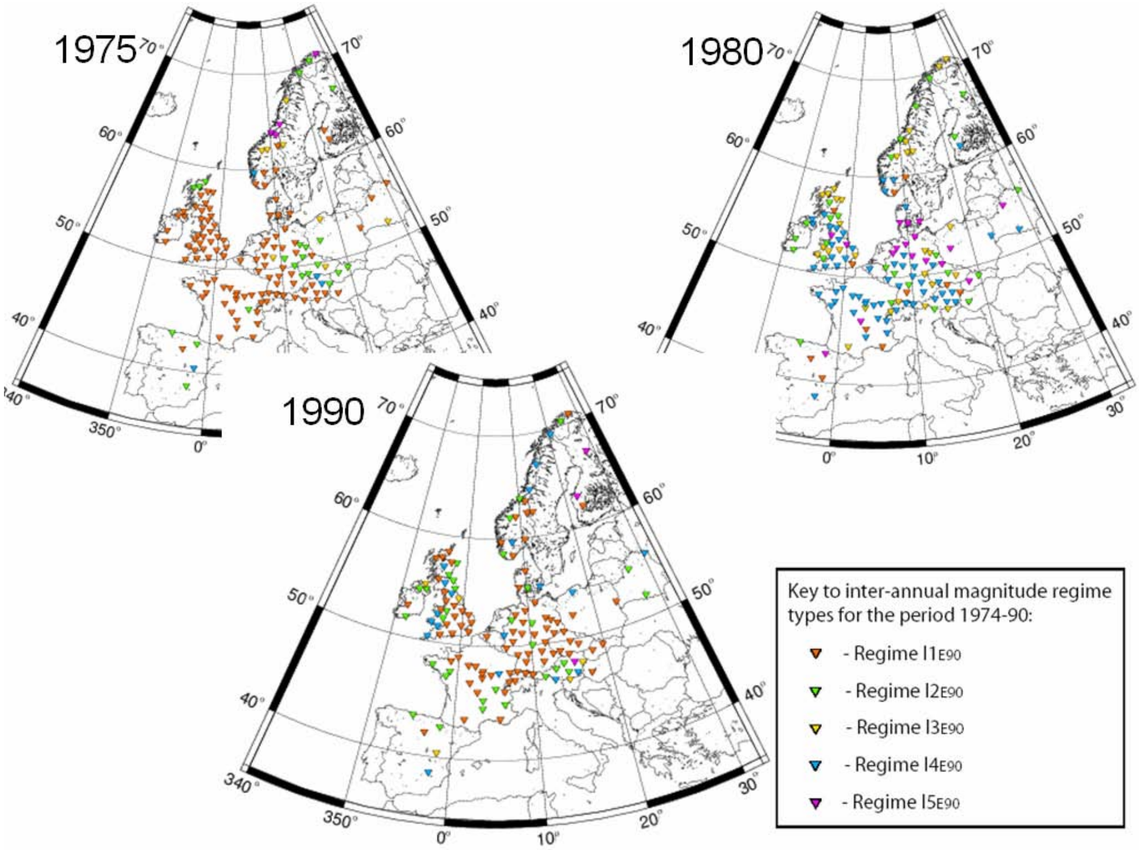

Figure 2.6 Variability in inter-annual river flow regimes across Western Europe (source: Bower; Hannah; McGregor) [Note: (1) This sample illustrates that in individual years certain regimes are prevalent, e.g. 1975=1, 1980=4 and 1990=1; (2) Lower magnitude regimes span larger geographical regions than higher magnitude regimes; this may reflect (hydro-)climatological conditions leading to their development – dry, high-pressure, anti-cyclonic systems tend to persist over a larger area than low-pressure cyclonic systems; and (3) Nordic countries tend to follow a different pattern of variability to that of the rest of Europe.]

Europe to assess the hydrological impact of climate change; this research is novel as it employs a probabilistic framework to yield a range of possible futures, rather than single central estimates.

At the basin scale, detailed modelling has been conducted to downscale climate change scenarios and analyse impacts on high and low flow indicators for UK rivers. Methods were developed to assess and compare the main uncertainties inherent to climate change impact studies and models run for current and future time-horizons. Stochastic rainfall generators have been used for broad-scale modelling of runoff, which shows potential for estimation at ungauged sites and simulation of future river flow conditions.

Modelling hydrological fluxes and water use (theme 4)

At the global scale, the WaterGAP model has been applied to investigate hydrological (water resources) and water use patterns. This work entails model development and application of models; it is geared towards assessing the current situation and deriving scenarios of global change. Groundwater recharge is the major limiting factor for the sustainable use of water resources. Using a global hydrological model, specifically modified to obtain good estimates of groundwater recharge in the semi-arid and arid regions of the globe (WaterGAP Global Hydrological Model WGHM), the impact of climate change on groundwater recharge was assessed (Figure 2.7; Döll and Flörke, 2005). In some semi-arid areas (northeast Brazil, southwest Africa and the southern Mediterranean rim), groundwater recharge will decrease markedly by the 2050s according to the four climate scenarios applied.

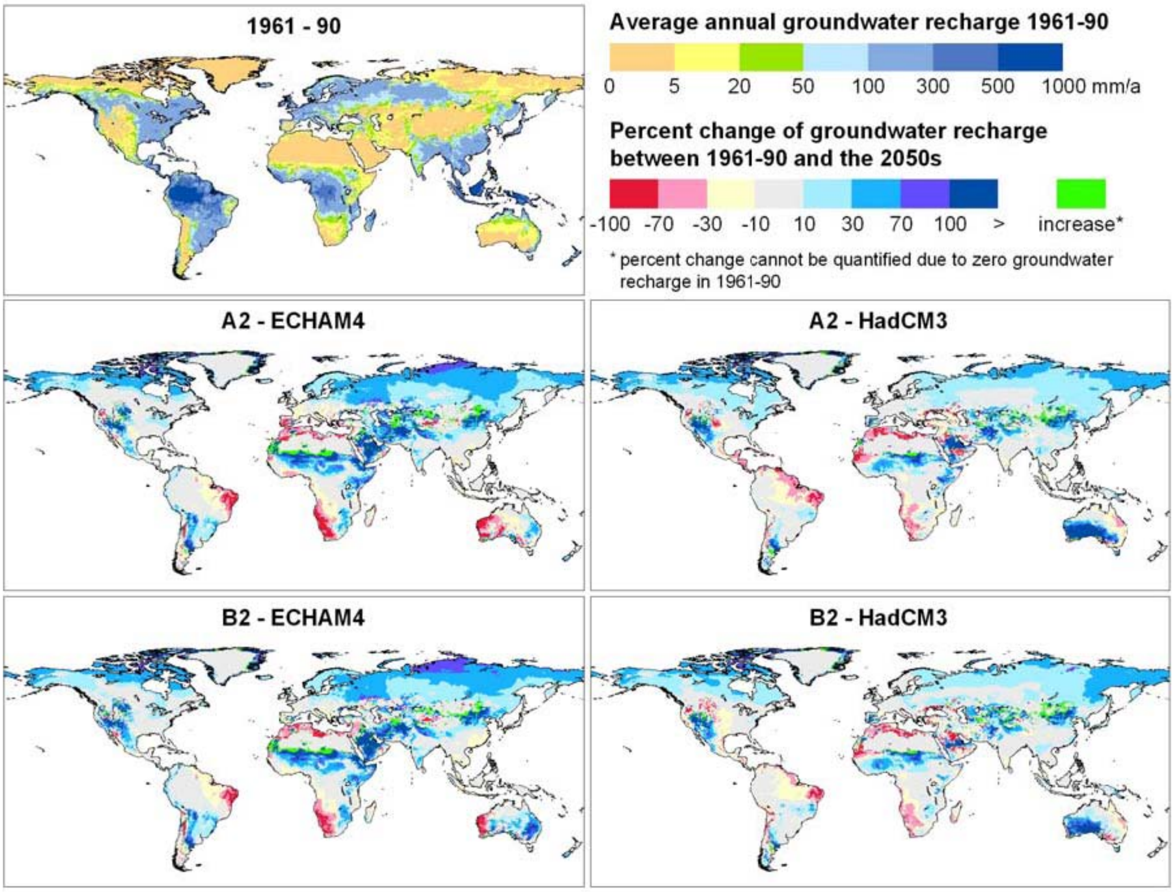

Figure 2.7 Average annual groundwater recharge: baseline (1961-90) and scenarios for the 2050s showing the impact of climate change (source: Döll and Flörke, 2005; http://www.geo.uni-frankfurt.de/ipg/ag/dl/publikationen/index.html)

2.3.3 Techniques for extreme rainfall and flood runoff estimation

The research of the group focused on real-time forecasting and simulation for design purposes, frequency estimation of peak flows and flood inundation, and the understanding of runoff generation processes. In most of the catchments studied not only rainfall but also snow is important. A central aspect is an effort to estimate uncertainty in the predictions. The following sections describe the topics studied in more detail.

Assimilating satellite-derived snow-covered area (SCA) in hydrological models

A major cause of flooding in Norway is the combination of intense snowmelt and precipitation. To be able to forecast these flooding events, reliable forecasts of precipitation and temperature are needed, along with a good estimate of the snow reservoir and its coverage in the catchment at the time of the forecast. Modelling the SCA correctly is considered a prerequisite for the applied rainfall-runoff model to capture the dynamics of the snowmelt-induced spring flood, and through this study, an analytical link between SCA and the parameters of the spatial distribution of snow water equivalent (SWE) has been developed.

The spatial distribution of snow water equivalent (SWE) is modelled as a two-parameter gamma distribution with parameters dependent on the number of accumulations and ablations. The strict analytical control of the spatial distribution of SWE at all times allows for the development of algorithms which relates accumulated or ablated snow to changes in the snow-covered area (SCA) of a catchment. The algorithms are further developed so that remotely sensed information of SCA can be used to update the snow reservoir and the spatial distribution of SWE.

The snow distribution model and the updating algorithms are implemented in the Nordic HBV model and have been tested for ten Norwegian catchments. The overall improvements on the prediction of discharge by updating several satellite-derived SCA scenes are modest, but significant improvements for some scenes are observed (Figure 2.8). Errors and temporal inconsistencies in the quantification of SCA from the satellite scenes are found, which may lead to serious errors in the predicted discharge. The methodology is totally dependent on the quality of the SCA data and special care in quantifying SCA has to be taken for operational use of the updating algorithms.

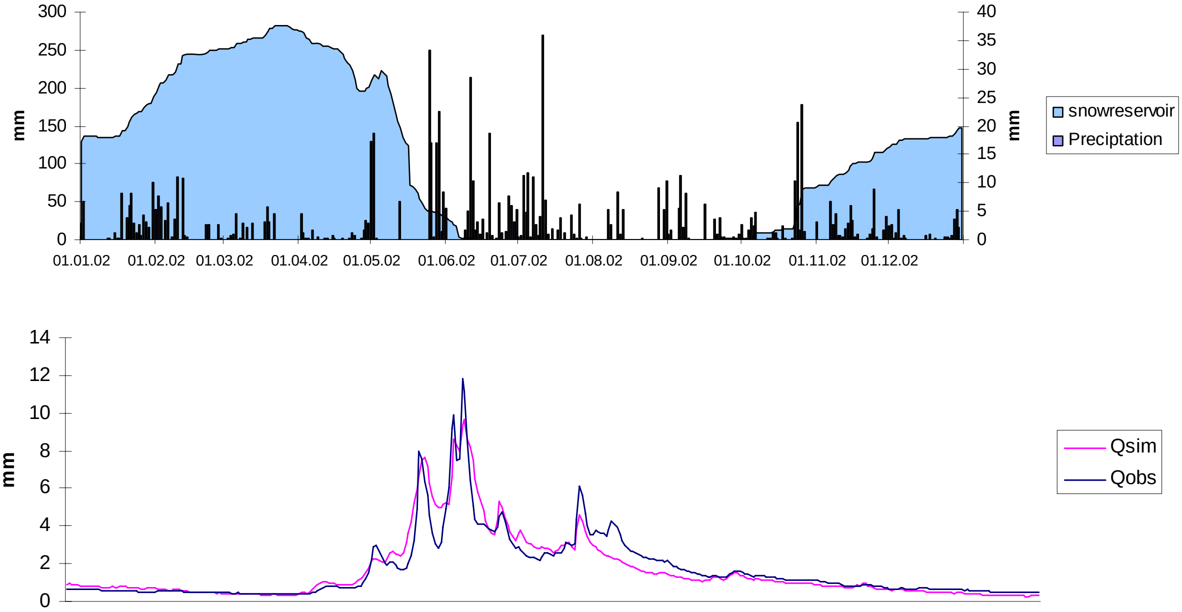

Figure 2.8 Successful updating for the Atnasjø catchment in 2002. Note how the snow reservoir in the top panel is sharply reduced in the middle of the melting period due to the assimilation of satellite-derived SCA.

Uncertainty in flood inundation models

Flood inundation models play a central role in both real-time flood forecasting and in floodplain mapping. In flood forecasting, inundation models should be as precise as possible to predict the approach of a flood correctly as well as to avoid false alarms. Flood mapping has to be accurate for a variety of reasons including decision-making for local planning or the insurance industry. A full understanding of the model and the uncertainty in the modelling strategy is therefore important.

Every flood inundation model will be an incomplete representation of reality as a result of multiple sources of uncertainty. We may distinguish the primary sources of uncertainty as follows:

- Choice of model structure as a simplification of reality (e.g. 1D or 2D flood inundation model or various representations of internal structures such as bridges)
- Numerical approximations in solution of equations defined in model structure
- Definition of boundary conditions, including input forcing data
- Choice of effective parameter values, including scaling and incommensurability effects.

Table 2.2 Flood events which have been studied within the FRIEND programme

Location	Date	Type of Data	Publication
Usti nad Orlici (Czech Republic)	1997	Geometry, flood extent and 26 level observations	(Werner *et al.*, 2005a)
River Morava (Czech Republic)	1997	Geometry, maximum level observations	(Pappenberger *et al.*, 2005b)

Key findings

- Model parameters are effective parameters (Pappenberger *et al.*, 2005a).
- Distributed observations of levels in floodplains have been shown to be most effective in constraining the uncertainty of flood inundation models (Werner *et al.*, 2005a).
- Observations of flood extent in large events where flood extent is constrained by embankments and steep valley sides may not be suitable enough to discriminate between various model structures (Werner *et al.*, 2005a).
- Sensitivity analysis of model performance against the calibration data shows that, as the number of land use classes increases, sensitivity to these roughness values decreases (Werner *et al.*, 2005b).
- Sensitivity to the uncertainty to the upstream boundary depends on the model structure chosen (Pappenberger *et al.*, 2005b; Pappenberger *et al.*, in press).
- Internal structures such as bridges can have a profound effect on model performance (Pappenberger *et al.*, in press).
- Under certain circumstances no parameter set or model implementation that fulfils all evaluation criteria can be established. We propose four different approaches to this problem: closer investigation of anomalies, introduction of local parameters, increasing the size of acceptable error bounds, and resorting to local model evaluation. Moreover, we show that it can be advantageous to decouple the classification into behavioural and non-

behavioural model data/parameter sets from the calculation of uncertainty bounds (Pappenberger and Beven, in press).

Uncertainty analysis of flood inundation models is essential to fully understand the limitations of the predictions and inundation models, and estimation of flood risk. However, there is no readily available guidance about how to do uncertainty analysis of flood inundation models. Future research in uncertainty in flood inundation models will have to concentrate on this topic.

Flood frequency computation within the uncertainty framework

Continuous simulation on hourly time-steps is used for the flood frequency computation. First short (100 years) simulations are computed. From those, behavioural simulations are selected based on three goodness of fit criteria:

- sum of absolute errors between a Wakeby distribution fitted to modelled annual peaks for each realisation and the regional estimate. The errors are computed on the first four quantiles (1-, 2-, 5- and 10-year return periods) for which we expect the regionalised estimates to be most robust.
- sum of absolute errors between the regional flow duration curve and modelled curve on all the 13 quantiles available
- sum of absolute errors between Wakeby distributions fitted to maximum annual snow water equivalents observed and modelled on five quantiles (up to the 20-year return period estimate).

With the behavioural parameter sets long (10,000 years) simulations are performed and uncertainty bounds are computed (Blazkova and Beven, 2002).

In the conditioning on "observed" flood frequency curve only quantiles up to a 10-year return period are used. This is because observed data are only one realisation of the underlying process producing extremes. They do not necessarily go through the centre of the distribution of the possible realisations. For ungauged catchments regional estimates can be used for conditioning instead of observed data (Blazkova and Beven, 2002).

Predictions of peak flow are always uncertain and would be better given and disseminated not as a single value but as a cumulative distribution (Figure 2.9). Because of the large uncertainty in the estimates of extreme phenomena, the fuzzy set theory seems to be a good tool for model evaluation. The combination of several criteria is easily implemented and linguistic descriptions can also be used.

Spatial response of hydrological models: understanding runoff generation

For computing flood frequency on a large catchment a rainfall simulator which produces precipitation events moving across the catchment should be used. Moreover, such simulations should be conditioned also on discharge and snow information from the subcatchments (Blazkova and Beven, 2004, 2005). An additional criterion for excluding unbehavioural simulations can be the agreement of the results of the precipitation simulator with the Probable Maximum Precipitation.

In small catchments the investigation of spatial responses means finding out if the wetting of the catchment in the model agrees with reality. Various procedures can be used from the simple mapping of the saturated areas during wet and dry events on the catchment (e.g.

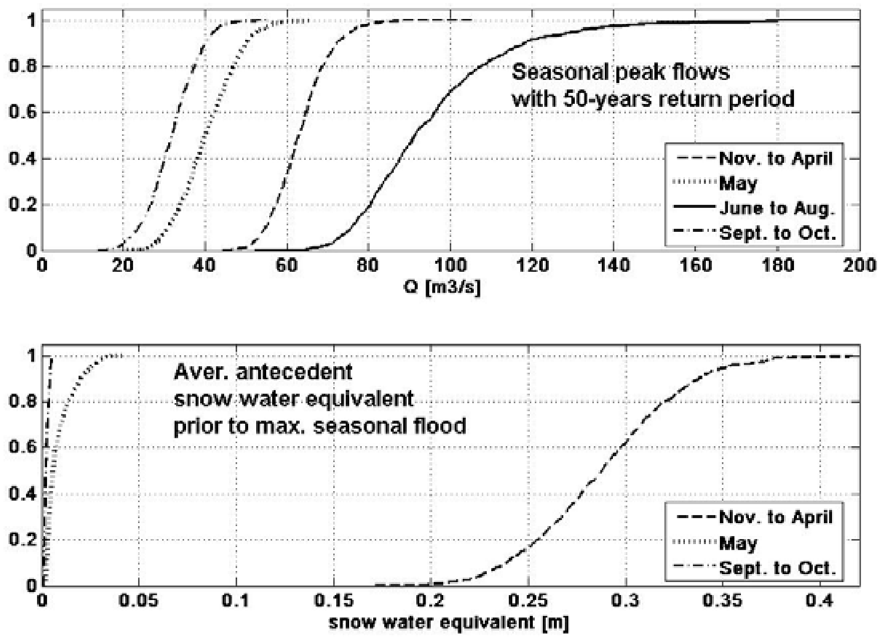

Figure 2.9 Predicted cumulative distributions of seasonal floods

Blazkova *et al.*, 2002a) to the more sophisticated use of a large number of piezometers (Blazkova *et al.*, 2002b). In the latter study about 50 piezometers were used in the Uhlirska catchment (1.87 km²) for one summer season (475 measurements altogether). Assuming hydrological similarity (all computing cells with the same value of the topographic index are hydrologically similar) prediction boundaries of water table depth have been estimated depending on the topographic index for a number of discharges.

Predictions of local water table levels with global catchment parameters gave results that were approximately correct but better reproduction of local water table responses might result from allowing local variations in the parameter values away from the global values. One of the most interesting issues is how far the local values reflect a real variation in soil properties, effective upslope contributing areas or other characteristics of the catchment, and how far they are compensating for deficiencies in the assumptions and structure of the model.

2.3.4 Catchment hydrological and biogeochemical processes in a changing environment

Hydrological studies performed mostly in small catchments addressed a variety of issues. They focused on several aspects of runoff generation including application of the knowledge in the assessment of the origin of nitrates in streams, lysimeter studies, snow hydrology and the assessment of impacts of anticipated climate and land use changes.

Runoff generation

Herrmann *et al.* (2001) developed the Integrated Catchment Approach (ICA) for application in catchment hydrology research. The ICA is based on combined application of tracers, GIS, mathematical models, etc. Runoff generation was studied in different environments with different land use: alpine-highland-lowland, dominant porous-fractured rock aquifer, agricultural (with/without irrigation)-forestry, humid mid-latitude-monsoon climate catchments located in Europe and South Asia. The analysis of runoff generation in eight central European catchments (Herrmann, 2002) showed that groundwater was by far the major component of flood hydrographs in all types of environments (lowland, highland, alpine). Several experiments with artificial tracers (Vitasin Blue AE-90, bromide, D_2O, mixtures of pesticides) in agricultural soils in Nepal and Germany showed that preferential flow paths may play an important role for the transport of agrochemicals and hence groundwater contamination (Schumann, 2004; Schumann *et al.*, 2004). The role of preferential flow in the leaching of nitrate from arable soils using the dual permeability model was studied also in the Czech Republic (Doležal *et al.*, 2004, 2005).

A number of issues connected with runoff generation were studied by Uhlenbrook *et al.* (e.g. 2002, 2003). Extensive field measurements in the network of boreholes clearly demonstrated the important contribution of groundwater during flood events in the Black Forest Mountains, Germany (Wenniger *et al.*, 2004). Long-term separation of hydrograph components in the Brugga catchment, Germany, (Uhlenbrook *et al.*, 2002) showed that during the period of almost three years the mean event water contribution to total catchment runoff was only about 11%. A modified methodology of 3- and 5-component hydrograph separations using ^{18}O and silica was proposed (Uhlenbrook and Hoeg, 2003). The analysis of uncertainties in hydrograph separations showed that only qualitative results on hydrograph components can be obtained by hydrograph separation.

Tesař *et al.* (2001) proposed the concept of a retention-evapotranspiration unit to explain the relationship between soil moisture regime and runoff generation in mountainous catchments of the Czech Republic. According to the concept, the catchment runoff is the result of two transformations. The first one, transformation of rainfall to the outflow from the soil into the more permeable drainage layer, represents the rainfall water movement through the soil in a vertical direction. The second one, transformation of outflow from the drainage layer to the runoff, represents transport of water in the drainage layer on the sloping impermeable horizon to the stream. The proportion of both transformations during runoff formation changes in accordance with the phase of the soil water regime. During the percolation phase, water flows through the soil into the drainage layer and outflows into the stream in discharge waves immediately reacting to precipitation. During the accumulation phase, the rainwater accumulates in the soil and does not outflow into the drainage layer. During the percolation phase, the rising hydrograph limb grows very quickly and its duration is short (a few minutes or hours). Later, the soil water content and consequently the outflow and runoff decreases, the accumulation phase begins and the falling hydrograph limb is generated.

Precipitation peaks are attenuated in the soil and in the drainage layer. The biggest attenuation takes place in the drainage layer. The runoff peak in the Liz catchment, southern Czech Republic, reached up to 10% of the precipitation peak. The source area, in which the runoff peak was generated, represented about 25% of the whole catchment area. The width of the source belt bordering the flow channels did not exceed about 90 m. During the whole vegetation season, 50% of seasonal precipitation sum was used for plant transpiration, 25% ran off and 25% was stored in the drainage layer.

Various aspects of the soil moisture/runoff generation relationship were studied also in the lowlands. Somorowska (2002) investigated the extreme stages of the wetness conditions in the lowland catchment of Lasica in central Poland. The temporal decrease of soil water storage was presented as a function of groundwater level change and storage coefficient. The function was used to estimate water demands needed to preserve the valuable protected wetland ecosystem during dry conditions (Somorowska, 2002a). Analysis of the long-term variability of precipitation, groundwater tables and discharges along with the assessment of soil water storage indicated that the catchment was more sensitive to water deficit than water surplus (Somorowska, 2003). The combined analysis of water storage in the soil profile and the recession analysis based on runoff measurements at the catchment outlet revealed substantial dynamics of the surface-subsurface interactions (Somorowska, 2004). Merging soil water storage at a plot scale with discharge and dynamic groundwater storage at a basin scale helped bridge observational and modelling scales of the soil water study. Measured soil moisture data was also used to evaluate the satellite products (NOAA NCEP/NCAR and ERA-40 ECMWF reanalysis data). It was found out that the reanalysis data products generally reproduced the dynamics of soil moisture correctly (Somorowska, 2005).

Doležal and Kvítek (2004) applied knowledge of runoff generation (schematised into recharge, transitional and discharge zones) for the explanation of the origin of nitrates in surface streams in the highland regions of the Czech Republic. Separation of runoff components in the small experimental catchment of the Kopaninský creek indicated that the highest concentrations of nitrates were connected with interflow. The finding was tested in other catchments in the region. While the interflow still seemed to be the "main polluter" in a slight majority of the catchments, the results indicated that baseflow or direct runoff were more important sources of nitrate pollution in other catchments. It was suggested that the nitrate concentration patterns could meaningfully characterise the peculiarities of individual regions and catchments. The tile drainage hydrographs and water quality patterns were similar to those of small surface streams but nitrate concentrations were significantly higher. The work resulted in the proposal to implement an alternative management system of soil and water protection on the landscape scale (Kvítek, 2005).

Lenartowicz (2003) applied a physically based mathematical model in the study of the movement of water and solutes in the lowland swampy catchment during the vegetation season. The hydrological cycle in such a catchment is dominated by the vertical component (net precipitation-evaporation-infiltration). The most important role in groundwater recharge of the catchment is played by long intensive precipitation events. The low intensity precipitation influences soil moisture only in the top layer of the soil. Apart from precipitation intensity, the rate of groundwater recharge and migration of solutes is controlled by the thickness of the unsaturated zone.

Lysimeter studies

Unique long-term lysimeter data (1941-2001) on the influence of vegetation on the water balance was presented by Van der Hoeven at al. (2005), Van der Hoeven and Warmerdam (2005a). Four lysimeters (25 x 25 x 2.5 m) were constructed in the dunes near Amsterdam. One lysimeter was left bare, the others were each planted with natural dune scrub, oak seedlings and Pinus Nigra Austriaca seedlings. The dune scrub was trimmed annually till 1972. Annual evapotranspiration from lysimeter 1 with the bare soil surface was practically constant (Figure 2.10). Lysimeter 2, overgrown with dune scrub, showed constant annual evapotranspiration while it was regularly trimmed. When the trimming was discontinued, the annual evapotranspiration gradually increased. Evapotranspiration in lysimeters 3 and 4 with oak and pine respectively increased rapidly during the first 10 years. Later, it remained constant. The bare soil lysimeter showed a ‘usable’ fraction of 75% of the average annual precipitation. The scrub, oak and pine vegetation left a 'usable' amount of 30%, 35% and 12% of the precipitation respectively.

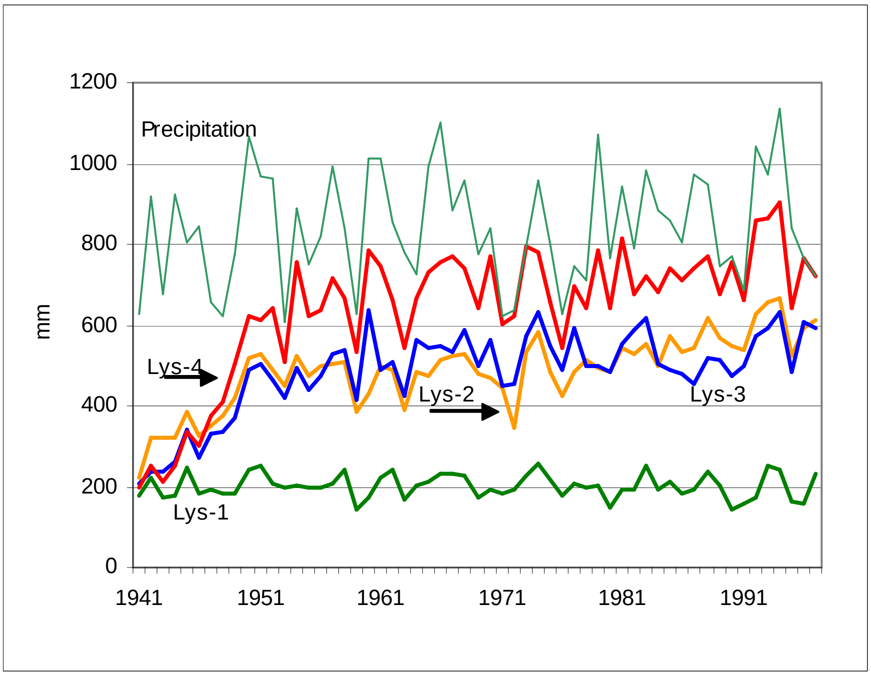

Figure 2.10 Annual values of precipitation (upper curve) and evapotranspiration from lysimeters with bare soil (Lys-1), dune scrub (Lys-2), oak forest (Lys-3) and pine forest (Lys-4) from 1941 to 1997 at Castricum, the Netherlands. Precipitation data in 1987-1997 were corrected for wind-induced errors.

The least-known component of the water balance is evapotranspiration. Lysimeter data from the lowland area at Rheindahlen, Germany (Schumacher and Wellens, 1993) were used to test several methods of evapotranspiration calculation (Van der Velde *et al.*, 2004) – Penman (2 modifications), Priestley and Taylor, Thom and Oliver, Penman-Monteith and Makkink. The comparison of computed and measured values was done separately for rainy and rainless days of the warm period (15 April to 15 September) from 1983 to 1991. The days were selected so that potential evapotranspiration was measured, i.e. the evapotranspiration was not limited by moisture supply. The following conclusions were drawn from the comparison:

- The mainly radiation-based methods (Makkink, Priestley and Taylor, Penman) showed substantially less scatter in the "calculated - measured" scatterplots than the remaining methods (Thom and Oliver, and Penman-Monteith), which are less radiation-based.
- The simple Makkink method (inputs: air temperature, global radiation) provided results similar to those of the more complex Penman method (inputs: air temperature, relative humidity, net radiation and wind speed). In practice, the Makkink method is a good alternative to estimate evapotranspiration involving a smaller investment and less intensive maintenance.
- There is a significant systematic underestimation of calculated evapotranspiration for rainy days. For the mainly radiation-based methods the discrepancy between the rainy and rainless datasets amounts to approximately 6%. For the less radiation-based methods the discrepancy extends to 10%. The most plausible explanation is that none of the methods used in this study account for the enhancing ET-effect by intercepted water. Only the Thom and Oliver and the Penman-Monteith methods can account for this effect by lowering the canopy resistance incidentally.

Snow hydrology

Stehlík and Bubeníčková (2002) and Jirák (2005) summarised the results of long-term measurements of snow depth and water equivalents at paired sites (forest-open area). The snow depths and water equivalents in the forest were for most of time smaller than in the open area. Only at the end of winter at some places was there more snow in the forest than in the adjacent open area. Snow depths and water equivalents decreased in the following order: young forest (highest values) – meadow - old forest. Snow depths and water equivalents at higher elevations were higher than at lower elevations, but the snow density was rather similar. Kulasová (2005) analysed the climatic and snow conditions of winter in the Jizera Mountains (the wettest part of the Czech Republic) during the period 1900-2005. The data indicate that trends towards milder or harder winters cannot be detected although the snow heights since the end of the 1980s are smaller (Figure 2.11).

The highest precipitation amount was measured in the winter of 1911 (889 mm). The coldest winter (mean air temperature –4.3°C) occurred in 1942. The longest winter was that of 1944; the snow cover duration was 198 days (12 November 1943 to 28 May 1944). The highest snow depth (235 cm) was measured in the winters of 1970 and 2005. Both winters were climatically similar. This indicates that, although the period after 1980 is considered to be influenced by climate change, hard winters still occur. Actually, since 2000 there have been several winters with a lot of snow.

Changing environment

The assessment of possible impacts of climate and landuse changes was presented in a number of studies. Uhlenbrook *et al.* (2003) analysed the possible impacts of global change on runoff generation processes of the Brugga catchment, Germany. They concluded that future climatic and land use changes would have significant impact on the recharge of the springs and consequently on the quantitative and qualitative characteristics of runoff. They highlighted the importance of the riparian zone and near-stream wetlands for water quality. Herrmann (2004) has worked out some aspects of the changes in land use impact on the runoff formation process. He argued that although climate warming is supposed to influence the runoff regime considerably, runoff generation would be influenced only gradually.

Woronko (2003) and Woronko and Zmudzka (2004) studied the water balance of the Welkie Batorowskie mountain peatland and investigated the influence of changing climatic characteristics. Changes in the climatic conditions of the 20th century seemed to favour the future development of the peatland into a semi-natural ecosystem. Precipitation trends indicated that the water supply of the peatland would continue. Higher spring air temperatures would positively influence the spring bog water supply.

In a study of the Biebrza wetland in Poland (Nauta *et al.*, 2005) the groundwater model SIMGRO was used to predict consequences of different land use management scenarios. One scenario considered the natural vegetation succession of the peatlands as a serious threat. The second scenario considered a man-made approach and was designed to check which changes in groundwater levels could be expected by blocking the existing drainage system on the Biebrza riverbanks. The study showed that, with regard to the impact on wetland conditions, the first scenario led to negative changes in simulated groundwater levels while the second scenario resulted in positive changes.

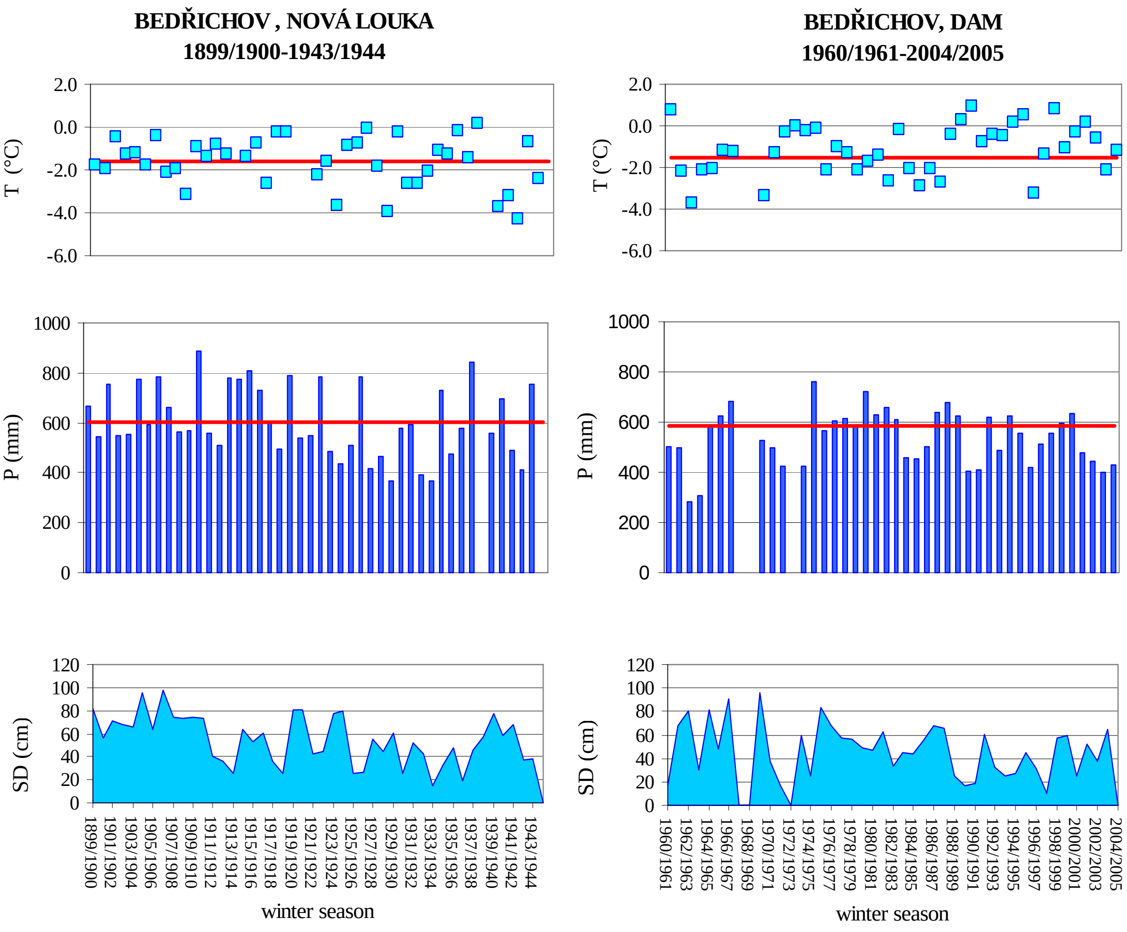

Figure 2.11 Climatic characteristics of the Bedřichov station during winter period (November-April); T-mean air temperature, P-precipitation mount, SD-mean snow depth. The red lines at the right and left sides represent long-term means for periods 1901-1950 and 1961-1990, respectively.

The physically based model SIMGRO was also used to estimate the impacts of climate change and drastic land use changes in the world's largest complex of wetlands in the Pantanal region, Brazil (Querner *et al.*, 2005). The scenarios were defined to represent the increased rainfall situation, land use change and mitigation measures. The results indicate that the increase of precipitation would have a great effect on the hydrology of the Pantanal. The change in land use would have a very small effect on the discharges.

Pecušová *et al.* (2004) showed that there was a pronounced decrease of snow water equivalent in the mountainous catchment of the upper Hron river in central Slovakia in the 40 years 1962-2001. The changes are visible especially in the southern part of the catchment. The highest mountain areas (elevations up to 2000 m a.s.l.) did not exhibit such a pronounced decrease. Holko *et al.* (2005) suggested that if the climate change follows the scenarios provided by climatologists, the snow water equivalent would be drastically reduced in the major part of the catchment.

Holko *et al.* (2005) reviewed 40 years of measured runoff data in three small European catchments. They discovered that, contrary to general opinion, the measured data did not indicate a trend towards higher occurrence of high flows in recent years. Similar data was presented by Pekárová *et al.* (2005) who analysed the long-term water balance data (1965-2004) including the runoff regime in several small micro catchments situated in the Slovak highlands.

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3 Alpine and Mediterranean (AMHY)

3.1 Introduction

The AMHY FRIEND project was launched in 1991. It involves several countries in southern Europe, the Middle East and north-west Africa. The Institute of Research for Development (IRD) has coordinated the project in Montpellier, France, since the beginning of 1999.

