United National Educational, Scientific and Cultural Organisation
International Hydrological Programme VI

Flow Regimes from International, Experimental and Network Data

Northern European FRIEND &
AMHY FRIEND
Joint Low Flow meeting

SUMMARY REPORT

A contribution to the UNESCO IHP-VI program on "Hydrological Extremes" (Theme 2, Focal Area 2.1).

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12-15 May 2004
Bratislava, Slovakia

Executive Summary

A joint meeting of the Northern European FRIEND and the AMHY FRIEND groups working on low flow and drought was held at the Comenius University in Bratislava (12-15 May 2004). The objectives of the joint meeting were:

i) to present recent research on low flow and drought
ii) to identify gaps in our current knowledge on low flow and drought
iii) to define future outlook, including proposals for cooperation and joint research activities

Totally 33 participants from 15 countries contributed to the meeting through presentations, discussions and by compiling session reports. This summary report is written as a contribution to the UNESCO IHP-VI program on "Hydrological Extremes" (Theme 2, Focal Area 2.1). The report presents a number of recommendations for further research, joint activities and cooperation within the field of low flow and drought, of which a brief summary is given below:

Research topics:

- Drought forecasting (including seasonal forecast based on links between the climate system and catchment response)
- Impact of land use and climate change on drought
- Continuously simulation modeling
- Propagation of drought through the hydrological cycle (process understanding)
- Link between drought and stream ecology
- Accounting for seasonality and non-stationarity in extreme value analysis
- Need for good quality, long-term data (easy access)

Other aspects:

- Improved coordination of research and operational activities
- Cooperation through workshops and joint research projects
- Transfer of knowledge through international study courses and workshops (Education and Dissemination)
- Communication to policy makers and the public
- Establish a European Drought Centre as a framework for future cooperation and to raise the awareness of drought as a natural hazard

Northern European FRIEND & AMHY FRIEND joint Low Flow meeting

Faculty of Natural Science, Comenius University, Bratislava

SUMMARY REPORT

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BACKGROUND

From 12 to 15 May 2004 a joint meeting of the Northern European FRIEND and the AMHY FRIEND groups working on low flow and drought was held at the Comenius University in Bratislava (Slovak Republic). FRIEND activities are part of the so-called "cross-cutting theme" of the UNESCO IHP-VI program. The objectives of the joint meeting were:

- **i)** to present recent research on low flow and drought
- **ii**) to identify gaps in our current knowledge on low flow and drought
- **iii**) to define future outlook, including proposals for cooperation and joint research activities

The joint FRIEND meeting was organised in seven sessions over four days. The first six sessions focused on key issues related to the objectives of the meeting, whereas the last session synthesised and summarised the findings. The participants contributed to the sessions related to their scientific expertise by presenting papers and by contributing to the discussions in the other sessions. Presenters of the workshop provided examples of research activities that related to and supported the objectives of the meeting. Each session was managed by a "session team" comprising the chair of the session, the paper presenters and the session rapporteur. Their function and responsibilities can be described as follows:

The session chair introduced the session theme, and gave clear links to the three objectives of the meeting. He/she briefly introduced the paper presenters and the session rapporteur, and was also responsible for keeping the time schedule and guide the discussion. The paper presenters addressed, in addition to key issues of the session subject, also the objectives of the meeting as an integrated part of their scientific presentations. At the end of each session sufficient time was reserved for a discussion on the common objectives formulated for each session. The session rapporteur extracted the key results from the session in respect to the purpose and objectives set out for the meeting. Supported by the session chair he/she stimulated the discussion to achieve a common agreement about needs for research on low flow and drought. The latter was presented in the summary session at the end of the meeting. Following the discussions in the last session the rapporteurs compiled a final session report.

The main outcome of the joint meeting is summarized in this report as a contribution to the IHP-VI program on "Hydrological Extremes" (Theme 2, Focal Area 2.1). The individual session reports present recent research (Presentations), discuss research gaps (Discussion), and future research needs (Recommendations). Finally, the conclusions of the summary session are given (Session 7).

SESSION REPORTS

Session 1: Users requirements and Knowledge Transfer

Chairperson: Siegfried Demuth
Rapporteur: Erik Querner

There were four presentations in the session, which focused on transfer of knowledge. Less was presented on users requirements (as it is a different society).

1.1 Presentations

Alan Gustard presented the achievements and prospects of low flow research within the Northern European FRIEND. Since its inception in 1985 the low flow research group has made a major contribution to establishing research partnerships across Europe, in supporting the development of a pan-European hydrological data base, the European Water Archive (EWA), in carrying out an active research program and transferring the knowledge gained to other regional FRIEND groups around the world. The low flow group was successful in attracting national and international funding which enabled it to grow in size and to develop new regionalization procedures (e.g. river network estimation procedures and visualization methods to monitor the growth and decay of droughts at the European scale). Furthermore, a real time monitoring tool was developed, which might serve as a basis for a European Drought Watch System. In addition to the research projects participants have been active in publishing their work including three participants being awarded the prestigious IAHS Tison award for a paper on drought frequency analysis based on the threshold level approach. Gustard mentioned the often lack of data and knowledge on hydrogeology and the interaction between surface water and groundwater. Especially for the ungauged site it would be helpful to use an index accounting for hydrogeology. An important element of the work within the low flow group is capacity building and education. Many PhD and MSc thesis have been delivered during the course of the project, along with an exchange of students and staff and joint excursions, involving universities and research institutes.

