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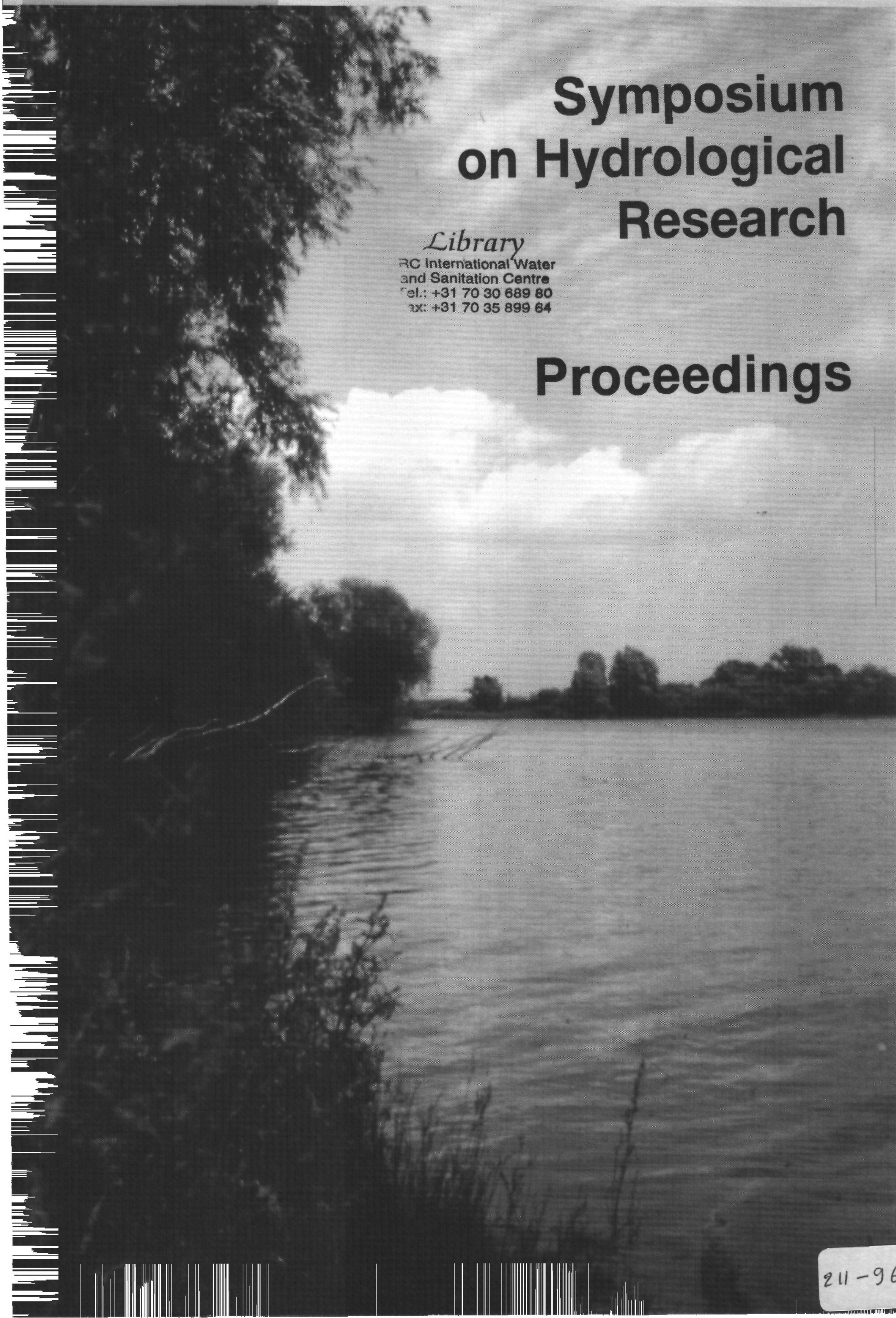

Symposium on Hydrological Research

Proceedings

Netherlands National Committee for the
International Hydrological Programme (IHP) of UNESCO and the
Operational Hydrological Programme (OHP) of WMO

Report
96.1

Symposium on Hydrological Research

within the

International Hydrological Programme (IHP) of

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WMO

Proceedings

Report 96.1

Delft, the Netherlands

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Introduction to the Symposium

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1. Purpose of the Symposium

There are various reasons why the Netherlands National Committee for IHP-OHP has decided to organize a one day Symposium on Hydrological Research in 1995.
First, we like to inform the Netherlands hydrological and meteorological community on IHP-V (1996 - 2001), the fifth phase of the International Hydrological Programme of UNESCO, on OHP, the most important sub-programme of HWRP, the Hydrology and Water Resources Programme of WMO, and on research activities of the CHR, the Commission for the Hydrology of the Rhine basin.
Second, we will focus on potential contributions of Netherlands research institutes and experts to IHP-V and OHP.
Third, during the last phase of IHP and OHP several Netherlands experts were involved in specific projects. They will present their experiences. And finally, the National Committee like to pay special attention to the subject "International co-operation in research" by means of a forum discussion.

The addresses given during the Symposium have been collected in these Proceedings. A summary of the forum discussion, chaired by Mr. J.J. de Visser, Netherlands Permanent Representative with UNESCO, has been added as last part.
We highly appreciate that Dr. A. Szöllösi-Nagy and Dr. A.J. Askew have accepted our invitation to present the headlines of the IHP and HWRP programmes of UNESCO and WMO respectively.
As an introduction to their addresses a short overview is given on the international research organizations and -programmes related with water.
Furthermore, the headlines of former IHP-phases are presented, as well as the focal-points of the Netherlands National Committee during the fourth phase (IHP-IV, 1990-1995).

2. International Research Organizations

Several international non-governmental organisations take care of a world-wide exchange of knowledge and scientific results and promote science and technology through their international networks. Also initiatives to international research programmes are taken, such as the IGBP (International Geosphere-Biosphere Programme) of ICSU, the International Council of Scientific Unions. Figure 1 shows the place of the water sciences and the meteorology in the network of international non-governmental organizations.
As these organizations have hardly financial resources, they look for support from Intergovernmental

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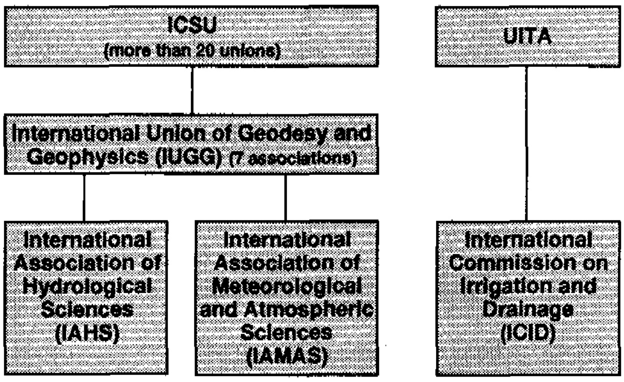

Figure 1. Non-Govermental organisations dealing with waterscience and meteorology
ICSU - International Council of Scientific Unions
UITA - Union of International Technical Associations

Organisations, such as:

- United Nations Educational, Scientific and Cultural Organization (UNESCO);
- United Nations Environment Programme (UNEP);
- United Nations Development Programme (UNDP);
- Organization for Economical Co-operation and Development (OECD);
- World Bank;
- World Meteorological Organization (WMO).