20 countries participate to the project: Albania, Algeria, Bulgaria, France, Greece, Hungary, Italy, Lebanon, Malta, Moldavia, Morocco, Palestine, Portugal, Romania, Serbia, Slovenia, Spain, Switzerland, Tunisia and Turkey.

AMHY FRIEND also has contacts in these countries: Austria, Belgium, Cyprus, Croatia, Egypt, Finland, Ireland, Israel, the Netherlands, Poland, Macedonia, Russia, Slovakia, Sweden and the United Kingdom.

The active scientific topics dealt with in the project are given below:

- Data base
- Low flow and droughts
- Extreme events
- Erosion and solid transport
- Hydro-climatic variability and impacts on water resources
- Integrated water resources management
- Rainfall runoff modelling

A major event organised by the AMHY project was the international conference held in Montpellier in April 2003 on the topic Hydrology of the Mediterranean and semi-arid regions.

The scientific topics have not all had the same level of activity during this last four-year period. Activities of the more active amongst them are detailed below.

3.2 The AMHY database

In 2004, an effective collaboration between the FRIEND AOC, AMIGO and AMHY projects was launched in order to bring together the 'database' topics of these three projects. This collaboration was adopted during the FRIEND Intergroup Coordination Committee meeting in Koblenz in 2004 and is carried out by the three institutions in charge of this topic: L'Instituto de Meteorologia de Cuba, L'Instituto Mexicano de Tecnologia del Agua et L'UMR HydroSciences Montpellier.

All three projects will contribute to a centralized database in order to provide the FRIEND community with high-quality hydrometeorological data, each one from its own area and with strong links with the research topics of its own FRIEND project. The similarity between the information to be managed on one hand and the provision of functionality on the other hand increase the necessity of collaborating and of sharing technical solutions.

At first, collaboration between the three database topics consisted in defining and choosing a common conceptual database scheme. That meant using the same physical database structure because the data used in the three projects are the same. After that, it was easy to put together implementation tools and techniques to present the data on the Internet. Figure 3.1 shows examples of the homepage designed to display the measurement station metadata on both the FRIEND AOC and the FRIEND AMHY websites. It can easily be seen that these two web pages are similar except for the logos and the colours. This similarity was possible by sharing the same database structure and the same tools of implementation.

Other applications and tools are shared by the project. One example is the MAPGEN application which is a tool to point out and select a station on a dynamic map on the website.

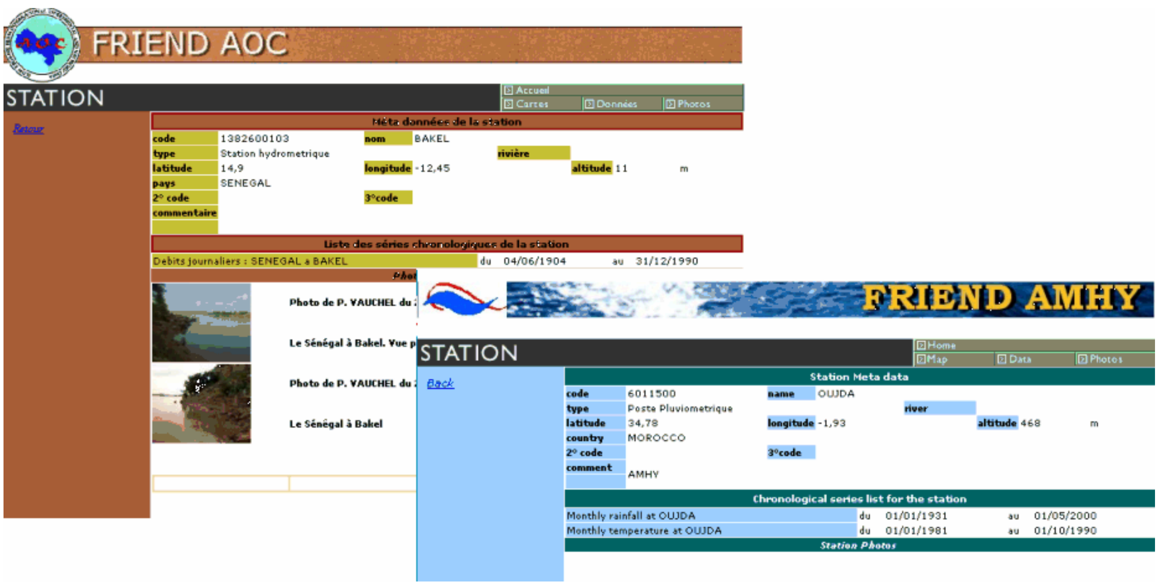

Figure 3.1 Examples of AOC and AMHY FRIEND database webpage showing their structural similarities

The ORION software is another example. This software provides the database manager and his team with functions to visualise, to criticise and to import the data in ASCII files. This tool runs only on the Intranet network of the service in charge of the database management.

These tools and this scheme are thus the official implementation framework for the team in charge of the development phase for the three projects (FRIEND AOC, AMHY and AMIGO). Working sessions, organised for the engineers in charge of the database development, have taken place in Montpellier, La Havana and Cuernavaca during the last two years.

Figure 3.2 presents the final architecture for the implementation and for the system of these three databases.

For the FRIEND AOC project, the website is: http://sfriendaoc.agrhymet.ne/friendaoc, or, http://armspark.msem.univ-montp2.fr/friendaoc which is more accessible.

FRIEND Environmental Portal
System Architecture

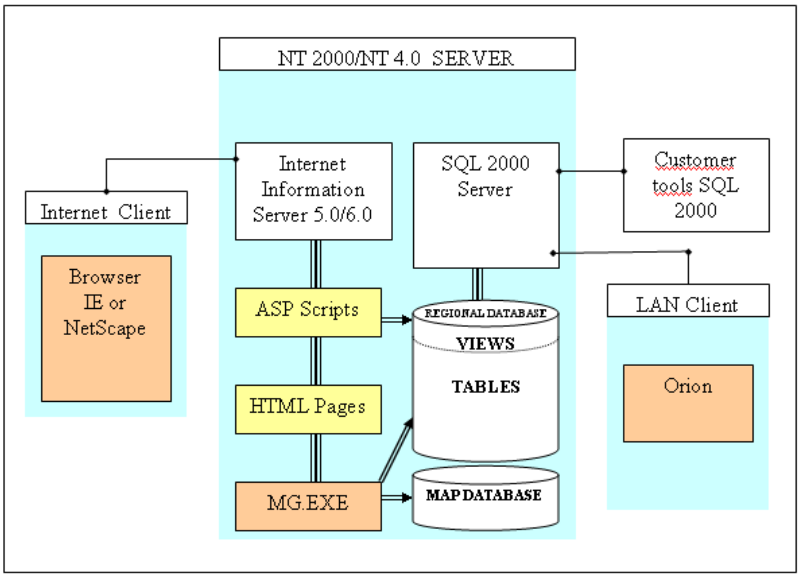

Figure 3.2 System for implementation of the three databases

For the FRIEND AMHY project, the website is: http://armspark.msem.univ-montp2.fr/amhy

For the FRIEND AMIGO project, the website is: http://www.friend-amigo.org.

3.3 Research projects

3.3.1 Low flow and droughts

The first stage of research in low flows in the AMHY region concentrated on analysing low flow distribution and on different methods of low flows and drought regionalisation. After 2002 the research concentrated more on finding adequate models for low flow forecasting and creating a drought early warning system. This was implemented in the following ways:

- By improving and extending compilation of reliable data on the various indicators of droughts, from both physical and hydrological data such as agricultural losses and wildfire impacts

  During the 20th century there were three periods which were characterised by long and severe droughts, namely 1902-1913, 1942-1953 and 1982-1994. During the first period the drought years were approximately 20% of the total number and they increased to 40% during the second period. In the 1982-1994 period they were approximately 50% (Koleva *et al.*, 2004). In this context, the droughty period 2003 in the Balkan area and in the Danube basin showed similar phenomena to the peak droughty year of 1946 (Adler, 2004, Trninić and Bošnjak, 2004). However, the duration of 2003's hydrological drought reached a record 103 days in contrast to the one in 1946 that lasted 98 days. The deficits were accentuated by increasing water use – anthropogenic influence. Some authors were of the opinion that this droughty period was accentuated by aspects of climate change (Trninić and Bošnjak, 2004, Dakova, 2004), a conclusion which was not supported by other researchers who analysed the longest data series in Europe and in the Danube basin (Pakarova and Miklanek, 2004) and identified only some decreasing tendencies in different periods, linked by the alternation of droughty and rainy periods. The final conclusion of temporal analysis of different series of data is the reliability on long period. Selected drought indexes could bring some variations in interpreting the length and intensity of the phenomena.

Although drought can occur in all types of climate, the semi-arid Mediterranean regions such as Algeria, Tunisia, Morocco, Greece, Cyprus, etc. are the most vulnerable because they are regularly affected by a water deficit and by a high variability of precipitation (Bergaoui and Boufaroua, 2004, Boufaroua, 2004, Carmi, 2004, El Garouani, 2004; Samadi *et al.*, 2004). Here, a more careful analysis of drought conditions should improve the early warning system in these areas. The efforts of the FRIEND-AMHY programme were supported by the implementation of different parallel projects, one of the most important for the period 2002-2006 being WOISYDES (Water Observation and Information System for Decision Support) coordinated by IRD France (see under References for selected BALWOIS Conference papers).

- By integrating and interpreting the data with easily accessible and understandable tools which provide timely and useful information to decision-makers and the general public

Processing data in a user-friendly manner and providing cartographic products to support decision-making during periods of drought was another direction of research in the AMHY group. Identifying homogeneous regions for low flow frequency analysis (Saravi, 2004: case study in Iran) and providing cartographic products (Dakova, 2004; El Garouani, 2004) were the first steps in encouraging drought forecasting

- By developing models for drought forecasting

Developing models for drought forecasting are efforts concentrated at different scales – synoptic models and hydrological models. In the first category, we noticed interesting results showing the main points inducing drought periods, such as the remote climate processes underlying drought events in the Mediterranean (Crisci *et al.*, 2005) and analysis regarding atmospheric processes linked to droughts in the Balkans and central-eastern Europe (Rimbu *et al.*, 2002; Mares *et al.*, 2004; Andreeva and Martinov, 2004).

Differences are produced with regards to atmospheric circulation features (storm track and geopotential heights at different troposphere levels) and surface parameters (sea level pressure, precipitation, temperature) in years when the monsoon was stronger and weaker than the climatic average. Results show an evident link between the monsoonal regime of Asia and Africa with the summer Mediterranean climate; this connection appears to change in time as the summer season progresses and depends on the monsoon system under consideration, even if the two monsoons are closely linked. The Asian monsoon affects mainly the eastern Mediterranean climate, while the West African monsoon affects the western Mediterranean. It is argued that the latter effect, even if rather localised, can induce heavy and prolonged summer droughts in the western Mediterranean. These atmospheric processes offer the opportunity of providing a hydrological forecast, defining the meteorological conditions and determining the base of an early warning system. Hydrological models for regarding water balance in the basin add the needed tool at the hydrological scale for providing drought forecast or low flows in different intervals (Aksoy *et al.*, 2002; Aksoy, 2003; Carmi *et al.*, 2004).

- By facilitating drought preparedness and mitigation programmes which lead to effective response activities.

  Some early warning systems have been planned and installed in different countries to improve the impact of drought. Such examples have been given by some researchers such as Carmi *et al.* (2004) in Palestine, El Garouani (2004) in Estimation of regional evapotranspiration and soil moisture conditions using remote sensing data and GIS – Application in the Asilah region (Morocco) and the lower Medjerva Valley (Tunisia), Jacobsen *et al.* (2004) in Water resources strategies and drought alleviation in western Balkan agriculture, Samadi *et al.* (2004) in Drought early warning system in I.R. of Iran, Sancho *et al.* (2004) in The automatic hydrological informational system of the Jucar Basin as a warning system in Spain. Another interesting aspect was attempted in Cyprus by Iacovides (2004). Regarding the competing and conflicting water uses; this showed that another important tool should be available during droughty periods: an adequate decision-support system (Iacovides, 2004: the Cyprus case study).

Trying to integrate the research results provided for different climatic areas in the AMHY hydrological region, some working meetings were organised, bringing together AMHY national representatives, as well as NE FRIEND representatives (see Annex 3).

3.3.2 Extreme events

The Extreme Events Group comes from the merging of the topics heavy rains and rare floods, taking advantage of the skills of the different researchers working in these fields. The group deals with separate rainfall and flood events, also taking into account the combined approach of the rainfall-runoff modelling. In more recent years, AMHY researchers have focused their attention on special issues, such as the statistical and stochastic analyses of extreme events at different time and spatial scale, and the characterisation of convective storms in the Mediterranean area.

Attention has also been focused on comparative synoptic analyses of hydrological and meteorological data from simultaneous heavy rainfall events, which produce floods in geographically distant regions with specific climatic features. The research aims to identify features responsible for extreme rainfall and floods over areas at different spatial scales and to compare the rainfall-runoff dynamics of different European regions.

In many of the countries involved in the FRIEND project, scientific reports have been produced on the most disastrous hydrological events, analysed from both hydrological and meteorological points of view, and in some cases also accounting for societal impacts and people's perception. The data base of the case studies on extreme events has rapidly grown since the high frequency of flood occurrence caused by heavy rainfall intensities in the years 2002-2006, which affected several European countries causing enormous damage.

Heavy precipitations

In recent years most of the countries involved in AMHY-FRIEND have actively contributed to research concerning hydrological and meteorological analyses of extreme rainfall events, aiming at both the regionalisation and characterisation of these events in the Mediterranean area.

Particularly in-depth analyses of typology and magnitude of extreme rainfall events and statistic and stochastic modelling of extreme rainfalls at different time and space scales have been carried out through collaboration among some AMHY working teams producing interesting results.

Analysis of meteorological and hydrological conditions triggering extreme rainfall events

This ongoing research moved from the necessity of defining features to classifying exceptional rainfalls in the Mediterranean region. Particularly the Spanish working team devoted great attention to this issue by means of different approaches to distinguish between convective and stratiform rainfall, using a parameter that is related with the greater or lesser convective character of the precipitation event, and its time and space distribution throughout the entire series of the samples. This important kind of analysis, though not easy, is based on the very short time aggregation rainfall data (at least 5-min rainfall rate data), their structural organisation and their physical features, obtained from the meteorological radar.

Statistical and stochastic modelling of heavy precipitations

The possible presence of trends and shifts in precipitations, generally measured as high quantiles of daily precipitations amount for extreme rainfalls and as monthly or annual precipitations for larger temporal scales, has been examined in many areas of Mediterranean Europe. This ongoing research, focusing attention on several AMHY countries, aims at finding common features for fixed temporal aggregation rainfalls in different regions and examining locally statistical relationships between extreme short rainfall events and larger time scale aggregation rainfall data.

Seasonality of larger temporal aggregation rainfalls has been modelled through different approaches. A possible approach assumes the existence of a deterministic component in the discrete domain through Fourier series analysis, which most frequently has proved to explain the rainfall variability through two harmonics component (Figure 3.3). The comparison among residual values of different decades is generally based on normal probability plots, non-parametrical tests and some other tests based on stochastic independence. Other common approaches are based on statistic techniques including homogeneity tests and anomalies and trend analysis.

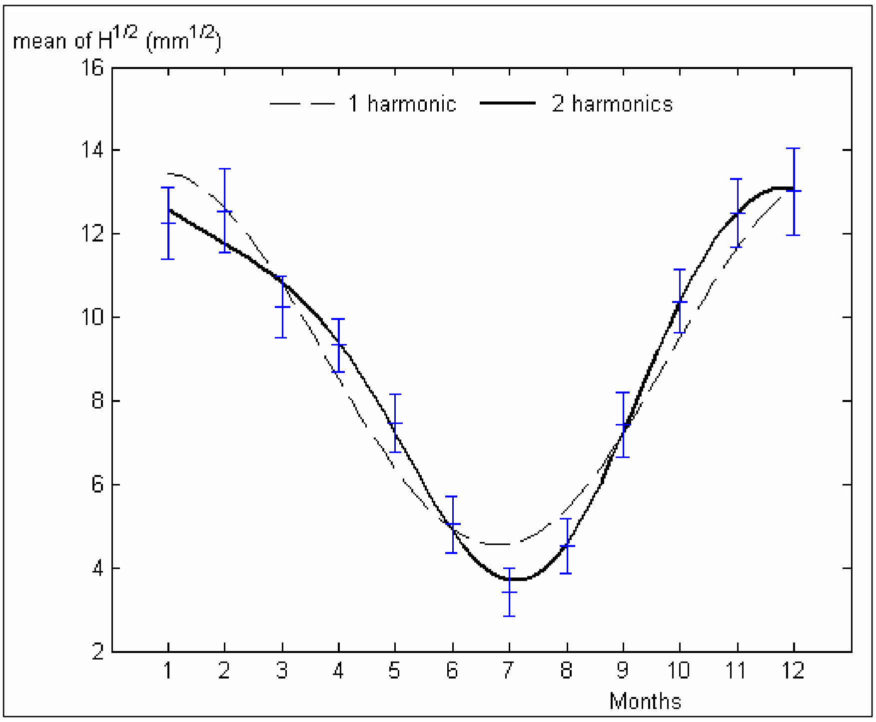

Figure 3.3 Truncated Fourier series for mean of square root transformation of average monthly rainfalls observed in Crati basin, southern Italy (Sirangelo and Ferrari, 2003)

Precipitation frequency analysis

The exceptional storms recently experienced in Europe have induced revision of the statistical distributions for rainfalls estimation, particularly as regards their asymptotic tails over extreme values. To this aim, regional approach of heavy tailed probability distributions for estimation of rare daily rainfalls has been further exploited, through the analysis of the statistical behaviour of the coefficient of variation of the yearly maximum daily rainfalls. The regional distribution obtained has led to a significant increase in the depth of rare rainfall.

Moreover, statistical analysis of the spatial distribution of daily rainfalls has been conducted in some regions (Portugal, southern France and Italy), providing relationships of area reduction factor depending on area and return period for distinct homogeneous regions within the examined regions.

Finally, the annual maxima of heavy rainfalls with a duration ranging from five minutes to several hours (48-72), observed at a set of rain gauges in Portugal and Romania, were analysed to provide intensity-duration-frequency curves for different return periods, local estimation of probable maximum precipitation and relationships for rainfalls at hourly and sub-hourly temporal scale.

Rare floods

Analysis of case studies

During the period 2002-2006 several serious floods due to heavy rainfalls hit Europe, thus suggesting an increased recurrence and magnitude of such events in the last decades. Some of the most serious events occurred in France, Czech Republic, Germany, Romania. Although extreme rainfalls are more easily recorded than extreme floods, meteorological and hydrological analyses of the most important heavy rainfall and flood events recorded in different regions of Europe have been made, pointing out common features characterising different events. These analyses, following heavy rainfalls over extensive areas, have taken geological, morphological and even social features into account, in an attempt to characterise the triggering causes and to foresee the effects of the phenomena (Spain, Romania, France, Turkey).

Flood frequency analysis

The ongoing research on the statistical features of the most important flood evaluation models, cross-validated on different national databases, has provided practical improvements in flood quantile estimation procedures, through the renewed use of peaks over threshold sampling techniques and historical information (France, Yugoslavia). Moreover, some specific characteristics of the models have been successfully transferred from one method to another, thus confirming the flexibility of the models examined, applied to different hydrological environments.

Space distribution of maximum floods across Europe

The analyses of European extreme floods (Figure 3.4) have provided an overall knowledge of the space distribution of flood potential across Europe, thus showing a link with the meteorological features of the different countries (Stanescu, 2004). Significant differentiation between countries has been found due to particular differences in the climate features. Some

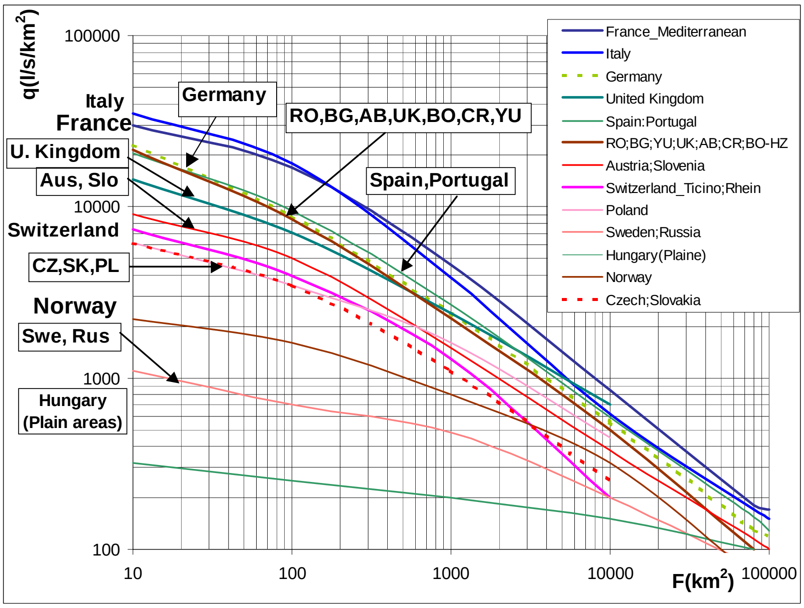

Figure 3.4 Regional curves of the maximum specific discharges of outstanding floods in Europe (Stanescu, 2004)

of these processes, such as the input of warm air masses increasing atmospheric humidity and producing intense rainstorms, are manifested across the directly influenced countries such as France (southern region) and Italy that show the highest flood potential. The countries located in the central and south-eastern zone of Europe are under the influence of both the Mediterranean Sea and the cold fronts originating from the Atlantic Ocean, producing abundant but less intense rainfalls. In other countries with pronounced relief such as Switzerland, southern Germany, Austria and Slovenia the relief has an impact that overwhelms the differences in the climate features.

The flash floods originate either in the meteorological context of wet air advection where the vertical motion and the cumulus effect are very intensive or in the context of instability at the local scale. These circumstances are strongly manifested in the Mediterranean region but equally in the central and south-eastern countries where the presence of mountain chains having steep slopes in small basins associated with heavy rains results in a flash flood potential comparable with that of the Mediterranean countries.

Analysis of the links between heavy rains and flash floods

Distributed rainfall-runoff models

Particularly the analysis of meteorological and hydrological links between flash floods and heavy rains deals with distributed modelling of rainfall-runoff transformation. Some advances have concerned research on distributed event-based rainfall-runoff models, based on both conceptual and physically-based schemes, generally developed for the description of the hydrological response of small and medium size catchments in Italy. Most of the models allow for the computation of the different contributions to storm runoff conceptually routed to the catchment outlet with different IUHs, which account for the different scales of velocity taking place on hill slopes and stream network.

The various parameters are generally estimated by calibration, with different algorithms. Besides the traditional split-sample tests, the validation of the models has been performed through more general tests sounding the physical reliability of the model against hydrological common sense: evaluation of model ability in reproducing different runoff generation mechanisms, evaluation of estimated runoff production spatial distribution and of simulated behaviour of internal variables, evaluation of model response plausibility for ‘virtual’ applications representing different hydrological situations.

Also, to contribute to a more accurate mitigation of flood risk, a European database on recent large flood events and related triggering rainfall could be useful for this issue.

Data base on extreme events

Interaction among the working teams of the AMHY group, aiming to achieve a detailed database for the period 1992-2006 focused on extreme events, has been initiated. For most of the rainfall and flood phenomena recently experienced in Mediterranean countries, the database tries to describe the main features of the events and provide quantitative values at local spatial scale, which can be very useful for ongoing researchers on rainfall-runoff modelling and extreme frequency analyses. Some links to scientific reports and specific data of the events complete the database.

3.3.3 Integrated water resources management

Activities related to the integrated management of water resources are particularly prevalent in the south of France and in Tunisia, Algeria and Morocco. The geographical aspect is quite circumstantial but is justified by the existence of an embryonic network and by the timely implementation of European and French regional projects for integrated management.

At the time of writing, these projects are either still underway or nearing completion. A network of institutions and researchers thus exists in the three Maghrebian countries with people who work together at joint work sites and who meet periodically at seminars to develop decision-support tools and/or methods to be shared by everyone. Finally, a number of students from the three countries obtained doctoral fellowships and take part in activities at joint work sites and are consequently in the position to continue running a network of competencies on the management of water resources in Tunisia, Algeria and Morocco.

Valorisation and impact of hydraulic facilities

Since the region is semiarid, flows in the three Maghrebian countries are mostly intermittent, rapid and sometimes violent. Little use is made of water while it is flowing; users wait until it is stored in surface or underground reservoirs. Thus water management most often means managing water in reservoirs whose composition depends on the type of reservoir but also on intra and interannual variations in flows.

Tunisia, Algeria and Morocco have built a series of installations for water and soil conservation: benching at the head of the catchments, small reservoirs in the hills and big dams downstream.

Building these structures changed the characteristics of the flows and the spatial distribution of the resource. The distribution between surface and groundwater was also modified by the fact that some reservoirs are also used to replenish water-bearing beds. It is thus very useful to analyse how developed catchments function in normal and abnormal conditions (drought, floods) to deduce real and potential valorisation as well as induced risks taking into account upstream-downstream impacts.

The tools used now are coupled and distributed hydrological models that are quite laborious and require a lot of data. Efforts are currently underway to obtain less sophisticated tools that do not oversimplify the processes.

Management of the demand for agricultural water

In Maghrebian countries, irrigated agriculture is by far the biggest consumer of fresh water (80%). Tunisia, Algeria and Morocco already exploit almost all their conventional water resources. The only possible gains remaining would be using unconventional water resources (desalination, re-utilization of wastewater) but these techniques are costly, their impact is not yet controlled and they are not easily accepted by the general public.

To meet new demand (drinking water, industry, and tourism) while respecting the environment (conservation of aquatic ecosystems), farm irrigation should have a more equitable share of existing water resources. This means reducing its share. At the same time, irrigation enables 50% of world food production and, given the increase in the population of the world, food production will have to be increased. The farm irrigation sector is thus faced with a serious challenge: how to produce more while using less water. This challenge can be met through better management of the demand for water by examining the range of management measures available, be they economic or regulatory.

This second group of activities resulted in the creation of a number of tools to measure the pertinence and efficiency of the measures listed above: action models (Olympe) to be used at the farm scale, regional action models (Zonagri), Multi-Agent Simulations for the biggest structures. All have the same objective, to try and measure the gain to be obtained by a given measure in terms of saving water and in terms of economic valorisation of water. In the majority of cases they also specify the impacts the measure concerned will have, especially in terms of economic viability of the farms.

Management institutions and organisations

The implementation of measures that were judged pertinent for previous works raises a number of problems for local and regional stakeholders. These are linked with technical, social and economic constraints they have to face.

At the same time, the mode of governance is moving toward more local and participatory management with the creation of new management structures (GICs in Tunisia, for example). But the areas of competence of these new organisations are not yet clearly defined and they are not yet functioning optimally since the new 'managers' lack the relevant experience (as does the State). What is presently happening is that past principles of governance are disappearing without any new principles really being applied. This situation encourages a high degree of permissiveness with respect to laws and regulations, resulting in a rapid increase in 'unauthorized' wells and boreholes, the exact number of which and the total amount of water tapped is not known.

The activities carried out around this topic are primarily aimed at analysing the pertinence of these new organisations, smoothing their way and training them to use the analytical tools that are being developed.

3.3.4 Erosion and solid transport

Erosion and solid transport are crucial subjects in the countries of the Mediterranean basin. It is the case, for example, of Northern Algeria which suffers from a deficit in water resources. This is fought by building dams which silt up due to an intense and strong process of erosion in the catchments.

The generalisation of the topic in all Mediterranean countries proved to be particularly difficult and complex, considering events arisen in Algeria these last years.

The themes studied are:

- Exploitation of measures and available models to quantify the flow
- Estimation of the silting-up and the sedimentation of the dams
- Exploitation of hydrological knowledge for fighting against erosion and the consequences of the induced facilities on hydrological regimes (resources, solid stream flows, groundwater, etc.)
- Solid transport by swells and currents in coastal zones
- Impact of dams on the environment.

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4 Latin America and Caribbean (AMIGO)

4.1 Introduction

4.1.1 Regional characteristics

From the hydrological point of view, the Latin American and Caribbean region is very complex. In this region, practically all the types of climate that have been described in the world exist and the temporal and spatial water distribution is unequal. In this region many remarkable meteorological phenomena influence the regional hydrology – cold fronts, hurricanes, El Niño Southern Oscillation (ENSO) – causing water scarcity or excesses as common regional hydrological characteristics. On the other hand, the impact of human activity on water is significant. In this part of the world, there is a mixture of very old and traditional water use techniques and intense hydraulic exploitation. Deforestation also seriously affects the hydrological regime.

Three important influences on the behaviour of the hydrological cycle in this region are the ocean, the relief and the glacier. The influence of the sea through the Atlantic and Pacific oceans, Caribbean Sea and Gulf of Mexico and the prevalence of a very mountainous relief mitigates the South American and Central American climate, while the warm waters of the Caribbean Sea and the Atlantic Ocean influence the Caribbean climate. The hydrology of South America and Central America is distinguished by its wide and dense network of rivers with remarkable flow and some shared basins. South America has very big rivers, including the Amazon, the biggest river in the world. In the Caribbean, river basins are small and the short rivers flow quickly to the sea, while basins and aquifers have strong saltwater intrusion. Frequent torrential rains and flash floods characterise the hydrology of the countries within this region. Heavy rains may occur throughout the year, but the more intense are associated with the tropical regime and, specially, with tropical storms.

4.1.2 FRIEND AMIGO project

The FRIEND AMIGO project was launched in 1999 covering the Central American and Caribbean region, but in 2004 this project extended its activities to the whole Latin American and Caribbean (LAC) region. As part of the FRIEND community, the objective of this project is to develop analytical tools to understand and to characterise the processes of the hydrological cycle and to establish specialised databases of reference. In their conception, the

FRIEND AMIGO also includes an important component of training, directed at reinforcing the capacity of the national hydrological services to evaluate the water resources.

The LAC FRIEND AMIGO scientific agenda includes the following topics:

- Database and website
- Ecohydrology
- Extreme hydrological processes
- Climate change.

Moreover, the strategic work plan of this project for the next UNESCO IHP phase has been centred on three general objectives:

- To be a strong regional project for the whole Latin American and Caribbean region
- To make advances in the scientific topics of database and website, hydrological extremes and ecohydrology, and climate change and water quality
- To contribute to the invigoration of the International Hydrological Programme in the Latin American and Caribbean region and to increase its world visibility through the FRIEND world agenda.

4.2 Research projects

4.2.1 FRIEND AMIGO database

This has been a high-priority goal in the AMIGO project. The website is an active way to exchange data and information among regional experts and institutions, and to establish regional technical services through the Internet. At the moment the FRIEND AMIGO websites are specialised on drought (http://www.friend-amigo.org and http://www.met.inf.cu/sequia/amigo.asp).

FRIEND AMIGO and Alpine and Mediterranean (AMHY) FRIEND are working together in the database area and this collaboration enables the FRIEND AMIGO to gain technological strength and to qualify experts from the Latin American and Caribbean region. The LAC and AMHY FRIEND vision of the website and database could help the world FRIEND community to understand the importance of having a global FRIEND web and database system. In 2004 Havana City in Cuba hosted an important IHP/AMHY/AMIGO/WWAP workshop on databases, during which the implementation of a common database system in the Latin American and Caribbean and the Alpine and Mediterranean regions was discussed.

4.2.2 Drought

The advance made in this field is remarkable. The working group in charge of this activity has made many valuable scientific and applicable contributions for the Central American and Caribbean region and in particular for each country in this geographical area. A detailed evaluation of the drought behaviour in each Central American and Caribbean country is a relevant study resulting from this work.

The study of the behaviour of drought over a number of consecutive months facilitates the analysis of the evolution of drought in Central America and the Caribbean. The main techniques used for the determination of the behaviour of precipitation are the *Standardized Deviation* and the *Deciles* criteria. According to the behaviour of rain, the periods are classified in light deficit (D), moderate deficit (M) or severe deficit (S), which is based on international and traditional practice in different countries and takes into account the experience acquired in the individual development of the work in the region. This analysis has a strong meteorological and climatological support linked with the hydrological analysis.

The results on minimum hydrological phenomena can be read and downloaded free of charge from the Internet (http://www.met.inf.cu/sequia/amigo.asp). The LAC FRIEND AMIGO project is working on a regional drought prediction service and will expand the drought study to the South American countries.

4.2.3 Floods

A project profile on rain and flow regional curves, based on experience made in Costa Rica, is being prepared with the purpose of establishing, through the Internet, a service of the probabilistic evaluation of the maximum hydrological variables. This proposal has the following objectives:

- To support the work of the meteorological and hydrological services in extreme hydrological situations by:
  - improving the knowledge of the hydrological processes linked with heavy precipitation
  - developing the appropriate method for the analysis of extreme hydrological phenomena
  - creating a hydrological and physiographic database which permits the following to be carried out:
    - regional and singular analysis of the maximum extreme values of precipitation and flow
    - vulnerability and risk analysis
    - digital maps of precipitation and flow index
    - quality control of the available information
  - implementing a technological platform for the work and collaboration among the participant countries
  - developing national and regional capacity-building in human and technical resources
- To contribute to the struggle against poverty by improving the preparedness of the region to face extreme phenomena and the effectiveness of the mitigation measures
- To contribute to the environmental education of politicians, decision-makers and the population in general.

These objectives are based on results and technologies developed by the Costa Rican Institute of Electricity. The Costa Rican experience and technology will be transferred to the whole region.

4.2.4 Ecohydrology

For this topic a detailed evaluation of the fluvial water uses in the Caribbean region was carried out and published under the name Survey of methods for setting minimum instream flow standards in the Caribbean basin (Scatena, 2003). An extensive bibliography related to this topic in the Caribbean has been compiled. This was obtained with the active participation of all the insular Caribbean States. In the field of ecohydrology, FRIEND AMIGO is working in synergy with ecohydrology regional projects in the Latin American and Caribbean region.

4.2.5 Climate change

The impact of climatic variability and climate change has been studied by the AMIGO project since 2002. Several results have been presented and published. Similarly, a new thematic project on climatic change has been presented with the objective of summarizing and systematizing the knowledge contributed by the national communications to the United Nations Convention on this topic.

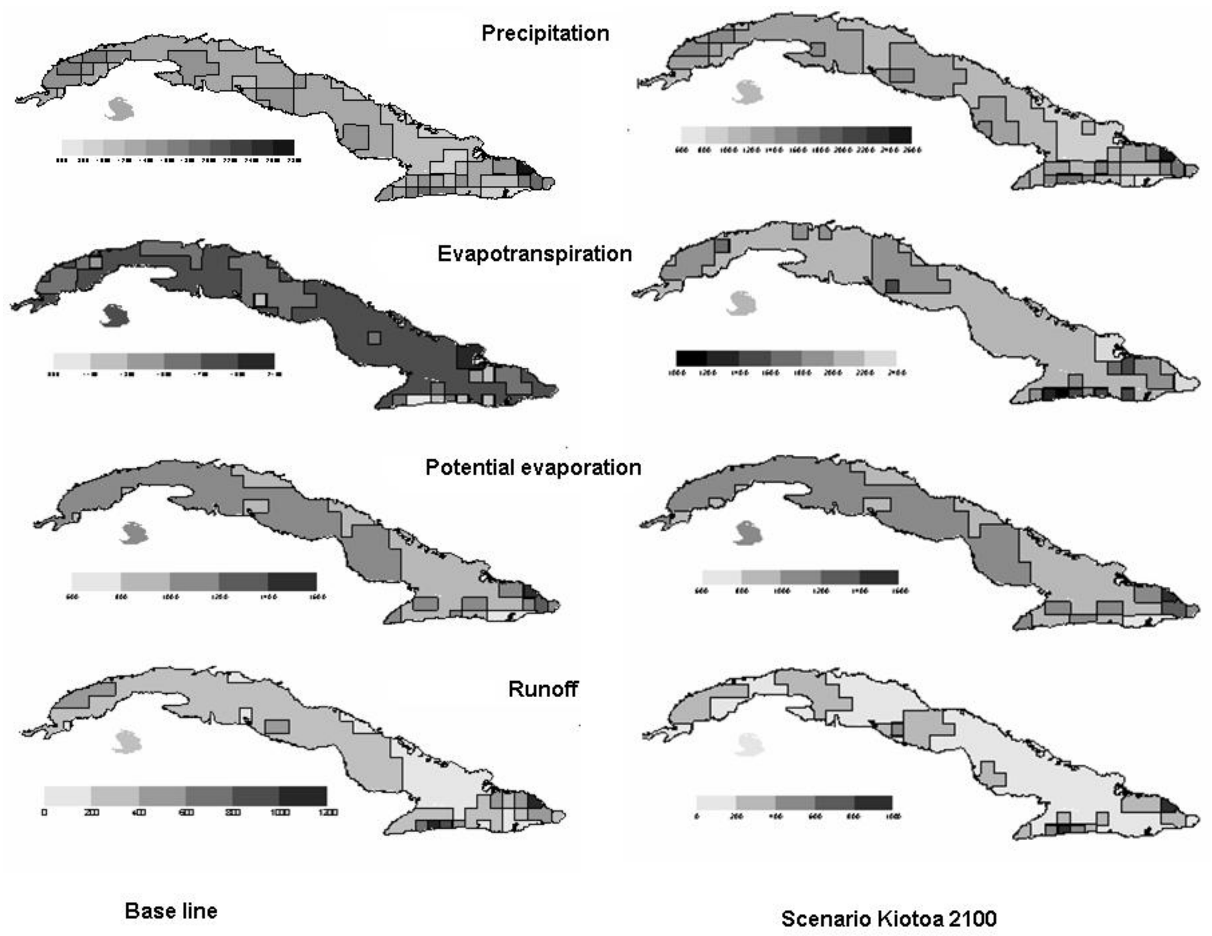

Figure 4.1 Climate change impact on the water resources spatial variability in Cuba (Planos 2002)

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5 Southern Africa – SA-FRIEND

5.1 Introduction

5.1.1 Regional characteristics

The Southern Africa FRIEND region is vast, covering approximately 6.8 million km² and stretching from one degree south of the equator, across the Tropic of Capricorn, to the Cape of Good Hope at 35°S (Figure 5.1). It is home to almost 150 million people, in some of the poorest countries in the world. The region is one of diverse geography and climate. Much of it is lowland plains and plateaux at elevations of 1000 m or more, but there are also substantial mountain ranges in the east. The climate is mostly tropical and semi-arid conditions predominate over large areas. There are also significant areas of extremely arid climate, including the Namib Desert, one of the world's driest places, characterised by huge sand dunes and practically zero rainfall. In the east, a variety of much more humid climates are found, with small areas of rainforest on some of the eastern mountains. Rainfall is typically highly seasonal, with the rainy season in the austral summer, but ranges from an equatorial pattern of two rainy seasons per year in northern Tanzania to a Mediterranean type of climate in the extreme southern Cape where the main rains occur in winter. This wide range of climates produces a complex water balance, characterised by high spatial, seasonal and inter-annual variability. Some of the main water resource issues are:

- Water scarcity – Increasing population and lack of infrastructure means that many people have inadequate access to water, with severe impacts on livelihoods and health.
- Extreme variability of water resources – Droughts are common, and extreme events (such as the current major drought and previous ones in 1992 and 1995) lead to widespread hardship, with the economic consequences felt at all levels from the individual right up to the national level. Floods can have similar consequences; the devastating Mozambique floods in January 2000 led to widespread loss of life and required an international emergency response.
- Shared resources – A substantial proportion of the water resources come from international basins shared between several countries (e.g. Limpopo, Okavango, Orange and Zambezi), emphasising the need for regional cooperation to ensure effective management and response to problems.
- Lack of hydrological data and under-funded, poorly maintained gauging networks – National hydrological agencies and research organisations alike suffer from low levels of funding, leading to difficulties in retaining staff and low capacity to manage resources.