Lena Tallaksen presented the EU project ASTHyDA (Analysis, Synthesis and Transfer of Knowledge and Tools on Hydrological Drought through a European Network). The ASTHyDA project addresses through a consortium of primarily European experts the need for a concise review and dissemination of knowledge and estimation methods for the prediction of streamflow and groundwater in period of water scarcity. Drought is considered to be the least understood of all major natural hazards. The project mainly involves the compilation of a textbook to transfer the knowledge on hydrological droughts. The textbook provides a comprehensive overview of processes and estimation methods for streamflow and groundwater. An important goal of the project was the initiation in 2003 of a European partnership on drought (European Drought Centre), which was formally established at the Bratislava meeting. Within the framework of the project a Mediterranean Expert meeting and a Water Manager Workshop (Montpellier, March 2003) were organized to disseminate the work and receive feedback on the textbook. An International Study course (Wageningen, October 2003) helped to finalize the final version of textbook and to disseminate the work to an academic audience.

Gwyneth Cole of CEH presented an initiative by EurAqua (Network of European Freshwater Research Organizations) to promote the discussion on Europe's approach to droughts. A discussion document entitled: "Towards a European Drought Policy" (EurAqua, 2004), aimed for European policy makers and Water Directors to raise the awareness of drought was presented. The document was triggered off by recent droughts and summarizes a number of recent research projects, studies, workshops and conferences on droughts at a European scale. The economic impact of the 2003 drought in Europe is estimated to be as high as the damage caused by recent floods. The document is based on the extensive experience of the FRIEND low flow group especially gained through the ARIDE project. It was suggested to implement the recommendations in the document.

Mary-Jeanne Adler of the National Institute of Hydrology and Water Management of Romania presented a study on the 2002 and 2003 drought in Romania. It is an extensive study that can assist in planning the use of water resources during future droughts. Water resources are important for Romania, because of the occurrence of water scarcity periods. Water managers need information to base their decision making for water allotment. It is recommended to carry out such a study for the whole Danube Basin.

1.2 Discussion

After the presentations the general discussion was focusing on the need for practical tools to give answers to practical water management questions on drought issues. It was emphasized that it is necessary to close the gap between research and practical water management. As an example the initiative of the International Meuse Commission was given to set up a working group on drought management taking into consideration transboundary aspects[1].

1.3 Recommendations

Recommendations for future work included tele-connections, forecasting, drought propagation, non-stationarity, continuous simulation modeling and hydro-ecology. The success is greatly contributed by having workshops, conferences and joint research projects and recognition. It was recommended that a second edition of the textbook should add more material on semi-arid regions. The organization of workshops and study courses (cross-cutting theme to other FRIEND regional groups) was greatly supported. The textbook as a basis for international study courses could be implemented in an education program of the FRIEND Low Flow Group to support dissemination trough education. The establishment of a virtual European Drought Centre could be done similar to the ESPACE program, and could also act as a platform for co-operation in education (e.g. exchange of students, PhD, MSc, joint excursions).

[1] An international meeting will be held in Heer sur Meuse (B), 15 June 2004.

Session 2: Data and Monitoring

Chairperson: Pavel Miklanek
Rapporteur: Gwyn Rees

Although only two papers were presented in this session, the ensuing discussion was one of the liveliest of the week. In this session report, key points from both papers and the discussion are summarised. These yielded a number of recommendations, which are presented at the end of the report.

2.1 Presentations

Siegfried Demuth, Director of the German IHP Secretariat, gave a presentation on "Hydrological networks as a basis for water resources management". The key points of his presentation were as follows:

- Hydrometeorological data are inadequate and networks are in decline in many, if not most, parts of the world;
- The problem is particularly acute in Africa and South America: regions where, arguably, need is greatest;
- Possible solutions may be achieved through:
  - the application of modern technologies
  - rational network design
  - national, regional and international cooperation (data sharing);
- There is danger, in some quarters, that model output is considered to obviate the need for monitoring.

The second presentation, "Small dams water balance – experimental conditions, data processing & monitoring", by ***Mohamed Boufaroua*** of the Soil and Water Conservation Department of the Ministry of Agriculture, Environment and Water in Tunisia, described:

- Hydrometric data management in Tunisia;
- That 80% freshwater resources in Tunisia is used for agriculture;
- A national plan to construct more that 1000 small dams to meet water needs in the semi-arid part of the country – 600 of which have already been built;
- Of these, 32 "representative" dams have been equipped with automatic data recording which is transmitting data in real-time to a central database;
- That the data are available to national institutes, universities and international organisations enables such groups to work together towards improving hydrological understanding in the country and the region.

2.2 Discussion

Many participants contributed to the discussion at the end of Session 2. The comments were summarized as follows:

- Participants stressed the importance of good quality, long-term hydrometeorological data;
- There is a need for continued monitoring and technical development of hydrometeorological networks to improve data;

- With demand and competition for freshwater resources increasing, problems of water stress are frequent, particularly during periods of low flows and, consequently, there is also a need for the systematic collection of data on artificial influences on river flows (abstractions, discharges, impoundments, etc.); guidelines and standards for collection of such data are required;
- Despite many resolutions and directives, free and unrestricted access to data is still a problem, although access has improved in some countries due to its publication on the WWW;
- Regional and international databases (e.g. FRIEND European Water Archive, and the Global Runoff Data Centre) have helped considerably over the last 10-15 years, but regular updates are required;
- To encourage agencies to invest in monitoring and provide data freely, research community must better demonstrate use of data, the value of the "outputs", and deliver "tools" for management & planning of water resources;
- It is a responsibility of the hydrological research community to influence governments and agencies in our own countries;
- In EU, the implementation of the WFD provides an opportunity to argue/lobby for more resources towards improving hydrological data.
- New measurement technologies may enable agencies to provide data of better quality, but, for many countries, cost is often a limiting factor and such technologies are beneficial only if they provide a cheaper, or an efficiency-saving, alternative;
- Improving data is a particular problem in developing countries, where resources (i.e. financial, qualified staff) are limited; funding agencies must be encouraged to provide long-term support to hydrometric monitoring and capacity building.