3. International Research Committees and Programmes dealing with Water

In the course of the last decennia several scientific committees were established to analyze water problems and to formulate research needs.
ICSU as well as the UN-agencies UNESCO and WMO have started specific international research programmes in the same period. The most important ones, included the year of beginning, are listed below.

- Scientific Committee on Problems of the Environment (SCOPE) of ICSU - 1967;
- Scientific Committee on Water Research (SCOWAR) of ICSU -1994;
- World Climate Programme (WCP) of WMO and ICSU - 1979;
- International Geophysical and Biological Programme (IGBP) of ICSU - 1989;
- International Hydrological Decade (IHD) of UNESCO
- 1964-1974;
- International Hydrological Programme (IHP) of UNESCO - 1975;
- Hydrological and Water Research Programme (HWRP) of WMO -1988 with as most important sub-programme the Operational Hydrological Programme (OHP).

As one can see, the IHP of UNESCO started in 1975 as a follow-up of a recommendation at the end of International Hydrological Decade in 1974.

4. International Hydrological Decade 1964 - 1974

Because of the dependency of human civilization on water, UNESCO started the International Hydrological Decade (IHD) in 1964. The aim was to investigate available surface- and groundwater resources through study of the processes of the hydrological cycle.
The outcome of efforts in many countries was wide, among others hydrological maps of Africa, Arabia, Latin America and Asia were produced, regional water balances were calculated and technical and post-university courses on hydrology and water resources were initiated.

5. International Hydrological Programme 1975 - 1995

In the beginning of the seventies it became clear that economical and social activities in the world reinforced the variations in the hydrological cycle, and that there showed up an increased pressure of urbanization and population growth on the fresh water reserves.
Moreover, there was a worldwide recognition that the application of scientific knowledge for the solution of many practical problems in the field of water resources management should be strengthened.
These facts and further considerations as result of the preceding Decade have led to the start of the International Hydrological Programme in 1975. The main goal was to contribute to the solution of problems in countries:

- at different latitudes and climatological zones,
- and different economical and technical development.

The execution of the programme is based on:

- a network of National Committees in many countries;
- co-operation with non-governmental organizations (especially IAHS);
- co-operation with the HWRP (OHP) of WMO.

There is a wide range of programme-activities, such as workshops, symposia, problem analysis by rapporteurs, state-of-the-art reports, case-studies, guidelines, manuals and other scientific or technical reports as output of international working groups.

During the first phase of IHP (1975 - 1980), the programme-activities were directed on:

- estimation parameters of Engineering Projects;
- hydrological aspects of periods of drought;
- human impact on hydrological cycle;
- hydrological problems because of production of energy;
- social-economical aspects of urban hydrology;
- pollution and protection of water resources;
- land subsidence because of groundwater withdrawal.

The programme of IHP-II (1981 - 1983) was structured along four main sections:

A. Scientific projects related with four major fields: hydrological processes, hydrological parameters, influence of man on the hydrological regime, assessment and management of water resources.
B. Education and training.
C. Awareness of the public, planners and decision-makers.
D. Aspects of infrastructures in the field of water resources, including distribution of scientific and technical information.

In the period 1984 - 1989 the activities of IHP-III were directed on a broad scope of 18 themes.

Without going into detail on the various themes and projects of IHP-IV (1990 - 1995), it can be stated that all are dealing with the leading subject of this phase: sustainable development in a changing environment. Attention is given to hydrological research as well as to management of water resources and education and training.
Special mention is made of the contribution of IHP-IV to the actual issue of climate change through the project: impact of a possible climate change on the distribution of water resources in time and space.

The Netherlands National Committee selected the following themes and projects of IHP-IV as focal points for its activities:

- atmosphere - vegetation - soil - interactions;
- humid tropics;
- hydrological consequences of climate change
  * sea change
  * discharge of large rivers (Rhine, Meuse);
- ecological recovery of large rivers (Rhine, Danube);
- salt water intrusion from the sea;
- urban hydrology;
- education and training
  * especially IHE - Delft, ITC Enschede and the Netherlands universities are involved in this item.

Concerning IHP-V and the newest OHP-programme the National Committee will also select a number of themes and projects to focus the Netherlands input. The interests of the scientific community and of hydrological and meteorological services will play a crucial role in the selection-process.
For more information on the headlines of IHP-V and OHP it is referred to the following addresses of Dr. Szöllösi-Nagy and Dr. Askew.

,Outline of IHP-V

Andras Szöllösi-Nagy
UNESCO, Paris

1. Introduction

Mr. Chairman,
Ladies and Gentlemen,

It is a great honour to address you this morning and report to you on the preparations for launching the fifth phase of IHP which will cover the period 1996-2001. Indeed, in a few days time IHP-V will commence. Therefore, it is particularly opportune to meet representatives of the Dutch hydrological community and to discuss how to continue a very successful collaboration. The Netherlands has always been one of the key players of IHP and I am very glad to see, this meeting is a living example, that it will remain the same in the future as well.

Access to water is considered a basic human right. But is there enough water to go round? Is water indeed a free commodity which is available in an unlimited quantity? It certainly is not. This recognition led, some three decades ago, to the launching of the International Hydrological Decade of UNESCO with the basic objective of assessing the availability of water at various scales, from regional to global. The Decade came up with some very basic data that are still widely used in characterizing the global water situation. Although there are some refinements the basics are still valid, such as 97 and a half per cent of all water on earth is salt water, primarily in the oceans. The remaining 2.5 per cent is fresh water, almost all of which is stored in the ice caps of Antarctica and Greenland and as shallow ground water. The most accessible water resource for human and ecosystem use is the fresh water available in lakes, reservoirs and rivers. This amounts to only 0.26 per cent of the total amount of freshwater storage or 0.007 per cent of all water on Earth.

Clearly, fresh water is, although renewable, a very limited and vulnerable resource.

This was recognized well before the scientific circles upon whose recommendations UNESCO, when the Decade ended, continued its involvement in freshwater resources by launching the International Hydrological Programme. The importance of water came through the UNCED process as well. It certainly is not an accident that Chapter 18, which is devoted to the protection of the quality and supply of freshwater resources, is the lengthiest of all chapters. Of course, it is not the length but rather the content that determines the importance of the document. Contentwise Chapter 18 is indeed a very remarkable document as it sets the path for the application of integrated approaches to the development, management and use of water resources.

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Of the seven programme areas identified for the freshwater sector, IHP is directly involved in five areas ranging from water resources assessment to the impacts of climate change on water resources.