The challenge for sustained economic growth and poverty alleviation to meet the Millennium Development Goals (MDGs) in the Southern Africa region is closely associated with sustainable use of natural resources and better management of the environment. The Commission for Africa report (2005) recommends a doubling of arable land under irrigation by 2015 and the World Bank water resources strategy (2004) calls for increased investment in water infrastructure in Africa. The NEPAD (New Partnership for Africa's Development) environment initiative (2003) states that addressing environmental issues is necessary for achieving goals of sustainable growth and development and a lasting solution to the eradication of poverty. Development of the water resources of Southern Africa in a sustainable manner, through the application of a range of technical, economic and institutional measures, is clearly recognised as critical to economic development in Africa. Southern Africa FRIEND takes a demand-driven approach to tackling some of the water resource issues outlined above, which can be seen as a step towards the overall goal of making an effective contribution to the sustainable management of regional water resources and poverty alleviation.

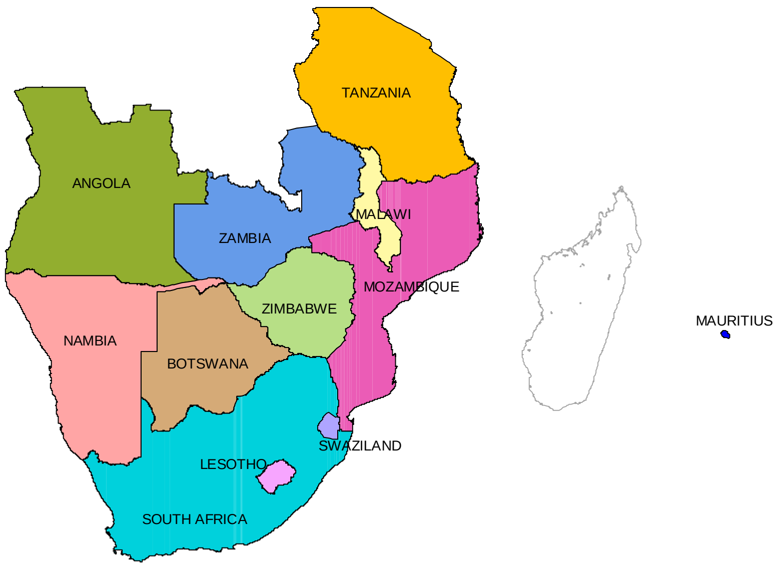


Figure 5.1 Extent of Southern Africa FRIEND project

5.1.2 Southern Africa FRIEND project

Southern Africa FRIEND has twelve member countries, represented by the national hydrological agency in each. They are Angola, Botswana, Lesotho, Malawi, Mauritius, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe (Figure 5.1). These are all the member countries of the Southern African Development Community (SADC) except for Democratic Republic of Congo and Seychelles, which have not yet participated in FRIEND. In addition to the national hydrological agencies, three research institutions participate in the project: the University of Dar es Salaam, Tanzania; Rhodes University, South Africa; and the Centre for Ecology and Hydrology, Wallingford, UK (CEH).

From an administrative point of view the project is organised at four levels: the UNESCO/IHP umbrella, the Steering Committee, the Co-ordination Centre at the University of Dar es Salaam and project groups who are responsible for specific activities. From a technical viewpoint, organisation of the project comprises a flow of data and information from country databases to research projects and back to countries as scientific outputs. The main objectives of the programme are:

- to promote and provide facilities for the free exchange of data for hydrological and water resources studies in the region
- to promote cooperation between water resources managers and researchers and to provide a channel for the exchange of expertise, information and ideas
- to develop improved operational hydrological methods based on knowledge of flow regimes and to establish them in hydrological agencies in the region.

The first phase of Southern Africa FRIEND (1992-1997) (UNESCO, 1997) was generally thought to have been successful and the second phase (2000-2003) (UNESCO, 2004) was designed to build upon its achievements, focusing on the needs for capacity-building and improved tools for water resources management in the region. The specific objective of Phase II was:

- to establish in the hydrological agencies improved operational hydrological methods and knowledge in flow regimes, that are demand-driven and thematically coordinated.

On this basis, a series of themes and projects was developed at an initial strategic appraisal meeting in August 2000 (Meigh and Mkhandi, 2000). They were amended and then agreed by the Steering Committee at their meeting in November 2000. Progress and achievements in these various project components form the basis of this chapter.

5.2 Databases

High quality, long-term datasets, representative of the region, are essential for understanding the spatial and temporal variability of hydrological regimes. Between 1992 and 1997, Southern Africa FRIEND Phase I established flow time series and spatial databases to provide common regional datasets to underpin analytical research projects, such as the development of decision support tools for water resources management (UNESCO, 1997).

The flow time series database contains data from 676 stations across the region, and the period of record ranges from 1940 to 1992 and from 1 to 51 years per station, with an average of 23 years per station. The time series database is held by the University of Dar es Salaam, with copies in the national hydrological agencies of the 12 participating countries.

The spatial database contains region-wide, standardised coverages on a common geographical reference system of those thematic factors considered significant in determining flow regimes and extremes. The spatial data cover the following types:

- National boundaries
- Hydrometric boundaries
- Major river basins of Africa
- FRIEND flow gauging stations
- Geology
- Soils
- River network
- Raingauge locations
- Vegetation
- Precipitation
- Potential evaporation
- Temperature
- Mean annual runoff
- Wetlands

The database is held by CEH Wallingford. In Phase II, the spatial database and bespoke browser software were distributed on CD-ROM to the national hydrological agencies and other organisations in the participating countries, as well as 30 representatives of other FRIEND projects (UNESCO, 2004). The "Southern Africa FRIEND spatial data browser" provides easy access to the data and documentation on their origin and interpretation. It works in conjunction with the freely available GIS software ArcExplorer (ESRI, 1998) and distribution of the CD-ROM was supplemented by support and training in GIS at an introductory level. More details of the spatial data and the functionality of the browser software are given in Fry *et al.* (2001a) and UNESCO (2004).

Although the databases were intended to be used for regional research projects, two such projects in Phase II experienced some difficulties using the time series database due to: insufficient coverage of the range of basin areas, geomorphological conditions, climates and flow regimes; poor geographical spread, especially in the more arid areas; lack of information about artificial influences affecting flow regimes; and lack of long, validated records of good quality. Furthermore, the database was by then at least 10 years out of date.

There was no provision to update the time series or spatial databases in Phase II and their usefulness as a resource for research projects is thereby diminished. There is a need to review the status and likely future need of both databases and provide for updates and maintenance, and increased accessibility, if considered appropriate. A possible way forward might be the formation of a database group, similar to that in other FRIEND regions, to take on responsibility for populating the databases with new data, applying quality control standards and distributing the data to participating countries and FRIEND researchers for use in accordance with the data exchange agreements.

5.3 Research projects

5.3.1 Regional water resources and flow modelling

During the first phase of Southern Africa FRIEND, one of the main themes was rainfall-runoff modelling, led by the Institute for Water Research at Rhodes University, South Africa (UNESCO, 1997). The focus was on testing existing models (both monthly and daily time-step) with samples of the available data in the region to determine their broad applicability. Rainfall-runoff models were identified as potentially useful tools that could provide a vital component in the regional assessment of water resources availability. However, it was also recognised that there was a lack of experience within the region in the use of such tools, as well as inadequate access to the software required to apply models, little common understanding of the benefits of different models and their results and a lack of a common database required for setting up and running models.

In a parallel development, the need for an assessment of regional surface water resources was identified by SADC. Project Concept Note (PCN) 14 was conceived as a project proposal that would enhance the surface water resources assessment capabilities in the region (SADC, 2001; Hughes *et al.*, 2002). The overall aim of the PCN 14 project is to improve the ability of SADC member states to make surface water resource assessments that support environmentally sustainable development through broad strategic water resource planning that is based on information and approaches that are reliable and mutually acceptable within the region. PCN 14 was the first step taken by SADC to spearhead the process of assessing and quantifying the surface water resources of the whole of Southern Africa in a coordinated and unified manner, as well as building capacity within the region to make site-specific water resources assessments.

The ideas of Southern Africa FRIEND in the area of rainfall-runoff modelling and of PCN 14 clearly have much in common. Therefore, the Phase II work programme under this theme was designed as a contribution to the larger long-term study, focusing on providing some initial pilot results and helping to move towards the larger, eventual aims of that project. The following three focus areas were identified as being of value and achievable in the available time:

- A contribution to the development of the models and software tools required to undertake a regional water resource assessment study within SADC, coupled with a limited programme of training in the use of such tools
- A regional application of the Pitman model in the Kafue basin, Zambia, to assess the model and associated software tools capabilities, identify problems related to data availability and build capacity in the use of the model (see also Chapter 10)
- The integration of other ongoing applications of the Pitman model within the SADC region into the Southern Africa FRIEND project, in particular the Okavango basin.

The modelling work was again led by the Institute for Water Research, in collaboration with a number of other organisations. More information about the model application to the Kafue and Okavango basins, including data sources and assumptions, is provided by Hughes *et al.* (2003) and UNESCO (2004).

Model and tools

The rainfall-runoff modelling work in this theme uses a modified Pitman model (Pitman, 1973). The Pitman model has become one of the most widely used monthly time-step rainfall-runoff models within Southern Africa. It formed the basis of the South African WR90 modelling study (Midgley *et al.*, 1994), which simulated natural flows for 1946 quaternary catchments, using regionalised model parameters based on calibration against naturalised observed flows. Whilst designed largely to support strategic level water resource availability assessments and the preliminary design of abstraction schemes, additional benefits have included the estimation of groundwater contributions to surface flow, environmental requirements of rivers and estuaries and the impacts of streamflow reduction activities on water availability.

The version of the Pitman model used in Southern Africa FRIEND (Figure 5.2) includes modifications added during Phase I (UNESCO, 1997). This version has now been incorporated, together with a reservoir water balance model, into the SPATSIM (SPatial and Time Series Information Modelling) package (Hughes, 2002). SPATSIM is a software package designed as a database, data analysis and modelling system, specifically for hydrological and water resource applications. A screen dump of the main window of the software is shown in Figure 5.3.

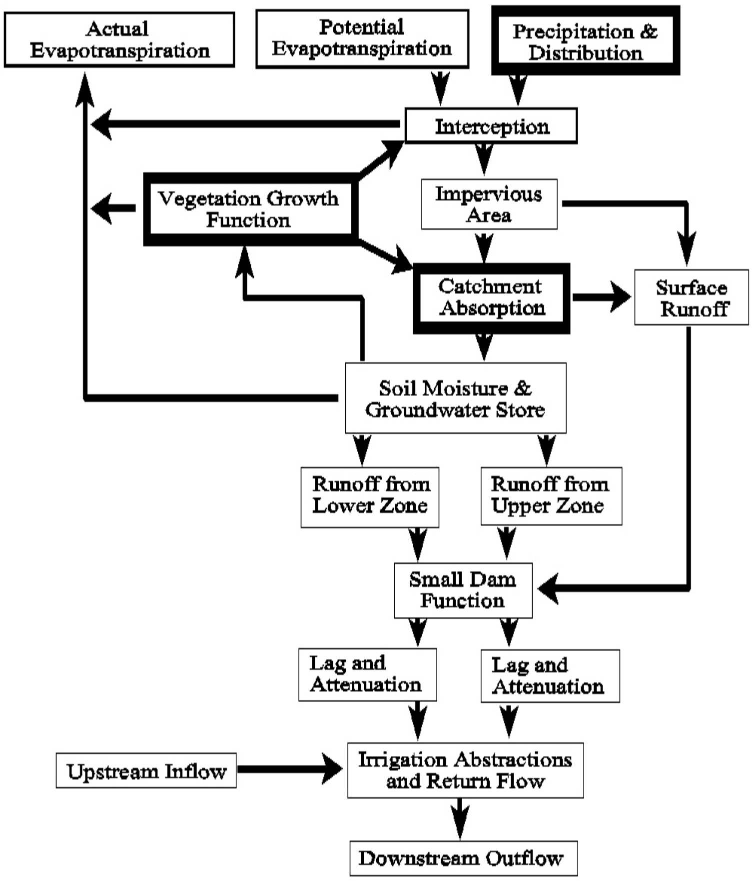


Figure 5.2 Flow diagram representation of the Pitman model

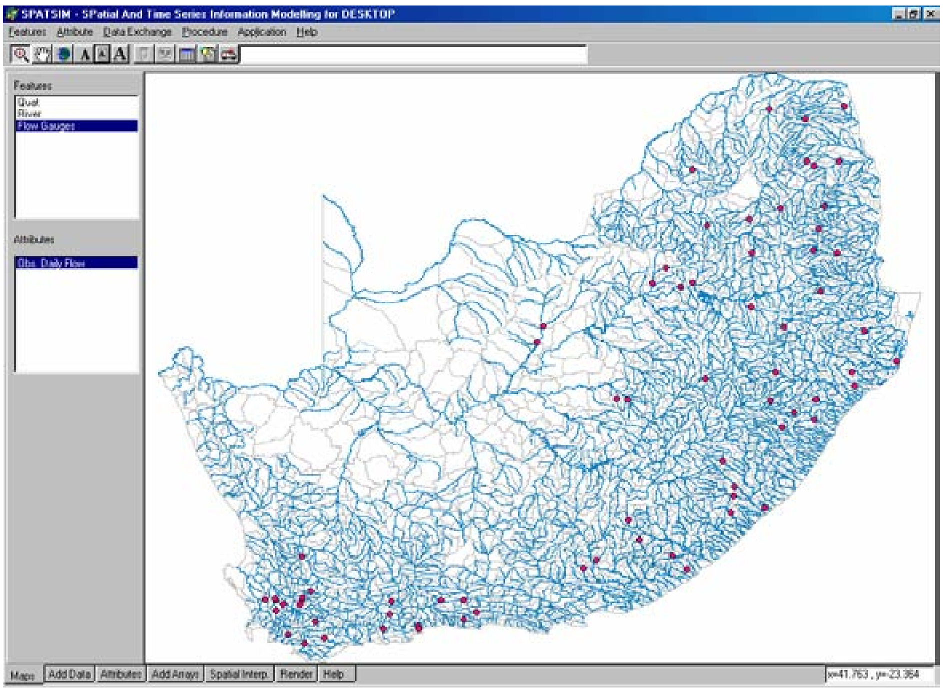


Figure 5.3 Main window of SPATSIM package

Regional context

One of the objectives of the Phase II work under this theme was to evaluate the SPATSIM package and its version of the Pitman model for use in this type of regional hydrological modelling study. The results from the case studies showed that, despite the limitations of the data, there are clear indications that regionalised rainfall-runoff modelling of catchments in Southern Africa is feasible (UNESCO, 2004). Furthermore, whilst it was not part of this work to investigate the impacts of future changes to the rainfall and evaporation regimes of the basin due to climate change, the model has the potential to investigate such scenarios. However, a particular challenge is presented with respect to the design of model parameter regionalisation procedures in a larger study, where several teams may be involved in modelling, if anomalous and confusing results at major basin boundaries are to be avoided. One possible solution might involve utilising the gridded spatial datasets used by the GWAVA model of eastern and southern Africa (Meigh *et al.,* 1998; 1999; see also section 5.3.4) and developing relationships between the abstracted basin characteristics and calibrated model parameter values.

5.3.2 Drought assessment and monitoring

Droughts have always occurred in Southern Africa and south-east Africa is traditionally regarded as particularly drought-prone. Droughts can have severe environmental, sociological, financial and political implications for large numbers of people, particularly the poorer people who have traditionally had lower levels of reliability of access to fresh water supplies. There has been some progress in mitigating the impacts of, and vulnerability to, drought but responses (at both national and international levels) are still often inadequate (Houghton-Carr *et al.,* 2002). The need to urgently address this water resource problem is accentuated by the water scarce situation that is developing in the region with increasing levels of population, higher levels of urbanisation and possible climate change impacts.

The drought assessment and monitoring theme of Southern Africa FRIEND Phase II was called ARIDA (Assessment of the Regional Impact of Drought in Africa) and aimed to enhance the abilities of the participating countries to analyse historic water resources droughts and to monitor ongoing droughts. Because of the wide variety of hydrological regimes across the region, a combination of different approaches was needed. The key objectives of the work were to investigate better methods for identifying river flow droughts in Southern Africa and to develop tools that water resources managers in the region could use to monitor droughts. Progress and achievements in this theme were reported on in Gustard and Cole (2002) and described in detail in UNESCO (2004). However, in order to provide a complete review of the activities of Phase II in this report, the methods and software developed are summarised below.

Drought analysis methods

The wide range of hydrological regimes that are present in the Southern Africa region means that no single approach to drought assessment is likely to work satisfactorily across the whole area. Various drought analysis methods were investigated by testing on flow data from 15 gauging stations across the region, abstracted from the flow time series database (section 5.2). The stations were chosen to represent a wide range of climatic conditions (average annual rainfall from 162 to 1370 mm), catchment sizes (52 to 104,000 km²) and geomorphological situations, as well as having high quality, long and continuous records without significant artificial influences. The data covered the period 1941 to 1997, with record lengths from 17 to 51 years. Of these, four approaches were assessed as appropriate for the realistic determination of the characteristics of river flow droughts in the region (Tate *et al*., 2000; Tate and Freeman, 2000; Meigh *et al*., 2002). The methods were:

- Low flow frequency analysis – to identify the probability of occurrence of low flows over a particular period of time
- Run-sum analysis (Figure 5.4) – to identify periods of flow below a specified threshold as well as such characteristics as drought duration and the corresponding total volume of water deficit
- Runoff accumulation analysis (Figure 5.5) – to determine volumes of accumulated runoff from specified dates and enable estimation of associated probabilities
- Ranking of flows and comparison with extremes – to allow comparison of current flow data against historic means, maxima and minima.

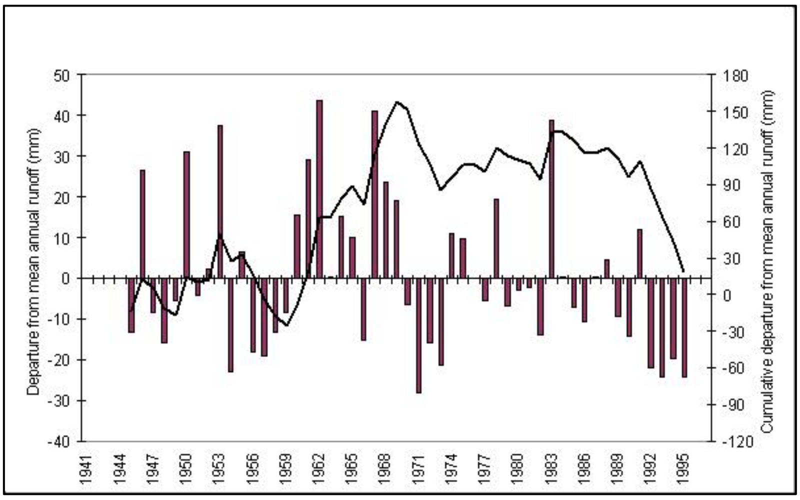


Figure 5.4 Rum-sum analysis method for long-term droughts (showing the departure and cumulative departure from the mean) for the Okavango river at Rundu

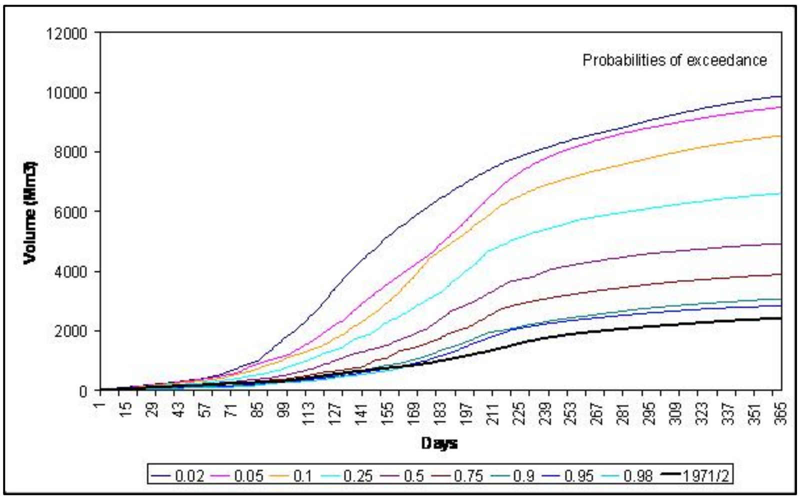


Figure 5.5 Accumulated runoff analysis for the Okavango river at Rundu

Software development

The drought analysis methods were incorporated in a software tool, also called ARIDA (Fry *et al.*, 2001b). The software links directly into the HYDATA database and analysis system (IH, 1999; CEH, 2001) which is used as the hydrometric archive in many Southern Africa countries as well as for the Southern Africa FRIEND flow time series database. ARIDA includes graphical representation of flow or drought characteristics at a site and provides easily exported summaries of the state of a current drought relative to historical events. Multiple graph and statistic sets for different methods and for different flow series can be produced simultaneously, and the background settings for each method can be set and saved individually for each flow series for future use. Statistics are produced for each drought period, providing a means of assessing the relative severity of droughts as measured by each method. When new data become available, the methods can be re-applied, and statistics for the current drought updated, allowing its severity relative to historical droughts to be re-examined.

Regional context

The usefulness of the various graphs, tables and statistics indicating the likely relative severity of the current situation, produced by ARIDA for water resources management and for drought mitigation in the region, was assessed during the drought regional training workshop at which the software was released to the participating countries (UNESCO, 2004). A project running through the workshop was designed to place participants in the position of hydrologists monitoring a developing drought, and required them to produce regular reports on the progress of the droughts as seen by each of the different methods and to comment upon the effectiveness of each. The simpler of the methods, the monthly bulletin reports and accompanying statistics placing the months' flow within the context of the whole record, proved most readily understandable. Other methods, while more difficult to set up, provided more information on the length of the drought or the water deficits created. Overall, it was considered a useful tool. ARIDA has also been distributed, on request, to hydrologists working in other countries in Africa, including Ghana, Kenya, Nigeria and Somalia.

5.3.3 Water resource assessment (Low Flows 2000 - SA)

In Southern Africa, water resources management is important because of the scarcity of water, the major role of water within the economies of many countries and the levels of vulnerability of populations, especially the poor, to the water stress that can occur through drought, inadequate access and poor water management. At every level, from small catchments to international basins, water management needs to be carried out with the consideration of all stakeholders and with all possible awareness of what the future may bring. In practice, this means that water allocation decisions need to be made by water resource managers with all information concerning the natural resources available, the effects of existing water use on these resources, the water needs of stakeholders and the predicted change in these factors in the future. As water demand and water stress increase, the margin for error in assessing both water resources and the impacts of water use becomes smaller.

Under this Phase II theme, a prototype GIS tool for water resources management in Southern Africa countries was developed (Fry *et al.*, 2003). The tool acts as a decision support which can provide estimates of water availability anywhere on the river network. It allows water use information to be stored and visualised through the GIS interface. The water availability estimates and the water use information can be integrated to show the effects of both existing water use and future water use scenarios. It is based on a tool used in the UK (Holmes *et al.*, 2005), but has been adapted to make it suitable for conditions in the region. The study comprised two parts:

- Development of hydrological models to estimate flow statistics at ungauged sites
- Development of GIS water resources software incorporating the hydrological models.

Malawi was selected as the pilot region. Malawi is located at the southern end of the East African rift valley and is dominated by Lake Malawi, the third largest lake in Africa. The water resource demands and problems faced in Malawi can be considered representative of those in many countries across the region. The work was a collaboration between CEH and the Ministry of Water Resources Development in Malawi. A Malawian hydrologist spent one month at CEH working on the development of the methodology underlying the GIS software. Participants from the other eleven Southern Africa FRIEND countries were trained in the hydrological methods and the software during the water resources regional training workshop (see Chapter 10). More information about the development of the model and GIS water resources software is provided in UNESCO (2004).

Model development

The flow duration curve provides estimates that are indicative of the average, long-term flow regime of a river, e.g. Q_{70}, the flow exceeded, on average, 70% of the time (Gustard *et al.*, 1992). This is significantly simpler to model than the flows from specific rainfall events. Flow duration curves contain information appropriate to a decision support context, as they provide estimates of variability within the year which, combined with estimates of mean monthly and annual flows, indicate the long-term availability of the resource. The results are useful for assessing the potential of locations for supply to a variety of uses but, of course, do not provide the full spectrum of information needed for the detailed day-to-day planning of abstractions. The method of estimating flow duration curves at ungauged sites in Malawi is summarised in Figure 5.6.

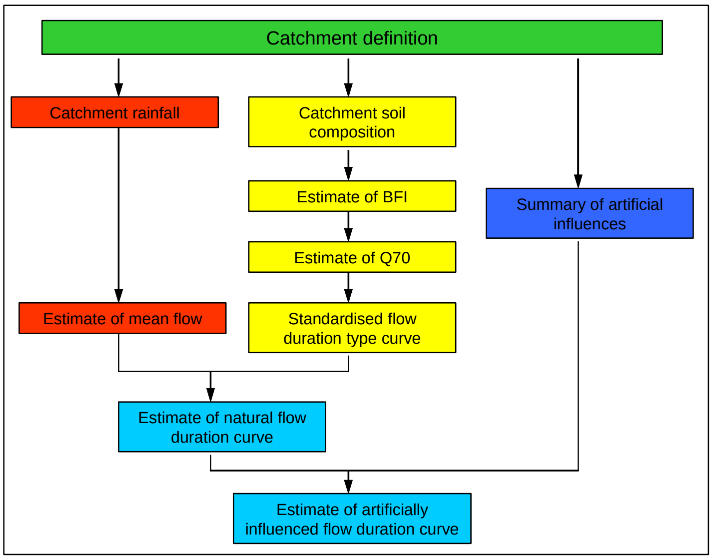


Figure 5.6 Schematic diagram of stages in flow estimation procedure

The method was developed using relationships between spatial catchment characteristics and naturalised flow regimes for gauged catchments in Malawi. Relationships were derived first between soil type and base flow index (BFI) (Gustard *et al.*, 1992) and then between BFI and Q_{70}, thus allowing Q_{70} to be estimated for any location on the Malawi river network. A further relationship between rainfall and runoff was derived so that mean annual and mean monthly flows could similarly be estimated for any location, based on the mean annual rainfall. Finally, the Q_{70} statistic was used to select a standardised flow duration type curve (Figure 5.7), which could then be re-scaled using the mean flow value to provide an estimate of the actual flow duration curve for the catchment. Where there are artificial influences (e.g. abstractions) in the catchment, their combined effect is then calculated, so that the influenced flows and flow duration curves can also be estimated (Figure 5.8).

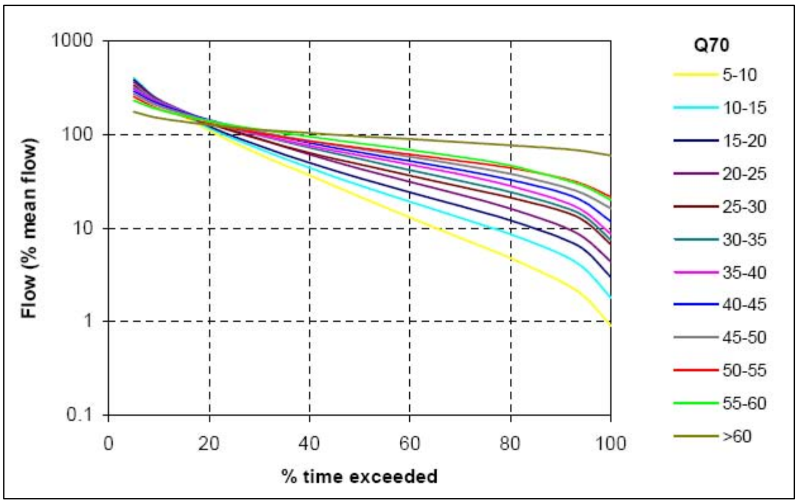


Figure 5.7 Standardised flow duration type curves for perennial rivers in Southern Africa (UNESCO, 1997; 2004)

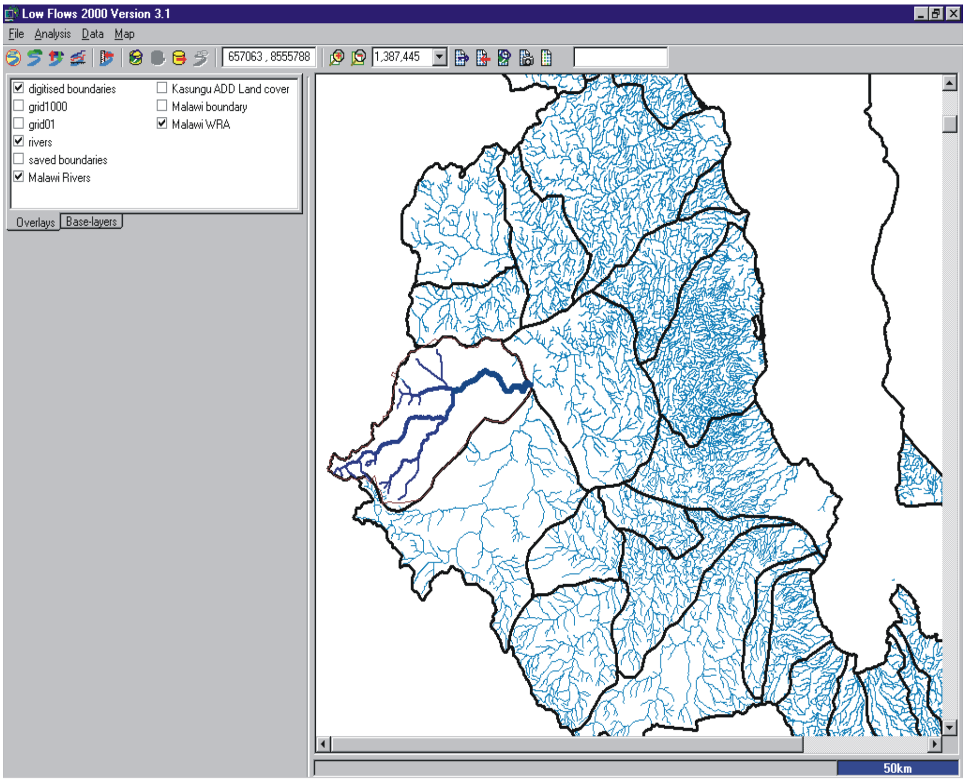
Software development

In order for the method for estimating flow characteristics at ungauged sites to be made practically applicable within licensing and water resources management operations, it was incorporated within a software tool in which the digital datasets can easily be visualized and interrogated. The bespoke software tool developed, LF2000-SA (Fry *et al.*, 2003), was based upon the Low Flows 2000 software developed by CEH for the UK Environment Agency (Holmes *et al.*, 2005). Key elements of the software are:

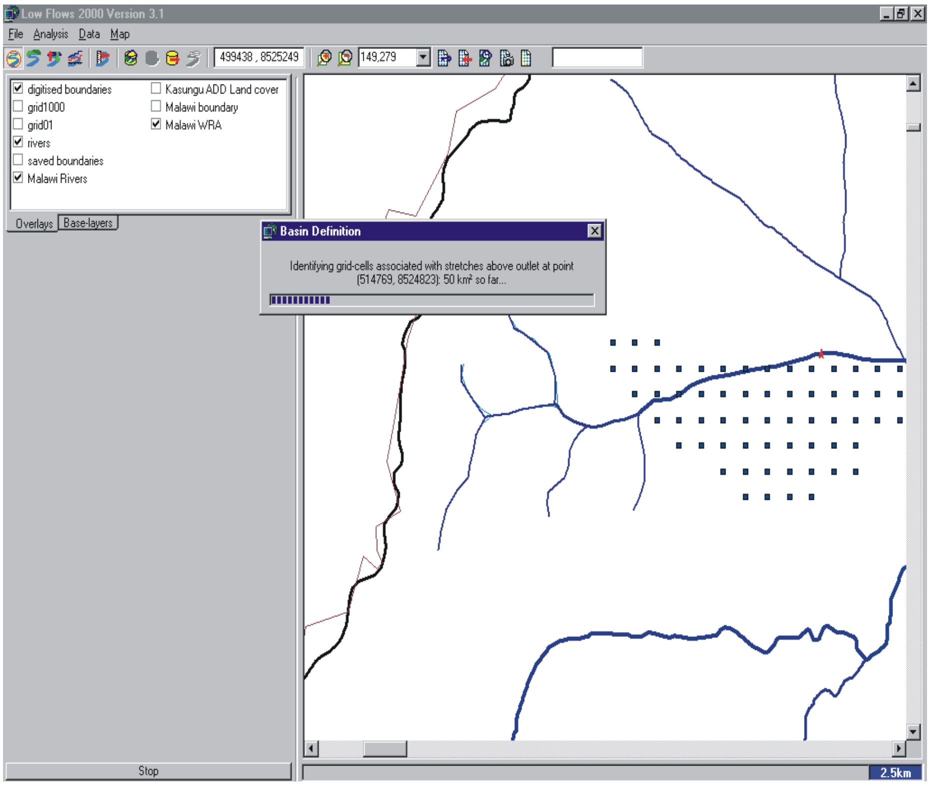
- Visualisation of rivers, artificial influences, gauging stations and other spatial features
- Storage of artificial influence information
- Storage of catchment characteristics – rainfall and soil types
- Derivation of catchments at any point on the river network
- Retrieval of characteristics (rainfall and soil type extents) for given catchment
- Production and visualisation of natural flow duration curve
- Visualisation of the impacts of existing artificial influences upon natural flow regimes
- Creation of ‘scenario’ flow statistics under predicted future influences

- Ease of use for potential users of all levels
- Consistency of flow estimates
- Usability of outputs within existing procedures
- Maximisation of the usefulness of data management tools
- Consistency of interface with common GIS applications and software.

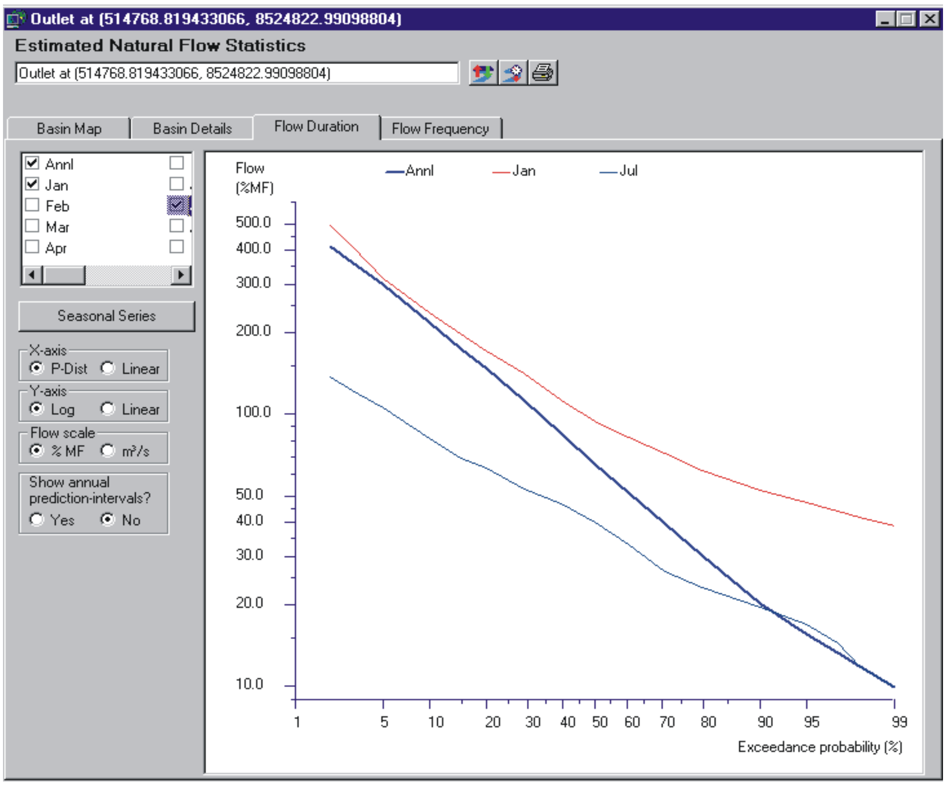
The software is based around a GIS user interface, and some example screen dumps of steps in the flow duration curve estimation process are shown in Figure 5.8. LF2000-SA was set up as a pilot version for three areas of Malawi – the Bua, Lilongwe and South Rukuru catchments – covering about one fifth of the country. This was considered sufficient for an analysis of the applicability of the system and the outputs within the Malawian procedures for water resources management. The assessment of the system by the Ministry of Water Development revealed that the software could provide a leap forward in the capacity of the Ministry to process licence applications, particularly in its ability to obtain and to summarise the important hydrological data pertinent to the allocation decision. This provides an effective tool to support decision-making.