2.3 Recommendations

The following recommendations may be distilled from the discussions:

- Continued monitoring and technical development of all hydrometeorological networks is required to improve the data available for hydrological research;
- Funding agencies must be encouraged to provide long-term support to hydrometric monitoring and capacity building, particularly in developing countries;
- Systematic collection of artificial influences data are required to improve the management of water resources during periods of low flows, together with guidelines for doing so;
- Agencies responsible for hydrometeorological data should be encouraged to comply with international resolutions and obligations to enable easier access to data;
- To encourage organisations to provide data, the hydrological research community must better demonstrate use of data, the value of the "outputs", and deliver "tools" for the management and planning of water resources;
- The hydrological research community must take responsibility for influencing governments and agencies on the need for good quality, long-term hydromoeteorological data and the free and unrestricted access to it.

Session 3: Drought patterns and characterization

Chairperson: David Hannah
Rapporteur: Hege Hisdal

In this session five presentations covering a wide spectre of research within the topic of drought patterns and characterisation, were given. The presentations illustrated that at present research is focussed on the applicability of various drought characteristics in different climates and for different purposes such as monitoring, forecasting and water management as well as frequency analysis. Another recent research topic is the regional aspects of drought including drought patterns in time and space and how these are linked to climate, climate variability and river flow regimes. This is especially important in the context of climate change and drought forecasting.

3.1 Presentations

Donna Bower presented a recent paper entitled "Seasonality of river flow regimes – a Western European perspective". It illustrated a multivariate statistical flow regime classification technique applied for Western Europe (Bower *et al.*, 2004). The results are especially useful in identifying spatial and temporal structures in the timing and magnitude of the low flow season, the number of low flow periods in a hydrological year and the duration and rapidity of onset\-cessation of low flows.

The second presentation "Hydrological Drought - a comparative study using daily discharge series from around the world" by ***Anne Fleig*** summarised a master thesis (Fleig, 2004) on comparing the applicability of various low flow and drought characteristics to flow records from different hydrological regimes. Intermittent, perennial and ephemeral streams were included in the data set. A list of recommendations was given evaluating the methods with respect to their applicability for drought studies: depending on regime type, to compare different regimes, and with respect to data requirements and limitations.

In the third presentation "Identification and characterization of drought – Case study in Tunisia" ***Mohamed Boufaroua*** focussed on drought patterns and characteristics in the semi-arid and arid regions of Tunisia, and demonstrated how these patterns can be taken into consideration in water management.

The last presentation by ***Wojciech Jakubowski*** entitled "Nizowka software - new concepts and solutions" illustrated how frequency analysis is influenced by the drought characteristics of a basin. When studying the two drought characteristics drought duration and drought deficit volume, it can often be noticed that the probability distribution contains two peaks. One modelling alternative is to introduce a two-dimensional distribution. The bivariate GP distribution or the bivariate Pearson type III distributions were suggested.

3.2 Discussion and Recommendations

To fill in the gaps in our current knowledge about drought patterns in time and space as well as drought characterisation, we need data. High quality long time series and a sufficient spatial coverage are of uttermost importance. In the context of forecasting and climate variability and change, updated records are needed. Even if a variety of drought

definitions and characteristics exist, there is still a need to characterise droughts for specific purposes, e.g. both agricultural and socio-economic drought characteristics are requested.

Regarding selection of drought events, recommendations on objective procedures are needed, e.g. treatment of summer droughts continuing into a cold winter season. Further, there is still a need for research on extreme value analysis of different drought characteristics, especially how to treat non-stationarity and heterogeneous data.

A severe drought, starting as a precipitation deficit will propagate through the hydrologic cycle, resulting in soil water, ground water and streamflow deficits. Research is still required to investigate the influence of catchment characteristics in the development of a drought in the different parts of the hydrologic cycle.

Even if it is know that specific weather patterns cause droughts, we are still not able to forecast droughts. This is a major research topic. The consequences of climate change to drought patterns in time and space is another area with a gap in current knowledge.

Based on this the following research topics related to drought patterns and characteristics were identified:

- Identification of drought characteristics for specific purposes;
- Selection of drought events and handling non-stationarity in extreme value analysis;
- The link between climate – land surface – hydrological processes. Further knowledge is of vital importance for drought forecasting and climate change effect studies.

Session 4: Processes and Tools

Chairperson: Miriam Fendekova
Rapporteur: Mary-Jane Adler

During Session 4 the major components of water balance were considered. The presentations focused on processes related to low flows in the arid and semi-arid areas such as evaporation and evapotranspiration. In addition the interaction between surface flow and groundwater via base flow was discussed. Three scientific contributions were presented within the session.

4.1 Presentations

Abdelkader El Garouani gave a presentation on "Estimation of regional evapotranspiration and soil moisture conditions using remote sensing data and Geographical Information System – Application in the Asilah region (Morocco) and the lower Medjerda valley (Tunisia)". By monitoring runoff and estimating soil moisture using satellite data (land use/land cover mapping) evapotranspiration and actual evaporation were modelled. ET is an important process during droughts in semi-arid and arid areas where this component represents 80-87% of the water balance. Estimating ET will improve our understanding of river drying in semi-arid areas. To regionalize the ET-ETP relationship (P: potential) different empirical models were applied, trying to identify the most appropriate model for different catchment conditions. For calibration of the models, remote sensing data were used and a GIS cartographic data base was delivered. Land data from meteorological stations were used – mainly temperature and global radiation. Important when using these results to estimate and forecast dry periods are the errors related to the spatial modelling of the process. Sometimes these are greater than the component to be estimated.

The second presentation "Application of the ET algorithm to estimation of groundwater runoff" was presented by ***Edmund Tomaszewski.*** A common method for forecasting low flows is base flow separation. Different methods were evaluated and advantages-disadvantages of each were presented. It is concluded that a new algorithm would be useful, using log-transformed data with the aim to increase the precision in the estimate of the base flow component. The proposed methodology allows a more precise identification of the base flow to be made. A comprehensive application was presented for Poland.