While speaking of assessment I would like to mention that, as follow-up to UNCED, the UN Commission for Sustainable Development decided two years ago to launch a special project on the Comprehensive Assessment of the Freshwater Resources of the World and invited governments and various UN Agencies to take part in the study. UNESCO's IHP, together with the World Meteorological Organization, was made responsible for the part on assessing the supply, availability and use of the World's water resources. This contribution is essentially based upon a major international research effort conducted by IHP over the past six years entitled "World Water Resources at the Beginning of the XXIth Century" the results of which will soon be published in a series of monographs.
As you will recall the 28th session of the General Conference approved the continuation of the International Hydrological Programme that will lead us into the next Century. The preparations for the Fifth Phase started quite some time ago, in fact before the Rio conference, and over the past four years an extremely wide consultation process has taken place for assisting the design of the programme that, as you know, is the only science and education programme on freshwater resources within the United Nations system. This phase will be devoted to "Hydrology and Water Resources Development in a Vulnerable Environment" and will basically be centred around four principal areas:

2. The role of scales in hydrological processes

The *first* deals with the role of *scales* in different earth processes including scale transitions, down-scaling and up-scaling. Understanding the complex interactions of the hydrological and biochemical cycles is of prime importance for both their quantitative and qualitative role which must be understood at global, regional and basin scales with all the exchanges and interactions taking place between these scales. Each has specific characteristics. The climatic zones of the humid tropics and the arid and semi-arid regions are quite different, for example, in terms of the characteristics of their cycles and thus require very different water and land management approaches from those developed for, and used in temperate zones. We are far from being able to predict the impact of possible climate change on the spatial and temporal distribution of water resources in different parts of the world and at different time scales.

We are still in the scenario business from doomsday to nothing-will-happen.
Hydrology plays an important, if not determining, role in the change as its land phase represents a major feed back in the climate system. Still, if someone looks at how this phase is generally handled in global scale models the picture is rather disturbing. Areas of continental size are represented by simple elementary reservoirs. Today the uncertainties and risks associated with different climate change scenarios are still too great, not only due to our limited understanding but also due to the very limited data available. There are continents where there are less hydrological data than in a medium-sized industrialized country.
Therefore, it is an extremely important mission to build up and *maintain* endogenous water science capacities in the developing world. This is not only a moral obligation but also a rational *must*. Take, for example, Africa, where the hydrological capacity is less than it was fifteen years ago. There are more data on the hydrology of Africa outside the continent than inside. So, how can we talk of understanding and modelling global processes if the sample data sets refer almost exclusively to the developed world?
Any conclusion drawn from such data is necessarily biased and subject to huge uncertainties. IHP plays a role here to assist focusing our efforts to changing this bad situation.

3. Vulnerability of the environment

The *second* area is that of the vulnerability of the environment. As the carrying capacity of the environment is increasingly stressed due to the growing needs of the growing population and improper use of the resources, the vulnerability of the environment also increases.
As a result of rapid population growth more and more land is being taken for agriculture, urbanization and infrastructural development. Large scale deforestation often followed by improper land use practices leads to increasing stresses on the environment, often exceeding its absorptive capacity. It is a fact that highly productive land, especially in the humid tropics, is endangered by erosion. Downstream users suffer from increased suspended load and sedimentation. Reservoir capacities are under strain. Land use is a big problem that affects the pathways and partitioning into which precipitation is transformed into surface runoff, soil moisture, evaporation and ground water. Drainage of wetlands, river training, reduction of flood plain areas also cause significant changes. Therefore, river wetland and ecosystem re-vitalization is an important area for the future for IHP.

I should also mention the degradation of groundwater resources due to over extraction and contamination. In this respect research dealing with the unsaturated zone is far from sufficient. In the final analysis what happens in the unsaturated zone determines what happens to the hydrological cycle. Although contamination may originate at the land surface, its migration is greatly affected by processes occurring in the unsaturated zone. Ground water is particularly vulnerable in coastal regions because of highly concentrated populations and extreme local exploitation. Small islands are under threat. The long-term impact of destroying the peculiar freshwater lenses there is irreversible. As urbanization and industrialization have expanded, so modern chemical compounds have made their way to ground water. Agricultural practices generate non-point contaminants including inorganic constituents as well as organic compounds which put the groundwater resources at high risk — the signs are already around us. Ground water is to be given the greatest protection - and this will indeed be the No. 1 priority of IHP during the forthcoming six years.

4. Integrated water resources management

The *third* area of importance is that of *integrated water resources management* which as part and parcel of river basin development accommodates physical, economical and social linkages and interactions over different time scales for different climatic zones.
I have already mentioned the striking difference between technologies needed under temperate vs. humid and arid climatic zones. Considering that countries within the humid tropics, arid and semi-arid zones will contain nearly 70 per cent of the total world population of the estimated 6.5 billion by the year 2000, special emphasis should be given to their water research and management programmes.
Development in the arid and semi-arid regions is limited by the scarcity of water resources. With the high population growth rates of almost all the countries in those regions, this situation could lead to a serious water crisis in the coming years and to possible conflicts in the case of shared water resources.
The final statistics I am going to quote are in the urban context, since it has also been estimated that by the year 2000, half of the world population will be living in urban areas. As a result of this large concentration of humanity there are changes that are bound to occur in the urban environment, both in its physical and socio-economic aspects.
Only about half of the urban population in these countries has access to sewage disposal. Most of the existing collecting systems discharge directly into the receiving waters without any treatment. This vulnerable environment requires special attention and the solution of such complex and interdisciplinary problems indeed calls for integrated water resources management.
Water as a scarce and commonly shared resource may become, as I have mentioned several times, the subject of conflict. This may range from conflicts between different use and users of water at the local level up to major political situations around international water systems. Conflicts over transboundary water systems (rivers, lakes, aquifers) have already occurred in the past and are likely to intensify in the future accompanying the increasing water stress. In the majority of cases the conflicts have a strong cultural component, stemming from the different perceptions of the value of water under different socio-cultural environments. Water resources projects needed for socio-economic development and the resulting environmental changes are inseparable. IHP has a special project in this regard together with de Decade for Cultural Development.

5. Education, training and transfer of knowledge, information and technology

The *fourth* and last area I am going to discuss briefly is education, training and the transfer of knowledge. Research and education enjoy the same Yin Yang relationship as environment and professional training at all levels has become universally accepted. It is strongly believed that we should encourage the internationalization of education and training and co-operate as much as possible with international, regional or national human reserve development programmes in order to help integrated river basin development become a reality. Of course, education must be considered in a larger context. We are all challenged here: How to put water into the minds of people? It should involve the transfer of knowledge at all levels, otherwise there is no way of solving the emerging water problems, particularly in the developing world. Education is a cross-cutting theme in all the IHP activities foreseen, research included.

6. The need for co-operating partners

Ladies and Gentlemen,

IHP-V, being a science and education programme at global level, covers a wide spectrum of planned activities. The execution of this ambitious programme requires strong co-operation both intellectually and financially. As the range of activities envisaged for IHP-V is far too large for execution by UNESCO alone there

is a strong need for *Co-operating Partners* who will take part in the programme execution both intellectually *and* financially. It is envisaged that national and international funds earmarked for funding national research and education programmes in hydrology will also be mobilized to achieve the goals of IHP. A number of large-scale activities can only be conducted if external funding from national and international donor agencies contribute to their execution. As IHP, an intergovernmental programma, is the common denominator of the national governmental hydrology and water resources research and education programmes it is expected that the national efforts will be channelled into the international effort by earmarking, to the extent possible, national activities and funds for inclusion in the international ones.
IHP should be a two-way street on a give and take basis. Unless it is given the recognition it deserves by adequate funding the IHP programme will soon become a one way street, if not a dead end. Given the magnitude of the world's water problems, particularly in the developing countries, this would be a fatal mistake with global consequences especially if one considers the alarming scenarios outlined for the not too distant future.