(a) Malawi river network and test catchment



(b) Definition of ungauged catchment boundary by stream climb



(c) Example monthly and annual flow duration curves for ungauged site

Figure 5.8 Example screen dumps from pilot GIS water resources software

Regional context

This project provided a direct example of transfer of technology from the UK and adaptation to Southern Africa conditions. From this perspective, the viability of the pilot tool and its appropriateness in the context of existing water allocation processes in the region was of particular interest. Feedback from the national hydrological agencies in the 12 participating countries suggested that such a system would integrate well with the water resource management procedures already practised in many countries and that it would provide a huge leap forward in GIS facilities, flow estimation and water resource management in the region. It is hoped that funding may be found to enable extension of this highly relevant tool to other countries in the region.

5.3.4 Water resource assessment (GWAVA – Global Water AVailability Assessment)

Declining water availability is an increasing concern worldwide and especially in developing countries. Increases in population combined with urbanisation, and industrial and agricultural development will create extra demands for water. At the same time, it is likely that climate change due to global warming will affect both the availability of supply and the demands for water, leading to further uncertainty about the future balance of water supply and demand. Translating these global changes down to the local basin scale at which planning and adaptation for the future is needed presents an enormous challenge. In the context of Southern Africa, there is a clear need to improve the abilities of the countries themselves to make water resources assessments in relation to the potential impacts of climate change, which guided the work under this Phase II theme.

The work was carried out as a case study for Swaziland, a land-locked country bordering South Africa and Mozambique, with a surface area of 17 400 km^2. Swaziland's economy is heavily reliant on agriculture, which accounts for approximately 95% of all water abstractions and intensification of agriculture is a primary objective. Water resource availability assessments for the current "baseline" situation and for various scenarios to identify the potential scale of future water resource problems were made using the grid-based GWAVA model (Tate, 2002). The work was a collaboration between CEH and the Water Resources Branch of the Swazi Ministry of Natural Resources and Energy. The Swazi team were involved in collecting data, setting up, calibrating and running the model, developing scenarios and presenting the results to the other countries in the region during the water resources workshops (see Chapter 10). Data sources and assumptions in applying the model to Swaziland are described more fully in Tate *et al.* (2002) and UNESCO (2004).

The GWAVA model

The GWAVA grid-based model was originally designed to address the problem of making improved estimates of current and future water resources (Meigh *et al*., 1998; 1999). Many studies have examined country-wide aggregates of resources and demand, masking variations between parts of the same country. In Swaziland, the model was applied on a 0.5 degree grid (approximately 55 km by 55 km) capturing a broad spatial pattern. The GWAVA model includes a number of water resource components which make assessments more realistic, and improves on other hydrological and water resource modelling approaches, for instance, Shiklomanov (1997), Arnell & King (1998), Alcamo *et al.* (1997; 2000). Key elements of the model are:

- A consistent methodology which can be applied across all countries and regions;
- Within each grid cell, surface water resources are assessed using a rainfall-runoff model;
- The individual grid cells are linked to represent the flow patterns of the natural drainage;
- The effects of lakes, reservoirs and wetlands, of water consumed and return flows, and of inter-basin transfers, are all included;
- Seasonal and year-to-year variability in the surface water flows are taken into account to assess the amount of water which is actually available for use;
- Both surface and groundwater resources are included so that the total water availability at any location can be assessed;
- Water demands are assessed, including those for human and livestock consumption, industry and irrigation;
- Maps of water availability indices highlight regional variation in water stress.

A key point is that water resources and water demands are both assessed and compared at the scale of the grid cell to derive an index of water abundance or scarcity for each cell. More information about the GWAVA model is given in Meigh *et al.* (1998; 1999).

Results

The baseline results (Figure 5.9) showed that over much of Swaziland the situation is already tending towards water stress, reflecting the current climate pattern and the large areas of

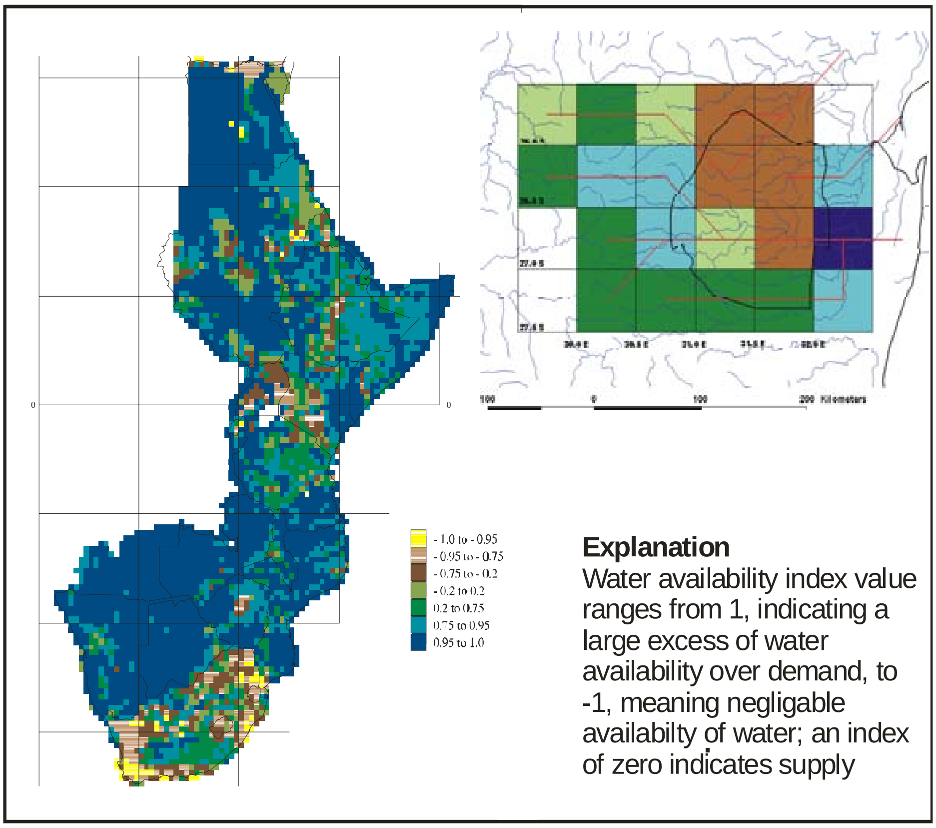


Figure 5.9 GWAVA water availability index for the present situation for eastern and southern Africa, with detail for Swaziland

irrigation and forest with their heavy demands for water, as well as the more populated areas, where demands are also high. The results from the various climate change scenarios indicated that, in the future, a general decline in river flows is expected. Combined with increasing demands due to growth in population, per capita consumption, irrigation and industrial use, this would lead to an increase in water stress – that is, a shortage of available water compared to demand – across the whole country with substantial shortfalls in most areas. The central and eastern parts are expected to have the greatest deficit in water availability compared to demand.

Regional context

GWAVA has also been applied regionally to the whole of Eastern and Southern Africa in a general water availability assessment study (Figure 5.9) and at basin level to the transboundary Okavango basin to investigate impacts of hydropower development and climate change on streamflows entering the Okavango delta (see Chapter 11). The successful application of GWAVA at country (by Swazi partners), basin and regional scales shows that it is an appropriate tool for improving the ability of participating countries to make surface water resources assessments, specifically in terms of the long-term impacts of future changes in climate and in water demands, both increasing concerns in the Southern Africa region.

5.4 Conclusions

The second phase of Southern Africa FRIEND (UNESCO, 2004) focused on research projects to develop improved tools for water resources management in Southern Africa, interlinked with capacity building (described in Chapter 10) and resulted in the following key achievements:

- Development of browser software to support the regional spatial database
- Application of the modified monthly Pitman model in the Kafue and Okavango basins as a contribution to a SADC-led regional study to assess and quantify surface water resources
- Development of ARIDA software to support drought assessment and monitoring methods
- Development of pilot GIS water resources software incorporating a new method for estimating natural and artificially influenced flow duration curves at ungauged sites in Malawi
- Application of the GWAVA water availability assessment model for making surface water resource assessments and studying the long-term impacts of future change scenarios in Swaziland.

The objectives of any third phase of Southern Africa FRIEND will include consolidating the achievements of the first two phases, as well as developing new research directions, as set out in Chapter 11. At the same time, whilst Africa remains the focus of international development priorities (Commission for Africa, 2005; World Bank, 2004), it is important to support efforts towards more efficient coordination of research activities within the region by developing links to other regional initiatives that have priorities that align with those of Southern Africa FRIEND.

Acknowledgements

The Southern Africa FRIEND Steering Committee convey their appreciation to UNESCO for supporting the Southern Africa FRIEND project since its inception and to the UK Department for International Development for funding much of the activity under Phase II as a component of the UK contribution to the International Hydrological Programme of UNESCO. The Steering Committee also pay tribute to the contribution of Dr Jeremy Meigh, who led the CEH component of Southern Africa FRIEND Phase II.

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6 West and Central Africa (AOC)

6.1 Introduction

The West and Central African FRIEND group was initiated in 1992 in Ouagadougou, Burkina Faso with the support of UNESCO and ORSTOM (now IRD – Institut de Recherche pour le Développement), Montpellier, France, and set up in 1994 in Abidjan, Côte d'Ivoire. This gradually developed into a project based on the community of African hydrologists with a limited number of targeted research topics.

After completion of the first phase with the AOC-FRIEND seminar and the steering committee meeting in Yaoundé, Cameroon in December 1999, the second phase began and continued until 2002.

In 2002, the Steering Committee expressed the wish for AOC-FRIEND research teams to be involved in international research projects in order to extend the possibilities for interesting prospects in terms of research design and operation for members.

The aims of AOC-FRIEND are to:

- develop scientific activities in the region with the aim of becoming operational at the scale of regional development
- create a network of research teams to extend scientific cooperation with respect to the hydrological cycle at the African continental scale
- facilitate the dissemination of information and research results in Africa.

The first two phases received financial support from Coopération Française and UNESCO, the second stage is still in need of funding. Nevertheless, with the help of IRD and UNESCO, hydrologists in the sub-region have continued to work and to maintain the dynamics of the network, as well as to organise and/or take part in scientific meetings and steering committee meetings.

In 2002, the number of research topics, apart from the database, was reduced from six to four: variability of water resources, minimum flows, modelling of hydrological processes and the dynamics of material flows. In contrast to the first phase when project leadership was in the hands of individuals, responsibility for scientific coordination now belonged to institutions. These institutions were, in the order of the topics cited above, École Inter-États d'Equipement Rural (EIER) and IRD, Ouagadougou, Burkina Faso; Water Research Institute (WRI), Accra, Ghana; University of Benin, Cotonou; and Centre de Recherches Hydrologiques (CRH), Yaoundé, Cameroon. AGRHYMET was in charge of general coordination, the database and the website.

Among these activities, the substantial and active participation of members of the FRIEND-AOC group at the 4th international FRIEND conference held 18-22 March 2002 in Cape Town, South Africa represented a major challenge. This challenge was met and a large number of presentations (20% of the total number of papers and poster presentations) were made by members of AOC-FRIEND.

In 2002, two coordination meetings were held one after the other in Cotonou, Benin on two different topics (modelling and dynamics of material flows) coupled with a scientific workshop. Particular emphasis was placed on participation by members of AOC-FRIEND in the Envirowater symposia held in Ouagadougou, Burkina Faso in November 2002 and in Montpellier (France) and IAHS in Tokyo in 2003.

A large number of our members took part in the Envirowater conference held 4-8 November, 2002. With financial assistance from UNESCO, a steering committee meeting was held during the conference, during which the general conditions for the search for funding were drafted. At this meeting it was also decided to change the topic 'Minimum flows' to 'Minimum flows and dynamics of subsurface flows' to be coordinated by the Cheick Anta Diop University (UCAD), Dakar, Senegal. On the same occasion, AOC-FRIEND also agreed to take part in the African Monsoon Multidisciplinary Analysis (AMMA) symposium in Cotonou, Benin in November 2003.

From this time on, AOC-FRIEND activities focused on encouraging members to prepare and submit papers for the above-mentioned symposium. These efforts succeeded, and many papers and posters were presented, thanks to financial assistance from UNESCO.

On the occasion of this symposium, a steering committee meeting was held on 8 November, 2003, bringing together the coordinators of the AOC-FRIEND and AMMA projects. One of the main objectives of the meeting was to define the type of partnership that could be envisaged between the two projects since a number of AOC-FRIEND members are also involved in the AMMA programme and the two projects take place in the same sub-region on data that may well overlap.

At the same steering committee meeting, the future general coordination of AOC-FRIEND was assigned to CRH, Cameroon. The project was enhanced by the addition of a new topic, ecohydrology, the coordination of which was assigned to the University of Lomé, Togo, and EIER, Burkina Faso. The wish to create a research topic entitled Ecohydrology having been fulfilled, the coordinators were requested to define its fields of application in more detail. The topic Modelling was reviewed and renamed Modelling ungauged catchments. A summary of AOC-FRIEND research topics are given in Table 6.1.

These topics cover the major hydrological problems in the region and try to take into account phenomena due to human activities that can affect the environment. One characteristic of hydrology in West and Central Africa is the high level of variability of the variables of the hydrological cycle, mainly rainfall, and surface and subsurface water resources. The high degree of variability observed throughout the region since the 1970s and human activities have had a serious impact on the ecosystem and in particular on the availability and quality of water destined for different uses.

Table 6.1 General coordination: Hydrological Research Centre (CRH), Yaoundé, Cameroon

No	Topics	Coordination
1	Minimum flows and dynamics of subsurface flows	Cheick Anta Diop University, Dakar, Senegal
2	Dynamics of material flows	Hydrological Research Centre, Yaoundé, Cameroon
3	Variability of water resources	EIER/IRD
4	Modelling ungauged catchments	University of Abomey Calavi, Benin
5	Ecohydrology	University of Lomé, Togo / EIER, Burkina Faso
6	Database and website	AGRHYMET, Niamey, Niger

While waiting to find funding, our activities have mainly focused on scientific animation on the Internet and electronic messaging. Obviously not all AOC-FRIEND researchers have access to the Internet under the same conditions because of the technological gap in some countries, however every effort is being made to make sure members receive information concerning the various symposia, possibilities for funding for research projects and educational grants. In this way, many members were able to submit summaries for the IAHS symposium in Foz do Iguaçu, Brazil, 3-9 April 2005. Members were also encouraged to prepare papers to ensure the active participation of AOC-FRIEND members at the international conference Impacts climatiques et anthropiques sur la variabilité de ressources en eau, organised by the joint research unit HydroSciences, in Montpellier in November 2005 and at the Fifth FRIEND World Conference in Cuba in November 2006.

Up to the most recent steering committee meeting held in Montpellier in November 2005, the general coordination division encouraged the exchange of data and scientific information between members with the aim of answering calls for papers and scientific publications. Below we describe the activities connected with each topic in more detail.

6.2 Database

The AOC-FRIEND network has a database that consolidates rain-gauge data and hydrological data and is located at the AGRHYMET regional centre in Niamey, Niger. The idea behind installing the AOC-FRIEND database at AGRHYMET was to create a link with CILSS (Permanent Interstate Committee on Drought Control in the Sahel) and HYCOS (Hydrological Cycle Observing System) to allow input of historical data into the AOC-FRIEND database. The management of the database failed to meet all these expectations. The Cheick Anta Diop University has agreed to take over the running of the database in the coming years, and to try and create a new momentum by:

- making the AOC-FRIEND database visible on the Internet (inventories)
- regularly updating the database (within the limits of possibility)
- making data from the database available to network members for studies that contribute to the aims of the project.

6.3 Research projects

In the absence of specific funding for the AOC-FRIEND programme, AOC-FRIEND activities have decreased over the last four years. Nevertheless certain activities have been maintained or even expanded.

6.3.1 Minimum flows and dynamics of subsurface flows

Originally coordinated by the Ghanaian Water Research Institute, work on this topic stopped for a while due to the nomination of UCAD as project leader. Following the Cotonou meeting, the new coordinating committee drafted a project document that was sent out to all topic coordinators together with a registration bulletin. In this document the topic was divided into five sub-topics

- Dynamics of flows
- Hydrologic budget at the plot and catchment scale
- Study of impacts on and vulnerability of water resources
- Water, environment and the health of the population
- Modelling and management of water resources.

A working document is currently being compiled that will include all the topics studied by AOC-FRIEND and AMMA. This reflects the plan for a partnership between the AMMA follow-up committee AMMA and the AOC-FRIEND steering committee originally put forward at the Cotonou meeting in 2003. A memorandum listing procedures for collaboration is currently nearing completion.

6.3.2 Dynamics of material flows

The activities concerned with this topic were mainly focused on animation, education and training, and structuring of the data and bibliographical references.

One of the main concerns was creating and maintaining links between the approximately 20 members of this topic group by exchanging data and information about various scientific events. This is why five out of seven papers by members of AOC-FRIEND that were accepted for the IAHS symposium in Foz do Iguaçu, Brazil in April 2005 were on the topic of DYNAFLUX.

A database containing information on suspended matter was created and currently contains data and the results of studies on this topic made in Cameroon over the last 50 years. A doctoral thesis on this topic and funded by Coopération Française, IRD, UNESCO and AOC-FRIEND describes the model. Subsequently it is planned to encourage other members working on the topic to work in the same way in order to create a sub-regional database similar to those that already exist for rainfall and flows.

The coordinating division also envisages creating a databank of bibliographical references on works on soluble and suspended matter in the sub-region that could be put online on the AOC-FRIEND website.

In January 2003, the coordinator of this topic welcomed two IRD researchers from the joint research unit HydroSciences (IRD, Ouagadougou), in Yaoundé for a number of work sessions on, among other topics, the AOC-FRIEND project and hydrochemical measurements at Ngoazik station on the Ntem river. The two researchers then went on to Libreville to publicise AOC-FRIEND, to talk about some of its activities and to establish contacts with a view to possible collaboration with hydrologists in Gabon. This mission also enabled them to present papers at the scientific workshop organised by the Research Institute for Human Sciences (IRSH), CENAREST, Gabon within the framework of the World Day for Humid Regions held on 2 February 2003. This sub-regional event also enabled a Gabonese colleague to take part in the AMMA symposium in Contonou.

In addition, a Congolese colleague who, within the framework of a FRIEND scientific exchange concerning hydrochemical measurements, spent some time at the Hydraulics Research Centre (HRC) in 2002, will now be using the same methods as the HRC for the Projet de conservation et de protection des ecosystèmes du Nord-Congo (PROECO) in Congo.

In addition to ongoing research projects on the topic in several different countries in the sub-region, a project entitled Effects of climate change on water, the environment and health was implemented in 2004-2005 in Cameroon, financed by the IRD within the framework of a call for tenders by JEAI of the IRD Department for Education and Training Support for Southern Communities. This project is being implemented by the Hydraulics Research Centre in partnership with the Joint Research Unit HydroSciences in Montpellier. Two doctoral theses are being written within the framework of this project.

Following a proposal by the topic coordinator, five members took part in the GEMS/water workshop organised by the United Nations Environment Programme (UNEP) in July 2005 in Ouagadougou on the quality of water in countries under the Niger Basin Authority (ABN).

6.3.3 Variability of water resources

The coordinators of this topic have mostly been involved in the search for funding, as well as in organising an international seminar and a research project within the framework of the international AMMA programme, and finally in animating the AOC-FRIEND network with an Internet forum. An international seminar entitled Variability of water resources was held at HydroSciences, Montpellier, bringing together researchers working on this topic from all over the world who belong to the FRIEND network.

- VRE Internet forum

  This forum continues to be run by Jean Emmanuel Paturel from Ouagadougou or from Montpellier.

- Research Programmes

  The ICCE-BF programme on hydrology, erosion and soil fertility in the Nakambé basin, Burkina Faso was officially selected as the African component of the AMMA programme and European funding was received for the part of the project in the period 2005-2008. The Nakambé basin was chosen as a pilot basin for the UNESCO Hydrology for the Environment, Life and Policy (HELP) programme.

  In Mali two research programmes concerned with VRE will receive funding until 2007. They are being undertaken in partnership with ENI and IPR. The topic of the first programme is Management practices of savanna ecosystems in Mali and their consequences for the soil, water and biodiversity (CORUS-Coton). The aim of the second National Hydrological Research Programme is improving the hydrological modelling of the River Niger using spatial data gathered by remote sensing.

- Young associated team (Jeune Equipe Associée), IRD

  A contract for a young research team from the CRH, Yaoundé, associated with IRD and financed by the DSF of IRD since 2004, received a contract on the topic Water resources: possible effects of climate change and human activity on these resources. A mid-term report has been written and funding for the third year (2006) will be available.

- Conferences

  Foz do Iguaçu, Brazil. IAHS Conference, April 2005
  Dakar, Senegal. AMMA Conference, November 2005
  Montpellier, France. International FRIEND VRE Seminar, November 2005
  Havana, Cuba. 5th FRIEND World Conference, November 2006

6.3.4 Ecohydrology

Two coordinators (EIER and the University of Lomé) were asked to co-author a 'white book' on the topic ecohydrology, but this was impossible to accomplish within the specified time limit.

6.3.5 Modelling ungauged catchments

Activities around this topic were concerned with organising the topic meeting and a workshop as well as exchanges with AMMA. Three papers on the topic were presented at the AMMA seminar.

In the framework of the CORUS call for tenders and in collaboration with ENSA, a project was submitted on the impact of variability in food crops in Benin.

Acknowledgements

We cannot end without gratefully acknowledging all the organisations and institutions who made every effort to support the AOC-FRIEND group, namely *Coopération Française*, IRD, UNESCO Nairobi, and all the research institutes and universities of the sub-region who supported the project through one or other of the coordinating bodies. This support enabled the Coordinator and members of AOC-FRIEND to organise and/or take part in several scientific meetings.

7 Asian Pacific – AP-FRIEND

7.1 Introduction

Asian Pacific FRIEND, initiated in 1997, is directed by the IHP Regional Steering Committee (RSC) for Southeast Asia and the Pacific (UNESCO, 1999). Currently, the countries that participate in the Regional Steering Committee include Australia, Cambodia, China, Democratic People's Republic of Korea, Indonesia, Japan, Republic of Korea, Lao PDR, Malaysia, New Zealand, Papua New Guinea, the Philippines, Thailand and Vietnam but there has been additional representation from the island states in the Pacific from 2002, as well as observer representation from India, Mongolia, Myanmar and Nepal. The more formalised participation of Pacific Small Island Developing States in the IHP has been promoted, by rotational participation in the IHP Regional Steering Committee for Southeast Asia and the Pacific and AP FRIEND.

AP-FRIEND is now embarking on its second phase of research activities. The research undertaken was detailed in Gustard and Cole (2002). A key factor in the evolution of AP-FRIENDhas been the publication of five volumes of the Catalogue of rivers for southeast Asia and the Pacific, presenting detailed information for 114 rivers from 13 countries (RSC, 1995, 1997, 2000, 2002 and 2004). Work is underway for a sixth volume of the Catalogue of rivers which will include shorter time step information and updates of some of the present river data.

Two surveys were carried out by member countries IHP committees in 2002 and 2003 to investigate what were the critical issues of IHP-VI for AP-FRIEND to focus on. The results were used to direct the research effort of the Technical Steering Committee of AP-FRIEND. It was found that issues involving extreme rainfall events and the resulting flooding in both rural and urban areas were the primary concern of most countries. The next concern was the investigation of droughts and low flows and sustainable water resources management for the growing cities of Asia. The Pacific Small Island Developing States had water resources sustainability as their number one priority and this has been detailed in the report of the Pacific regional meeting on water in small island countries, held in Sigatoka, Fiji from 29 July to 3 August 2002. From this meeting the regional action plan on sustainable water management was developed (SOPAC-ADB, 2003). The research section below will detail the research activities.

7.2 Asian Pacific Water Archive

Great efforts were made in the first phase of Asian Pacific FRIEND to collect and archive hydrological data and to establish an Asian Pacific Water Archive. The archive contains river flow data, hydrometeorological and other related water resources information, which has been collected for the Catalogue of rivers for southeast Asia and the Pacific, Asian Pacific FRIEND research projects and other IHP-related activities of member countries.

The archive is web-based and consists of a central node at the Regional Humid Topics Hydrology and Water Resources Centre in Kuala Lumpur, Malaysia (http://htc.water.gov.my/apfriend/wa/), with two national nodes at the Bureau of Meteorology in Melbourne, Australia (http://www.bom.gov.au/hydro/wr/unesco/friend/apfriend.shtml/) and in Kofu, Japan (http://titan2.cee.yamanashi.ac.jp/FRIEND/) at the Yamanashi University.

The addition of Volumes IV and V of the Catalogue of rivers has increased the size of the data base.

7.3 Research projects

Following discussions during the 11th RSC meeting in Fiji, October 2003, and examination of the survey results of the member countries, it was decided that themes such as high flows and low flows (including droughts) should be continued from phase 1 to phase 2 of AP-FRIEND. The theme of anthropogenic effects in terms of urbanization and changing land uses would be embedded in these themes. Because rainfall analysis is an essential input to prediction of high flows, low flows and drought analysis and had been surveyed as a priority in many countries, it was proposed that activities initially be focused on rainfall, specifically in terms of:

a) what data are available in countries in the region
b) how accessible is the data for research within each country
c) how accessible is the data for research outside the country
d) availability and origin of design rainfall guidelines/standards in countries
e) investigation of development of regionally consistent rainfall design techniques and guidelines.

The report (RSC-AP FRIEND, 2005) summarises the activities carried out in the initial stage of the Asian Pacific FRIEND Phase 2 and the results presented at the Intensity frequency duration and flood frequencies determination meeting held in Kuala Lumpur in June 2005. Nine countries participated and contributed to the data set for further analysis.

The research themes from the symposia held in the period 2002-2005 under the auspices of the RSC and AP-FRIEND have included extreme rainfall analyses, floods and flood frequencies as well as modelling, and the anthropogenic effects on the hydrological cycle both in the urban and rural context, as well as surface and ground water. Urbanization and the effects on the hydrological cycle both with respect to quantity and quality is of a major concern to many countries in this region now. Some specific results of research in Asian Pacific FRIEND are now presented in this section.

7.3.1 Rainfall research

Analysis of extreme rainfalls from AP-FRIEND (Region Asia Pacific)

This working group stems from the AP-FRIEND workshop held in June 2005 in Kuala Lumpur. The annual maximum series of durations ranging from 5 minutes to over 15 days were supplied by participating countries. Countries that supplied data were:

Australia	10 sites
People's Republic of China	3 sites
Indonesia	5 sites
South Korea	2 sites
Malaysia	3 sites
New Zealand	3 manual sites and 3 co-located automatic sites
Philippines	8 sites
Vietnam	3 sites
Japan	5 sites

Each country has analysed, or is in the process of analysing, the data for all countries using their locally accepted design rainfall analysis techniques. In a recent project in Australia (Jakob *et al.*, 2005) five three-parameter distributions were tested for the best fit. These distributions were the Generalised Logistic, Generalised Extreme Value (GEV), Generalised Normal, Pearson Type III and Generalised Pareto. In the majority of cases, the GEV gave the best fit and also gave an acceptable fit to site data in greater than 90% of cases for durations from 1 hour to 72 hours. The Australian analysis for this current project was therefore done using the GEV distribution and the fitting procedure, as recommended by Jakob *et al.* (2005). The work by Jakob *et al.* (2005) is the first step of a larger project to update the Australian IFD procedure.

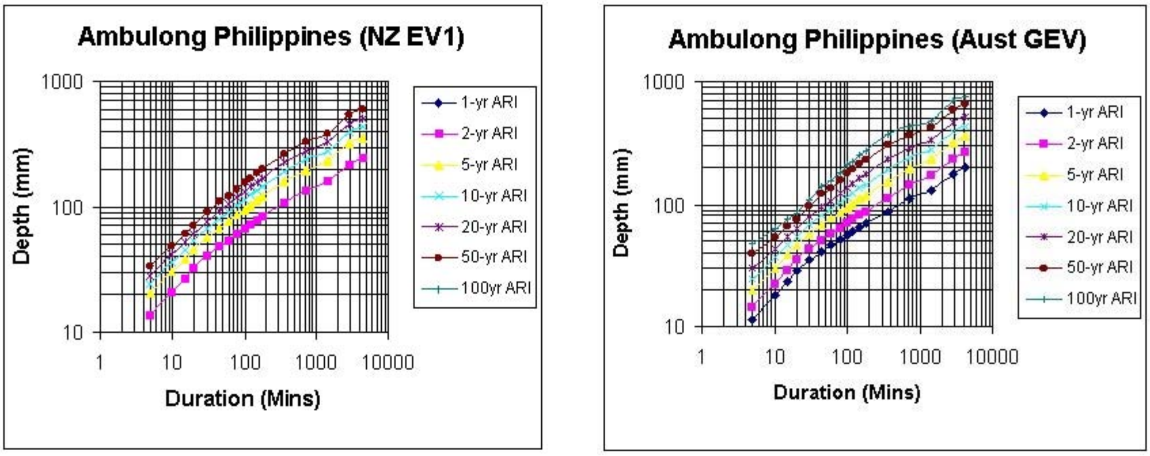
The L-moments for the data were calculated and the parameters of the GEV distribution were estimated. The IFD values were calculated for each station at the durations of the data provided and for ARI of 1, 2, 5, 10, 20, 50 and 100 years. In Australia recommended practice is to calculate IFD for the more frequent events (ARI of 1, 2, 5 and 10 years) from the partial duration series. Therefore, the IFD values for ARI of 1, 2, 5 and 10 years calculated from the provided annual maximum series were adjusted using the relationship between the ARI from annual maximum series (T_A) and partial duration series (T_P) given by

$$T_A = e^{1/T_P} / (e^{1/T_P} - 1)$$

The ARI for the annual maximum series corresponding to the partial duration series ARI of 1, 2, 5 and 10 years were 1.58, 2.54, 5.52 and 10.51 respectively. Figures 7.1 (b) and 7.2 (b) show the plots of the results for the GEV for Ambulong in the Philippines and for Adelaide in South Australia. If these were to be used for design purposes, the curves would need further smoothing.

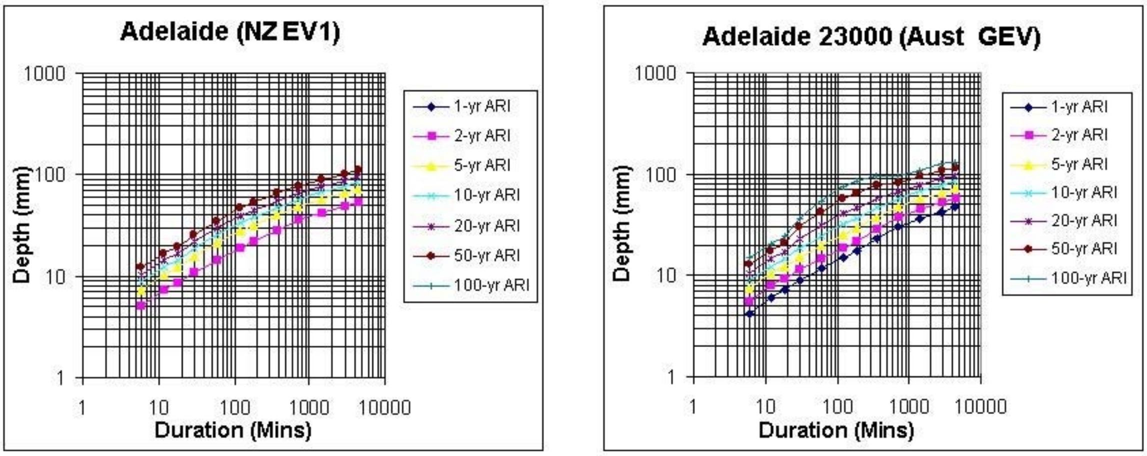
The New Zealand approach was to fit the annual maximum series from each site to an Extreme Value distribution type 1 (EV1) or Gumbel distribution, using probability weighted moments. A full GEV analysis was also undertaken, but as a number of the sites had very short record lengths (for example, the Vietnamese data), it was felt that the subsequent fitting of the shape parameter from so few data would provide very unreliable and extreme quantile estimations.

Quantiles for the range of durations and for average recurrence intervals (ARI or return periods) for 2, 5, 10, 20 and 50 years were estimated, as were their variances. Variances were estimated from the method provided by Phien (1987), as corrected by Madsen *et al*. (1997). Figures 7.1 (a) and 7.2 (a) show the plots of these results for the EV1 for Ambulong in the Philippines and for Adelaide in South Australia.



(a) (b)

Figure 7.1 IFDs for Ambulong in the Philippines (a) by EV1and (b) by GEV



(a) (b)

Figure 7.2 IFDs for Adelaide in Australia (a) by EV1and (b) by GEV

Further work is still in progress and detailed comparisons of all participating countries' data will be undertaken. Both Vietnam and the Philippines analysed the data sets and further comparisons need to be made when analyses from the other participating countries are available. Papers presented in RSC symposia with rainfall as a major topic include a study of extreme rainfalls in Malaysia (Desa *et al*., 2003), rainfall prediction methods in China (Liang *et al*., 2004), in Okayama, Japan (Chikamori and Nagai, 2003) and in Australia (Coombes, 2004). The scaling effects of rainfall input to hydrologic models have also been of concern to modellers (Shrestha *et al*., 2003; Chikamori and Nagai, 2004). There have been a number of researchers using radar rainfall input to flood forecasting models including Seed *et al.* (2002) in Australia and Zhijia *et al.* (2004) in China.

Research on rainfall and the Southern Oscillation Index (SOI), Interdecadal Pacific Oscillation (IPO) and North Pacific Index (NPI)

There have been a number of papers on this subject (Kawamura *et al.*, 2003; Kawamura *et al.*, 2004; Kawamura *et al.*, 2005). There is evidence of a strong relationship between El Niño Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO) for low rainfalls and severe droughts (Daniell and White, 2005). The ENSO effect is a natural fluctuation of the tropical Pacific atmosphere and ocean. ENSO variability is defined in terms of the Southern Oscillation Index (SOI) which is the Tahiti minus Darwin mean sea-level pressure difference, normalised with a base period of 1933–1992 (Troup, 1965; Folland *et al.*, 2002). Sea temperatures, winds, and rainfall patterns in the Pacific show a distinct difference between the El Niño and La Niña phases. In the El Niño phase, when the SOI is strongly negative, the key feature is that tropical sea surface temperatures in the central and eastern near-equatorial Pacific can become several degrees warmer than normal. The resulting climate on the east coast of Australia is one of drought. The Interdecadal Pacific Oscillation (IPO) or Pacific Decadal Oscillation (PDO) is a natural fluctuation of sea surface temperatures and winds in the Pacific. The IPO has been shown to modulate interannual ENSO-related climate variability over Australia (Power *et al.*, 1999). The key difference is that IPO operates over decades, whereas ENSO operates over 2 to 7-year cycles, and the IPO involves higher latitudes (particularly the North Pacific) as well as the tropics and New Zealand (Salinger *et al.*, 1995). The IPO is characterised by the time series of an Empirical Orthogonal Function of 13-year low pass filtered global sea surface temperatures, as shown in Figure 7.3 (Folland *et al.*, 1999; Power *et al.*, 1999).

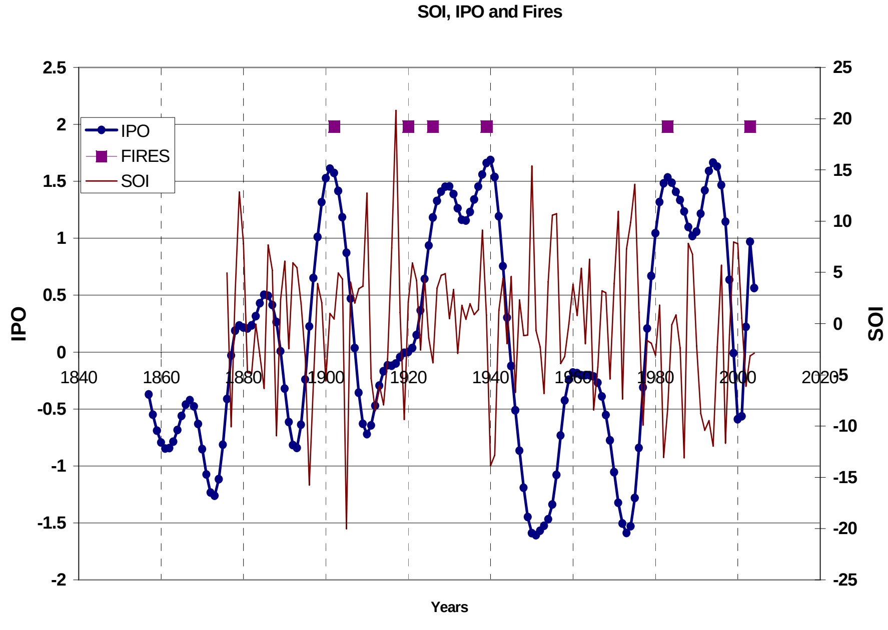


Figure 7.3 Southern Oscillation Index (SOI), Interdecadal Pacific Oscillation (IPO) and Cotter Catchment Bushfire Occurrence

Three main phases of the IPO have been identified during the 20th century: a positive phase (1922 – 1944), a negative phase (1946 – 1977) and another positive phase (1978 – 2000). The positive phases of the IPO correspond to generally drier periods in eastern Australia. The PDO index (PDOI) is the leading principal component of monthly sea surface temperature (SST) anomalies in the North Pacific Ocean (Zhang *et al.*, 1997; Mantua *et al.*, 1997). The PDOI data since 1900 were used by Kawamura *et al.* (2004) and the correlation between precipitation and various indices is shown in Figure 7.4.