Lies Peters described "Groundwater droughts – some temporal and spatial topics". Another tool to better understand drought process is groundwater modelling. The changes in the frequency distribution of drought deficit and duration as a result of the propagation through the groundwater system were simulated for two different climatic types – sub-humid and semi-arid, using a linear reservoirs approach. Comparing the recharge and discharge distribution for the two climates, the conclusion is that overall the number of droughts decreases in both climate regions, meaning less small droughts and more large droughts. This effect is more pronounced for the semi-arid region, i.e. the effect of the groundwater system is stronger. The effect of non-linearity is to increase the drought duration and decrease drought intensity. Drought deficit mostly increases.

4.2 Discussion

Precise estimation of evapotranspiration is one of the weakest links in water balance calculation. At the same time, evapotranspiration represents one of the most important inputs for drought assessment and prediction. There are many factors, which influence the precision in the estimated or calculated evapotranspiration. Among them, the lack of existing gauging stations plays an important role. These limiting factors are especially important in climatic conditions of arid and semi-arid regions. On the other hand, these regions have an advantage; they are relatively homogeneous and well suited for remote sensing methods. A usable tool for evapotranspiration estimation at the regional scale in arid and semi-arid regions seems to be the utilization of satellite data. Drought propagation through the unsaturated and saturated zone can only be monitored by a dense network of monitoring tools, resulting in long-term observation data. Building and maintenance of such a system can be expensive and resource demanding.

The process of drought propagation differs depending on drought causes, soil and geology, climate and aquifer properties. Up today, methods of analysis and result assessment are not developed and verified sufficiently. Hydrogeological models, including an appropriate soil moisture module are effective tools for studies of drought variation within an aquifer under different boundary conditions. Regarding the behaviour of an aquifer two different types of data series were identified regarding drought, i.e. a seasonal and a multi-seasonal drought. This is an important conclusion, which emphasizes the need to apply different statistical methods to obtain drought characteristics for the two populations of events. It is further important to ensure that there are no anthropogenic influences in the data series generated that will be subject to further statistical analysis.

Gaps in knowledge:

- Lack of methods for more reliable estimation of actual evapotranspiration in different climatic types;
- Relationship between actual/potential evapotranspiration in different regions;
- Drought propagation patterns under different aquifer properties, climatic types and drought causes.

4.3 Recommendations

It is recommended to focus the research on large scale modelling, looking into patterns of atmospheric processes which induce hydrological drought periods within Europe. A better understanding of these processes could lead to the development of instruments for drought forecasting and improved water management at the larger catchment scale. Further recommendations are:

- Verification of possibilities to use remote sensing data for estimation of evapotranspiration at regional scales, utilization of the data gained in GIS;
- Development of automatic procedures for base flow separation from streamflow hydrographs, verification of procedures in catchments with different geometric properties, climatic, hydrological and hydrogeological conditions;
- Development of generic methods for drought propagation patterns under different catchment control, initial and boundary conditions

Session 5: Drought Forecasting, Prediction and Simulation

Chairperson: Lena Tallaksen
Rapporteur: Gwyneth Cole

This session addressed three important topics for the operational management of drought and water resources, namely prediction, simulation and forecasting. The distinction between each approach was stressed by the rapporteur, as reported below. Four excellent presentations were made during this session, three focusing on the statistical prediction of low flow and drought at the ungauged site and one presenting an innovative advance in daily flow simulation for intermittent rivers. There were no presentations on drought forecasting, although some general points were raised during Session 7. The presentation of results from contrasting environments (humid and semi-arid) resulted in a valuable exchange of information and a lively discussion, with all gaining an improved appreciation of the differing requirements and problems in each area. All presenters highlighted gaps in knowledge and made suggestions for future work which are outlined below under each topic.

5.1 Drought Prediction

The estimation of future conditions without reference to a specific time using either statistical or physically based models, possibly in combination with historical data

5.1.1 Presentations

Mohsen Mohseni Saravi, Prof., University of Tehran, Iran, gave a presentation on "Identification of Homogenous Regions for Low Flow Frequency Analysis". This presentation highlighted the scale of the drought problem in semi-arid regions and the difficulties of flow prediction in a data sparse region, with highly intermittent flows. *Saravi* outlined the use of multivariate and CV based tests to identify homogenous regions in a 2658 km^2 study area in Iran for low flow frequency analysis. The main findings were: the log-Pearson III distribution gave the best fit to the 7, 15, 30 and 60 day annual minimum series; component analysis showed that 4 out of 17 variables (area, slope, annual precipitation and % pervious cover) could explain 87.8% of the total variance in 7 and 10-day annual minimum discharges (10 year return period); a CV based test demonstrated that the region was heterogeneous, and multivariate analysis was chosen as the preferred method for determining homogenous regions.

Hege Hisdal, Norwegian Water Resources and Energy Directorate & University of Oslo, presented a paper entitled "Estimation of low flow indices at the ungauged site – the Norwegian experience". This presentation demonstrated the operational importance of accurate determination of low flow indices in Northern Europe. The "common low flow" is used in Norway for legislative purposes (instream flow requirement), as the basis for licensing, and as the starting point for setting residual low flows and ecological instream flow requirements. Different methods for estimating common low flow at the ungauged site were evaluated: 10% mean flow was the simplest, but most inaccurate (overestimating for small catchments, underestimating large catchments); use of analogous gauged catchments was time-consuming and subjective; regression was the preferred method. A new regional regression analysis relating the common low flow directly to catchment

variables, and based on longer flow records and GIS data, did not result in a significant improvement in prediction compared with indirect regression or analogous catchment approaches. The lack of hydrogeological data was felt to be a contributing factor.