Finally, Mr. Chairman, let me emphasize once more: Water is going to be the issue of the next century as the ultimate resource and as a potential source of conflict. Conflict over water has already begun and we all have our responsibility to avoid the aggravation of the situation and to achieve a less risky world. UNESCO has a lot to do in this regard. President Kennedey once said: "Anybody who can solve the problems of water will be worthy of two Nobel Prizes, one for peace and one for science". We can only hope that with the strong involvement of the Dutch hydrologists IHP will be one of the candidates.

Land use and hydrology in the humid tropics: problems and priorities for research

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Extended summary

Despite widespread concern and increased international efforts at conservation, the world's tropical forests continue to disappear at an alarming rate. Vivid descriptions of the environmental havoc wrought by 'deforestation' have led many to believe that tropical forest alteration or removal will automatically cause: major floods, the choking of rivers, reservoirs, irrigation channels and coral reefs with sediment; lower water yields of springs and streams; lower and more erratic rainfall and hence 'desertification', etc. Hamilton & King (1983) and Bruijnzeel (1990) have shown that apparently conflicting views of the role of various land-use types with regard to hydrology and sedimentation in the humid tropics can be reconciled by describing the impacts of specific activities and types of conversion, rather than by lumping them under such general terms as 'deforestation'.

Forest subject to occasional fire (be it 'natural' or in the context of shifting cultivation), cyclones, or selective logging, may recover more or less to their previous state if left alone for a sufficiently long period. Such disturbances may therefore be ranked as being of intermediate intensity. The environmental impacts of various logging regimes have been reviewed in detail by Bruijnzeel (1992). Vast tracts of tropical forest are being subjected to slash and burn agriculture or converted to livestock ranches, extractive tree plantations (rubber, oil palm, cocoa) and, to a lesser extent, forest plantations, settlements, and mining. These must all be considered as high intensity perturbations. The associated hydrological changes have been discussed in detail by Bruijnzeel (1990), whereas various specific aspects (e.g. the water and nutrient dynamics of tropical montane 'cloud' forests; the hydrology of fast-growing plantations; the possible changes in rainfall after 'deforestation' and soil fertility aspects) have been dealt with by Bruijnzeel & Proctor (1995); Bruijnzeel (1996a), (1996b) and (1995), respectively.

One overall conclusion drawn in these reviews is that wise management of natural resources in the humid tropics is chiefly a matter of putting into practice what is known already, rather than requiring massive new research efforts. Nevertheless, four major problem areas were identified in which further research is particularly needed, including:

(1) Effects of large-scale forest conversion on regional rainfall patterns, particularly under maritime (as opposed to continental) tropical conditions;

(2) The impact on total and seasonal water yield when

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reforesting degraded grassland with fast-growing trees (Acacia, Eucalyptus, Pinus spp.) for different combinations of soil type and rainfall regime; a related aspect concerns the maintenance of soil fertility, particularly in the case of nutrient demanding hardwoods grown in short rotations on poor soils; idem for a range of agroforestry systems;

(3) The hydrological significance of tropical montane 'cloud' forests and the determination of the potentially adverse effect on water yield after clearance for agricultural purposes (temperate vegetable cropping, pasture);

(4) The spatial and temporal dynamics of sediment transport in humid tropical landscapes, including 'highland-lowland' interactions;

The time is ripe for tropical hydrologists to join hands with ecologists, soil scientists and geomorphologists. Particular emphasis needs to be placed on the integration of process research and physically-based modelling exercises within an overall catchment hydrological context so as to facilitate the integration of the various disciplines at different levels of scale. A plea is made to concentrate future research efforts at a relatively small number of well-researched locations joined together in a pan-tropical network that captures the chief environmental variability encountered in the humid tropics. It is proposed that the coordination of such an international network be handled through, for instance, the Humid Tropics Programme within UNESCO's International Hydrological Programme.

At any rate, the continued rapid changes in land use in the humid tropics, coupled with steady improvements in equipment, data availability (including remotely sensed data) and computational facilities, guarantee that there are exciting timesahead for tropical hydrologists.

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The Netherlands activities in the field of administrative-hydrological research

Hans Wessel
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1. Introduction

This presentation of IHP activities in the Netherlands focusses on administrative-hydrological research. The target of this presentation is to describe the Dutch input into the Fourth Phase of the IHP (1989-1995) and to look ahead to the contribution which is intended for the Fifth Phase (1995-2001). This concentration on these two phases does not have the intention to ignore contributions to the program made under other phases. Nor does it want to understate the importance of the many contributions in this field made by Dutch authors to conferences, workshops and symposia, not listed in this presentation.
But before dealing with the more specific contributions, largely made by the IHE and the RBA Centre, I like to present impressions of the state of the art in the Netherlands in general, on the water related administrative research in this country. These impresssions are based on material which was collected by miss Chantal Hendriks, who addressed the larger part of Dutch universities and research institutes*.

2. Administrative-hydrological research

During many years in The Netherlands activities have been performed in the field of administrative-hydrological research. This research can briefly be presented in three categories:

1. Legal studies
2. Policy/institutinal studies
3. Interdisciplinary administrative studies

2.1. Legal studies

Most of the administrative research on water bears a legal character. In the Netherlands situated at the Delta of four rivers, water management is of utmost important This water management needs sound administrative structures like the waterboards and good laws to manage effectively and on the principle of equity.
The laws have to be updated and many studies appear which elude the laws or propose changes to be made.

2.2. Policy/institutional studies

In recent years also studies in public administration have emerged. They are dedicated to such topics as evaluation of laws and institutions and the implementation of policy. Some studies have the character of policy analysis.

** Reactions were received from the following universities and institutes: IHE, TUD (RBA Centre, CT and SEPA), Twente U, Wageningen U (2x), Leyden U (2x), Utrecht U 9 (3x), KUB (Tilburg), Groningen. Not included are Amsterdam (2x), Maastricht and Nijmegen (2x).*

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Apart from the studies by universities and other outside institutions, the policy studies made by the governmental departments should be mentioned. From these we mention those of the National Environmental Policy Plan (NMP), and of the 3d Policy Document on Water.

2.3. Interdisciplinary administrative studies
With the approach of the area of integrated water management, awareness has risen to combine legal and policy studies closer to hydrological research. Building models for river management or decision support systems nowadays intends to include legal and administrative data, restrictions and instruments. At Delft University of Technology there exists a Working Group on Integrated Water Management, formerly chaired by prof. Van Dam and at present by me.
Interdisciplinarity has also been fostered by two other types of studies such as environmental and nature conservation-types of studies and disaster-related studies.
The study of water-related problems has been influenced by the importance of problems connected to the environment and nature conservation. Studies on the management of flood plains have been conducted at Leyden and Utrecht University. Groundwater studies have been made at the Universities of Utrecht and Twente.
Also studies have been made about the heighthening of the dikes, like those of the Boertien 1 Commission.
Disasters such as the Delta-flood of 1953 have given rise to policy studies on the Eastern Scheldt. Also the recent disasters of the flooding of the Meuse and the evacuation of part of the polders on the Lower Rhine have given rise to studies, like those of the Boertien 2 Commission.