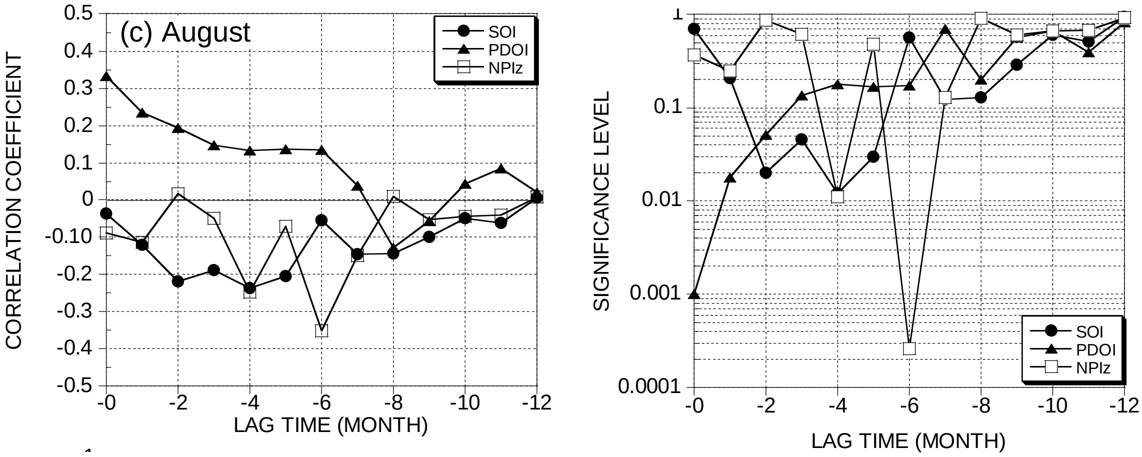


Figure 7.4 Cross-correlation between Fukuoka precipitations in August and corresponding SOI, PDOI and NPI_Z with significance level, respectively (Kamamura *et al.*, 2004)

Kawamura *et al.* (2005) have also studied the correlation between South Korea rainfall and Fukuoka and SOI. Daniell and White (2005) at a FRIEND Conference in Montpellier also showed the relationship between lack of rainfall and hence drought and bushfires in Australia with ENSO and IPO. There is a strong link between the occurrence of ENSO events and positive IPO events, as shown in Figure 7.3. During positive IPO periods, there are frequent or more intense El Niño events which are highly correlated with drought and risk of fire in the eastern regions of Australia (Verdon *et al.*, 2004). Bushfires that have occurred in the Canberra region are marked on Figure 7.3. The combined natural and human-caused severe fires in the Australian Alps occurred in the fire seasons of 1851/52, 1902/03, 1938/1939 and 2002/2003. These all correspond with positive IPO and the occurrence of an ENSO event.

It is possible now to estimate the probability that rainfall and temperature will be above or below the median for up to a season ahead in Australia, using relationships such as IPO and the Southern Oscillation Index (SOI). Other factors that impinge on bushfires, such as fuel load, are harder to predict without field investigations. ENSO has the greatest impact on the Australian region, but it needs to be borne in mind that linear correlation coefficients of SOI with regional rainfall are at most in the range of 0.6 to 0.7 (Verdon *et al.*, 2004) and many regions are lower than this. Further research is being carried out in this area.

7.3.2 Hydrological problems from urbanisation

Urbanisation and flooding

One of the major themes coming from the survey and the workshop in Kuala Lumpur (2005) was the problem of designing for flooding in urban areas. The problem has been exacerbated by development into catchments without controlling the runoff from changing land use. Research from different countries within the region has highlighted some of the issues of urbanisation on the hydrological cycle: flood forecasting problem in China (Liu Jinping, 2002); urbanisation and flooding in Japan (Yoshitani, 2004); flooding in Kuala Lumpur (Varley and Marr, 2004); and water quality management and flooding in Australia (Daniell *et al.*, 2002; Lawrence and Phillips, 2002). The production of the Urban Stormwater Management Manual incorporating both water quality and water quantity management strategies in Malaysia is one approach to improve urban systems (Phillips *et al.*, 2002).

A recent study in the rapidly urbanising southeast Asian city of Kuala Lumpur, Malaysia, by Varley and Marr (2004) indicates that the impacts of urbanisation on flood hydrology can be much more significant than has been found in temperate climates. Figure 7.5 shows that the mean annual flood peak in the centre of Kuala Lumpur (at Sulaiman Bridge) appears to have increased by a factor of three over two decades, and large investments in flood mitigation

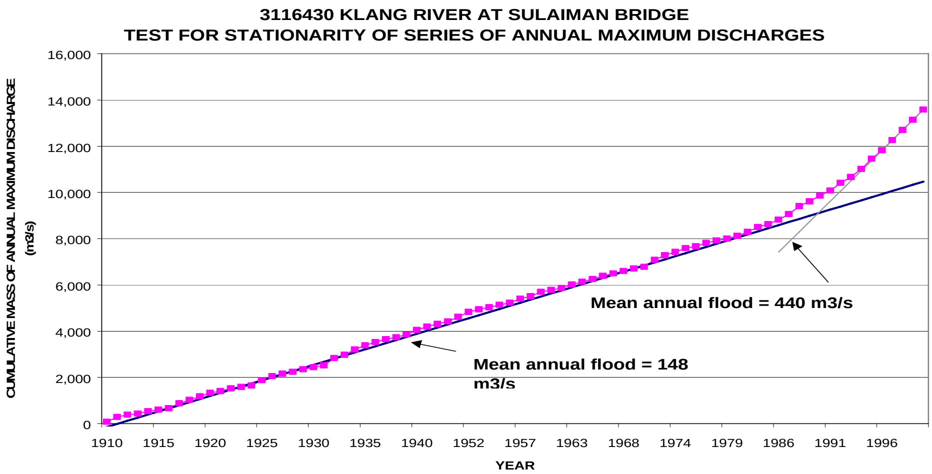


Figure 7.5 Cumulative plot of annual floods for the Klang river in Kuala Lumpur (Varley and Marr, 2004)

works have not provided the intended level of protection.

Previous investigators had expected that urbanisation of natural catchments would increase flood discharges by approximately 30%, based on their experience in temperate climates. Varley and Marr (2004) show that investigators greatly underestimated the impact of flooding from urbanisation of the forested catchments within the Klang Basin and of the effects of other changes in land form. The principal causes appear to be sedimentation of channels by material eroded during land development, concrete lining of drains producing peakier hydrographs, reduction of infiltration into soils by removal of forests and remodelling of land without replacing top soils, and reduction of storage by filling tin mine ponds and flattening of spoil heaps.

These problems were also felt in other southeast Asian cities where urbanisation has protruded into catchments, such as in the Tsurumi river basin which runs along the border of Yokohama, Kawasaki and Inagi cities in Japan, as described by Yoshitani (2004). This is a smallish catchment of 45.8 km² but urbanisation resulted in flood peaks doubling because of land-use change and channelisation.

Tatchikawa *et al*. (2005) reported on the largest ever flood since hydrologic observation began in the Asuwa river basin in Fukui Prefecture, Japan, which occurred on 18 July 2004. Heavy rainfall occurred, with 265 mm in six hours. The city area of Fukui was inundated due to breaching of dykes along the River Asuwa. One of the limitations of hydrologic data collection is that there is generally insufficient hydrologic data to estimate a design flood in small scale basins but the information on large floods near or above the magnitude of a design flood is even rarer, especially as catchment land uses are changing. In this study Tatchikawa *et al*. (2005) examined how well or badly the largest ever 2004 flood in Fukui, Japan, was predicted using a state-of-the-art physically based distributed rainfall-runoff model. The source of flood prediction uncertainty and a direction to reduce the uncertainty and enhance the reliability of flood discharge prediction were also discussed.

Urbanisation and water resource problems

Promma (2004) described urban growth into shallow groundwater resources that have sinking groundwater levels and high concentrations of iron and manganese. Shallow groundwater levels in areas surrounding Phitsanulok City, Thailand, have declined at rates of 0.1–0.5 m/yr in the past 20 years due to overexploiting groundwater resources for irrigation of rice. The natural groundwater recharge rate for this region is 2,620 m³/ha/yr but the withdrawal rate for irrigation is 9,755 m³/ha/yr. In addition, the groundwater is rich in iron (12.5 mg/l) and manganese (0.7 mg/l). The residents in new urbanised areas that use groundwater now must remove iron and manganese before drinking or using the water for household purposes.

Xu and Li (2005) described the growing water scarcity concern in China, especially in the semi-arid North China including Beijing. Xu and Li (2005) reviewed water needs and water availability in Beijing. The issues of increasing population and intensifying agricultural and industrial activities together with natural climate variability have led to a major increase in the demand on both the quantity and quality of water resources in Beijing. The increasing population in Beijing correlates with the observed decline in water resources in the city, the rising temperatures, and the deteriorating pollution of water bodies from both natural and human activities. Data on freshwater resources and on the distribution of different sectoral water uses is presented and discussed.

Water Sensitive Urban Design (WSUD) is another aspect of urban water resources design which was discussed extensively in both the Kuala Lumpur symposium in 2002 (Lawrence and Phillips, 2002; Phillips *et al.*, 2002) and the Adelaide symposium in 2004.

Urban stream restoration projects

Lee *et al*. (2005) described the plight, in the Republic of Korea, of the River Anyang, which is located in an urban area near Seoul. The river was originally designed and managed focusing on preventing floods, supplying home and industrial water, and coping with rapid industrialisation and urbanisation. Over a period of 25 years the river degraded into nothing more than a putrid stream. Its channel was straightened by concrete and water quality deteriorated to BOD 190 mg/l. In addition, water quantity decreased and in some seasons dried up. Therefore, the river ecosystem, the landscape and community amenity seriously deteriorated, with people rejecting any recreation along the urban river. From 2001, a 10-year master plan was begun to restore the river, centring on recreating a healthy river to which fish have returned, a safer river with respect to floods and droughts, and a pleasant river which citizens visit. As a result, its water quality was remarkably improved by BOD 5 mg/l in 2005 and some upper zones were improved enough to allow people to swim. Lee *et al.* (2005) described how water was allocated to help the environment and consequently fauna have returned to the river with the community enjoying recreation activities along it. The Anyang River Restoration Project is recognised as the first comprehensively planned and restored urban riverine environment in Korea. Much interest in this area is being shown throughout southeast Asia because of the degraded nature of urban river environments which leads us to the question, "How much water do they need?"

7.3.3 Environmental flows and ecohydrology

There has been much discussion on how much flow is required for the environment. Ibbitt and Biggs (2005) proposed that there are many situations where comprehensive scientific assessments to closely link the requirements of river management objectives to a flow regime are not required. They highlighted that two approaches are often used to regulate abstractions and help protect riverine values. The first is that of a ‘standard’ minimum flow, which is usually some proportion of the median flow or mean annual 7-day low flow (MALF). This is often a useful ‘surrogate’ measure of the flow that sets the upper limit on viable living space. However, using this is not the best approach for many circumstances. The second approach is that of flow-sharing between abstractions and riverine needs and this is useful where the minimum is well below the optimum flow for a target value. The ratio between what is abstracted versus what is left in the river has no specific basis in science. Ibbitt and Biggs (2005) stated that there were no set formulae for these numbers. The idea is that flow-sharing enables a greater level of protection for riverine values if the minimum flow is poorly defined.

Figure 7.6 shows an example of using hydraulic habitat simulation to determine how habitat availability (the vertical axis) for some common New Zealand invertebrates changes as a function of flow in the Moawhango River, central North Island, New Zealand. Note that in this example, the point of ‘diminishing returns’ for many of the species is less than the mean annual low flow, suggesting that the natural low flows in this particular river are greater than optimum for a productive benthic invertebrate community. These types of curves can be used to generate time series of habitat suitability so that variations in available habitat can be tracked through the year as a function of temporal changes in flow regime.

The hydraulic habitat for some species such as the midge *Tanytarsus* peaks at low flows (i.e., they prefer lower velocities), whereas other species require higher velocities and associated higher flows (e.g., the stonefly *Zelandoperla*). Minimum flows can therefore be based on what species are ‘desirable’ (often the mayfly *Deleatidium*). For the example shown, the dark arrow defines the minimum flow (1 m^3/s) that might be recommended if only *Deleatidium* were to be considered because that is the point at which an increase in habitat per unit of flow starts to decrease on habitat suitability. The interaction between the hydrologists and the ecologists was developed at the symposium held on ecohydrology (Sayama *et al.*, 2005; Koyabashi and Takara, 2005).

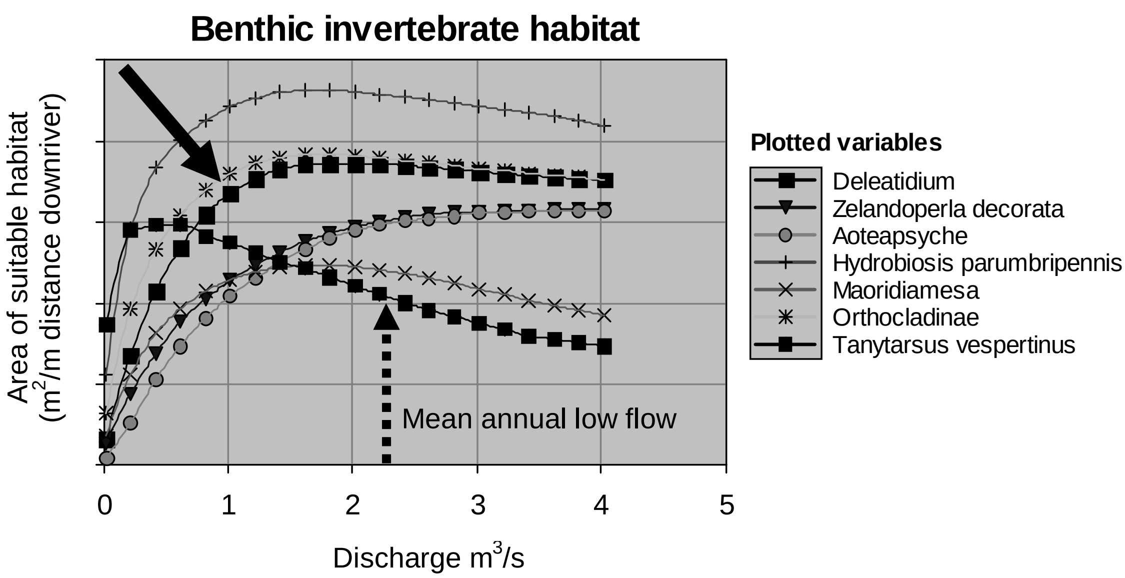


Figure 7.6 Variation of habitat suitable for benthic invertebrtes with flow (Moawhango river) (from Ibbitt and Biggs, 2005)

7.3.4 Island water resources

The symposium on Managing water resources under climate extremes and natural disasters (Takara and Kojima, 2003) held in Sigatoka, Fiji, included many papers on the critical nature of water resources in the Pacific Islands. Most importantly the process that had been undertaken by Pacific countries through the Pacific regional meeting on water in small island countries, held in Sigatoka, Fiji, from 29 July to 3 August 2002 (SOPAC-ADB, 2003) was spoken about. This meeting, resolved through consultation between the participating countries, the identification of national priority actions. The development of agreed regional actions through this meeting and the process of plenary discussion, working group review and delegation approval was indeed far-reaching for these island communities. The main actions from two of the six thematic areas that are pertinent to AP-FRIEND and IHP research were:

Theme 1: Water resources management which includes water resources assessment and monitoring, rural water supply and sanitation, integrated water resources and catchment management.

- Key message 1: Strengthen the capacity of small island countries to conduct water resources assessment and monitoring as a key component of sustainable water resources management.
- Key message 2: Implement strategies to utilise appropriate methods and technologies for water supply and sanitation systems and approaches for rural and peri-urban communities in small islands.
- Key message 3: Implement strategies to improve the management of water resources, and surface and groundwater catchments (watersheds) for the benefit of all sectors including local communities, development interests and the environment.

Theme 2: Island vulnerability which includes disaster preparedness, dialogue on water and climate.

- Key message 1: There is a need for capacity development to enhance the application of climate information to cope with climate variability and change.
- Key message 2: Change the paradigm for dealing with island vulnerability from disaster response to hazard assessment and risk management, particularly in integrated water resource management.

As many communities in southeast Asia live on islands or have similar problems to those in the Pacific there has been a great deal of interest in the activities undertaken for securing good water supplies for island communities (White *et al.*, 2003).

Specifically atoll groundwater systems are extremely vulnerable to contamination through human-produced processes and seawater intrusion. Severe impacts on groundwater quality and human health result from settlements, animal production and agro-chemicals over the very permeable coral soils. The trade-off between maximising extraction, protecting groundwater resources and optimising overlying land use and crop production presents a dilemma for island communities and their governments. There are major tensions between the demands of an urbanised society and traditional practices of subsistence cultures (White *et al*., 2005).

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8 Hindu Kush Himalaya HKH-FRIEND

8.1 Introduction

8.1.1 Regional characteristics

The Hindu Kush-Himalayas (HKH) are home to nearly 150 million people, extend about 3500 km from Afghanistan in the west to Myanmar in the east and influence the life of more than three times as many living in the downstream basins and plains. They are one of the largest water towers of the world where the mighty rivers Indus, Ganges, Brahmaputra and Mekong originate to supply water to nearly 500 million people. Figure 8.1 shows the major HKH river basins. Water is a critical resource because of the rapidly increasing demand resulting from rural, urban and industrial development in the region and the rapid increase in population. Proper utilization of this resource could generate enormous hydropower, manage floods, irrigate millions of hectares of land to improve the economy, and thereby contribute towards poverty reduction and sustainable development in the region.

Many of the HKH rivers traverse several countries before reaching the sea, hence regional cooperation in hydrological sciences and research is essential. The region in general is very fragile with steep slopes, active geology, and high spatial and temporal variability of precipitation. The south-westerly monsoon, from June to September, provides more than 80% of the region’s water, although its influence decreases from east to west such that the most western part of the region receives very little summer precipitation. The strong seasonal nature of the region's climate results in "too much" or "too little" water. The understanding of the hydrology of mountainous areas is not yet well developed. The combination of high altitudes, topography, geology and intense monsoon precipitation poses a tremendous challenge for understanding the hydrological processes. There have been several projects in the past to transfer knowledge and understanding from the European experience to the HKH region. These projects have looked at testing and adapting the models from other regions and developing new ones more applicable to the region. Such studies must be based on reliable and adequate data on hydrology, meteorology and other relevant parameters. Hence, the generation and sharing of reliable data among researchers of the region is of fundamental importance. The HKH mountains are a difficult area in which to establish and operate a dense network of hydrometeorological stations in terms of cost, accessibility and territorial conflicts. With annual precipitation ranging from less than 100 mm to more than 10 000 mm, the climatic and hydrological diversity of the region is immense and presents a formidable challenge. Efforts to understand these complexities through a concerted, collaborating research programme, sharing relevant hydrometeorological data, as initiated by HKH-

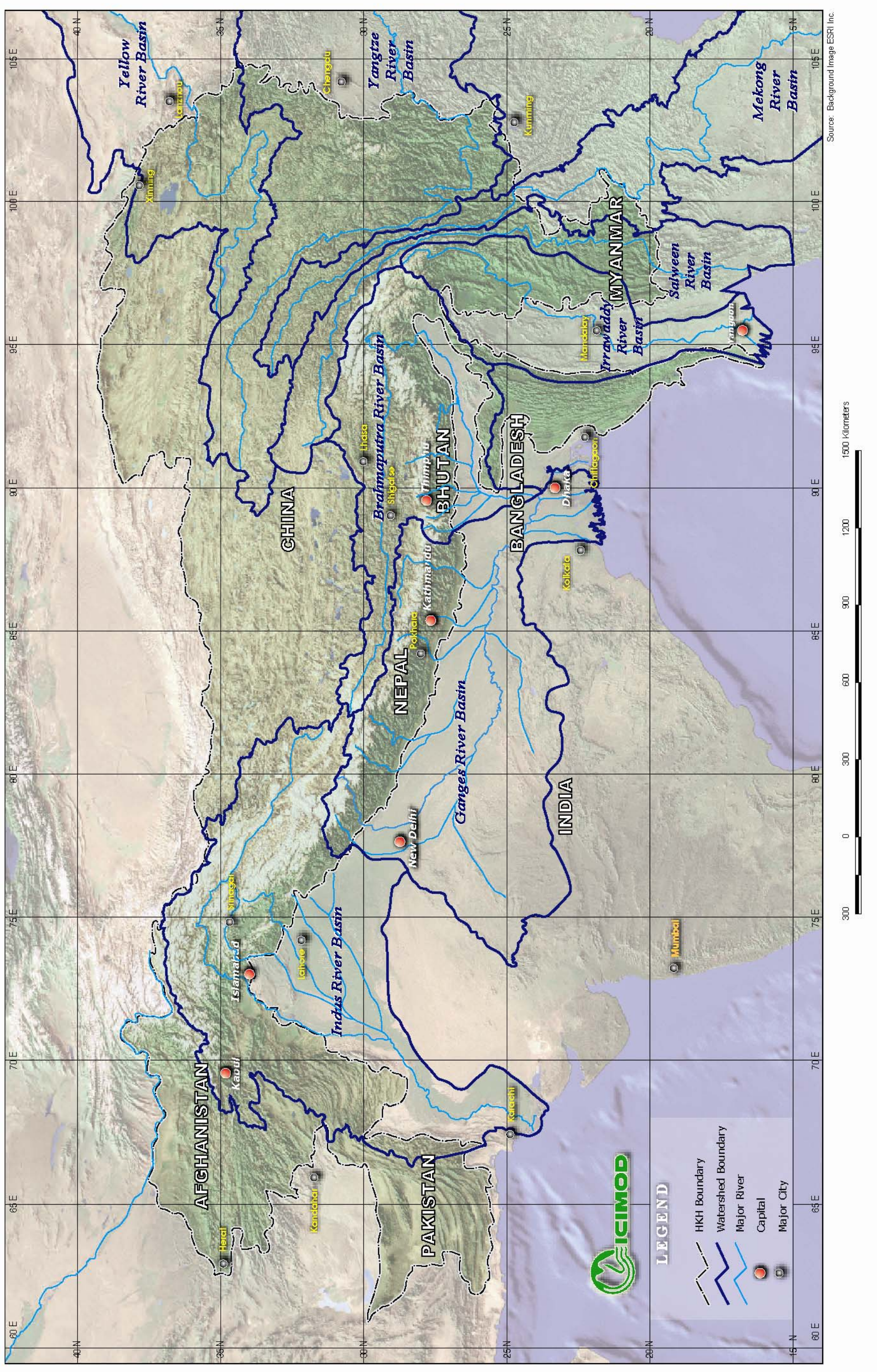

Figure 8.1 Major river basins in the HKH-FRIEND region

FRIEND, is a positive step towards meeting such challenges (Chalise, 1997).

8.1.2 Main hydrological issues in the HKH region

Reports indicate that over the last 100 years, the global climate has warmed by an average of 0.5°C, substantially affecting the hydrological cycle. This will have a destabilizing effect on the hydrological cycle resulting in greater variability in precipitation and stream flows, and increasing the intensity of extreme hydrological events (Bergkamp *et al.*, 2003). The HKH region is no exception and is faced with an increasing intensity of extreme events of floods and droughts. The region has experienced major climate-induced disasters in recent years, such as the catastrophic monsoon floods in Bangladesh during 1987 and 1998, the Indus basin floods of September 1992 and February 2005 in Pakistan, and the major disaster caused by floods and debris flow in south-central Nepal in July 1993 and 2002. Flash floods are particularly common in the HKH region due to the geological setting, fragile mountain ecosystem and intense monsoon precipitation. Floods also include the glacial lake outburst floods (GLOFs), landslide dammed flash floods, high rainfall-induced floods and floods in ephemeral rivers (which remain dry for almost eight months a year). In October 2004, flash floods occurred in the Indian state of Assam. Around 130 people were feared dead and tens of thousands of people were rendered homeless because of the sudden floods. Similar kinds of flash floods have adversely affected the HKH countries and have resulted in the loss of lives and property.

Deglaciation and glacier retreats are also important issues affecting the hydrological behaviour of the major river systems of the region. These rely considerably on the snow and glaciers of the HKH mountains for their perennial flow. Studies have shown that glaciers in this region have been in a general state of retreat since 1850 (Mayewski and Jeschke, 1979; Miller and Marston, 1989; Yamada, 1991; Kadota *et al.*, 1993), although examples of both advancing and retreating glaciers have been reported from the Karakoram and Kunlun Mountains. A recent study of maximum air temperatures in Nepal for the period 1971-1994 shows a significant warming trend since 1977, with increases of 0.06-0.12°C $year^{-1}$ in most of the middle mountain and high Himalayan regions and <0.03°C $year^{-1}$ in the southern Siwalik and Terai plains (Shrestha *et al*., 1999). As a consequence, the number of glacial lakes in the eastern Himalayas, in Nepal and Bhutan, with an increased vulnerability to glacial lake outburst floods is increasing (Mool *et al*., 2001a and 2001b). Glacial lakes, if managed properly, could also serve as natural reservoirs of freshwater, which could be used to augment low flow during the dry period and even generate hydropower, e.g. Tsho Rolpa Lake in Nepal (Chalise *et al.*, 2005). It is therefore important that the impacts of global warming on snow and glacier melting and water resources are better understood.

Though the theoretical water availability in the region is high, access to clean water remains a major challenge for the region. Overall, inland surface water quality in the monsoon season is within tolerable limits with respect to standards set by each country in the region but it deteriorates during the dry season. It is estimated that about 16% of the population of South Asia does not have access to improved water supplies and 53% to improved sanitation facilities. In Bangladesh alone, more than 20 million people drink water exceeding the national standard for arsenic levels (UNEP, 2001). It has been estimated that 30% of all the reported cases of illness and 40% of deaths in Pakistan are attributable to water-borne diseases (Kahlown and Azam, 2004). Surface water in the region is unprotected from untreated industrial and municipal wastewater, runoff pollution from chemical fertilizers and pesticides used in agriculture, and oil and lube spillage from the operation of sea and river ports in the coastal areas. Since clean water is a primary requirement for good health, knowledge of water quality is needed for the safe and sustainable use of water. However, in the past, the quality aspect of river water has not received much consideration in this region compared to quantity. It is important to monitor the ecological state, especially given the variety of pressures and impacts they have been subjected to in recent years.

A low priority is given to investment in hydrological and meteorological research in most of the countries of the region, except China and India. This partly reflects the level of development of the countries of the region, where scientific research is, in general, not considered a priority. It is important therefore to undertake projects that highlight the benefits of hydrological research, not only to develop the rich hydropower and irrigation potential, but also to save life and property from floods, which are occurring with increasing frequency and magnitude. The population in the HKH region is expected to double within the next 35 years and hence the demand for water will increase tremendously, with all countries in the region showing an accelerated pace of development.

To what extent such demands can be met depends very largely on the ability to manage water effectively, both within the normal variability of climate and the abnormal variability due to climate change. Unfortunately, little is known about even the normal variability of climate and in a region where spatial and temporal variability is the rule rather than the exception, it is difficult to make a distinction between what is normal and what is abnormal variability.

8.1.3 Hindu Kush-Himalayan FRIEND project

The evolution of HKH-FRIEND goes back to 1989 when the International Centre for Integrated Mountain Development (ICIMOD) in Kathmandu, Nepal and UNESCO/IHP jointly organised a workshop on the hydrology of mountainous areas in collaboration with the Department of Hydrology and Meteorology of His Majesty’s Government of Nepal (DHM). This led to the establishment of a regional working group (RWG) on mountain hydrology. HKH-FRIEND was formally launched in March 1996, evolved through a series of regional consultations and meetings of the RWG.

Activity within HKH-FRIEND is overseen by a steering committee with representatives from Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. It has six research groups comprising scientists and technical staff from universities, operational agencies and research institutes throughout the HKH region.

HKH-FRIEND has the following three main objectives:

- To promote and undertake research for optimal utilization and better management of water resources in the Hindu Kush-Himalayan region, which is the key resource to enhancing productivity in agriculture, hydropower generation and reducing poverty in the region
- To promote free exchange of data for hydrological research in the region through the Regional Hydrological Data Centre (RHDC) located at ICIMOD, Kathmandu
- To build capacity in hydrological research and water resources management through mutual exchange of information, training and skill transfer.

8.2 Research projects

The current six research groups of HKH-FRIEND are as follows:

- Database
- Low flows
- Floods
- Rainfall-runoff
- River water quality
- Snow and glaciers

Scientific and research activities are initiated at individual and institutional levels and proposals submitted to the Steering Committee for consideration (ICIMOD, 1998, 2000, 2003). The HKH-FRIEND received funding from the United Kingdom Department for International Development, through the Centre for Ecology and Hydrology, Wallingford, for their research and capacity-building activities for a three-year period which came to an end in 2003 (Rees, 2004). There was also seed money provided by UNESCO for research and capacity-building activities for the reporting period.

8.2.1 Database

In the HKH region hydrological data is not openly shared within countries or across national borders. Often relevant spatial information and maps are classified and not available even to researchers within the country. Data between regions may be incompatible due to differences in the types of instruments and methods of data collection, and varying standards and accuracies. The problem is most acute in areas under snow and at higher elevations, where access is difficult. Many of these are regions of territorial conflict. Fragmentation of information and restrictions on the free use of information has posed serious problems for generalizing hydrological processes in the region and the lack of a long-term historical database on hydrometeorology has been a major scientific constraint.

In response to such problems the thematic group on database was formed having the primary goal to create a common database to facilitate research on the hydrological behaviour of basins in different physiographic and climatic zones across the region. A dialogue on data-sharing was initiated and in May 1998 (ICIMOD, 1998) the Regional Hydrological Data Centre (RHDC) was established to archive and maintain the hydrological data generated by different research groups. A strategy document was completed in October 2001 and formally endorsed by the Steering Committee in January 2002 (Rajbhandari *et al.,* 2004). The RHDC continues to operate under the overall guidance of the Database Group. Data experts from other regional FRIEND groups also provide guidance and technical advice as required. The RHDC serves to facilitate and coordinate the collection, exchange, processing and archiving of relevant hydrological data and information from participating institutions in the HKH region. A METADATA catalogue has been prepared for Nepal. Other countries have yet to provide information.

All participating countries are committed to providing time series of river flow and precipitation data to the RHDC, but so far only Nepal has provided data. The RHDC has received monthly and daily river discharge data from the Global Runoff Data Centre, Koblenz, Germany (GRDC) and Department of Hydrology and Meteorology (DHM), Nepal for selected rivers. This includes 19 stations in Pakistan, 4 in India, 1 in China and 30 stations in Nepal from GRDC and daily discharge data for 36 stations in Nepal from DHM. Additional station information such as latitude, longitude, elevation, drainage area, data quality and meteorological point data, such as rainfall and temperature are also provided.

Regional Hydrological Data Centre (RHDC)

One of the primary achievements of RHDC since its establishment has been the design and development of the hydrological web database system. The database system provides a mechanism of "user" and "provider" for hydrological information using the Internet platform. The website http://www.hkh-friend.net.np shown in Figure 8.2 has been launched to provide information about HKH-FRIEND activities as well as to be an Internet platform for RHDC.

Figure 8.2 HKH-FRIEND website

Work has been ongoing to develop a suitable hydrological and climate database, with emphasis on initially developing a metadata database. The database has been designed using the GIS platform to provide the visual GIS interface and also for superimposing the relevant GIS data layers such as drainage network, land-use, DEM, satellite imagery, etc.

The usefulness of RHDC and its activities are very much dependent on the proactive participation of the different research groups and the sharing of information. Efforts are also underway to integrate some pertinent applications and serve through the RHDC website, and this will be seen as encouragement to other research groups in the HKH-FRIEND network.

Attempts have been made to integrate other hydrological database projects within Nepal, such as Optimization of water use in Kathmandu valley, supported by the Asian Development Bank (ADB), National irrigation sector programme, supported by the World Bank, and others.

8.2.2 Low flows

Due to the seasonal variability of precipitation over the HKH region, there is either plenty of water during the monsoon or a deficit during the dry season. In a data-limited region, it is important to have reliable and practical methods for assessing low flows for the planning and design of infrastructure such as hydropower, irrigation and water supply schemes.

The objective of the Low Flow Group is to develop a range of design methods for calculating low flows at gauged and ungauged sites in the HKH region. These should lead to the more accurate design of a wide range of water resource schemes, including estimation of dry season flows, river abstraction, public water supply and irrigation, preliminary estimates of storage yield relationships, reservoir design, and estimation of the energy available for run-of-the river hydropower schemes.

Since its inception, the Low Flow Group has worked on regional capacity-building for estimating and managing low flows through training and research projects. The three-year project (1998-2001) Regional flow estimation for small-scale hydropower assessment (REFRESHA) resulted in a valuable tool (Figure 8.3) for assessing the flow duration curve and, hence, the hydropower potential of the ungauged catchments of Nepal and Himachal Pradesh, India.

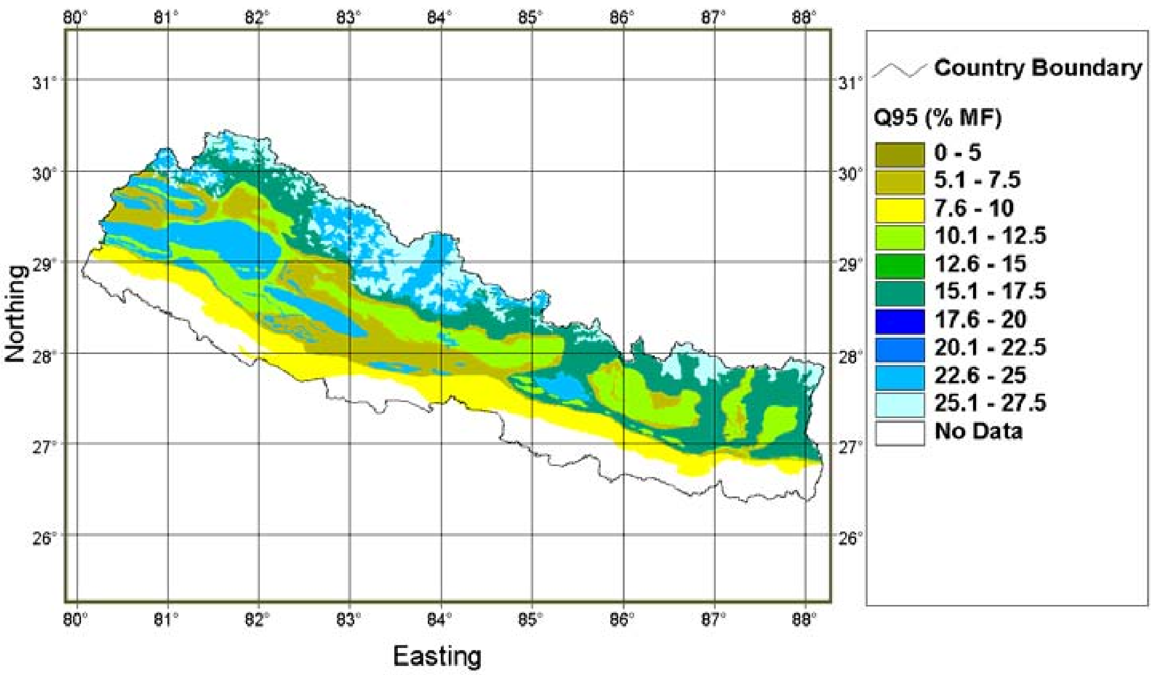

Figure 8.3 Modelled distribution of Q95 (as % of mean flow), derived during the REFERSHA project, which is used to estimate the flow duration curve and hydropower potential at ungauged sites in Nepal

The HydrA software that resulted from the project is now used by many developers and planners for better planning and wise utilization of the water resources in the region for hydropower development and small scale irrigation and water supply schemes.

To further improve the understanding of the low flow variation a regional recession model to estimate dry-season flows in ungauged catchments was developed, focusing on areas spanning Nepal and the northern Indian state of Himachal Pradesh with similar topographical and climate conditions. A selection of gauged catchments in Nepal and Himachal Pradesh, India were chosen to develop the regional recession model having good hydrometric quality and natural flow regimes. On the basis of recession constant (k), flow at the beginning of the recession (Q_0) and recession start time (T_0), regionalised equations for predicting each parameter based on catchments characteristics were developed. Performance of the model was found to be reasonably good. The results suggest that such a regional model provides a relatively robust technique for estimating average annual recession flows at ungauged sites and provides water resources managers with the ability to estimate not only the magnitude of flows in ungauged catchments, but also the timing of the flows (Rees *et al.*, 2004). The regional recession model was then incorporated into a modified version of the Low Flows 2000 integrated water resources management (IWRM) tool (Young *et al.*, 2003) and applied to the West Rapti river basin in Nepal (Figure 8.4) and the Uhl in Himachal Pradesh, India. The aim of the application was to demonstrate the potential for improved water resources management in the HKH. First, the tool enables estimates of the natural dry-season low flows

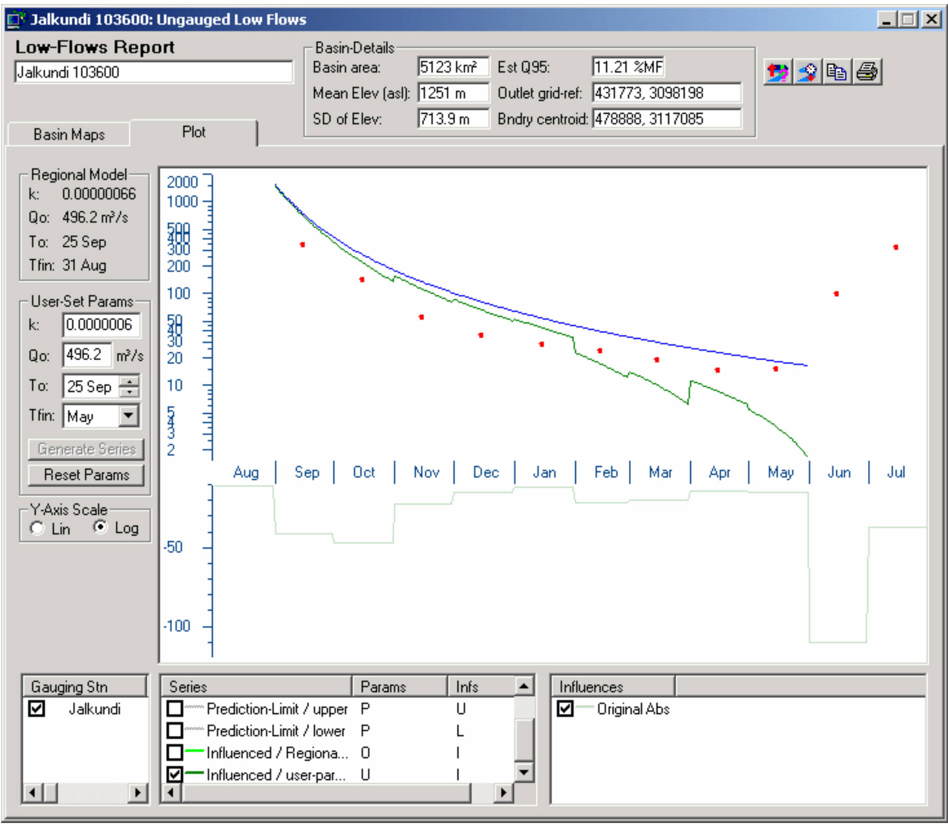

Figure 8.4 Application of the regional recession model in the Low Flows 2000 software, comparing the estimated natural recession curve (blue) against the estimated artificially influenced recession curve (green) and observed data (red dots) for the West Rapti river at Jalkundi, Nepal

in ungauged catchments to be derived, using the regional model. Second, it enables the impact of water use or "artificial influences" within the catchment to be simulated. Workshops to disseminate the model and the software to local and regional water practitioners were held in Nepal and India in May 2003.