Gregor Laaha, Institute Applied Statistics and Computing, Vienna, Austria, presented a study on "Low flow analysis of Austrian catchments". Stream flow data from 325 natural Austrian catchments were used to compare the predictive performance of a number of different methods for estimating Q95. At each gauge Q95, Q95/mean flow, a circular seasonality index based on the mean number of days flow is below Q95 and a measure of the strength of the seasonality were calculated and mapped. Seasonality was found to be a better indicator of homogenous regions than catchment characteristics, with regional regression equations explaining 70% of the variance in Q95. Methods for apportioning Q95 by area for nested catchments and allowing for climate variability when incorporating historic data were presented.

5.1.2 Discussion and Recommendations

Many common issues were raised in the presentations and discussions, as summarized below:

- The different scale/impact of the drought problem in arid and humid regions. The applicability of methods developed for humid regions to semi-arid regions was questioned, due to the differing requirements of drought analysis in each region - in Norway and Austria the main requirement is setting ecological flows, whereas in semi-arid regions it is for determining if there is any water for basic human life;
- A point reiterated by all presenters was the requirement for good quality rainfall, flow, catchment characteristic and ideally soil moisture data. Even in humid regions lack of data is a problem. *Hisdal* highlighted the relatively sparse coverage of Norwegian monitoring stations with good quality data (46 stations for the whole region) and the increased uncertainty of low flow measurement due to poor low flow ratings and unstable sections, with most analysis focusing on the mid-flow range. In Norway there are no soil or geology maps, while in Austria hydrogeology has to be inferred from other mapped variables. It was suggested that limited resources might be better spent on mapping these variables than on developing more complex models. As *Saravi* demonstrated, problems are magnified in semi-arid regions with sparse monitoring networks (e.g. 16 stations with between 7-26 years of data over a 2658 km^2 study area) reflecting a lack of funding, the inaccessibility of terrain and a lack of trained technicians. These networks are often inadequate for monitoring rainfall and flows which are highly irregular in space and time, with much missing or poor quality data and short record lengths. Other problems include a lack of water quality data and the difficulties of modeling frequent zero flows. The use of analogous catchments with longer data records had been considered, but was not adopted due to poor data;
- The cost/benefits of flow gauging were discussed. *Laaha* showed that in Austria one year of continuous stream flow data could significantly improve the flow estimate and outperform sophisticated regression models. Climate variability adjustment using analogous catchments was required with these short records. More than 5 years of continuous flow data had low errors due to climate variability, while spot gauging only slightly improved low flow estimation. In Norway spot gauging was felt to be important for improving and checking the low flow rating;

- Both *Hisdal* and *Saravi* drew attention to the fact that multivariate analysis assumes homogeneity, yet there may be insufficient monitoring stations to adequately divide an area into homogenous regions. It was suggested that definition of regions should be more processed based. *Laaha* found that for Austria, seasonality was a strong indicator of hydrological processes with 8 homogenous regions identified from mapped seasonality indicators;
- A recurring theme was the high intercorrelation of dependent variables in low flow regressions making it difficult to determine the best predictive model and to avoid misleading conclusions;
- A general question was posed as to whether Q95 is the most appropriate index for determining the ecological low flow in the WFD. *Hisdal* responded that it was dangerous to use only one low flow index for all situations and seasons (e.g. common low flow), as species requirements varied throughout the year. *Demuth* explained that in Swiss Law Q95 was regarded as the minimum low flow. Studies in Baden Würtemberg in Germany showed that it was not possible to rely on one procedure for all catchments. *Gustard* referred the meeting to Chapter 10 in the Hydrological Drought textbook (Clausen *et al.*, 2004), which suggests that both simple estimates and complex ecological modeling has its place depending on the situation;
- The operational applicability of the methods presented by *Saravi* was questioned. He explained that this was still at the research stage, although operational agencies had been involved. There was interest in extending the analysis to the whole of Iran, although the karst regions would pose particular problems. The method is being used to identify drought-prone areas, with return period used as an indicator of drought severity;
- *Laaha* was questioned on his method of apportioning Q95 for nested catchments. He confirmed that local adjustment was preferable for optimizing Q95.

5.2 Drought Simulation

The simulation of flows or state variables (e.g. groundwater levels) at an annual, monthly and daily time step, evaluated by its ability to reconstruct the statistical properties of historical time series

5.2.1 Presentations

Hafzullah Aksoy, Istanbul Technical University, presented a study on "Markov chain-based modeling techniques for stochastic generation of daily intermittent stream flows with a focus on recession curves". An innovative method for simulation of daily stream flow hydrographs for intermittent streams using Markov chains was presented. The method divides the flow series into one ascending and two recession sections (above and below the mean flow) fitting a two-parameter gamma distribution to the ascending section and an exponential decay to the recession. A probabilistic two-parameter Markov chain was used to generate the recession from the peak flow value. The simulation was successful in preserving both short and long term flow statistics and the hydrograph shape.

5.2.2 Discussion and Recommendations

The presentation and discussion emphasized the following points:

- The value of continuous simulation for filling in gaps in the data record, for storage-yield analysis and for assessing uncertainties in forecasting and prediction;
- It was agreed that this presentation was a significant advance on existing methods by moving from a monthly to a daily time step and from perennial to intermittent streams. Stochastic modeling using Markov Chains was seen to offer considerable potential with the meeting encouraging the extension of the technique to other types of rivers.

5.3 Forecasting

The estimation of future conditions at a specific time

There were no presentations on this topic but the following points were raised during discussion sessions:

- Medium term forecasting offers the most potential, as droughts are regional events caused by persistent and large scale atmospheric circulation patterns;
- Further research to investigate links with atmospheric circulation and sea temperatures;
- Re-analysis of climatological time series and weather patterns for past drought events;
- Clear identification of user requirements is required when developing forecasting tools;
- Drought forecasting should be part of an early warning system and include real time monitoring. Research is required to determine which are the most important indicators of drought in a region to ensure they are monitored;
- There may be potential in combining predictive and simulation approaches to determine the daily flow hydrograph at an ungauged site for short and medium term flow forecasting.