3. Presentation by Grijns en Wisserhof

Already in 1992, Mrs. Lambert Grijns and Johan Wisserhof collected information on all types of water related research, among these also information on the present topic.
In their report they mention that especially in the Netherlands in order to deal with problems in integrated water management specific fields of interdisciplinarity are developing, such as public administration and systems and policy analysis.
Their task is to guide the right types of organization and financing systems and also instruments, such as standards-setting.
They had found expertise in public administration at University of Twente, Utrecht University and Delft University of Technology.

4. Present data

At present the situation has changed somewhat. Recent data (which concentrate on fresh water studies) show that more groups at various universities have entered the field of water-related administrative research.
For *legal studies* the centre of gravity is at Utrecht university; also at Rotterdam university many activities are developing.
Attention is mostly given to water law in general.
At Rotterdam University we also find a specialisation on liability for water pollution. Attention to the history of water law and waterboards is given at Leyden University. For the *policy and institutional oriented studies* mentioning should be made of Utrecht and Twente University. Emerging fields of attention within this discipline are the study of networks and of policy instruments. At Delft attention is given to policy analysis. At different places studies have been made of institutional aspects. Here we find the special attention given by IHE to capacity building.

At Delft university much attention is given to *interdisciplinary* and comparative studies both of a legal and public administration-type, such as needed for studying integrated water management. This field of research is covered by Wageningen, Utrecht, Leyden, Delft and Rotterdam. Many studies are mainly problem-oriented, partly to themes, partly to objects, such as rivers or river basins.
At Rotterdam university again attention is given to clean technology. As far as rivers are concerned attention is awakening for integrated river basin approach studies. Studies on the Rhine have been performed by Universities of Utrecht, Rotterdam and Delft. The Meuse has been studied by Rotterdam and Delft. On the Scheldt the following universities made contributions: Rotterdam, Wageningen and Delft. Studies have been made of transboundary water pollution by Rotterdam and Delft University. Studies on small brooks have been performed at Leyden and at Tilburg. Studies on wetlands at Leyden and Utrecht.
Areas endangered by the polluted rivers are the North Sea, as part of the North East Atlantic and the Waddensea nature area. Studies on these topics have been performed at Rotterdam, Groningen and Utrecht. The management of large waters has been studied at Utrecht University.

5. Foreign language

Most legal studies and a large part of the policy studies are conducted on Dutch problems in Dutch language. This is the case at Tilburg, Leyden, Utrecht and at TUD.

But also articles in foreign languages appear, most of them in English. Some of them are about the Netherlands, others have a wider perspective. Publications in the English language are mainly distributed by IHE, RBA Centre, Twente, Wageningen, Utrecht and Rotterdam (3).

6. Comparative studies

During the last years administrative studies on problems in other countries have appeared. Some of them are of a comparative nature. A growing number of Dutch universities is contributing in this field. Among them are Twente, Utrecht, Delft and Rotterdam. Sometimes only a foreign country is studied. This is the case with legal studies at Wageningen University on irrigation management in Bali and Sri Lanka.

7. Contributions to the IHP-programmes

7.1. Activities of IHE

The IHE (which stands for International Institute for Infrastructural, Hydraulic and Environmental Engineering) is a large important Institute mainly directed towards the training of people from abroad. Besides this they do research and stimulate the development of the administrative-hydrological research. They took an important share in the Dublin conference by organizing a preliminary symposium. The papers and proceedings have been published as IHE-report nr. 24 as "A strategy for Water Sector Capacity Building". Afterwards they held another important symposium.

As to the fifth phase they intend to contribute to Theme 4: International water systems - Conflict analysis and resolution and to project 4.3 Non-structural measures for water management problems. They also have planned to contribute to theme 8: Transfer of knowledge, information and technology (especially public awareness issues related to hydrology).

7.2. Activities of Wageningen Agricultural University

In Wageningen many groups are active in IHP-programs on other topics. An activity which was carried out under the IHP-IV programme (subprogram E with connections to M-M-2: The use of internationally available information systems), was a course on decision support techniques called "Multicriteria Analysis in Water Resources Management" organised by prof. dr. J.J. Bogardi (Wageningen Agricultural University) and prof. dr. H. Nachtnebel (University of Technology, Vienna).

7.3. Activities of RBA Centre

At the Delft University of Technology in 1989 the RBA Centre was founded which has conducted several interesting studies and is participating in various international water oriented research projects. The Centre, of which I am the Director, started at the Faculty of Technical Social Sciences, but was transferred to the Faculty of Civil Engineering on January 1 1995. Also this year a project Manager was nominated, Dr. Erik Mostert. Among the current projects are 4 basin studies on the rivers: Rhine, Danube, Meuse and Scheldt. And one comparative project: Eurowater, comparing the water management in France, Germany, England, Portugal and The Netherlands. In 1996 another comparative project will be started by the same team, concerning the European water management needs for the next century, called Water 21. Already in 1992 the exploratory study of Grijns and Wisserhof on trends in national and international water-related research was completed.
In 1990 a Tempus project was started along with a series of Rhine-Danube Workshops. Main participants were the TU Budapest (prof. Ijjas), the University of Karlsruhe (prof. Hahn) and the RBA Centre. The project was supported by the universities of Wageningen (Bogardi), Vienna, Eötvös Lorånd Univ. Budapest (prof. Bandi), Baja, Novi Sad, Belgrade, Sarajewo and Timosoara. During 4 years six Rhine-Danube workshops were held. Under the Tempus project many exchanges were performed, bringing more than 50 mainly Hungarian researchers and students to the RBA Centre, where they wrote many exploratory and descriptive and some analytical studies on the water management in these river basins.
Thus a firm basis is laid for more analytical and synthetic studies to be performed in future.
In the past years the RBA Centre has contributed to theme M.5-2 (Cooperation in the management of international water systems) by organizing a Symposium on "Transboundary river basin management and sustainable development" held at Delft and Rotterdam on May 18-22 1992.
The proceedings of this symposium were printed at Unesco, Paris as a contribution to the Series on Technical Documents on Hydrology. At present one Ph.D. thesis is being prepared on Cooperation in river basins.
In coming years the RBA Centre intends to contribute to the Themes 2 (2.3. Interactions between river systems, flood plains and wetlands), 4 (4.1. International water systems; 4.3 Non structural measures for water managment problems), and 5 (water resources managment for sustainable development in arid and semi arid zones) by Ph.D. theses of AIO's and maybe some workshops on a more modest scale as the contributions coming from IHE.

8. Conclusions

In the past and still at present administrative-hydrological input to the IHP is mainly given by the IHE and the RBA Centre. Given the contributions listed from different universities mentioned above, there is s strong potential to be motivated to contribute to the IHP activities as well.
My present contribution was intended to be an incentive to such future activities.