The project Low flow studies in the rivers of Bhutan, was recently initiated by the Low Flow Group and ICIMOD with the support of UNESCO/IHP. The project seeks to improve the database on hydrological information on the rivers of Bhutan, analyse the available low flow data and develop a preliminary methodology for the prediction of low flow in the rivers of Bhutan. The project was due to be completed in March 2006.

Collaborative research was undertaken with the NE-FRIEND Large-scale Variations Group with the aim of (1) identifying large-scale hydroclimatological patterns across Nepal and (2) establishing precipitation-flow regime associations to aid assessment of current and future (under climate change) water availability dynamics for gauged and (extrapolation to) ungauged basins.

The following specific objectives were achieved:

- characterisation of spatial and temporal variability of long-term average and annual river flow and precipitation regimes (shape and magnitude)
- understanding of controls upon large-scale hydro climatological patterns
- assessment of the sensitivity of river flow regimes to precipitation
- application of precipitation-flow associations to predict future river flow and for ungauged basins.

The study produced the following key observations:

- The controls upon spatial patterns in Nepalese precipitation include length and timing of the summer monsoon, orographic and convection effect of the mountains generating rain shadows and localised precipitation 'hot spots' and westerly winter precipitation (Kansakar *et al.*, 2004).
- The factors governing annual flow regimes are the onset and cessation times of the summer monsoon, meltwater and groundwater contributions, and local topography (Hannah *et al.*, 2005b; Kansakar *et al.*, 2002).
- Substantial meltwater (snow and glacier) contributions reduce the inter-annual variability in the flow regime shape, although a similar relationship does not exist for magnitude, which is generally more variable.
- Precipitation-flow links for shape are different for different regions while links are generally more straightforward for magnitude (Hannah *et al.*, 2004, 2005a).

Perhaps most importantly, the results stress that future water resource management and decision-making in the Nepalese Himalaya must (a) be scientifically well-informed and (b) recognise the significant spatial (local and regional scale) and temporal (year-to-year) variation in basin hydro climatological response.

8.2.3 Floods

The main objectives of this research group are to conduct flood studies to help mitigate flood damage and to develop regional design procedures for estimating floods at gauged and ungauged sites in the HKH region.

The project Flood risk and vulnerability mapping using GIS: A case study from Ratu river in central Nepal has been recently completed by the group. The study used GIS and remote sensing data to map flood risk vulnerability and sought to identify community-based disaster mitigation activities to reduce loss of life and property. Findings were disseminated during a national seminar on Flood risk and vulnerability mapping of the Ratu river basin in January 2004 to 45 participants from national, district and local levels. The seminar was also used to discuss project components for the second phase of the project including flood disaster mitigation, development of coping mechanisms, implementation of structural and non-structural measures for flood disaster mitigation and institutional set-ups in the watershed.

The second phase of the study used detailed topographic information and prepared an accurate hydraulic model, using Hydrologic Engineering Center’s River Analysis System (HEC-RAS) for a selected site in Jaleshwor, proposed by the stakeholders. The model predicted accurate water levels and defined inundation areas and identified escape routes during floods of various recurrence intervals. A detailed socio-economic survey was also conducted to check the results obtained from the model with the actual ground information.

A significant development with regard to regional floods was also initiated as a contribution to the floods theme of HKH-FRIEND. The project Regional cooperation for flood forecasting and information exchange in the HKH began in 2001. The project has achieved full cooperation from five participating countries, Bangladesh, Bhutan, China, Nepal and Pakistan, with India as an observing member. Four years of deliberations have resulted in a series of high-level meetings and national consultations which have laid the foundation for regional cooperation, strengthened existing bilateral arrangements and enriched institutional linkages. The project conducted a demonstration and testing phase, during which the five fully participating countries exchanged near-real-time hydrological data from twelve pilot stations. Following the successful completion of this phase, the partners have recommended that the project should proceed to a second phase and increase the station network to make meaningful interpretations of the real-time data and increase the lead time so that more lives and property can be saved from floods. The project seeks to improve the technical capacities, infrastructure and know-how of the partners.

8.2.4 Rainfall-runoff

The main objective of the group is to develop rainfall-runoff models for the region, which will contribute to flood forecasting activities, design of water resources schemes, interpolation of missing data, extension of short hydrological records and investigation of the impacts of land-use change upon downstream river flow regimes. Although regional research has not yet started, individual research is conducted by participating institutions in different countries.

8.2.5 River water quality

Water quality has received little attention in the region, despite being of equal importance to water quantity. Deteriorating water quality is limiting the availability of potable water in the region. The main objectives of the River Water Quality Group are to

- review national databases of water quality to identify critical parameters, suitable methods and frequency of sampling, sample processing and analysis, and parameter units

- identify an appropriate archiving system and an organisation with the necessary facilities and expertise to establish a river water quality database
- undertake analysis and modelling.

ICIMOD, as part of the HKH-FRIEND network, has been conducting training workshops on water quality since 2000 with the support of partners in an effort to begin water quality assessment and information sharing in the region. There exist some knowledge and databases on the physical and chemical status of river water quality in the region; however, no work has been done on the application of bio-indicators to evaluate river quality. A training workshop held in Dhulikhel, Nepal from 10-14 May 2003 recommended further research and capacity-building on biological indicators of river water quality in the region. As a follow-up to this recommendation, a three-year research project, Assessment system to evaluate the ecological status of rivers in the Hindu Kush-Himalayan (ASSESS-HKH), was initiated with financial support from the European Commission. The aim of the project is to develop a methodology for assessing the ecological status of rivers in the region. The project brings together academic and research institutions from Europe (Austria, Czech Republic, Germany) and Asia (Bangladesh, Bhutan, India, Nepal, Pakistan) led by the University of Natural Resources and Applied Life Sciences (BOKU) in Vienna, Austria.

In this study, aquatic macro-invertebrates are used as indicators to assess the ecological status of rivers. Aquatic macro-invertebrates is the scientific name for the bottom-dwelling river fauna such as mussels, clams, snails, worms, leeches, crayfish, crabs and a large variety of insects like dragon flies, damsel flies, caddis flies, mayflies, water beetles, water bugs and water strides. These organisms are capable of reflecting different human-induced deteriorations like organic pollution, acidification, habitat modification, and the overall deterioration and disturbances to the river. The comparison of communities in disturbed river reaches with communities under near-natural conditions enables the degree of deterioration to be evaluated. Two major pressures, organic pollution and flow alteration due to river damming/engineering, have been selected for analysis. Figure 8.5 shows the sampling demonstration in Old Bramhaputra River in Bangladesh during the second project meeting.

Figure 8.5 Sampling demonstration in Old Bramhaputra River, Bangladesh

The study focuses on a total of 187 river sites in five eco-regions (Himalayan subtropical pine forest, Western Himalayan broadleaf forests, Eastern Himalayan broadleaf forest, Upper Gangetic plains moist deciduous forest and Lower Gangetic moist deciduous forest). The

HKH Eco-data management tool (ECODAT) will be developed to assist scientists in the user-friendly evaluation of the ecological status of rivers in the region. It is planned to produce water quality maps of river sections representative of the region, which will lead to the identification of environmental hot spots that require immediate action or sites that are not yet impaired but at high risk. Based on the analysis of the results of the ECODAT tool and the water quality maps, a sustainable management strategy will be drawn up in the form of a policy recommendation to establish an HKH transboundary river and stream monitoring programme as a basis for sustainable water management.

8.2.6 Snow and glaciers

In the HKH region snow and glacier melt water maintains stream flow during the dry season. A sound knowledge of temporal and regional snow melt and glacier ablation is therefore very important. The main aim of this group (ICIMOD, 1999) is to develop a snow and glacier melt runoff model (SGMRM) for calculating the amount of melt water, which will help water resources development in the region. The group will focus on snow cover simulation, glacier mass balance study, and water balance, snow and glacier melt study.

A workshop on the Hydrology of glacierised basins, 4-5 March 2004, Roorkee, India was organised by the National Institute of Hydrology (NHI), Roorkee, India. The workshop focused on discharge observation and related problems of glacier-fed rivers, melting of glaciers and modelling of runoff. Participants from Nepal and Bhutan gave presentations on glaciers and glacier melt in their respective countries and contributed to the workshop, which was attended by snow and glacier hydrologists from across the region.

Significant research work is being undertaken in Bhutan, China, India, Nepal and Pakistan, some examples of which are outlined below. In Nepal, DHM are conducting a long-term scientific research on the Langtang glacier as part of the Snow and glacier aspects of water resources management in the Himalayas (SAGARMATHA) project which included the installation of an automatic hydro-meteorological station for monitoring. In India, the Glacier Research Group at Jawaharlal Nehru University, New Delhi, has been actively engaged in conducting research on the Dokraini and Gangotri glaciers in the Bhagirathi-Ganga Basin, Ganga River headwater, including glacial hydrology, glacier hydrochemistry, sediment transfer, sub-glacial hydrology and mass balance studies.

ICIMOD, with support from UNEP and national institutions of the regional countries, has been engaged in major studies to prepare an inventory of glaciers and glacier lakes of the member countries of Bhutan, China, India, Nepal and Pakistan. It is necessary to have an accurate knowledge of the distribution of glaciers to estimate the runoff from snow and glacier melt. According to this inventory, there are 3252 glaciers and 2323 glacier lakes in Nepal, of which 20 glacier lakes are identified as potentially dangerous. The results of this study, based mainly on secondary data such as maps, satellite images and aerial photographs, have to be verified by first-hand field observations. Similarly, the inventory shows 677 glaciers and 2674 glacier lakes in Bhutan (Mool *et al.*, 2001a & b).

The three-year research project, SAGARMATHA, funded by DFID, was undertaken as an activity of the Snow and Glacier Group and led by a team from CEH Wallingford. The project was completed in April 2004. The project developed a physically-based semi-distributed regional hydro-glaciological model to assess the potential effects of deglaciation on the water resources of the Himalayan region. The project also investigated the possible impacts of deglaciation on livelihoods, developing strategies to help local agencies and people adapt to assumed changes in water resources availability. The regional hydrological model gave estimates of annual and seasonal river flows for a period of up to 100 years for a variety of climate change scenarios. The results showed that the impacts of deglaciation vary

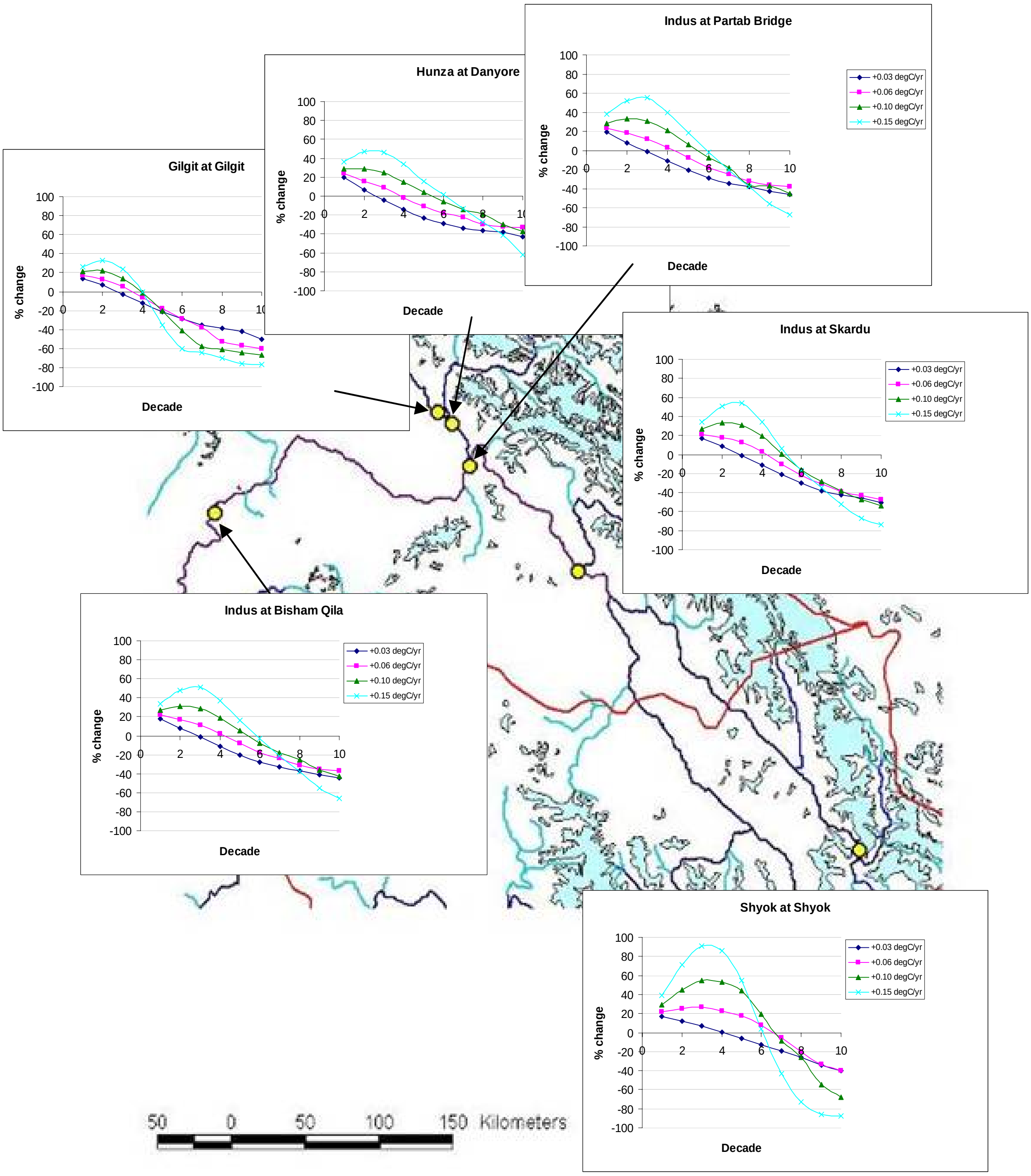

Figure 8.6 Modelled decadal variation in mean flow at selected locations in the Upper Indus for four climatic warming scenarios, +0.03°C year^{-1} (dark blue), +0.06°C year^{-1} (magenta), +0.10°C year^{-1} (green) and +0.15°C year^{-1} (cyan)

considerably within the region and within catchments. Highly glaciated catchments and catchments where melt water contributes significantly to the runoff appeared to be the most vulnerable to deglaciation. In the Indus basin, for instance, some of the scenarios considered suggest deglaciation may result in significant reductions in river flow over the next few decades (Rees *et al.,* 2004). Figure 8.6 shows the modelled decadal variation in the mean flow of the Upper Indus for the climatic warming scenarios considered. The assessment of the impacts of deglaciation on livelihoods was conducted at three spatial scales: community, basin and regional. Through field investigations and stakeholder consultations adaptation strategies were identified at different scales which included changing cropping patterns, increasing crop diversity and changing animal husbandry techniques. The adaptation strategies also included improved water saving, improving systems of data collection, developing sustainable water management strategies, public awareness and improving communication and infrastructure in mountain areas (Sullivan *et al.*, 2004). This study has involved local scientists and has contributed to the work of the Snow and Glacier Group.

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9 Nile basin – FRIEND Nile

9.1 Introduction

The FRIEND/Nile project is one of the major UNESCO projects to strengthen and enhance the research cooperation between Nile basin countries for a better understanding of hydrological regimes of Nile basin. The FRIEND/Nile project is a fund-in-trust project funded by the Government of Flanders for the duration of four years starting November 2001 and aims at enhancing capacity-building and networking for the Nile countries. The project is executed by UNESCO Cairo Office and implemented by The Water Resources Research Institute in Egypt, UNESCO Chair in Water Resources in Sudan, University of Dar Es Salaam in Tanzania, University of Nairobi in Kenya and the Ministry of Water Resources in Ethiopia.

Four research themes are supported by the project:

- Rainfall-runoff modelling (RRM)
- Sediment transport and watershed management (STWM)
- Flood frequency analysis (FFA)
- Droughts and low flow analysis (DLFA).

9.2 Research projects

The main target of the research activities of all the project research components (each component according to its specific discipline) is to obtain output and results in such tools that can be applied to improve design procedures of the necessary future development project in the Nile basin countries. The following points summarise the research activities of all research components during the reported period:

- Data processing and analysis
- Selection and introduction of the suitable models
- Application of the selected models
- Reporting (semi-annual and annual progress reports)
- Way forward activities.

9.2.1 Data processing and analysis

The required data for the implementation of the research activities of the four components were collected and acquired through the various theme researchers in Egypt, Sudan, Kenya, Ethiopia and Tanzania. Each country theme researcher worked with his data according to its availability in each country with the available techniques and methodologies in that country. The data acquired for all research themes is now almost available, known and well-defined. Consequently, some case studies, based on the availability of data, were selected in each country. The details of the acquired data and the selected case studies in each country for each component were presented in the data-processing report. The exchange of research results is based on mutual trust and confidence developed among the research teams in the course of this project.

9.2.2 Selection and introduction of suitable models

The selection of a unified suitable model for each research theme was a very important task for all the project teams. After many investigations and discussions from all project teams and experts (coordinators, focal researchers, Flemish counterparts and resource persons), the recommendations were to select the following models:

- The Watershed Modelling System (WMS) for the implementation of the research activities of the RRM component;
- Galway Flood Forecasting System (GFFS); SWAT and HEC-HMS were introduced for the implementation of the research activities of the RRM component;
- The Surface Water Modelling System (SMS) for the implementation of the research activities of the STWM component
- The Extreme Value Analysis (ECQ) model for the implementation of the research activities of the two components of the FFA and DLFA.

These models were introduced with training manuals to all theme researchers of the four components through various training workshops. Advanced training and application of these models were carried out using real data of the selected basins in the Nile basin during the training workshops over the four-year period of the project. It was also agreed to use any additional suitable models available to the thematic coordinators and researchers.

9.2.3 Application of selected models

Training on the application of the selected models WMS, SMS, GFFS and ECQ was the main objective of the training workshops held in Dar es Salaam (19-26 May 2002) and Alexandria (20-25 July 2003). In STWM workshops, SMS using real data from the selected case studies was successfully applied. The SMS model is suitable for channel sedimentation only. It gives the variation in the sediment load and the bed variation, and good quality results have been obtained. The Egyptian research team guided the training of the STWM group and they solved most of the application problems. In RRM workshops, applications of the models WMS, HMS, SWAT and GFFS using real data from the selected case studies were made. WMS is suitable for a single storm, while GFFS is suitable for a continuous series of rainfall storms. Both models require rainfall as an input and give the hydrograph and its characteristics as an output. The results were obtained and analysed. The resource persons guided the training and solved most of the application problems. In FFA and DLFA workshops applications of ECQ using real data from the selected case studies in different countries were successfully carried out. The application of the selected models for the four components is presented below.

Sediment transport and watershed management component

The SMS simulation of a long reach of the Awash river did not give good results since the RMA2 module is limited in steep slope conditions. Hence the hydrodynamic modelling for a segment of the reach was carried out to improve the velocity magnitude, water depth and water surface elevation outputs. In the case of the Sondu basin, the river channel is long with numerous meanderings and waterfalls, so there were many complications during the calibration of the SMS; therefore, after some serious consultation, the conclusion was reached that the SMS works better in river channels that do not have steep waterfalls and as a result the Sondu basin had to be divided in portions of 5-km-stretches for ease-of-handling and in order to produce good results.

The two modules of the SMS model, namely the hydrodynamic (RMA2) and the sediment (SED2D) modules, were applied to the Simiyu catchment. The results obtained were reasonable but another independent station had to be used to check the accuracy of the simulation. To run SMS-RMA2, it was necessary to use the downstream water level above the highest bathymetry. This is only correct in flood plains and thus not applicable in hilly areas such as the Simiayu river. SMS was also applied on the selected study reach of the Blue Nile and the problems facing SMS modelling application were addressed. The information collected including the sediment to generate flow profiles, river morphology and expected changes regarding sediment concentration through using SMS model were used. The SMS and capacity-building for the technical staff in SMS model application was also mastered.

The SMS was also applied on TOSHKA and AHDR (Aswan High Dam Reservoir) to study the effect of sediment on the current and future backwater curve and to study the stability of data deposits. The available data for SMS are banks and bed elevations in X, Y, Z coordinates, water surface elevations, flow rate (discharge), velocities, channel and floodplain characteristics, wind velocity, water temperature, and latitude. For future work runs of the SMS model for the small regions of 20 km long were recommended for the estimation of bed profile of these regions, estimation of water surface profile and velocity distribution in 2-D, and future prediction of the sediment deposition in the Aswan High Dam Lake.

Rainfall/runoff modelling component

Single storm events in the wadis were modelled using the WMS and HMS in the three selected basins, Wadi-al Arbain, Wadi Gudierat and Wadi Sudr in Sinai, Egypt. Many parameter estimations and objective functions were tried for hydrograph calculations. River flows of the Awash catchment on the Ethiopian plateau using naturalised and regulated river flows were also modelled. The HEC-HMS model and GFFS software were applied to the Nzoia River and the other selected basins on the north-eastern side of Lake Victoria, and results were obtained. The SWAT model was applied and calibrated in the Simiyu catchment on the south-eastern side of Lake Victoria with the required data, and good results were obtained. Data of the Blue Nile and Eddeim catchments were identified and used for the applications of the HMS, WMS and GFFS models, and good results were obtained and presented. Table 9.1 shows the catchment characteristics of the researched catchments and Table 9.2 gives the best model efficiency criteria results in the countries participating in the FRIEND/Nile project.

Table 9.1 Catchment characteristics of the researched catchments

Country	Region	Topography	Land-Use	Climate
Egypt	Sinai	Mountainous	Not defined	Semi desert
Ethiopia	Awash	Hilly	Not defined	Wet
Kenya	Nzoia, Nyando	Hilly & mild	Grass/Woodland, Cultivated	Wet / Dry
Sudan	Eddeim	Not defined	Not defined	Wet / Dry
Tanzania	Simiyu	Mild	Grass/Woodland, Cultivated	Wet / Dry

Table 9.2 Best model efficiency criteria results

Country	Simulation mode	MOCT	Parametric / Updating mode	Remarks / Area in km2
Egypt	WMS - (HEC1)	-	(HEC1)	Good fits
Ethiopia	72% (ANN)	80% (SAM, WAM, NNM)	80% (SLM)	7,656
Kenya	67% (LPM, SMAR)	-	97% (SLM, LPM)	3,450 / 12,676
Sudan	91% (LPM, LVGFM)	92% (WAM, NNM)	97% (LPM, LVGFM)	254,230
Tanzania	50% (LVGFM)	66% (NNM)	-	5,320

Drought and low flow analysis component

The POT method to analyse all available data on river discharges or surface water levels on the appropriate time scale relevant in the country was used. A drought index for drought analysis was developed and the drought results were regionalised. The Q-Q plot of the ECQ software was used in all the country applications. 10-day average flow discharge covering 24-40 years of at least 3 stations in the River Sobat catchment, with monthly flow discharge covering 130 years of a station on the main stream of the River Nile were used in the analysis. The annual rainfall data covering 28-30 years of about 3 stations in the River Sobat catchment were also used. Daily flow discharge with monthly rainfall and evaporation in the Blue Nile and Atbara river catchments were used in the analysis. Daily average flow discharge covering about 30 years of stations in the catchments on the north-eastern side of Lake Victoria and daily rainfall data covering about 30 years of about 150 stations in the Lake Victoria catchment were used in the analysis. Daily flow discharge and daily rainfall data in the catchments on the south-eastern side of Lake Victoria located in Tanzania were used in this analysis. The results of all applications were obtained, discussed and presented.

Flood frequency analysis component

The harmonized methodology of the RFFA has been conducted in the pre-defined areas by the coordination centre WRRI and theme researchers of Sudan, Tanzania, Kenya and Ethiopia. Based on the analysis of Q-Q plots, a normal distribution tail is found for the most of the rivers. Therefore, the selected distributions are evaluated in the exponential Q-Q plot for EV1/Gumbel using MOM, ML and PWM, while the others are evaluated in Pareto. The whole range of observations does not follow one flip-flop distribution at some sites. This might be explained by flooding influence along the river. Therefore, it is suggested to calibrate a separate distribution for two sub-populations, one for the non-flood part and the other for the flood part. A comparison of the calibration results has been carried out for the distribution parameters (for EV1/Gumbel and for GEV, and according to different parameter estimation methods ML, MOM and PWM).

A regionally calibrated relation between the Mean Annual Flood (MAF) and the catchment characteristics (area, average slope and average annual rainfall) was established using multiple linear regressions. This relation, together with the developed regional frequency curves could be used to estimate flood magnitudes with various return periods for ungauged catchments in any homogeneous region with the regions under consideration. Although most countries did not achieve the final results, they recommended follow-up training on the GIS tool which can be used to extract catchment physiographic characteristics such as land cover, slope and elevation in order to improve the regionalisation analysis.

10 Education and Training Programmes

10.1 Northern European FRIEND

10.1.1 Project group: Low flows

Several of the Low Flow group members are university staff and thus regularly contribute to the dissemination of knowledge and recent developments in low flow and drought research through their professional teaching and supervision of master and PhD theses. The textbook on hydrological drought has been incorporated in the curricula of several higher education organisations and has been used as a contribution to the UNESCO/IHP Water Education and Training Programme.

Textbook

"Hydrological drought – processes and estimation methods for streamflow and groundwater" is a textbook for university students, practising hydrologists and researchers (Tallaksen and van Lanen, 2004). Following its initiation in the NE-FRIEND Low Flow group, it was completed with the support of the ASTHyDA project. The main scope of the book is to provide the reader with a comprehensive review of processes and estimation methods for streamflow and groundwater drought. It includes a qualitative conceptual understanding of drought features and processes, a detailed presentation of estimation methods and tools, and concludes with human impacts, ecological issues and key aspects of operational practice. The methods are demonstrated using sample datasets and tools that are provided on the accompanying CD. The drought phenomenon and its diversity across the world are illustrated using a global set of daily streamflow series, whereas regional and local aspects of drought are studied using a combination of hydrological time series and catchment information. A majority of the examples are taken from regions where the rivers run most of the year. The material presented ranges from well-established knowledge and analysing methods to recent developments in drought research. Its nature varies accordingly from a more traditional textbook with its clear overview to that of a research paper which introduces new approaches and methodologies.

Handbook

Within the framework of the WMO-HWRP working group on disaster mitigation, Floods and Droughts (hydrological aspects), a manual on the estimation and prediction of low flows, has been initiated. The manual was initiated by the Commission for Hydrology of HWRP of WMO and involves key members of the NE-FRIEND Low Flow group. It will be published in a new series of manuals and guidelines within the WMO Quality Management Framework in Hydrology. The handbook will be a state-of-the-art manual for estimating, predicting and forecasting low river flows at sites with and without observational data. It is aimed at operational agencies for a wide range of applications including national and regional water resource planning, abstraction management, public water supply design, setting in-stream flows, estimating the dilution of effluents, navigation, design of run of river hydropower schemes, design of irrigation schemes and operation of water resources during low flow conditions. The manual will include a worldwide inventory of existing methodologies and legal frameworks on low flow management and methods of low flow estimation, prediction and forecasting. The endeavour would be to survey available practices and adopt the most suitable practices for various hydro-climatic and hydro-geological conditions including national case studies.

International study courses

The NE-FRIEND Low flow group has been involved in the organisation of two international training courses on low flow and drought. The main objective has been to exchange experience, knowledge and tools on drought studies between researchers, advanced students and water managers with experience from different hydroclimatological regions and water sectors. These events can be considered the first international study courses of their kind that have brought together scientists in low flow and drought hydrology with a wide audience of students and young hydrologists. Study course participants as well as the lecturers found that the events offered a very stimulating atmosphere to discuss and to increase knowledge on drought. The opportunity to meet other experts from, and even beyond, the region may have long-term benefits. MSc and PhD students appreciated receiving a certificate for the courses (assigned 3 ECTS study points).

A one-week international study course based on the hydrological drought textbook was organised for selected students and professional young hydrologists in Wageningen in 2003 as part of the ASTHyDA project (Figure 10.1). A group of 27 international students attended the course which was organised by Alterra, Green World Research. Nineteen students came from Europe; the others came from Algeria, Argentina, Bangladesh, Morocco, Mauritius, Palestine, Puerto Rico and Tunisia. Plenary sessions briefly introduced the textbook, the datasets and the estimation tools, whereas separate case studies organised as parallel sessions addressed the following topics: statistical modelling of drought, physical-based modelling of drought and setting in-stream flow requirements. In each session, a group of students worked on a case using data and estimation methods from the textbook and CD. The course ended with a plenary session where the students presented their cases.

Six members of the Low Flow group contributed to the International Training Course on Hydrological Drought and Low Flows at the Regional Humid Tropics Hydrology and Water Resources Centre (HTC), Kuala Lumpur, Malaysia in 2005. The study course was convened and sponsored by UNESCO Paris and the IHP/HWRP National Committee of the Federal Republic of Germany and co-sponsored by the UNESCO Regional Office Jakarta and WMO. The workshop was a contribution to IHP-VI, Water education and training (Theme 5, Focal area 5.4) and to the Programme on Capacity Building in Hydrology and Water Resources of the HWRP. Altogether 24 participants from South East Asia attended the course.

Figure 10.1 International study course on hydrological drought and low flow, Wageningen, the Netherlands, 2003

10.1.2 Project group: Large-scale variations in hydrological characteristics

A masters programme in hydrology has been set up at the University of Costa Rica in San José (Faculty of Physics) in collaboration with the University of Oslo (Department of Geosciences). This is the first hydrology masters degree course in Central America, with students enrolled from Costa Rica, Panama, El Salvador and Guyana (in San José) and Norwegian students (in Oslo). The course is run partly as distant learning with lectures given during intensive blocks, taught in parallel at San José and Oslo. This programme includes, among other things, methods for studying large-scale spatial and temporal variation and teleconnections. Etienne Leblois (Cemagref, Lyon) gave a course in stochastic interpolation methods and GIS in Costa Rica in February 2005.

10.1.3 Project group: Catchment hydrological and biogeochemical processes in a changing environment

An exchange of students has been fostered at the university level. In 2003 two students from Wageningen university worked on their thesis in Slovakia (October-December), where they studied the surface/ground water relationship in the alluvium of a small mountain creek. In 2004 one student from Wageningen university worked on her thesis in Slovakia (June-August) on the hydrological response of a mountain catchment.

10.2 Alpine and Mediterranean FRIEND (AMHY)

The AMHY contribution during the last four years was essentially to provide support to young scientists. Several Algerian and Moroccan researchers were able to benefit from a stay in the Laboratory 'HydroSciences Montpellier' in France. Three Lebanese students passed their PhDs in the field of hydrology during last years. This was the result of a collaboration established between St Joseph University in Beirut and HydroSciences Montpellier in France.

Many students from Maghreb countries and from Lebanon were welcomed to the Montpellier Masters courses where they could improve their knowledge and skills in the field of water sciences.

10.3 Latin America and Caribbean FRIEND (AMIGO)

The project FRIEND AMIGO has promoted the building of institutional capacities and the training of experts through workshops that have resulted in the transfer of technology, as, for instance, in the case of the approach to the diagnosis of drought. The universities of several countries – University of Pennsylvania in USA, Buenos Aires University in Argentina, University of Havana in Cuba and University of Talca in Chile – have strong relationships with the FRIEND AMIGO project.

10.4 Southern African FRIEND

10.4.1 Regional water resources and flow modelling

Training

SPATSIM (SPatial And Time Series Information Modelling; Hughes, 2002) is a database, analysis and modelling system designed specifically for hydrological and water resource applications. Part of the development of the system was supported by the Water Research Commission of South Africa to address some of the database and modelling requirements of the ecological reserve component (determining environmental flow requirements of rivers) of the South African water law.

Training of DWAF (Department of Water Affairs and Forestry) staff, as well as some of the key DWAF service providers, in the use of SPATSIM began during 2002 and continued into 2003. Additional training of interested people within the SADC region was carried out under Southern Africa FRIEND Phase II and included individuals from Swaziland, Tanzania, Zambia and Zimbabwe.

Postgraduate studies

Mrs Elenestina Mwelwa, funded by the UK Department for International Development, completed her MSc at the Institute for Water Research, Rhodes University, South Africa and was awarded her degree, with distinction, in 2005 for a thesis entitled "The application of the monthly time-step Pitman rainfall–runoff model to the Kafue river basin of Zambia" (Mwelwa, 2004).

The Institute for Water Research currently has two postgraduate students from Zimbabwe, both funded by the institute. Mr Evison Kapangaziwiri is working on parameter identification issues associated with the use of the Pitman rainfall-runoff model in the SADC region, while

Mr Tendai Sawunyama is involved in a project aimed at reducing uncertainty associated with water resource assessments.

10.4.2 Water resource assessment

Training

A series of regional training workshops were carried out in Southern Africa FRIEND Phase II which were designed to strengthen capacity in the region for surface water resources assessment, planning and management, particularly in the areas of low flow estimation, drought assessment and water resources. The low flows and drought workshops were reported on in Gustard & Cole (2002) and all three workshops are described in UNESCO (2004).

The water resources workshop was the last of the workshops to be held, in February 2003, at the Roodeplaat Dam Training Centre of the DWAF near Pretoria, South Africa. It was attended by 17 participants from national hydrological agencies in 11 countries (Fry *et al.*, 2003a; 2003b). A representative from the Lesotho Highlands Development Authority also attended. The main aim was to give the participants a sound background in the following, all within the context of integrated water resources management:

- The need for accurate water resources assessment
- The need for hydrological data within the assessment procedure
- Knowledge of the techniques used to produce low flow statistics from gauging station data for this purpose
- An introduction to the concepts and realities of modelling flows at ungauged sites
- How to produce catchment characteristics from GIS systems for input into such models
- Water resources issues within Southern Africa
- Modelling water resources for the future using climate change scenarios.

The focus of the workshop was the pilot GIS water resources software (LF2000-SA; Fry *et al.,* 2003c). Participants were given an understanding of the underlying principles and of the practicalities of using the software, thereby providing skills which could be applied to any similar system. The application of the GWAVA software (Global Water AVailability Assessment; Tate, 2002) in Swaziland was also presented, specifically in the context of using climate change scenarios to model future water resources. A field trip to Hartebeespoort Dam and the DWAF offices, to view their flow and flood monitoring systems, demonstrated the type of advanced facility that is possible within the region (Figure 10.2).

Water resources concepts were introduced throughout the workshop, stressing the practical applications within participants' countries and focussing on what the national hydrological agencies could input to water resource management procedures. A session was given over to presentations from the participants on topics relevant to the workshop theme and their countries' current approach. As with the previous two workshops, participants welcomed the insight provided by the opportunity to share water resource management experiences with counterparts from different countries, thereby developing international cooperation.

Figure 10.2 Field trip to the Hartebeespoort Dam on the Crocodile River during the water resources workshop, Pretoria, South Africa, 2003

10.5 West and Central African FRIEND (AOC)

10.5.1 Contribution of FRIEND-AOC

This subject concerns all the topic coordinators, each of whom feel the need to:

- train young scientists in order to ensure the future of hydrological research in the region
- encourage established scientists to make their work known through the international scientific community
- encourage researchers to take part in international programmes.

Three types of education and training were identified:

- 'Real' training courses to help teams working on the FRIEND-AOC project learn how to use new tools and new techniques
- Scientific workshops to facilitate advances in scientific thought through extensive comparison and diffusion of scientific results obtained by teams of FRIEND-AOC researchers
- Short-term regional exchanges that allow research teams involved in the FRIEND-AOC project to work more efficiently together on unconnected issues they share.

A training course for members of FRIEND-AOC entitled Geographic information systems applied to hydrology and water resources was held at the École Inter-États d'Equipment Rural (EIER) in Ouagadougou from 15 to 19 October 2001. The training programme organised by the GIS unit of EIER and IRD focused on three main topics:

- presentation of the concept and functionalities of GIS
- familiarisation with MAO INFO software

- review of different possible applications of GIS linked with water resources. Nine people from different countries took part in the course.

Other training courses

Other courses are envisaged for people from different backgrounds on subjects that are considered to be indispensable for all project topics. Three proposals have already been put forward:

- Surface states: definition, spatial reconnaissance, visual display with GIS (probably in partnership with EIER)
- Remote sensing: tools for FRIEND-AOC topics; satellites and sensors (probably in partnership with AGRHYMET)
- Modelling: aggregation and disaggregation techniques for hydrological parameters and variables; conversion from atmospheric to hydrological scales or from the scale of local heterogeneities to that of a hydrological basin (probably in partnership with Benin National University).

Ideally each course would cater for between 15 and 20 people.

10.5.2 Scientific exchanges

Mr Lienou from the Hydrological Research Centre in Yaoundé spent a month at the University of Yaoundé in Cameroon to work on his doctoral thesis entitled Climate variability and its impact on water resources in Cameroon.

Mr Sao Sangare, who is a hydrological engineer and who is head of the Data Analysis and Processing Division of the Directorate-General for Hydraulics in Guinea, spent one month with VRE coordination at EIER in Ouagadougou to start work on a study of the water balance of the upper Senegal and Niger river basins.

Mr Emmanuel Lawin, a student at the National University, spent one month with AGRHYMET in Niamey to learn data-processing techniques.

Mr Noël Moukolo, senior research fellow with DGRST/CERGEC in Brazzaville, spent one month at the Hydrological Research Centre in Yaoundé to work on material flows in catchments shared by Cameroon and Congo.

Mr Soussou Sambou, senior faculty member of Cheikh Anta Diop University in Dakar, spent three weeks at Benin National University to finish his dissertation on modelling the flow between reaches of a river.

These training courses and scientific exchanges enabled researchers to prepare papers for publication and presentations at conferences more efficiently.

10.5.3 Graduate training

In certain research topics in the programme, more specific graduate training was also organised.

Topic: Dynamics of material flows

For this topic, four doctoral theses, seven diplomas of advanced studies (DEA) and four diplomas of specialized studies (DESS) have already been defended or are underway.