Session 6: Human impacts on drought

Chairperson: Oldrich Novicky
Rapporteur: Elisabeth Peters

The topic of this session covered the whole range of interaction between human society and drought and can be approached in two ways. First the impact of society on drought can be studied. Second the change in vulnerability of our society to drought, both as a result of changes in our natural environment and as a result of changes within society can be investigated. The session contained examples of both approaches, although examples of the first approach were more numerous. Mainly the first presentation also illustrated the second approach. One of the most important aspects of our changing environment is the climate, which is changed by human impacts, and which subsequently changes our vulnerability to drought. The impact of climate change was therefore discussed in all presentations.

6.1 Presentations

Natasha Carmi (presented by Miriam Fendekova) discussed the impact of the 1998-1999 drought in Palestine and the political and physical background, which determined the impact of this drought. The original presentation scheduled by Fendekova was replaced by a presentation by ***Lotta Blaskovicova*** focusing on hydrological information from Slovakia, which recently was made available at: http://www.shmu.sk/cms/voda/kvantPVnew/kvantita_pv.html. The third presentation by ***Snejana Dakova*** was a detailed overview of low flow and drought problems in Bulgaria. Because of the large variability of climate throughout Bulgaria, the effects of the human impacts (in this case mostly reservoirs and dams) was highly variable. The last presentation by ***Erik Querner*** discussed the effect of climate change and water conservation measures on floods and low flows for a case study in the Netherlands.

6.2 Discussion

Research about human impacts on drought is concentrated on local case studies. This is not surprising considering the high variability of both human impacts and the environment. For example, *Dakova* showed that low flows could both increase and decrease as a result of reservoir construction, because of differences in the natural flow regime, climate and reservoir operation. The range of possible human impacts is very large, but most important appear to be climate change, land use change, construction of reservoirs and abstractions of ground and surface water. Locally, other human impacts can be important. Some examples are changes of the streamflow channel, irrigation, drainage and return flows from sewage plants or leakage from sewer systems. To date, the impact of climate change has been investigated mostly through changes in the average, as three presentations in this session show. However, for drought it is also important to study the changes in variance and persistence in precipitation and temperature, as Schär *et al.* (2004) recently showed. To study the impact of different changes separately, it is necessary to be able to identify the different impacts on observed streamflow. For example naturalised flows are needed to study the impact of climate change.

The presentations in this session were mostly concerned with *water quantity* during low flows and droughts. However, in general the human impact on *water quality* and temperature is equally important and studies investigating the human impact on water quality specifically during drought are rather limited. Often the average is studied rather than the situation during extremes. For studies examining ecological in-stream flow requirements there is a need to consider the whole streamflow regime, rather than only the low flows.

To study vulnerability of society to drought typically a multi-disciplinary approach is needed, in which hydrologists determine the changes in hydrological conditions, but were the impact on society is determined by for example economists and sociologists. This probably explains why this topic was discussed less. The first presentation, however, discussed how conflicting demands and lack of final water agreements influence the vulnerability to drought.

6.3 Recommendations

Despite the rather limited number of presentations, clear needs for further research could be identified:

- *Quantification of human influences and their effects on streamflow regime*. As also stated in Session 2, there is a need to observe the direct artificial influence on the hydrological cycle, for example the amount of water abstracted from ground- and surface water, the amount of return flow from sewage plants and the amount of leakage from and to drainage systems. However, the effects of many human impacts like land use change or changes in the stream bed cannot be identified using observations and need to be inferred from observed streamflow or groundwater levels. Thus there is a clear need for methods to analyse streamflow records with respect to changes as a result of human impacts. This includes not only changes in the average and variance but changes in the whole flow regime. These methods could include statistical methods as well as physically based models, such as those presented by *Querner* in his presentation.
- *Quantification of in-stream flow requirements*. Not only the changes in the flow regime need to be understood, but also the impact of these changes, especially on the ecosystem. In many cases, setting a simple minimum flow requirement is insufficient to secure the existence of a healthy ecosystem in the stream. It is important to know what features of the flow regime are important to ensure a healthy ecosystem. Naturally, this needs to be evaluated in conjunction with other stream and ecosystem conditions, like water quality. Ecosystems already weakened by low water quality or decrease in habitat area, may be much more vulnerable during low streamflow conditions. The need for this type of information has also been identified in the Water Framework Directive.
- *Risk assessment*. This third point is related to the second approach of this session, namely vulnerability of society to drought. Risk is the combination of the probability that an extreme event happens and the impact when it happens. Especially the second step requires a close co-operation between different disciplines. Not only economical damage, but also other types of damage should be included, like for example risk of water borne diseases, soil erosion and ecological damage. A clear example that unexpected losses may occur is the unexpectedly

high number of casualties (approximately 30 000) caused by a combination of heat, drought and soil pollution in the summer of 2003 in Western Europe (CRED, 2004).

- *Climate change in variance and persistence*. As stated above the studies examining the impact of changes in climate should not be limited to the changes in the average but also examine the changes in variance and persistence. Changes in these variables possibly have a larger impact on drought occurrence than the changes in the average.