Groundwater Monitoring and Modelling studies: the Netherlands contribution to IHP

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1. Introduction

Groundwater accounts for over 95% of global useable fresh water resources and is uniquely suited for drinking water. In the dry environments it is used in vast quantities for irrigating crops. Moreover it plays an important role in maintaining streamflow and wetlands. Therefore groundwater is key factor in preserving public health, agricultural food production and terrestrial and aquatic ecosystems. In many areas in the world groundwater resources are at risk because of population growth and changing environmental conditions. Adequate groundwater management is a prerequisite to prevent undesired situations, or to restore these in case of degradation. Groundwater monitoring and modelling are essential, and inseparable bounded parts of sound groundwater management studies. Therefore UNESCO stimulates in the International Hydrological Program (IHP) international scientific cooperative activities aiming at: (1) to improve knowledge of hydrological processes and associated groundwater modelling, and (2) to promote and to provide methodologies, e.g. groundwater monitoring procedures, for the assessment of groundwater resources (UNESCO, 1990).
In this paper two projects, to which the Wageningen Agricultural University has contributed, will be presented.
In the first part a framework for groundwater monitoring in (semi-)arid regions is described which has been elaborated by a team of experts from all over the world (IHP-IV M-1-1b).
In the second part some results of physically-based groundwater models are given, which are being developed and applied on a catchment scale to analyze natural and man-induced drought in Northwest and Central Europe (FRIEND, IHP-IV H-5-5).

2. Groundwater monitoring

Hydrological processes are highly variable in space and time. Data collection over all scales is difficult and expensive. Nevertheless data need to be gathered to provide the basis for understanding hydrological systems and to identify changes in the regional and global environments.

The IHP Monitoring project (IHP-IV M-1-1b) aims at the (semi-)arid regions because availability of water is (extremely) low, and the demand rises tremendously if the population increases. This easily can lead to an undesired situation (Fig. 1). In the project two different types of monitoring activities are distinguished, namely background monitoring and specific monitoring (Van Lanen, 1996).

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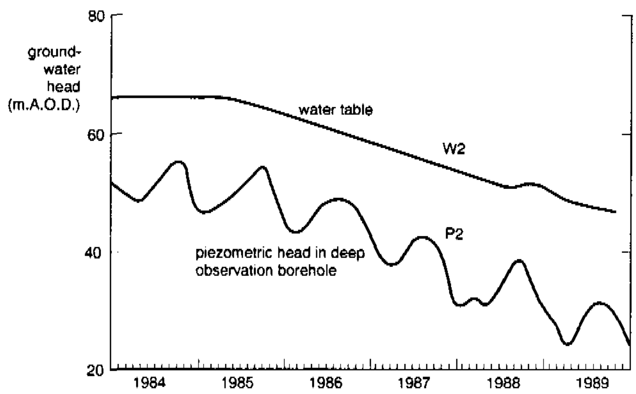


Figure 1. Decline of groundwater heads in Gujarat, Western India due to the over-exploitation of an alluvial aquifer (Rushton, 1996)

Background monitoring

Background monitoring is introduced because people need to start monitoring before significant exploitation of groundwater resources occurs with probably detrimental effects. Background monitoring is characterized by large areas and no significant abstraction (low technology). The objective of this monitoring is to identify the present state of the aquifer. It provides the initial conditions prior to significant groundwater development and gives the people data for future discussions on possible over-exploitation.

Before any groundwater monitoring can start the objectives to be derived from the national land and water policy must be clear. In the upper block of Figure 2 the main steps of the pre-monitoring investigations are presented. If groundwater monitoring is required, basic aspects of the area (e.g. a hydrogeological region), such

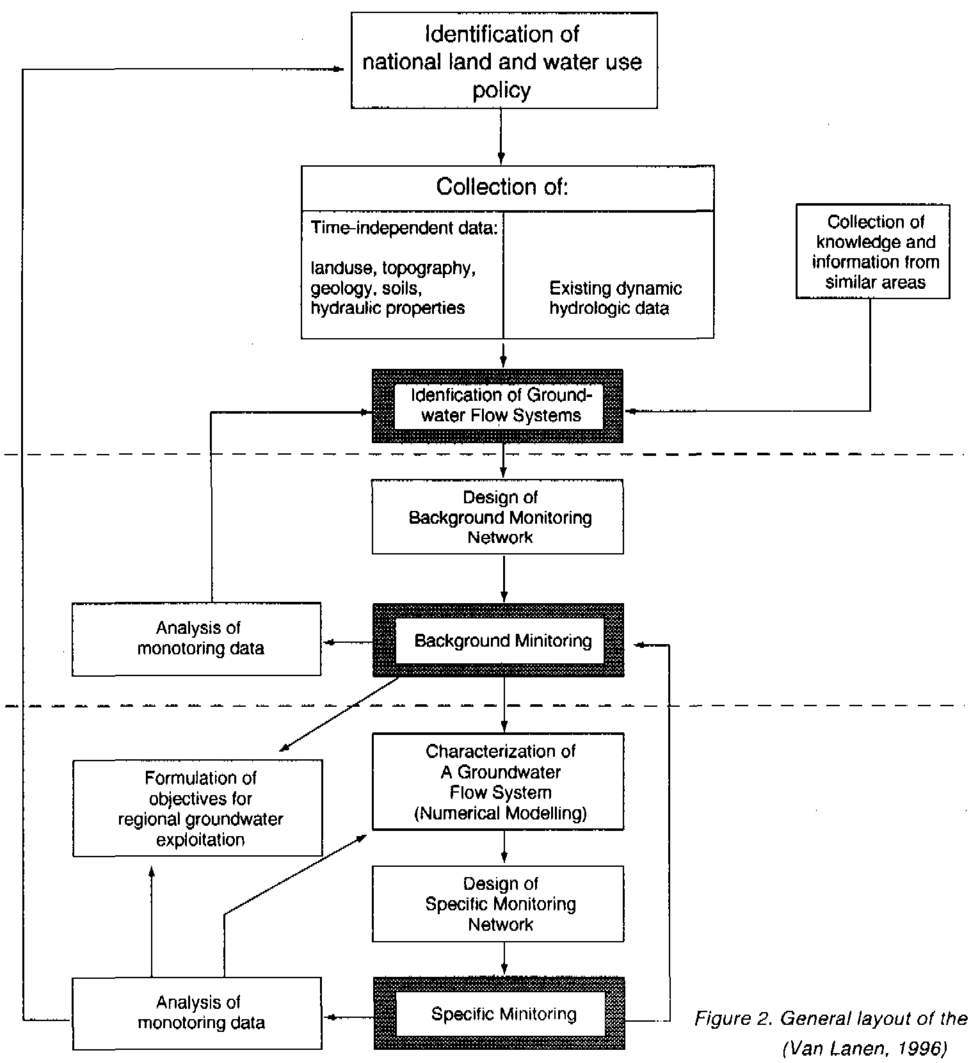


Figure 2. General layout of the groundwater monitoring procedure (Van Lanen, 1996)

as the geological framework and the hydrodynamic properties, need to be collected. Before the start of the monitoring the groundwater flow system in the area must be understood and described as far as existing data allow (identification of groundwater systems). These activities start with the collection of time-independent data, e.g. about geology, hydraulic properties, boundary conditions and hydrochemistry including a definition of groundwater flow systems. It is likely that at the start of the background monitoring phase knowledge is insufficient, because an objective of this monitoring is to improve the knowledge about the prevailing groundwater systems. Probably, other (semi-)arid areas should be investigated on similarities, which might allow transfer of knowledge to regions to be monitored (Fig. 2).