Doctoral theses (single theses at the University of Yaoundé I)

Gaston Liénou: Impacts of human activity and climate on the recent evolution of several representative catchments in Cameroon: climatology, hydrology, erosion, material flows

Dorice Kuitcha: Study of subsurface waters in and around the city of Yaoundé

Henriette Ateba: Bacterial study of water in Yaoundé and prevention of water-borne diseases

Joséphine Ndjama: Dynamics of hydrogeochemical and fresh-water pollution in urban areas: case studies of Ngoua and Bobongo (Douala, Cameroon)

Theses for Diplomas of Advanced Studies DEA (2004, University of Yaoundé I)

Mohammad Bello: Material flows in a catchment from Mayo Tsanaga to Bogo (North Cameroon): 2002-2003 measurement campaign

Guy Richard Kamgang: Material flows in a catchment from Lom to Bétaré-Oya (East Cameroon): 2002-2003 measurement campaign

Masters theses (2003-2004, University of Douala)

Suzanne Ngo Boum: Physico-chemical and piezometric characterisation of groundwater at Ndog-Bong (Douala)

Paulin Simplice Kouendjin Defonchada: Physico-chemical and piezometric characterisation of groundwater at Nkololoum (Douala)

William Yves Kamseu: Physico-chemical and piezometric characterisation of groundwater at New-Bell (Douala)

Erhard Rufin Assonfack Dongmo: Physico-chemical and piezometric characterisation of groundwater at Bassa (Douala)

Masters theses (2004, University of Dschang)

Aimé Nasser Mboussop: Measurement of solid discharge in the region of Mount Cameroon: example of a catchment from Mungo to Mundamé (measurement campaign 2002-2003)

Adzeh Roger Tamoken: Measurement of solid discharge in the coastal region of Cameroon: example of a catchment from Kienké to Kribi (measurement campaign 2002-2003)

Topic: Variability of water resources

Thesis examinations and ongoing theses

Daniel Sighomnou, state examination thesis at the Univeristy of Yaoundé I, October 2004 (funded by IRD with a grant for a short-term scientific exchange, enrolled at Yaoundé 1):

Analysis and redefinition of climate and hydrological regimes in Cameroon: possible future changes in water resources.

Pierre Diello is continuing his thesis at IRD (funded by IRD, enrolled at University of Montpellier 2, partners EIER, IRD) on the topic Relations between man, climate and the environment in the Bourkinabe Sahel – surface impacts and hydrological modelling.

Gaston Liénou is continuing his thesis (IRD funding, enrolled at Yaoundé 1): Impacts of human activity and climate on recent changes in a number of representative catchments in Cameroon: climatology, hydrology, erosion, material flows. His thesis will be examined in June 2006.

Télésphore Brou Yao continued to receive his grant for a short-term scientific exchange, after which he went to HydroSciences Montpellier with a grant from AUF. His thesis on the topic Climate, human activities and natural ecosystems in Côte d'Ivoire: study of the relations between climatic variability, socio-economic change and landscape dynamics was examined at HDR University of Lille 1 in December 2005.

10.6 Asian Pacific FRIEND

Training and capacity-building activities have been supported by Asian Pacific FRIEND through collaborative courses on hydrology at Nagoya University, Japan, and hydrology and water resources courses at the Regional Humid Tropics Hydrology and Water Resources Centre in Kuala Lumpur, Malaysia.

There have also been a number of meetings in the ecohydrology area including the Symposium on Ecohydrology, held in 2005, which contributed to IHP-VI Theme 3 Land Habitat Hydrology, Focal Area 3.2: Wetlands, as well as the Proceedings of the 2nd Asia Pacific Training Workshop on Ecohydrology (Hehanussa *et al.*, 2003). Ecohydrology is a new interdisciplinary basis for assessment of sustainable management of fresh water resources. It integrates biological and hydrological factors towards enhancement of resistance and resilience of fresh water ecosystems against anthropogenic stress.

10.7 Hindu Kush-Himalayan FRIEND

HKH FRIEND has given high priority to training, capacity-building and technology transfer. Most of the thematic research groups have conducted training courses and workshops to enhance the skills and capacity of regional countries in applying modern methods, tools and techniques in water resources management. Since 1997, more than 200 people from the region have directly benefited from the training courses of HKH FRIEND.

10.7.1 Regional training course on application of geo-informatics for water resources management

A regional training course on the application of geo-informatics for water resources management was held in March 2003 focusing mainly on the hydrological aspects of water resources management using ArcGIS software. A training manual was developed specifically for the two-week course and participants were introduced to GIS concepts in building a geo-

Figure 10.3 Participants and resource people of the training course Application of geo-informatics for water resources management

spatial database and data models of basins. Figure 10.3 shows the participants and resource people of the training course.

10.7.2 National training course on geo-information for water resources management (GI-WRM)

At the request of the partners a national training course on geo-information for water resources management was held in November 2003 in Dhaka, Bangladesh. This training course was in partnership with the Global Water Partnership for South Asia (GWP-SAS). The training course was held for 23 participants from a range of government and non-government organizations working in the water sector and focused on the application of geo-informatics for better management of water resources. Hands-on exercises on different software tools such as MIKEBASIN-1, MIKE 11 and ArcGIS were given to the participants. The trainees also worked on group projects to apply the knowledge gained during the course.

10.7.3 Training course on capacity-building for the monitoring of river water quality

A regional training course on capacity-building for the monitoring of river water quality in the Hindu-Kush Himalayan region was held in May 2003 in Nepal. The course was held in partnership with Kathmandu University, Nepal in cooperation with the German IHP/HWRP National Committee, Federal Institute of Hydrology (BfG), Koblenz, Germany and CEH Wallingford. The training course was a follow-up of the water quality course held in Islamabad, Pakistan in May 2001, which had looked into the chemical aspects of water quality monitoring. The week-long course with 16 participants focused on bio-monitoring and assessing the water quality using bio-indicators. The rapid field assessment technique, multi-habitat sampling and benthic macro-invertebrates were discussed during the technical sessions. The trainees were involved in the sampling technique during field work in the nearby streams as shown in Figure 10.4. The trainees expressed a lack of knowledge in

Figure 10.4 Demonstration of sampling technique, Nepal

biological monitoring to assess the ecological status of rivers in their respective countries and committed themselves to working further in developing a project to address this need.

10.7.4 Regional training course on glacier mass balance measurement

As a follow-up to the preparatory workshop on the development of a training manual for glacier mass balance, a training course was organised by the Jawaharlal Nehru University, New Delhi, with the support of UNESCO, IAHS-ICSI, HKH-FRIEND and the Department of Science and Technology of the Government of India and held from 25 September to 10 October 2002 in New Delhi. 21 participants from Bhutan, India and Nepal attended the course. The resource people were from Austria, Germany, Sweden, Japan, France and India. The objective of the training course was to build the capacity of the countries to improve the understanding of the glacier, mass balance measurements and to bridge the knowledge gap. A two-day lecture was held in Delhi followed by hands-on training at the Chotta Shigri glacier located in the Lahul-Spiti valley in Himachal Pradesh, India. A manual of mass balance measurement had been prepared and was circulated during the training programme. Three sets of steam drill have been handed over to the participating countries Bhutan, India and Nepal to continue the work in monitoring glaciers. A training manual has been published and widely circulated.

10.7.5 Benefits from training

The immediate benefits from the training courses were assessed by means of questionnaire surveys conducted after the training programmes. The trainees evaluated the effectiveness and performance of the training courses. In general, the trainees expressed satisfaction in the course content, materials provided and knowledge transfer. These training courses brought together experts from both within and outside the region, which has led to a clear dialogue and fruitful collaboration, both within the framework of HKH-FRIEND and beyond. This is a very encouraging and positive outcome. Another positive benefit is that it enables young researchers, scientists and experts from various countries to come together and share their scientific experience and knowledge. Such interactions between some countries in the region are difficult for political reasons. As a result of the evaluations given by trainees many useful suggestions and recommendations have been obtained to further improve the effectiveness and scope of such training programmes in the region. For example, participants of the snow and glacier mass balance training course suggested that there should be more exercises on data analysis and knowledge of glacier hazards in addition to the course provided in order to increase the effectiveness of such training courses in the future. Some trainees reported that in the long term the training they were given has helped them in their day-to-day work and in developing self-confidence.

10.7.6 Expansion of partnerships

Through the Water Quality Group the partnership has been expanded wider to other ongoing projects such as the South Asian Water Analysis Network (SAWAN) which addresses the issue of transboundary water quality. The main objectives of this programme is to promote cooperation in South Asia on environmental research, share regional information to build confidence, expand future cooperation, collect and share water quality information on a number of rivers throughout the region. The immediate interest of the programme is to collect and share water quality information among partner countries in order to understand the quality of the rivers. Such partnerships have brought together various organizations, researchers and developers working in the same field to share experiences and knowledge, and add value to the ongoing initiatives on water quality in each of their organizations.

10.8 Nile FRIEND

10.8.1 Training workshops

Training workshop on Data acquisition, data processing and data analysis, Dar Es Salaam, Tanzania, 19-26 May 2002

The aim of this training activity was to strengthen the capacity building of the researchers of the project in the field of data handling, processing and analysis. Various data processing techniques and data requirements for each research theme were discussed and presented by resource persons. During the workshop, the available data in each participating country in the project for each research component was defined. The outcomes of each component were specifically defined according to the overall objectives of each component. Additionally, common pilot areas/catchments to be used in the research activities of the four components were defined. Also during this activity, the data acquisition issue has been raised by the coordinators of the components as an essential procedure to collect data. Moreover, some future activities during the first year of the project were proposed for the different components. The total number of the participants was 30 persons.

Statistical hydrology training course for WRRI local staff, Cairo, Egypt, 14-19 December 2002

This training course addressed the issues of statistical hydrology and flood frequency analysis with special application on the Nile basin. About 15 engineers attended this training course.

10.8.2 Technical missions

Dr. Patrick Willems, the Flemish counterpart of the Flood Frequency Analysis Component (FFAC), conducted a consultancy mission to WRRI as the coordination Center of the FFA component during the period 25-30 October 2003. He reviewed the acquired data through the FFA theme researchers as well as the analysis and research activities carried out by the FFA research team. Also, he provided technical advice to WRRI staff to enhance the implementation of the FFA component research activities.

Dr. Khalid Hussen (Faculty of Engineering - Cairo University) provided a technical support and consultation assistance in the implementation of the research activities of the FFA component during June – August 2003. He also provided high-level training and theoretical background to the WRRI team. Moreover, Dr. Husssen provided for the use of WRRI a high-level flood frequency analysis computer program, which was developed by him and was curtailed, updated, and further developed to address the needs of the FRIEND/Nile project. A number of training sessions were conducted where the WRRI team was trained to perform the analysis using the computer programs.

Dr. Willy Bauwans worked with coordinating center in preparation to the Addis Ababa workshop (20-24 September 2004), conducted preliminary SWAT model applications to the Nile data, prepared data sets for demonstration in the workshop and produced demonstration data sets and SWAT model set-up guidance document.

10.8.3 Hardware and software

Required computers, printers and software of the selected models were purchased and delivered to all researchers (Coordinators and theme researchers). This activity was done by UNESCO Cairo Office (UCO).

10.8.4 Brochure and website

Continuous dissemination for the project brochure. Hard copies and CD's has been done to all water related agencies and institutions in the participating countries. This is done by WRRI and UCO. The project web-site is now hosted at the UNESCO Cairo office server. The address is (http://62.193.88.134/fn/). The project reports are now available on this address. This activity was done by UCO.

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11 Conclusions

The following sections summarise the key achievements of the various regional FRIEND groups and give a comprehensive overview of the strategic plan for the future.

11.1 Key Achievements 2002-2006

11.1.1 Northern European FRIEND

Project 1 European Water Archive

The Europe Water Archive (EWA) has been transferred from the Centre for Ecology and Hydrology, Wallingford, UK to the GRDC located at the Federal Institute of Hydrology in Koblenz, Germany. The EWA is a database independent from that of the GRDC. The new homepage of the EWA gives information about data availability and data access for different end-users (see Annex 5).

Project 2 Low Flows

The outcome of the review process on hydrological drought has been compiled in a textbook aimed at both professionals and students (Tallaksen and van Lanen, 2004). The textbook describes processes and estimation methods for streamflow and groundwater drought and is accompanied by a CD containing data, worked examples, case studies, self-guided tours, software and supporting documents. Software includes programs developed by the Low Flow group, i.e. the BILAN monthly water balance model and NIZOWKA, a frequency program for estimating drought characteristics from daily streamflow series. The concept of the textbook was presented to representatives of water management organisations across Europe and experts from the Mediterranean region at two workshops in Montpellier, France, in 2003. The purpose of the two expert workshops was to foster a cross-flow of information between the authors and the participants, and subsequently to incorporate feedback from the discussion into a final version of the textbook.

A major aim of the Low Flow group has been to promote collaboration and capacity building between scientists, hydrologists and water managers working on drought topics. This has been achieved through the organisation of workshops and training activities, and by the extensive participation of the consortium at national and international meetings. In 2005 and 2006 a session on low flow and drought was organised at the EGU conference in Vienna, Austria, with a substantial contribution from the Low Flow group, both as conveners and presenters.

To ensure a regular exchange of information outside the Low Flow group, the establishment of a European Drought Centre (EDC) (http://www.geo.uio.no/edc) was initiated in 2004. The EDC has been established as a virtual centre of European drought research and drought management organisations to promote collaboration and capacity building between scientists and the user community. The long-term objective of the centre is to enhance European cooperation in order to mitigate the impacts of droughts on society, the economy and the environment. A website and brochure have been produced, and several new initiatives in drought research and capacity building have already been taken. Group members have also been active in trying to raise the profile of drought among European decision-makers through participation at meetings and the authorship of a discussion document "Towards a European Drought Policy" prepared for EU policymakers (EurAqua, 2004). This document demonstrates that drought causes economic damage equivalent to that of floods in Europe, yet there is no European drought policy and no coordinated response to drought.

A joint meeting of the NE and AMHY-FRIEND Low Flow groups was held in Bratislava in May 2004. The meeting was a contribution to the UNESCO IHP-VI programme on Hydrological Extremes (Theme 2, Focal area 2.1) and the main outcome and conclusions from the meeting have been summarised in a report that can be downloaded from the EDC website (Tallaksen, 2004). Together with the textbook, which concludes with an outline of future research needs (Gustard *et al.*, 2004) a number of recommendations for further research, joint activities and co-operation are given. The call for progress in seasonal drought forecasting, the assessment of the spatial and temporal development of drought and improved understanding of the propagation of drought through the hydrological cycle are highlighted, also with regard to the impact of land use and climate change. In addition, the need for good-quality, long-term data is stressed, along with methods for estimation at the ungauged site, including the prediction of time series. At present it is a major concern that regional datasets, like the EWA, are not regularly updated.

Project 3 Large-scale Variations in Hydrological Characteristics

The key achievements of NE-FRIEND Project 3 during 2002-2006 include:

- Advancing regionalisation/interpolation and time-series analysis methods (e.g. regional frequency/risk analysis of extreme events, 'hydrostochastic' and geostatistical techniques)
- Improving understanding of climate-hydrology links and process interactions through empirical analyses and simulation modelling (e.g. developing a new air-mass classification for Western Europe, quantification of air-mass-river flow regime associations, composite analysis of climate fields associated with high and low flow conditions, and scenario-based modelling and downscaling of climate impacts on river flows)
- Developing and applying hydrological/water resource models at the global scale (e.g. the use of the WaterGAP Global Hydrological Model to assess the impact of climate change on groundwater recharge).

Project 4 Techniques for Extreme Rainfall and Flood Runoff Estimation

The Nordic HBV model, in which the snow distribution model and the updating algorithms were implemented, was tested for 10 Norwegian catchments. Remotely sensed information of SCA (snow-covered area) is used in order to update the snow reservoir and the spatial distribution of snow water equivalent (Norway). The sensitivity of flood inundation modelling within the uncertainty framework on two rivers in the Czech Republic (Orlice and Morava) based on data from the 1997 major flood was investigated. On the basis of the modelling, several approaches to the calibration of flood inundation models have been proposed (UK, the Netherlands). A new frequency version of TOPMODEL with snow accumulation, snowmelt and storms moving across the catchment was created for the Zelivka catchment in the Czech Republic (Czech Republic, UK). The distributed water table predictions of TOPMODEL for the Uhlirska catchment in the Jizera mountains have been tested (Czech Republic, UK). Furthermore, a method for estimating flood frequency on ungauged catchments within the uncertainty framework using regional estimates for conditioning was developed (Czech Republic, UK). Finally, the usefulness of the fuzzy set theory in a number of approaches to flood prediction problems have been tested (Czech Republic, UK).

Project 5 Catchment Hydrological and Biogeochemical Processes in a Changing Environment

Research in various catchments repeatedly confirmed the role of groundwater in catchment runoff (Herrmann, 2002; Uhlenbrook *et al.*, 2002). Preferential flow may play an important role in runoff generation and nitrate leaching (Schumann, 2004; Doležal, 2004) and the role of the unsaturated zone was recognised (Somorowska, 2002; 2004). Tracers are important tools in such research and the methods of their applications are continuously evolving (Uhlenbrook *et al.*, 2002; Uhlenbrook and Hoeg, 2003). Extended hydrometric measurements in small research catchments enabled the development of new concepts of runoff generation (Tesař *et al.*, 2001). Information on runoff and water quality generation was used to propose an alternative management system of soil and water protection on the landscape scale (Kvítek, 2005). Swampy catchments are dominated by the vertical component (net precipitation-evaporation-infiltration). Groundwater recharge of such a catchment is mostly influenced by long intensive precipitation events (Lenartowicz, 2003). The hydrological cycle and thus also runoff generation in the long-term view (hydrological years) is to a large extent influenced by vegetation (Van der Hoeven *et al.*, 2005; 2005a; Stehlík and Bubeníčková, 2002). The simple Makking method resulted in estimates of evapotranspiration similar to those of more complex methods, e.g. the Penman method (Van der Velde *et al.*, 2004). Anticipated climate and landuse changes would have significant impacts on runoff regime (Querner *et al.*, 2005), e.g. through the recharge of springs (Uhlenbrook *et al.*, 2003). However, runoff generation would be influenced only gradually (Herrmann, 2004). Mountain peatland should have a guaranteed supply of water also in the future (Woronko and Zmudzka, 2004). Although the snow water equivalents in a mesoscale mountain catchment of central Slovakia significantly decreased between 1962 and 2001 (Pecušová *et al.*, 2004), the analysis of long-term climatic and snow data did not indicate dramatic change over the last century (Kulasová, 2005). As far as flood runoff is concerned, measured data do not indicate an increase of high flows in the last decades (Holko *et al.*, 2005, Pekárová *et al.*, 2005).

11.1.2 Alpine and Mediterranean FRIEND (AMHY)

Some of the major key achievements concern the extreme events field of research which is more than ever topical as climate change in the Region could drive to more droughts and more heavy rains. So the following points can be mentioned regarding a topic which will probably be one of the most important in the Mediterranean Basin during next years:

- The *meteorological and hydrological analyses* on the convective structures responsible for heavy rainfalls pointed out assessments on the reliability of the investigated methodologies and proposal of classification of precipitation structures.

- The *return period of some heavy rainfall events* recently occurred in France and Italy has been estimated by means of comprehensive regional approaches, taking into account the surface covered by the heavy rainfalls according to given rainfall depths.
- *Regionalization approach for flood and rainfall frequency estimation* by means of the spatial analysis of the variation coefficients of rainfalls, performed in southern France, Italy, Portugal and Spain, confirms the hyper-exponential behaviour for extreme events, which can be taken into account by very skewed probabilistic distributions, like TCEV distribution.
- The *analysis of trends and shifts in precipitations* has shown different results, depending on the time aggregation of the data and on the physical and climatic features of the examined area. Some of the studies, carried on at local scale, have pointed out the influence exerted by length and limits of series on the results. Analyses performed over great number of sites within quite large regions better show climatic features, though they reveal relevant uncertainty as regards implication for return periods within smaller regions. Significant evidence of decreasing *monthly rainfall values* recorded in the most recent decades has been shown from seasonality analyses performed in southern Italy through a cross-validation procedure of monthly data explained through Fourier series (Figure 11.1). On the contrary anomalies and trend analyses of monthly rainfall series in Spain have shown no significant statistical trends. As regards *rainfall events analysed at shorter temporal scale*, statistical tests on climatic variability have not exhibit significant increase of the extreme rainfall frequency in various European regions, like southern France and Italy.

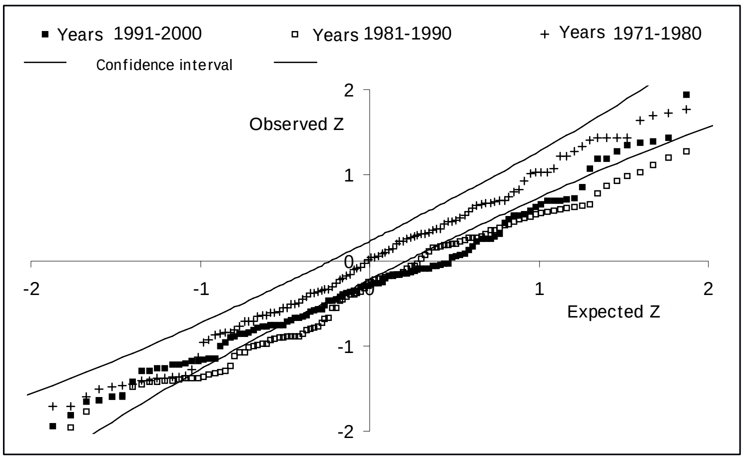

Figure 11.1 Average monthly rainfalls observed in Crati basin, southern Italy. Comparison between expected and observed Z variable of different decades. Confidence intervals of Z at significance level $\alpha = 0.05$ (Sirangelo and Ferrari, 2003)

- Researches on distributed event-based rainfall-runoff models in small basins of southern Italy, based on both conceptual and physically-based schemes, generally have suggested that catchment runoff is mainly produced by saturation excess mechanism, while hortonian overland flow is associated only with high intensity rainfall. Aiming at contributing to a more accurate mitigation of flood risk, the European extreme events database has been expanded to include recent large flood events and related triggering rainfall, which are often usefully described and analysed in local event reports.

- A database on extreme events, providing description and quantitative information on the most recent rainfalls and floods phenomena in Mediterranean countries, has been structured through joint efforts of AMHY working group. The data base, currently in provisional form, for each single extreme events provides several information at a local spatial scale, such as occurrence date, detailed localization, note and comments, affected region extensions, damages, casualties, main rainy intensities and flood peaks, web links to possible specific event reports and database with images and tables. The database will be completed and linked to AMHY-FRIEND web page during 2006.

11.1.3 Latin America and Caribbean FRIEND (AMIGO)

In the period 2002-2006 the project continued to gain strength and it has extended to the whole region of Latin America and the Caribbean, incorporating new topics in its scientific agenda. As part of a regional strategy, the project works in synergy with the other regional projects that exist in the area. An action plan has been drawn up for the phase IHP-VII 2008-2013.

- LAC-FRIEND AMIGO website (http://www.friend-amigo.org)
- Specialised website on "Minimum hydrological phenomena (drought)" (http://www.friend-amigo.org / http://www.met.inf.cu/sequia/amigo.asp)
- Regional evaluation "Instream flows and ecological uses of freshwater resources in Caribbean Region"
- Regional evaluation "Rain deficit in the smallest Antilles"
- Diagnostic of the drought in Meso-America and the Caribbean (http://www.friend-amigo.org / http://www.met.inf.cu/sequia/amigo.asp)
- Online system for the diagnosis of drought in Meso-America and the Caribbean
- (http://www.met.inf.cu/sequia/amigo.asp)

11.1.4 Southern Africa FRIEND

In terms of the main hydrological issues in the region and the overall objectives of Southern Africa FRIEND Phase II, work has concentrated on developing practical tools and strengthening institutional capacity to manage water effectively in the face of scarcity and high levels of variability of the resource. The new tools and techniques have been developed with the particular needs of the region in mind, through a process which includes direct feedback from the users, to ensure that they are adapted to their needs. The project also makes a significant contribution to the ongoing process of international cooperation, which it is hoped will eventually lead to improved water sharing across the region, a very significant need in a part of the world where a high proportion of the resources are held in common between several countries. Notable achievements within the themes include:

- Databases

  The project has continued to support region-wide databases and data sharing in Southern Africa, which are vital in a region with many transboundary rivers. In Phase II, the work concentrated on spatial data that are relevant to water resources, and on supporting and enhancing the GIS skills that are needed to make effective use of these data.

- Methods and tools

  Several improved tools for water resources assessment and management have been developed, tested and implemented in the region:

  - The application of the Pitman/SPATSIM approach in the Kafue and Okavango basins has shown the way towards improved assessment of the resource and is a step towards the extension of this technique to the entire region. Such assessments are an essential underpinning to all water resources planning.
  - Drought assessment and management abilities have been enhanced through the ARIDA software, using approaches that are appropriate to the particular hydrological characteristics of Southern Africa. Drought management is particularly significant in relation to the frequent occurrence and potentially massive impacts (especially for the poor) of drought in the region.
  - Further development of abilities to manage water resources, especially low flows and abstractions, was made through the pilot GIS water resources software (LF2000-SA). This work has provided an advanced and powerful tool which is also very accessible and easy to apply. So far, it has been implemented only in part of Malawi, but it has great potential for further application across the region.
  - Finally, considering the huge potential importance of climate change due to global warming, work in Swaziland has shown how rapid assessments of the water resources impacts can be made in an integrated way.

- Capacity-building

  Transfer of technology and capacity-building were important components of all aspects of the project, with the involvement and participation of water resources professionals in the region being integral to the project activities. Specific training activities were carried out through three regional workshops to a total of 51 participants to disseminate the work done in each theme. A further 18 people participated through in-situ software and other training. Support for a post-graduate student at a university in the region led to the application of the WR90 water resources assessment approach in Zambia.

- International cooperation

  The project has furthered the ongoing collaboration and cooperation between the hydrological agencies and other organisations in the region on water resources issues, helping to build trust through working together on capacity-building exercises, and through sharing data, ideas and problems.

The integration of the development and implementation of methods and tools with the capacity-building and technology transfer elements of the project has allowed for cutting-edge hydrological methods and software systems to be disseminated directly to users within the national hydrological agencies of the region with training on their use and on the hydrological ideas behind them. This has provided a continuity of learning within the institutions, an understanding of the work that FRIEND has accomplished and of how technologies could change water resources management in Southern Africa in the future.

It is also worthwhile to view the achievements of the project in terms of their contribution to broader international development objectives. The UK Government's White Paper "Eliminating world poverty: a challenge for the 21st century" (Department for International Development, 1997) sets out how the effective and sustainable management of water resources is an essential prerequisite to the provision of access to all for domestic use, reduction of water-borne diseases and improved livelihood options through the use of water for food production and small-scale industrial activities. Southern Africa FRIEND will, in the long term, contribute to the alleviation of poverty by helping to improve the assessment and management of water resources in the region.

11.1.5 West and Central African FRIEND (AOC)

The lack of financial resources for members of the FRIEND-AOC programme meant that FRIEND-AOC scientific activities did not come up to expectations, even if results were presented at a number of international scientific events and/or were obtained thanks to doctoral theses. Certain activities did continue but these were mainly focused on maintaining the dynamics of the network. For example, it was possible to hold the usual number of steering committee meetings each year.

At the most recent meeting of the steering committee in November 2005, FRIEND-AOC decided to limit itself to only four topics that will be coordinated by the following institutions:

- Hydrological changes and rainfall runoff relations – HydroSciences Montpellier (contacts: G. Mahe and J.E. Paturel).
- Minimum flows and dynamics of subsurface flows – Cheick Anta Diop University, Dakar (contacts: R. Malou and S. Sambou)
- Water quality – Hydrological Research Centre, Yaoundé (contacts: L. Sigha and D. Sighomnou)
- Ecohydrology – Ecole inter-états d’Ingénieurs de l’Equipement Rural de Ouagadougou and University of Lomé (contacts: A. Maïga and G. Kissao)
- Hydrological Research Centre, Yaoundé is responsible for the general coordination of the FRIEND-AOC project (contact: L. Sigha).
- Database and website - Cheick Anta Diop University, Dakar (contacts: R. Malou and S. Sambou).

It should be noted that the objectives of the FRIEND-AOC project can only be achieved if participating countries are willing to pool their hydrometeorological data. This pooling of information is indispensable if the network is to function satisfactorily and if it is to continue to expand to include the different scientific communities of West and Central Africa.

Through the general coordination of FRIEND groups and through the active participation of certain FRIEND-AOC members at the workshop held in May 2005 in Nairobi by the NEPAD, IRD, UNEP and UNESCO Scientific and Technological Forum, FRIEND-AOC was able to contribute to planning the setting-up of an African network of centres of excellence in water sciences and technology. Following the Nairobi workshop, a second meeting, limited to around 15 experts including three FRIEND-AOC members, was held in Pretoria in July 2005 to put forward proposals concerning these centres and the projects to be implemented by them. We also took part in meetings of the AMMA Africa Monitoring Committee in November 2004 (Niamey, Niger) and in May 2006 (Ouagadougou, Burkina Faso).

11.1.6 Asian Pacific FRIEND

AP-FRIEND has extended the publications of the "Catalogue of rivers for Southeast Asia and the Pacific" by adding Volume 4 (RSC, 2002) and Volume 5 (RSC, 2004), which now brings the number of rivers to 114 rivers from 13 countries in the region.

An annual Asian Pacific FRIEND symposium and the publication of the proceedings of the symposia (Desa *et al.*, 2002; Takara and Kojima, 2003; James *et al.*, 2004; RSC, 2005), as well as workshop proceedings on Ecohydrology and intensity frequency duration and flood frequencies, has maintained a consistent interaction between researchers.

From these proceedings it can be seen that more than 200 researchers from nearly all the countries in Southeast Asia and the Pacific have been engaged in a wide range of research activities on national and transboundary issues, covering the following main themes:

- studies and analyses of extreme of rainfall and the resulting consequences of floods and droughts
- impact on catchment hydrology and water resources caused by natural and human induced changes in land use practices
- modelling of hydrological processes
- impact of climate variability on water resources availability and management
- analysis of hydrological trends in terms of different time and space scales.

AP-FRIEND research has been especially aimed at enhancing specialists’ technical knowledge and identifying appropriate solutions to meet the urgent needs for water supply and flood control. It has also contributed to up-to-date training in hydrology and water resources management.

Collaboration with other related organisations and programmes such as GEWEX/GAME, PUB and the cross-cutting programme of Hydrology for Environment, Life and Policy (HELP) have been established. Many researchers that are part of AP-FRIEND are indeed researchers within these programmes. During the second stage of implementation of AP-FRIEND the major challenge has been to find the necessary support for all countries to participate in the working groups. The Technical Sub-Committee for Asian Pacific FRIEND and the Regional Steering Committee realise that financial support for working groups is required to enable good interaction and satisfactory completion of the tasks. In this regard, stronger collaboration with the wider ranges of national, international, regional and global organisations and programmes are an important aspect of Asian Pacific FRIEND. Collaboration with the World Water Assessment Programme (WWAP), HELP and the WMO Hydrology and Water Resources Programme (HWRP) will enable integrated research, experimental, training and capacity-building activities in the region. Asian Pacific FRIEND has much to share with and contribute to these organizations and programmes and will extend cooperation to organisations including Nagoya University in Japan, Hohai University and the International Research and Training Centre for Erosion and Sedimentation (IRTCES) in Beijing, China, the International Centre for Water Hazard and Risk Management (ICHARM) in Tsukuba, Japan, and the Regional Humid Tropics Hydrology and Water Resources Centre (HTC) in Malaysia, where training courses have been held. Lastly and most importantly, links with the governments of member countries are necessary for the development of a regional database so that data can be transferred easily between member countries.

11.1.7 Hindu Kush-Himalayan FRIEND

During the last four years HKH-FRIEND has continued the research and training activities through its six thematic research groups. The various training courses and workshops held have served as a springboard for several larger projects to initiate focusing on the issues of the region, for example the project on regional cooperation in flood forecasting and information exchange which seeks to reduce flood vulnerability in the HKH region by sharing real-time hydrometeorological information. The snow and glacier aspects of water resources management in the Himalayas (SAGARMATHA) is a further example of research work which developed a new regional hydrological model to give forecasts of annual and seasonal flows for a period of up to 100 years for a range of climate scenarios. Another example is the ASSESS-HKH project which seeks to develop an assessment system to evaluate the ecological status of rivers in the HKH region and which is a direct outcome of the regional training course on water quality monitoring. The support given by the Government of India for the Snow and glacier mass balance training course held in India in October 2002 is very encouraging. Similarly, technical and financial support from UNESCO/IHP, CEH Wallingford, U.K., the German IHP/HWRP National Committee, the World Meteorological Organization (WMO), the Global Runoff Data Centre (GRDC) at the Federal Institute of Hydrology, Germany, the Department of International Development, U.K., and ICIMOD has allowed HKH-FRIEND to continue its activities.

11.2 Strategic plan for the future

11.2.1 Northern European FRIEND

Project 1 European Water Archive

The European Water Archive remains a valuable resource and a prime example of what can be achieved by international cooperation. NE-FRIEND participants from all over Europe have spent considerable time and effort to make the European Water Archive the high-quality dataset for regional hydrological analysis it is today. Many scientists have already benefited from its existence using the data for their research. The EWA will become even more relevant as we aim to understand the impacts of climate and other changes to water resources, and threats from hydrological extremes, such as floods and droughts.

Project 2 Low Flows

The NE-FRIEND Low Flow group will continue the research work and fruitful cooperation within the framework of the FRIEND project, also in the next IHP period. The group is seen as a platform for cooperation within regional low flow and drought research, with a dynamic, bottom-up approach. It is anticipated that the work will continue to be organised in smaller groups, defined according to specific projects and research tasks, and combined with joint meetings every 12-18 months. The members will present their research work also outside the group, through the EDC, at national and international conferences and as scientific publications. The group will seek to strengthen the links with other regional FRIEND and international groups working on related topics. Further, new members will be encouraged to take part in the group, in particular younger scientists.

The members are encouraged to follow up the recommendations on future research needs given in the report to UNESCO (Tallaksen, 2004; see previous section), and in general seek funding for joint research, dissemination activities and cooperation in education, including activities outside Europe. Research visits, student exchanges and joint excursions, engagement in international study courses and workshops are means of cooperation that have proved useful in the past and will therefore be encouraged also in the future.

There is a continued need for improved coordination of research and operational activities, international collaboration and communication to policy makers and the public. The latter implies the development of hydrological characteristics and measures suitable for meeting new European water policies, e.g. the Water Framework Directive. Drought is a natural hazard that cannot be prevented, but its impacts can be reduced through mitigation, i.e. knowledge, preparedness and good-management practice. In this context the WMO handbook on low flows for operational agencies is seen as an important contribution. It will further be explored how drought research and management can be incorporated in the Integrated Water Resources concept (IWRM) similar to what is being done for Integrated Flood Management (IFM). The European Drought Centre (EDC) will interact with the scientific and operational communities as well as policy makers and society to raise awareness of the drought hazard and may represent an important platform for future European drought initiatives. The NE-FRIEND Low Flow group will continue to work actively to ensure continuation and further advances in drought research through the success of the EDC.

Project 3 Large-scale Variations in Hydrological Characteristics

In early 2004, the NE-FRIEND Project 3 group took the opportunity to review research foci and future directions. Subsequently, new members have joined, a core of active participants has been identified, and the group's scientific agenda updated. The group intends to continue research under the four themes outlined in section 2.3.2. In addition, there are a number of recently established initiatives that relate particularly to prediction and forecasting of hydrological variability, including floods and droughts (theme 5). These emerging activities include:

- seasonal river flow forecasting using outputs from dynamical models, statistical models and combined approaches
- exchange visits between Centre for Ecology and Hydrology (UK) and Cemagref Lyon concentrating on the application of Empirical Orthogonal Functions to atmospheric data to improve the skills of climate descriptors in forecasting low flows and droughts
- understanding the impact of climate and land use change on river basin functioning in Europe by examining soil-sediment-surface water-groundwater interactions for selected river basins – Meuse, Elbe, Ebro, Danube and Brevilles
- exchange visits between the University of Oslo and Cemagref Lyon focusing on preparation of a textbook on hydrostochastics – presenting new approaches for interpolation and regionalisation
- exchange visits and joint research between the University of Oslo and the University of Costa Rica focusing on developing approaches for hydrological regionalisation in the tropics and hydroecology
- visit by University of Oslo/NE-FRIEND Project 2 to the University of Birmingham to collaborate on hydroclimatology of drought.

In addition to continuing work on specific projects in smaller, defined research clusters, NE-FRIEND Project 3 will seek:

- to promote and encourage research expertise within northern Europe related to the research themes identified
- to sustain and expand links with other FRIEND projects/programmes and international groups working on allied themes
- to encourage new, especially younger, scientists to join the group
- to identify mechanisms by which the group can work together in a tangible manner to advance research (e.g. project proposals, student exchanges and joint training/teaching)

With respect to output and dissemination, participants will continue to present their research at international conferences (a number of papers are accepted for the 5th FRIEND World Conference, during which a Project 3 meeting will be held) and in peer-reviewed journal papers and popular outlets. Workshops will be organised focusing on new approaches to hydrological analyses and bridging the gap between academic researchers and practitioners/decision makers (e.g. international workshop on regionalisation of low flows to be held in Costa Rica, 2007, in collaboration with the University of Oslo). The NE-FRIEND Project 3 website will be updated and kept current to aid the dissemination of group activities. In addition to these routes for knowledge transfer, training and education will be undertaken.

Project 4 Techniques for Extreme Rainfall and Flood Runoff Estimation

The future planning of the group is based on two important papers published by Beven (2005b, 2006). The first one is entitled A manifesto for the equifinality thesis (Beven, 2005b) and the second one Working towards integrated environmental models of everywhere: uncertainty, data and modelling as a learning process (Beven, 2006). In the manifesto a new development of the GLUE methodology is introduced. It relies more on prior evaluations of model acceptability relative to observations and less on likelihood measures based on model residuals after a model has been run. This focuses attention, for example, on incommensurability errors (differences between the nature of observed and predicted variables due to scale and heterogeneity effects) and the effects of input errors, both of which are often ignored. Simulations (the parameter sets), the predictions of which lie outside the range of the effective observational error, are rejected.

With the ever increasing computer power and software (middleware) possibilities we will soon have computer models of everywhere, i.e. all places of interest will be represented. The data to constrain our models of particular places will assume greater importance than particular model structures. Models should be applied within a learning framework. Models, i.e. not only non-behavioural parameter sets but also the model structures which for a certain place are not in agreement with the observed data will be rejected.