Session 7 Drought Watch System and Partnership

Chairperson: Henny van Lanen
Rapporteur: Alan Gustard

7.1 European Drought Centre (EDC)

There have been several European projects and workshop reports, which have recommended improving the co-ordination of research and operational activities in order to mitigate the economic, environmental and social impacts of droughts in Europe. These include the Ispra workshop (Vogt & Sommer, 2000), the ARIDE project (Demuth & Stahl, 2001) and the ASTHyDA project (http://drought.uio.no). Following a proposal made at the previous ASTHyDA project meeting in Wageningen it was agreed to establish a European Drought Centre (EDC): a virtual centre for co-ordinating drought activities in Europe. Figure 7.1 illustrates the proposed structure of the centre and figure 7.2 lists some of the activities that could be carried out. It was agreed that although it would focus on European droughts it would encourage participation from surrounding regions e.g. North Africa and the Middle East, and would welcome co-operation with the proposed UNESCO Drought Agency in Southern Africa. A key task for the Centre is to establish the essential European dimension to the Centre that is to clarify the research, operational and economic benefits of working at the European scale.

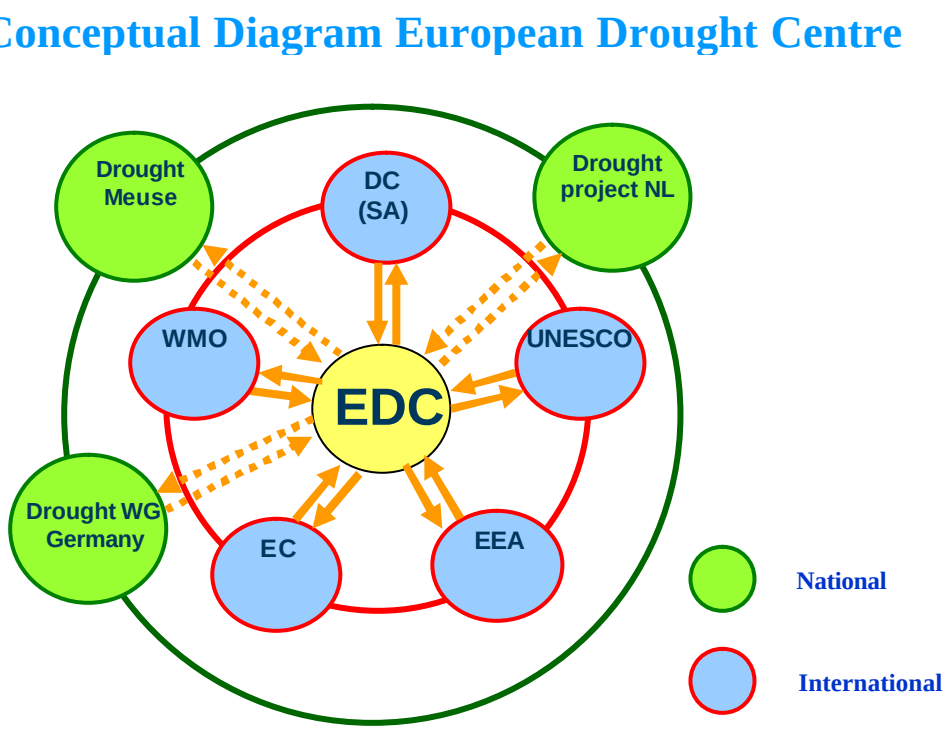

Figure 7.1 Proposed structure of the European Drought Centre (EDC).

7.2 Research Strategy

The importance of building links (but not duplicating research) with related research programmes was identified by a number of participants; including ocean-atmosphere and land surface interaction, agricultural droughts, hydrogeology and hydro-ecology and governance and policy. It was also agreed that the dialogue with operational agencies should continue to be strengthened. Opportunities for co-operation with hydrological organisations in arid and semi-arid countries would be actively pursued. It was recognised that the Northern European Low Flow Group had focussed its activities on drought frequency analysis and regionalisation and this was reflected in the presentations at the meeting. However this is only one sector of drought research and opportunities should be taken to build on the knowledge and experience of the group in related areas, e.g. continuous simulation, river flow forecasting and teleconnections and to identify the user requirements for drought forecasting to compliment the activities of the group in drought prediction.

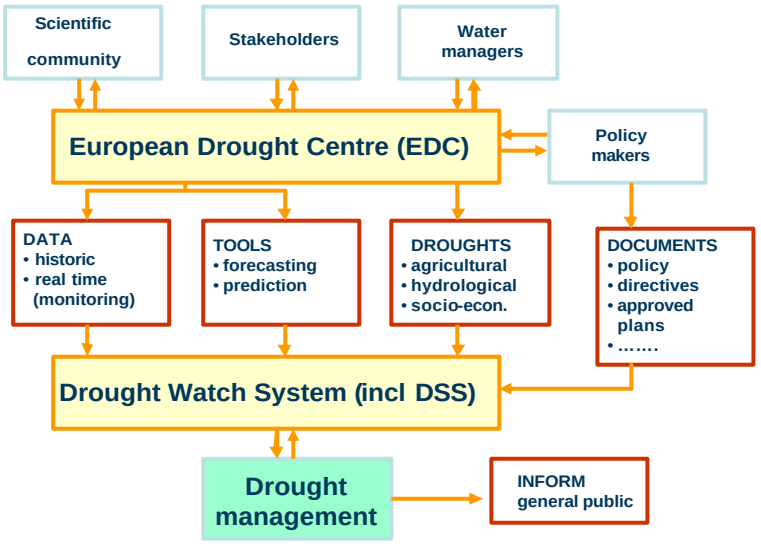

Figure 7.2 Suggested activities of the European Drought Centre (EDC).

7.3 Recommendations

This report has made a number of recommendations including the identification of research gaps, priorities for future research, improved co-operation with operational agencies and the establishment of a European Drought Centre. It is recognised that although some of these recommendations are directly relevant for establishing priorities for Unesco's International Hydrological Programme, many of the recommendations are relevant to the European Commission, Universities, research institutes and operational agencies. It was agreed that participants at the meeting had a responsible to endeavour to implement the recommendations in their own sphere of influence in local, national or international hydrology.