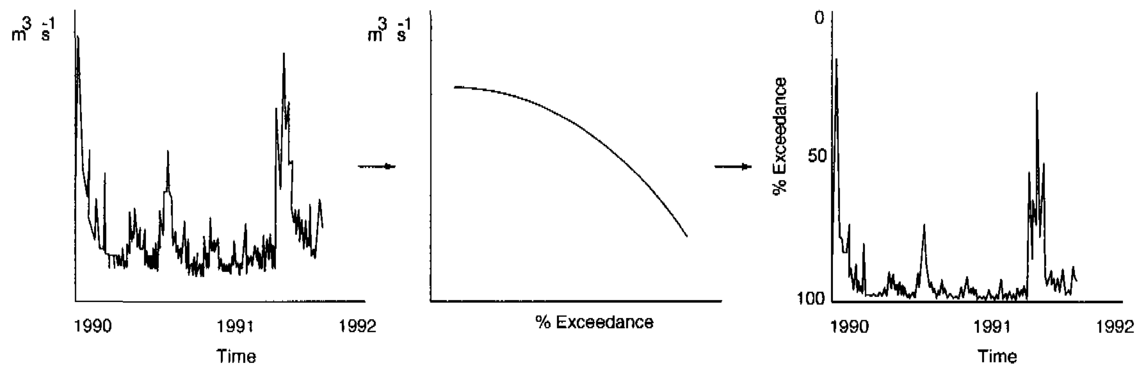
After the system identification phase, a first network for groundwater monitoring is designed (middle block Fig. 2). Systematic measurements of heads and chemical composition of groundwater in existing and abandoned wells should start, as well as the collection of meteorological, vadose zone, and spring flow and streamflow data. After the first or second year of systematic data collection, the initial version of the background monitoring network should be thoroughly analyzed. The earlier-defined versions of the groundwater systems and associated conceptual models should be refined. (Geo)statistics can help to improve the sampling density and frequency. It is likely that the analysis based on an improved knowledge of local hydrological phenomena will lead to an adaption of the first network version, which better represents the specific characteristics of the groundwater systems in the area of interest (Fig. 2).

The refinement of the background monitoring network should be a continuous process of analyzing incoming data, refinement of the description of the groundwater system and subsequent network adaption. It is likely that the network need to be adapted more than once. Background monitoring in the (semi-)arid zone is a long-term effort, because a key factor, the groundwater recharge, exhibits high variability over time and space. Reliable estimates of rational groundwater exploitation, also considering extreme meteorological conditions, can only be made by using long time-series of data.

Specific monitoring
Specific monitoring programs follow what happens in the groundwater body when it is substantially exploited for particular purposes. Specific monitoring characterizes the transient state of the aquifer and acts as an early warning for over-exploitation. The monitoring is restricted to those areas where effects are expected because of the significant abstraction and a larger aquifer accessibility. Potential problems are reducing spring flow, falling groundwater heads, falling well yields, deterioration of water quality (including sea water intrusion or upconing of brackish or salt water) and subsidence.
A specific monitoring network should be set up after people have decided to develop groundwater resources in a particular region. The decision should be based on a comprehensive analysis of background monitoring data. The conceptual model of the groundwater flow system is replaced by a numerical one (Fig. 2, lower block). This groundwater simulation model must specify the consequences of different abstraction scenarios in terms of groundwater heads, groundwater flow lines, residence times, changes in recharge conditions (e.g. induced recharge), chemical composition, and spring flow and streamflow.
Subsequently, the simulated consequences need to be translated into the earlier-mentioned potential problems. Then, specific monitoring aspects can be formulated, such as the boundary of the affected area, type of hydrologic variables to be monitored, and sampling density and frequency. A specific groundwater monitoring network might require adaption after collected data show that the response of the groundwater flow system is more or less different from the simulated one. Similar to background monitoring, specific monitoring needs continuous efforts in terms of collecting data, analyzing them, and refinement or incidently redefinition of the monitoring network.
The specific monitoring should be integrated into the background monitoring efforts (Fig. 2). Eventually the ideal situation in a country is to have a background monitoring network that covers its territory and specific monitoring networks in regions where groundwater resources are significantly exploited (nested monitoring networks).
In the IHP Monitoring document several experts describe what, how, where and when to monitor for both background and specific monitoring conditions (Van Lanen, 1996). These general concepts are illustrated by case-studies on network density (India), vadose zone monitoring (USA), remote sensing (Botswana), over-exploitation (India), subsidence (Mexico) and salt water intrusion (India).

3. Groundwater modelling

The groundwater modelling was done in the framework of the FRIEND (Flow Regimes from International Experimental and Network Data). The FRIEND research program (IHP-IV H-5-5) is an international collaborative study into regional hydrology. The primary objective is



a) Observes Hydrograph Time Series b) Flow Duration Curve c) Observes Drought Frequency Time Series

Figure 3. Deriving time series of drought frequencies (Gustard, 1996)

to improve understanding of hydrological variability and similarity across space and time in order to develop hydrological science and practical design methods (Gustard, 1994). In the FRIEND Low Flow project natural and man-induced droughts are studied (FRIEND Steering Committee, 1994). Droughts are defined in terms of drought duration, deficit volume and magnitude derived from observed and simulated streamflow time series. Physically-based models and regional statistical methods were developed to analyze these droughts.

The regional statistical approach identifies location, severity and timing of major droughts in Northwest and Central-European catchments. One approach consists of retrieval of observed daily flow time series for a long period from the European Water Archive, derivation of the flow duration curve from the observed data, and transformation of the daily flow time series of a particular period or year to a daily exceedence series (Fig. 3). This approach produces a drought time series expressed as the percentage of time a measured discharge on a particular day is exceeded. The frequencies are then mapped at the European scale to estimate the spatial variability of drought frequency. This approach was used to produce an initial set of maps for the Loire Garonne region of France. In this way the evolution of the 1976 drought from February to August was investigated (Gustard, 1996). This large scale analysis is appropriate for considering the climatic impact on spatial coherence of droughts at the European scale. It also identifies catchments with a deviating drought evolution pattern. Subsequently, physically-based groundwater models were developed for these catchments. The groundwater models enable the underlying hydrological processes of streamflow generation in a catchment, both climatic and hydrogeological, to be investigated more thoroughly. In this contribution results of five catchments with different hydrogeology and climate, i.e. the Hupselse Beek (Netherlands), the Gulp and Noor catchments (Belgium/Netherlands), and Cerná Nisa and Cerná Desná catchments (Czech Republic) will be presented. The models are also suitable to explore drought evolution in case something will change (man-induced drought), e.g. groundwater abstraction or a change in groundwater recharge. The effect of a change of recharge on streamflow of the Noor catchment (Belgium/ Netherlands) will be given.