The group intends to continue the modelling work in the suggested direction:

- taking into account the rating curves when conditioning simulations on observed flows
- using the method of functional classification and evaluation of hydrographs based on multicomponent mapping (Pappenberger and Beven, 2004)
- selecting design hydrographs of long return period from flood frequency simulation within the GLUE framework
- saturated areas mapping in small catchments and the use of the data for conditioning the spatial performance of TOPMODEL
- using the SCA (snow-covered area) data for modelling discharge in snowmelt periods.

Project 5 Catchment Hydrological and Biogeochemical Processes in a Changing Environment

It can be expected that future activities will be dominantly based on individual research projects of group participants. Individual research projects will develop the topics and approaches mentioned in the group report. The well-established cooperation of NE-FRIEND Project 5 and ERB will continue because of the similar research interest of both groups. Apart from the regular biannual ERB conferences, joint workshops on ad hoc topics will be organised in the years between the ERB conferences. Other joint activities will comprise:

- regular meetings on snow of the Slovak and Czech participants
- CRP Luxembourg-UNESCO-IHE cooperation in small catchments research.

Individual research projects will be focused on:

- investigation of relationships among runoff generation (and water chemistry) and factors like geology, geomorphology, climate, soils, land use, agriculture, fertilisers, nature conservation measures, water management policies, land consolidation, grassland promotion, afforestation, etc. in small agricultural catchments containing tile drainage systems
- flow regime in river basins under global change at different catchment scales
- stability and extremalization of hydrological cycle in different catchments
- assessment of flood impacts in urban catchments
- application of rainfall-runoff models for runoff prediction in global climate change of catchments
- hydrological predictions at multiple scales based on small-scale processes understanding, application of experimental data in the improvement of rainfall-runoff simulations
- further development of the Integrated Catchment Approach (ICA) to study catchment hydrology, study of preferential flow, numerical groundwater modelling, hydrological and hydraulic regionalisation

11.2.2 Alpine and Mediterranean FRIEND (AMHY)

Regarding Low Flows and Drought, an important role of the AMHY Group could be in developing new methods for drought forecasting and prediction, as well as in collaborating with the other regional FRIEND groups in building a drought survey system.

Regarding extreme events one has to notice that the research activities have to be organised in close coordination with the topics dealing with: climate change, hydrological modelling and, of course, integrated water resources management. So, one can list the following points:

Stochastic and statistical analyses of extreme events

Efforts will be devoted to the local estimation of extreme event frequency through the use of skewed probability distributions. The hierarchically structured use of these probability distributions will also be improved for a better regional estimation of extreme event frequency for ungauged sites, taking into account spatial distribution of the events. On the other side, more attention will be focused on shorter time aggregation data of extreme events, by means of stochastic analysis of partial duration series, in order to better exploit the information provided by the great amounts of extreme events data. Among the expected results, will be developed models for interpretation of marked point processes, formed by non homogeneous Poisson laws, to explain the occurrence process of extreme events, and different distributions for the process of peaks exceeding threshold values.

Joint analysis of extreme events

Improvements in joint analysis of meteorological and hydrological conditions triggering extreme events should be performed, with the combined use of ground measurements, remote sensing, digital elevation model, land use maps and geophysical features of the area. In fact both hydrological (based on ground observations) and meteorological (based on remote sensing) approaches to extreme event analysis are very important to get information about the physical processes governing climate and the effects of its change on human activities. Such analyses have to be harmonized to delineate standard procedures, thus allowing for actual upgrading of used techniques and comparison of the results carried out in different environments. A special example of the interesting results attainable from the combined analyses can be a better identification of flood prone areas, where ground observations are often used to verify the inundated areas obtained from processed images integrated by GIS techniques. Thus future efforts could be focused on tentative arrangement of guidelines for combined analyses of extreme events.

Augmentation of the database

Quantitative information on the more recent extreme events happened in the AMHY countries will be collected for the enlargement of the data base. Open discussion of the case studies of the most exceptional events in different European countries will be encouraged with proper agenda in meetings concerning extreme events.

Experimental basins

European databases must be carefully checked to allow reliable assessments on the link between heavy rainfalls and rare floods, particularly as regards to regional statistical approaches of extremes and investigation of rainfall-runoff processes. To this aim, AMHY group will check local catchments to mark them as experimental basins in which collecting flow and rainfall measurements for a safe calibration of hydrological models. To this aim it is worthwhile to recall that some researchers of different projects, such as FRIEND and HELP, both interested to validate experimental basins for arranging unquestionable hydrological data base, are trying to synergize their efforts by sharing information and collaboration.

To recapitulate, focus is on links between climate change modelling and hydrology, development of hydrological modelling which could be connected with GCM, stochastic procedures allowing the use of GCM information at hydrological scales, etc.

11.2.3 Latin America and Caribbean FRIEND (AMIGO)

The LAC-FRIEND AMIGO objectives for the future are focused on:

- Enhancing knowledge of flow regimes through the development of high-quality databases and models, with special attention to the hydrological extremes, floods and droughts
- Improving scientific understanding of hydrological processes and variability across various regional and sub-regional basin networks (in close collaboration with the cross-cutting programme HELP)

- Contributing to an enhanced knowledge base and building the capacity of decision-makers and practitioners in the management of freshwater resources in arid, semi-arid and urban areas, particularly in the developing countries (in close collaboration with other IHP regional projects and UNESCO regional centres like CAZALAC and CATHALAC)
- Strengthening research and capacity-building networks at regional and international scale to address water issues, particularly water supply related aspects, as a component of poverty reduction
- Improving the knowledge for developing an eco-hydrological approach and for its integration into regional natural resources development strategies (in close collaboration with the ecohydrology project)
- Increasing the scientific capacity to study the global change impacts on the hydrological regime
- Detecting climate variability and climatic changes
- Detecting human impact on the hydrological regime.

To achieve these objectives, a work plan based on three different scenarios of cost has been approved.

Zero cost: Activities in the region and their results that can be shared through the Internet or national activities, for example:

- Sharing available hydrological tools, methodologies and webpages
- Granting the UNESCO/FRIEND logo to books which are published in the region
- Establishing the UNESCO-FRIEND prize for students of hydrology or related sciences
- Promoting the FRIEND project in all the countries.

Low cost: **A**ctivities that are being developed in the countries or as part of the FRIEND ordinary budget, for example:

- Elaboration of technical monographs or methodologies on FRIEND topics
- Regional, sub-regional and national training
- Elaboration of regionalisation based on common investigations developed in the countries of the region
- Continuation of the establishment of the FRIEND drought system
- Strengthening the LAC-FRIEND website
- Definition of associations with regional institutions.

High cost: Activities linked with international, regional, sub-regional or national projects related to the FRIEND scientific agenda that can be used to improve the database, generalise information, tools and methodologies, for example, climate change research programme.

11.2.4 Southern Africa FRIEND

Priorities for future work

The Southern African region remains one in which institutional capacity and the skills base need to be continually improved in order to contribute to improved water resources planning and management, with their eventual impacts on poverty and the people's livelihoods. Within the context of Southern Africa FRIEND, it is proposed that future work should consolidate the achievements of Phases I and II and concentrate on three main areas:

- Enhanced capacity-building

  Research results are only useful if they are available to those who will best use them, at the time they need them, in a format they can use, and with findings that are comprehensible and adaptable to local circumstances. Future capacity-building activities should place greater emphasis on the dissemination of training to ensure maximum potential impact in terms of numbers of people reached. The focus should be:

  - Self-help training – training material released via CD-ROM, the internet and through courses at local universities so that staff can extend their knowledge and expertise whilst spreading their study over time so that it does not interfere with their normal day-to-day activities
  - Training for trainers – regional training workshops concentrating on educating those responsible for teaching hydrology, focussing on new methods for hydrological design and water resources assessment
  - Curriculum development – international cooperation between water resources institutes and academic staff to help redefine and improve the hydrology modules of undergraduate and post-graduate courses in the region
  - Support to post-graduate studies – continued assistance to students undertaking post-graduate research on relevant topics at universities in the region.

- Region-wide surface water assessment

  Lack of reliable information on the availability of water resources remains a major problem in Southern Africa. The Phase II regional water resources and flow modelling theme could be extended through involvement in the major SADC PCN 14 project to improve the ability of the member states to make water resource assessments that are environmentally sustainable and based on broad strategic water resource planning, using information and approaches that are reliable and mutually accepted within the region. Work should focus on the following areas, identified as being of high importance:

  - Improving the capability to assess water resources for ungauged catchments throughout the region by developing an appropriate and consistent model parameter estimation scheme and parameter regionalisation procedures through the use of GIS techniques.
  - Enhancing temporal assessment of water resource availability by disaggregation of the monthly flow series derived under PCN 14 to a daily time step. This is relevant to such issues as the assessment of run-of-river water supply potential, assessment of spate irrigation potential, design of micro-hydropower schemes and for setting environmental flow requirements.

  - Improving technical and institutional capacity within SADC government agencies to enable them to develop integrated water resource management plans and provide a framework for resolution of transboundary water disputes.

- Integrated water resources management tool for Southern Africa

  The pilot LF2000-SA decision-support software, that has so far been implemented only in part of Malawi, could be extended to make it applicable in other countries in the region. This could be achieved through the use of digital elevation models and the outputs from other water resources assessment work (such as that under PCN 14, discussed above), and the incorporation of a number of additional facilities.

In addition, it is proposed that the status and likely future need of the Southern Africa flow time series and spatial databases should be reviewed and, if appropriate, put under the guardianship of a database group responsible for periodic updates, maintenance and accessibility.

Several new research directions have also been identified by the Steering Committee for possible inclusion in any future phase of Southern Africa FRIEND: sedimentation issues, water balances of lakes, impacts of climate change, water use efficiency in irrigation, flood prediction and warning, transmission losses, environmental flows, transboundary water issues and future data collection strategies.

Projects aligned with Southern Africa FRIEND priorities

It is increasingly important to integrate the activities of Southern Africa FRIEND group with those of other parallel groups to try and prevent overlaps, develop more efficient coordination of research activities within the region and optimise the use of available funding sources. Other regional initiatives may be coordinated or funded by, amongst other, the EU, SADC, IAHS PUB, WaterNet, etc. The projects include activities that are strongly aligned to Southern Africa FRIEND objectives, and two examples are summarised below:

- Uncertainties associated with the application of hydrological and water resource models

  At the start of 2006, two postgraduate students (1 MSc, 1 PhD; mentioned in Chapter 10) from Zimbabwe registered at the Institute for Water Research at Rhodes University, South Africa, to work on projects associated with the reduction in uncertainty in water resource assessments and hydrological modelling. Both students are funded by the institute:

  - The MSc student is focusing on the application of a revised version of the Pitman rainfall-runoff model (with added surface-groundwater routines; Hughes, 2004). This project is designed to investigate calibration practices and issues associated with regional estimation of model parameters for ungauged basins within southern Africa.
  - The PhD student is focusing on broader issues of uncertainty associated with available data (Hughes, 2006a; 2006b; 2006c), model parameter estimation and application in ungauged basins. The objectives are to identify the main sources of uncertainty, quantify uncertainty in example basins and offer suggestions for reducing or accounting for uncertainty.

- Further modelling the water resources of the Okavango basin

  The EU-funded WERRD (Water and Ecosystem Resources in Regional Development) project, completed at the end of 2004, was designed to provide tools for assessing the impacts of climate change and water resource developments on the hydrology and ecosystems of the Okavango river basin and delta. The study involved the establishment of a hydrological model for the basin (Andersson *et al.*, 2003; Hughes *et al.*, 2006; Wilk *et al.*, 2006), and the use of that model to provide inflow scenarios to the delta, based on assumptions of future climate change and developments within the basin (Andersson *et al.*, 2006). One of the conclusions of the study was that an adequate hydrological model has been established despite problems with the lack of available hydrometeorological data. However, one of the major issues associated with the future use of the model is the need to rely on satellite rainfall data (Hughes, 2006a; Wilk *et al.*, 2006) in the absence of ground-based observations caused by the closure of observation networks.

The current EU-funded TWINBAS (Twinning European and third country basins for development of integrated water resources management methods) project has overlapping objectives to WERRD in the context of the Okavango basin. CEH Wallingford, UK, and the Institute for Water Research at Rhodes University, South Africa, are focusing on hydrological and water resource modelling of the basin, whilst DHI Water and Environment, Denmark, is focusing on modelling the impacts of flow regime changes on the hydrodynamics of the delta. The application of two modelling approaches to the basin (the modified monthly Pitman model and the monthly GWAVA model) were equally successful, and both faced similar problems and constraints, the latter largely associated with the lack of available data with which to define the model forcing variables (rainfall and evaporation), as well as information on the current and likely future water resource developments within the basin.

The TWINBAS project is just one example of an EU-funded project involving African water researchers. The EU actively encourages African researchers to become more involved in the design, planning and implementation of projects. African Water is a current EU initiative to increase the participation of Africans in the water-related research programmes of the EU (www.africanwater.net).

There is also a recognised need for better communication and coordination of the water-related research activities of donor development agencies. The EUWI-ERA-NET is another EU initiative, to provide a framework through which member states can work together, and with country partners, more effectively. The ERA-NET aims to assist country partners to develop a strategy and work plan to identify their priorities for water-related research and potential collaboration, and to establish tools for more efficient sharing of information on member state research programmes (www.euwi-era.net).

11.2.5 West and Central African FRIEND (AOC)

The FRIEND-AOC programme has not received any specific funding since phase 2 started. Activities connected with the different topics only continued thanks to the ability of the coordinating structures to implement activities on their own. These included providing counselling for a number of theses on the topics of local programmes such as ICCE-BF in Burkina Faso, CORUS-Coton and PNRH in Mali, SCAC/CRH Convention and one IRD Young Associated Team in Cameroon. These studies produced satisfactory scientific results, some of which were presented at regional and international scientific meetings.

However, it is true that these programmes could only be developed at the national scale and this explains the wish of members of the FRIEND-AOC network to set up programmes at the scale of the whole AOC region. This will only be possible if there is an increase in scientific exchanges between southern countries and if group training courses are held on the use of new tools for research and development.

The coordination division continues to encourage members of the FRIEND-AOC network to submit papers to international symposia and seminars.

Encouraged by the coordination division and by the topic Variability of water resources, the DSF of IRD decided to provide financial support for the FRIEND-AOC programme for a period of four years. This support began at the end of 2005 with the organisation of a FRIEND-AOC scientific workshop held in Montpellier in November 2005. The help should take several different forms:

- In particular it aims to provide support for teams to enable them to answer international calls for tenders. To this end, a group meeting of researchers was held in Bamako in March 2006 on the occasion of the presentation of the *Echel'Eau* project, to allow members of FRIEND-AOC to take part in this programme;
- It will also organise training courses targeting people from different horizons;
- Using tools for partnership that are already available in the DSF, it will facilitate exchanges between southern countries within the framework of joint research programmes with IRD teams.

Other sources of funding need to be identified to enable members of the AOC region to publicise their work through scientific publication, by taking part in conferences and by organising symposia and other events under the FRIEND label.

In the next two years, we expect to concentrate our efforts on the following activities:

- Revitalisation of regional research by increasing written and oral presentations of scientific results
- Organisation of awareness-raising seminars for government stakeholders and decision-makers
- Active participation in different international scientific events
- Organisation of training sessions aimed at people from different backgrounds on surface states, remote sensing and modelling
- Participation in the FRIEND 2006 conference in Cuba
- Preparation of a summary document on work already presented by members of FRIEND-AOC
- Continuation of south-south scientific exchanges
- Active participation in the *Echel'Eau* project in the Niger river basin.

11.2.6 Asian Pacific FRIEND

The immediate plan for the future is to address the challenge of the FRIEND community to include integrating their research into the policy-making and management of water resources in their various countries and regions, realising that climate change is a global phenomenon but that solutions to the resulting variability will be developed on a local scale.

The resolution of applicable IFD techniques for the region will continue to obtain an improved understanding of the design rainfall procedures currently used in each country. The main objective is to obtain a set of possible recommendations/guidelines for standardised procedures in the region and to assemble a regional data set to enable more extensive design rainfall analyses to be undertaken.

There was agreement at the Kuala Lumpur workshop in June 2005 that a plan be developed for design flood determination. A major part of this plan developed for the second phase of AP-FRIEND was to:

- Evaluate the design flood analyses undertaken in the region including flood frequency analysis
- Examine regional processes that were applicable to design flood estimation (e.g. flood frequency analysis)
- Evaluate quality control of data
- Evaluate and exchange software and techniques.

11.2.7 Hindu Kush Himalayan FRIEND

Efforts will be made to widen the links with other organisations and to strengthen the working relationship with IAHS and its various commissions, particularly ICSI and ICSW. Continuation of the projects momentum is difficult due to the resource constraints faced by regional research groups, but the major challenge in the coming years will be to consider how HKH-FRIEND can develop and sustain its activities.

11.2.8 Nile FRIEND

As follow up and recommendations for the second phase of the project the following requirements are stated:

- Enhancement of the communication between the thematic coordinators and the Flemish counterparts should be condensed;
- More care and importance should be given to the contents and time of delivery of the progress reports of the project.
- No change in the nomination of the focal persons until the end of the project to prevent any delay of work;
- Deep training on GIS applications may be necessary for focal persons of all components.
- A 2nd stage for the extension of the project is strongly recommended to complete and consolidate project results and outputs.

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Sayama, T.	Kyoto University	Japan
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Takara, K.	Kyoto University	Japan

Takeuchi, K.	University of Yamanashi	Japan
Yoshitani, J.	Public Works Research Institute	Japan
Jee, H.K.	Yeungnam University	Rep. of Korea
Lee, S.	Yeungnam University	Rep. of Korea
Shin, H.S.	Pusan National University	Rep. of Korea
Vitahaya, S.	Dept of Meteorology and Hydrology	Lao PDR
Mohd Nor bin Mohd Desa	Regional Humid Tropics Centre	Malaysia
Zalina M. Daud	University of Technology	Malaysia
Abustan, I.	University of Science	Malaysia
Lariyah M. Sidek	University of Science	Malaysia
Norlida M. Dom	Dept Irrigation and Drainage	Malaysia
Curry, B.	NIWA	New Zealand
Ibbitt, R.	NIWA	New Zealand
Thompson, C.	NIWA	New Zealand
Woods, R.	NIWA	New Zealand
Siohane, A.	Public Works Department, Niue	Niue
Virobo, M.	Dept of Environment and Conservation	Papua New Guinea
Liongson, L.	University of the Philippines	Philippines
Tabios, G.Q.	University of the Philippines	Philippines
Aekaraj, S. (Ms)	IHP National Committee	Thailand
Khao-Uppatum, V.	Dept of Water Resources	Thailand
Promma, K.	Naresuan University	Thailand
Winai, S.C.	Prince of Songkla University	Thailand
Tingsanchali, T.	Asian Institute of Technology	Thailand
Bui, Van Duc	Institute of Meteorology and Hydrology	Vietnam
Hoang, Tuyen	Institute of Meteorology and Hydrology	Vietnam
Tran, Thuc	Institute of Meteorology and Hydrology	Vietnam

Hindu Kush-Himalayan FRIEND (Coordinator: Mandira Shrestha)

Project group	Participants	Organisation	Country
Database	Shrestha, Basanta (coordinator)	International Centre for Integrated Mountain Development	Nepal
	Bari, M. F.	Bangladesh University of Engineering and Technology	Bangladesh
	Chalise, S.R.		Nepal
	Chandio, B.A.	SAU	Pakistan
	Chen, G.	Yangtzee Water Resources Commission	China
	Grabs, W.	World Meteorological Organization	Switzerland
	Ji, X.	Yangtzee Water Resources Commission	China
	Kahlown, M.A.	Pakistan Council of Research in Water Resources	Pakistan
	Moustofa, K.G.	Water Development Board	Bangladesh
	Rajbhandari, R.	TU	Nepal
	Rees, G.	Centre for Ecology and Hydrology	United Kingdom
	Shrestha, M.	International Centre for Integrated Mountain Development	Nepal
Low flows	Yogacharya, Kiran Shankar (coordinator)		Nepal
	Bari, M.F.	Bangladesh University of Engineering and Technology	Bangladesh
	Chalise, S.R.		Nepal
	Gustard, A.	Centre for Ecology and Hydrology	United Kingdom
	Kansakar, S.		United Kingdom
	Kumar, A.	AHEC	India
	Parida, B.P.	IIT	India
	Pokhrel, A.P.	Society of Hydrologists and Meteorologists of Nepal	Nepal

	Rees, G.	Centre for Ecology and Hydrology	United Kingdom
	Shrestha, A.	DHM	Nepal
	Shrestha, M.	International Centre for Integrated Mountain Development	Nepal
Floods	Thapa, Khadga B. (coordinator)	TU	Nepal
	Bari, M.F.	Bangladesh University of Engineering and Technology	Bangladesh
	Chen G.	Yangtzee Water Resources Commission	China
	Chhophel, K.	Hydromet Services, Dept of Energy	Bhutan
	Demuth, S.	IHP/HWRP Secretariat	Germany
	Ji X.	Yangtzee Water Resources Commission	China
	Khanal, N.R.	TU	Nepal
	Kahlown, M.A.	Pakistan Council of Research in Water Resources	Pakistan
	Moustofa, K.G.	Water Development Board	Bangladesh
	Parida, B.P.	IIT	India
	Pradhananga, D.	TU	Nepal
	Shakya, N.M.	TU	Nepal
Rainfall-runoff	Ji Xuewu (coordinator)	Yangtzee Water Resources Commission	China
	Bari, M.F.	Bangladesh University of Engineering and Technology	Bangladesh
	Chen G.	Yangtzee Water Resources Commission	China
	Merz, J.	International Centre for Integrated Mountain Development	Nepal
	Pradhanang, D.	TU	Nepal
	Shrestha, A.	Dept of Hydrology and Meteorology	Nepal
	Thapa, K.B.	TU	Nepal
	Tshering, K.	Ministry of Agriculture	Bhutan
River water quality	Bari, Muhammad F. (coordinator)	Bangladesh University of Engineering and Technology	Bangladesh
	Chandio, B.A.	SAU	Pakistan
	Hasnain, S.I.	JNU	India
	Demuth, S.	IHP/HWRP Secretariat	Germany
	Kahlown, M.A.	Pakistan Council of Research in Water Resources	Pakistan
	Merz, J.	ICIMOD	Nepal
	Nakarmi, G.		Nepal
	Sharma, S.	Kathmandu University	Nepal
Snow and glaciers	Pokhrel, Adrsha P.	Society of Hydrologists and Meteorologists of Nepal	Nepal
	Bajracharya, O.R.	Dept of Hydrology and Meteorology	Nepal
	Chalise, S.R.		Nepal
	Chandio, B.A.	SAU	Pakistan
	Grabs, W.	World Meteorological Organization	Switzerland
	Hasnain, S.I.	JNU	India
	Mool, P.K.	International Centre for Integrated Mountain Development	Nepal
	Rajbhandari, R.	TU	Nepal
	Rana, B.	Dept of Hydrology and Meteorology	Nepal
	Rees, G.	Centre for Ecology and Hydrology	United Kingdom
	Shrestha, A.B.	Dept of Hydrology and Meteorology	Nepal
	Thapa, K.B.	TU	Nepal

Nile FRIEND (Coordinator: Mohamed Abdel Motaleb)

Project group	Participants	Organisation	Country
Rainfall-runoff modelling	Mtalo, F.W. (coordinator)	University of Dar es Salaam	Tanzania
	Mutua, F.	University of Nairobi	Kenya
	Bashar, K.	UNESCO chair in Water Resources	Sudan
	Sonbol, M.	Water Resources Research Institute	Egypt
	Tarekegn, D.	Ministry of Water Resources	Ethiopia
	Bauwens, W.	Vrije University Brussels	Belgium
Flood frequency analysis	Motaleb, M.A. (coordinator) Email: Motaleb@wrrisnet.com	Water Resources Research Institute	Egypt
	Opere, A.	University of Nairobi	Kenya
	Mkhandi, S.	University of Dar Es Salaam	Tanzania
	Abdou, G.M.	University of Khartoum	Sudan
	Tadesse, L.	Ministry of Water Resources	Ethiopia
	Willems, P.	Catholic University Leuven	Belgium
Sediment transport and watershed management	Salam, A.A. (coordinator)	UNESCO chair in Water Resources	Sudan
	El Moatasm, M.	National Water Research Center	Egypt
	Gola, S.	Ministry of Water Resources	Ethiopia
	Ogembo, W.	University of Nairobi	Kenya
	Vanacker, V.	Catholic University Leuven	Belgium
Drought and low flow analysis	Mutua, F. (coordinator)	University of Nairobi	Kenya
	Mirghani, M.	UNESCO chair in Water Resources	Sudan
	Fahmi, A.H.	Water Resources Research Institute	Egypt
	Mongodo, R.	Ministry of Water and Livestock Development	Tanzania
	Willems, P.	Catholic University Leuven	Belgium
Training and capacity-building	El Dousoky, I.	Hydraulic Research Institute	Egypt

Annex 3 FRIEND meetings 2002-2006

Region	Event	Venue	Date
Northern European FRIEND	Steering Committee Meeting No. 9	Koblenz, Germany	16-17 June 2003
	Project 1 Database	Havanna, Cuba	November 2006
	Project 2 Low flows	Cape Town, South Africa	18 March 2002
		Prague, Czech Republic	1-3 July 2002
		Oslo, Norway	8-12 Jan. 2003
		Santo Domingo, Dominican Republic	11-17 Nov. 2002
		Montpellier, France	27-28 March 2003
		Montpellier, France	30-31 March 2003
		Montpellier, France	4-5 April 2003
		Wageningen, the Netherlands	28-29 Sept. 2004
		Wageningen, the Netherlands	30 Sept.-4 Oct. 2004
		Bratislava, Slovakia	11-12 May 2004
		Bratislava, Slovakia	12-15 May 2004
		Vienna, Austria	22-24 April 2005
		Kuala Lumpur, Malaysia	26-30 Sept. 2005
		Vienna, Austria	1-3 April 2006
		Havana, Cuba	November 2006
	Project 3 Large Scale Variations in Hydrological Characteristics	Nice, France	April 2002
		Oslo, Norway	Dec. 2004
		Lyon, France	June 2004
		Vienna, Austria	Nov. 2004
		Foz do Iguaçu, Brazil	April 2005
		Vienna, Austria	April 2005
		Montpellier, France	Nov. 2005
		Oslo – Lyon – Costa Rica	Jan. 2005
		Oslo – Lyon – Costa Rica	Sept. 2005
		Havana, Cuba	Nov. 2006
	Project 4 Techniques for extreme rainfall and flood runoff estimation	Bern, Switzerland	March 2002
		Nice, France	April 2002
		Rotterdam, The Netherlands	March 2003
		Nice, France	April 2004
		London, UK	July 2004
		Tromso, Norway	Oct. 2005
		Vienna, Austria	April 2006
	Project 5 Catchment hydrological and biogeochemical processes in an changing environment	Demanovska dolina, Slovakia	25 Sept. 2002
		Bucharest, Romania	26 Sept. 2003
		Torino, Italy	14-17 Oct. 2004
		Yundola, Bulgaria	6 Oct. 2005
		Luxembourg, Luxembourg	19 Sept. 2006

Region	Event	Venue	Date
Alpine and Mediterranean FRIEND (AMHY)	Low flow sub-group meetin	Montpellier, France	30-31 March 2003
	5th EGS Plinius Conference on Mediterranean Storms	Ajaccio, France	1-3 Oct. 2003
	International conference Hydrology of the Mediterranean and semi-arid regions	Montpellier, France	1-4 April 2003
	NE & AMHY FRIEND meeting	Bratislava, Slovakia	May 2004
	Société hydrotechnique de France, 175ème session du comité Scientifique et Technique 'Etiages et crues extremes régionaux en Europe perspectives historiques'	Lyon, France	28-29 Jan. 2004
	Workshop on Mathematical models for simulation of hydraulic and geological events	Cosenza, Italy	20-31 March 2004
	Low flow sub-group meeting at BALWOIS conference	Ohrid, Macedonia	25-29 May 2004
	International conference Complexity and integrated resources management	Osnabrück, Germany	14-17 June 2004
	International workshop Hydrological extremes – Modelling and managing low flows, droughts and floods	Koblenz, Germany	5-8 July 2004
	International conference Hydrology, science and practice	London, U.K.	July 2004
	Low flow sub-group meeting at NIHWM symposium	Bucharest, Romania	23-28 Sept. 2004
	2ème Congrès Méditerranéen, Ressources en eau dans le bassin méditerranéen	Marrakech, Morocco	14-17 Nov. 2005
	International seminar Climate change and water resources	Montpellier, France	Nov. 2005
	International workshop Hydrological extremes – observing and modelling exceptional floods and rainfalls	Cosenza, Italy	3-4 May 2006
	Future of drylands conference	Tunis, Tunisia	19-20 June 2006
Latin American and Caribbean FRIEND (AMIGO)	Workshop on Homepage/database and minimum hydrological phenomena	Havana, Cuba	2002
	Workshop on Regional vision of the drought in Meso-America, the Caribbean and other humid regions	Dominican Republic	2002
	Meso-America and Caribbean FRIEND/AMIGO Steering Committee	Santo Domingo, Dominican Republic	2002
	FRIEND/Northern Europe – FRIEND/AMIGO workshop for the formulation of projects in the Caribbean region	Barbados	2003

Region	Event	Venue	Date
	FRIEND/AMHY – FRIEND/AMIGO workshop on Databases	France	2003
	IHP/FRIEND AMHY/FRIEND AMIGO/WWAP workshop on Databases and Homepages	Cuba	2004
	Meeting of constitution of the FRIEND AMIGO group for South America	Uruguay	2004
	Database workshop	Mexico	2005
	Latin America and Caribbean FRIEND AMIGO Steering Committee meeting	Foz Iguaçu, Brazil	2005
	Fifth FRIEND World Conference Editorial Committee meeting	Havana	2005
	International seminar Climatic and anthropogenic impacts on water resources variability	France	2005
West and Central Africa FRIEND (AOC)	4th FRIEND World Conference	Cape Town, South Africa	March 2002
	Coordination meeting and workshops on Dynamics of material flow, and Modelling	Cotonou, Benin	May 2002
	Steering Committee meeting	Dakar, Senegal	June 2002
	Envirowater Conference & Steering Committee meeting	Ougadougou, Burkina Faso	Nov. 2002
	Steering Committee meeting/COPROMAPH3 conference/AMMA symposium	Cotonou, Benin	Nov. 2003
	5th FIGCC meeting	Koblenz, Germany	July 2004
	IASH symposium	Foz de Iguaçu, Brazil	April 2005
	Steering Committee meeting/Scientific workshop	Montpellier, France	Nov. 2005
	1st AMMA International conference	Dakar, Senegal	Dec. 2005
	Steering Committee meeting/International seminar	Bamako, Mali	March 2006
Southern Africa FRIEND	7th Steering committee meeting	Cape Town, South Africa	18 March 2002
	8th Steering committee meeting	Dar es Salaam, Tanzania	23-24 Feb. 2004
	Water resources workshop	Pretoria, South Africa	17-23 Feb. 2003
Asian Pacific FRIEND	7th Technical sub-committee meeting/10th RSC meeting	Port Dickson, Malaysia	18 Oct. 2002
	8th Technical sub-committee meeting/11th RSC meeting	Sigatoka, Fiji	30-31 Oct. 2003
	9th Technical sub-committee meeting/12th RSC meeting	Adelaide, Australia	Nov. 2004
	10th Technical sub-committee meeting/13th RSC meeting	Bali, Indonesia	Nov. 2005

Region	Event	Venue	Date
	AP FRIEND workshop: Intensity frequency duration and flood frequencies determination	Kuala Lumpur, Malaysia	6-7 June 2005
	2nd Asia Pacific training workshop: Ecohydrology – Integrating ecohydrology and phytotechnology into workplans of government, private and multinational companies	Cibinong, Indonesia	July 2003
	Symposium Managing water resources under climate extremes and natural disasters	Sigatoka, Fiji	Oct. 2003
	Symposium Comparative Regional Hydrology and Mission for IHP Phase VI of UNESCO	Kuala Lumpur, Malaysia	14-16 Oct. 2003
	IHP stream of international conference on Water sensitive urban design (cities as catchments)	Adelaide, Australia	Nov. 2002
	International symposium on Ecohydrology	Bali, Indonesia	Nov. 2005
Hindu Kush-Himalayan FRIEND	Regional training on Glacier mass balance measure in the HKH region		Oct. 2002
	Regional training in Application of geoinformatics for water resources management	Kathmandu, Nepal	March 2003
	3rd Steering Committee meeting	Kathmandu, Nepal	May 2003
	Regional training on Capacity-building for monitoring of river water quality	Dhulikhel, Nepal	May 2003
	Dissemination workshop on Development of regional recession model to estimate dry season flow in ungauged catchments	India and Nepal	May 2003
	National training in Application of geoinformatics for water resources management	Dhaka, Bangladesh	Nov. 2003
	National seminar on Flood risk and vulnerability mapping of the Ratu river basin	Nepal	Jan. 2004
	Local stakeholder consultation on Impacts of deglaciation on livelihoods of people	Pokhara, Nepal	April 2004
	International stakeholder consultation on Deglaciation: impacts and adaptations for water resources and livelihoods in the Himalayas	New Delhi, India	April 2004
	Regional water quality workshop	Kathmandu, Nepal	June 2004
	Local stakeholder consultation on Flood risk and vulnerability mapping in Ratu river	Janakpur, Nepal	Nov. 2005

Region	Event	Venue	Date
	ASSESS-HKH project meetings	Brno, Czech Republic	June 2005
		Dhaka, Bangladesh	Dec. 2005
		Essen, Germany	March 2006
Nile FRIEND	4th FIGCC meeting	Cape Town, South Africa	17-23 March 2002
	5th FIGCC meeting	Koblenz, Germany	4-10 July 2004
	Establishment of FRIEND/Nile research team in Uganda	Kampala, Uganda	15-19 June 2005
	2nd Phase preparatory meeting	Alexandria, Egypt	18-20 Oct. 2004
	FRIEND/Nile conference	Sharm El-Sheikh, Egypt	12-15 Nov. 2005
	2nd Project management meeting	Aswan, Egypt	6-7 Jan. 2003
	3rd Project management meeting	Mombassa, Kenya	10-11 Feb. 2004
	4th Project management meeting	Mombassa, Kenya	21-22 Feb. 2005
	5th Project management meeting	Sharm El-Sheikh, Egypt	14 Nov. 2005
	6th Steering committee meeting	Aswan, Egypt	Jan. 2003
	7th Steering committee meeting	Mombassa, Kenya	Feb. 2004
	8th Steering committee meeting	Addis Ababa, Ethiopia	Feb. 2005
	9th Steering committee meeting	Sharm El Sheikh, Egypt	Nov. 2005
	Rainfall-runoff modelling		
	Workshop	Alexandria, Egypt	20-25 July 2003
	Researchers workshop	Dar es Salaam, Tanzania	5-9 Jan. 2004
	Researchers workshop	Addis Ababa, Ethiopia	20-24 Sept. 2004
	FRIEND/Nile workshop	Khartoum, Sudan	25-30 July 2005
	Flood frequency analysis		
	Workshop	Cairo, Egypt	1-3 April 2003
	Workshop	Sharm El-Sheikh, Egypt	29 Nov. – 2 Dec. 2003
	Workshop	Borg El Arab, Egypt	22-24 June 2004
	Workshop	Nairobi, Kenya	26-29 Nov. 2004
	FRIEND/Nile workshop	Khartoum, Sudan	25-30 July 2005
	Sediment transport and watershed management		
	Focal persons meeting	Khartoum, Sudan	22-24 Dec. 2002
	Workshop	Dar es Salaam, Tanzania	2-6 Dec. 2003
	Workshop	Alexandria, Egypt	19-24 June 2004
	Workshop	Nairobi, Kenya	26-29 Nov. 2004
	FRIEND/Nile workshop	Khartoum, Sudan	25-30 July 2005
	Drought and low flow analysis		
	Workshop	Nairobi, Kenya	25-28 Aug. 2003
	Workshop	Alexandria, Egypt	18-21 June 2004
	Workshop	Nairobi, Kenya	23-26 Nov. 2004
	FRIEND/Nile workshop	Khartoum, Sudan	25-30 July 2005
	Training and capacity-building		
	Data acquisition, data processing and data analysis	Dar es Salaam, Tanzania	19-26 May 2002

Region	Event	Venue	Date
	Statistical hydrology training course for WRRI local staff	Cairo, Egypt	14-19 Dec. 2002
	Technical mission to Water Resources Research Institute	Cairo, Egypt	25-30 Oct. 2003
	Technical assistance to Water Resources Research Institute	Cairo, Egypt	June-Aug. 2003
	Technical visit of RRMC Flemish counterpart	Dar es Salaam, Tanzania	Sept. 2004

Annex 4 FRIEND publications 2002-2006

Northern European FRIEND

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Annex 5 Useful web links

NE-FRIEND	http://ne-friend.bafg.de
EWA – European Water Archive	http://ewa.bafg.de
EDC – European Drought Centre	http://www.geo.uio.no/edc
ASTHyDA – Analysis, Synthesis and Transfer of Knowledge and Tools on Hydrological Drought Assessment through a European Network	http://www.geo.uio.no/drought
AMHY-FRIEND	http://armspark.msem.univ-montp2.fr/amhy
AMIGO-FRIEND	http://www.friend-amigo.org
	http://www.met.inf.cu/sequia/amigo.asp
	http://www.unesco.org.uy/phi/friend
AOC-FRIEND	http://sfriendaoc.agrhymet.ne/friendaoc
	http://armspark.msem.univ-montp2.fr/friendaoc
AP-FRIEND	http://jakarta.unesco.or.id/prog/science/water/wa_friend.htm
	http://www.bom.gov.au/hydro/wr/unesco/friend/apfriend.shtml
	http://titan2.cee.yamanashi.ac.jp/FRIEND/
HKH-FRIEND	http://www.hkh-friend.net.np
Nile-FRIEND	http://62.193.88.134/fn/

IHP – International Hydrological Programme of UNESCO	http://www.unesco.org/water
HWRP – Hydrology and Water Resources Programme of WMO	http://www.wmo.ch/web/homs/hwrpframes.html
IHP/HWRP Germany	http://ihp.bafg.de
GRDC – Global Runoff Data Centre	http://grdc.bafg.de
GTN-R – Global Terrestrial Network for River Discharge	http://gtn-r.bafg.de
IAHS – International Association of Hydrological Sciences	http://www.wlu.ca/~wwwiahs/index.html
EU's Sixth (2002-2006) Framework Programme	http://cordis.europa.eu/fp6/