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Northern European FRIEND & AMHY joint Low Flow meeting

Faculty of Natural Science, Comenius University, Bratislava

12-15 May 2004

ANNEX I

MEETING AGENDA

Wednesday, May 12, 2004

14.00 – 15.30: ADMINISTRATIVE MATTERS

14:00-14:10	Opening ceremony, welcome of participants by representative of the Faculty of Natural Sciences, Comenius University in Bratislava
14:10-14:20	Introduction of participants
14:20-14:45	Minutes of previous NE-FRIEND Low Flow meetings (Cape Town, March 2002)
14:45-15:30	International activities (Koblenz, Balwois, EU programs, etc.)
15:30-16:00	Tea break

16.00 – 17.30 SCIENTIFIC MEETING

SESSION 1: USERS' REQUIREMENTS AND KNOWLEDGE TRANSFER

Chairperson: Siegfried Demuth
Rapporteur: Erik Querner

16.00-16.20	GUSTARD Alan: Nineteen years of low flow research in Northern European FRIEND: achievements and prospects
16.20-16.40	TALLAKSEN Lena M. & van LANEN Henny: The ASTHyDA project
16.40-17:00	COLE Gwyneth: Drought policy and the economic impacts of drought across Europe
17:00-17:20	ADLER Mary-Jeanne: Water management during 2002-2003 droughty period in Danube Basin
17:20-17:50	Discussion

Thursday, May 13, 2004

SESSION 2: DATA AND MONITORING

Chairperson: Pavel Miklanek
Rapporteur: Gwyn Rees

09:00-09:20	DEMUTH Siegfried: Hydrological networks as a basis for water resources management
09:20-09.40	BOUFAROUA Mohamed: Small dams water balance – experimental conditions, data processing and modelling
09:40-10:10	Discussion
10:10-10:30	Coffee break

SESSION 3: DROUGHT PATTERNS AND CHARACTERIZATION

Chairperson: David Hannah
Rapporteur: Hege Hisdal

10.30-10.50 BOWER Donna, HANNAH David and McGREGOR Glenn: Seasonality of river flow regimes – a Western European perspective

10.50-11.10 FLEIG Anne, TALLAKSEN Lena M., HISDAL Hege & DEMUTH Siegfried: Hydrological Drought - a comparative study using daily discharge series from around the world

11.10-11.30 BERGAOUI Med, BOUFAROUA Mohamed: Identification and characterization of drought – Case study in Tunisia

11.30-11.50 JAKUBOWSKI Wojciech: Nizowka software - new concepts and solutions

11:50-12:30 Discussion

12:30-14:00 Lunch

SESSION 4: PROCESSES AND TOOLS

Chairperson: Miriam Fendekova
Rapporteur: Mary-Jane Adler

14.00-14.20 EL GAROUANI Abdelkader: Estimation of regional evapotranspiration and soil moisture conditions using remote sensing data and Geographic Information System (GIS) – Application in the Asilah region (Morocco) and the lower Medjerda valley (Tunisia)

14.20-14.40 TOMASZEWSKI Edmund: Application of the ET algorithm to estimation of groundwater runoff

14.40-15.00 PETERS Lies and van LANEN Henny: Groundwater droughts – some temporal and spatial topics

15.00-15.30 Discussion

15:30-15:50 Tea break

15:50-17:00 Group discussions

Social event

Friday, May 14, 2004

SESSION 5: DROUGHT FORECASTING AND PREDICTION

Chairperson: Lena Tallaksen
Rapporteur: Gwyneth Cole

09.00-09.20	SARAVI Mohsen Mohseni: Identification of Homogenous Regions for Low Flow Frequency Analysis
09.20-09.40	HISDAL Hege: Estimation of low flow indices at the ungauged site – the Norwegian experience
09:40-10.00	LAAHA Gregor: Low flow analysis of Austrian catchments
10:00-10:20	AKSOY Hafzullah: Markov chain-based modeling techniques for stochastic generation of daily intermittent streamflow with a focus on recession curves
10:20-10:50	Discussion
10:50-11.10	Coffee break

SESSION 6: HUMAN IMPACTS ON DROUGHT

Chairperson: Oldrich Novicky
Rapporteur: Elizabeth Peters

11.10-11.30	CARMI Natasha: Drought & Climate Change – The Palestinian Experience
11.30-11.50	FENDEKOVA Miriam, NEMETHY Peter and BRUSKOVA Valeria: Groundwater abstraction as a factor of low flow occurrence in selected catchments of Slovakia
11:50-12:10	DAKOVA Snejana: Low Flow and Drought in Bulgaria caused both by climate and human interferences
12:10-12:30	QUERNER Erik: Analysis of low flow conditions resulting from climate change, using the SIMGRO/AlterrAqua modelling tool
12:30-13:00	Discussion
13:00-14:30	Lunch

SESSION 7: DROUGHT WATCH SYSTEM AND PARTNERSHIP

Chairperson: Henny van Lanen
Rapporteur: Alan Gustard

14.30-14.40	van LANEN Henny: Outline
14.40-14.50	TALLAKSEN Lena: Drought Partnership

14.50-15.00	Rapporteur Session 1: Main Findings
15.00-15.10	Rapporteur Session 2: Main Findings
15.10-15.20	Rapporteur Session 3: Main Findings
15:20-15:30	Rapporteur Session 4: Main Findings
15.30-15.40	Rapporteur Session 5: Main Findings
15.40-15.50	Rapporteur Session 6: Main Findings
15:50-16:10	Tea break
16:10-17:00	Discussion and Summarization: Conclusions and Recommendations for UNESCO-IHP report EXTREMES
17:00-17:30	**CLOSING SESSION** Summary of Action points Next meeting

Northern European FRIEND & AMHY joint Low Flow meeting

Faculty of Natural Science, Comenius University, Bratislava

12-15 May 2004

ANNEX II

PARTICIPANTS AT MEETING

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