Catchment characteristics

The Hupselse Beek is situated in the east of the Netherlands close to the German border (Warmerdam et al., 1982). The basin is relatively flat, its altitude varies between 24 and 33 m a.m.s.l.. Pleistocene eolian, fluviatile or glacial deposits, which usually consist of sand, cover Tertiary, marine clays. This clay is found at a depth of 1 m in the east and dips to the west, where the top is at 8 m below soil surface. The Pleistocene sediments form a small unconfined aquifer with relatively shallow water tables. Therefore the surface water network is dense. Agricultural landuse dominates, i.e. 70% grassland, 20% arable land and 6% forest. Some other characteristics are presented in Table 1. Streamflow data are available for the period 1969-1992.

Table 1. General catchment characteristics of catchments used for the modelling

Charac-teristic	Netherlands	Belgium/Netherlands		Czech Republic	
	Hupsel	Gulp	Noor	Cerná Nisa	Cerná Desná
Area [1]	6.5	46.5	10.6	1.9	4.8
hydro-geology	thin sand aquifer	chalk aquifer	chalk aquifer	weathered granite	weathered granite
P (mm)	770	765	765 [2]	1331	1522
Q (mm)	289	300	300 [2]	887	1112

The Gulp and Noor catchments are located in the undulating Belgium-Dutch border area (Nota et al., 1988; Van Lanen et al., 1995). The elevation of the Noor catchment varies from 90 to 240 m a.m.s.l..
The maximum elevation of the Gulp catchment is 360 m, and the outlet is at 90 m a.m.s.l. Folded Palaeozoic shales and sandstones mostly form the impermeable base. The consolidated rocks are discordantly overlain by subhorizontal Upper-Cretaceous deposits, viz. locally sands underlying clayey silt with sandstone layers and chalk, which form a multi-aquifer system. Unconfined conditions occur in the chalk, whereas semi-confined conditions prevail in the sands or sandstone layers. The Noor and Gulp drain dissected plateau landscapes with shallow water levels in the valley and deep levels under the plateau (e.g. >50 m). The surface water system mainly consists of the main stream. Landuse in the Noor basin comprises 62% grassland, 35% arable land and 1% forest. In the Gulp catchment (southern part) the grassland area amounts 90%, arable land and forest cover 2 and 7%. In the analysis discharge data from 1978-1993 were used for the Gulp catchment and from 1992-1994 for the Noor catchment.

The Cerná Nisa and Cerná Desná basins are located in the Jizera Mountains in the north of the Czech Republic near Germany and Poland (Kovar & Svitak, 1994). The elevation of the Cerná Nisa and Cerná Desná catchments is between 770-890 m and 780-1020 m a.m.s.l., respectively. The catchments are developed in wheatered granite overlying fractured granite, which implies that a shallow unconfined aquifer occurs (Van den Akker & Van Haselen, 1995). Shallow water tables prevail in the valley and locally on the slope (seepage faces).
The surface water system mainly consists of the main stream. Discharge data are available from 1982-1993.
The catchments used to be covered predominantly by forest (1981: 95%). However due to acid deposits most of the forest died, and grassland is the dominant landuse now (Cerny & Paces, 1995). Some areas are afforested again.

Daily flow data from the catchments (except the Noor because of shortness of the time serie) were used to calculate the flow duration curve (FDC). The streamflow was standardized by the mean flow in the FDC to eliminate different catchment sizes (Fig. 4). The FDCs show thatthe streamflow of the Gulp has little variation, whereas the discharge of the Hupsel substantially varies. In the period 1969-1992 the Hupsel dried up for about 5-10% of the time.
In the high flow domain, the two Czech basins show a similar behaviour than the Hupsel. In the low flow domain, the behaviour of these basins is intermediate. The behaviour of the catchments is discussed below.

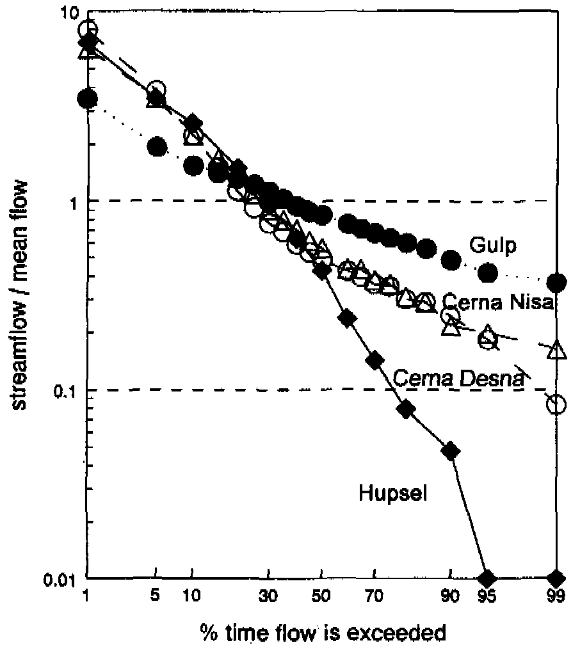


Figure 4. Flow duration curves for two Czech, a Belgium-Dutch and a Dutch catchment

Model description
In this study two different types of physically-based models were applied, i.e. BILAN and MODFLOW. The BILAN model belongs to the single-cell type, where the entire catchment is represented as one cell. MODFLOW is a distributed model which accounts for a possibly complex geometry of the catchment and spatially distributed hydraulic parameters, (e.g. permeability) and boundary conditions (e.g. rainfall).

BILAN
In the water balance model BILAN, developed by the Czech Water Research Institute (Kaspárek & Krejcová, 1994), most hydrological processes, such as the generation of surface runoff or base flow, are simulated by using empirical relationships.
The model uses catchment rainfall, snow and potential evapotranspiration data as boundary conditions, and produces monthly data of streamflow, catchment evapotranspiration and water storage. The model has six free parameters, which are calibrated with an optimization technique using simulated and observed streamflow data series. Direct runoff is first subtracted from the input precipitation using a quadratic rainfall-runoff equation in the summer season. For the winter season, direct runoff is estimated from air temperature. The amount of water accumulated in snow is added to the precipitation of the first summer month.

Soil moisture is either added to or subtracted from the soil moisture storage depending on whether the net precipitation that infiltrates into the soil in a particular month is greater or smaller than potential evapotranspiration. Water subtracted from the soil is returned to the atmosphere by evapotranspiration. The soil is characterized by the soil moisture supply capacity. When the soil is fully supplied with water (soil moisture capacity is reached), the excess water is available to feed base flow and interflow.
A parameter determines the distribution of excess water over base flow and interflow. The base flow is determined from groundwater storage. The total streamflow equals the sum of direct runoff, interflow and base flow.

The model BILAN uses a monthly time step, which enables simulation of the monthly water balance over a long period of time. Other models have to be used to simulate streamflow for shorter periods. For example, in the Cerná Nisa catchment Kovar & Svitak (1994) used the rainfall-runoff model KINFIL2 together with a GIS to calculate design discharges for different rainfall events for a certain recurrence time. BILAN had been applied in the framework of the FRIEND study to investigate the effects of climate and hydrogeology in different catchments over Northwest- and Central-Europe (Kaspárek, 1996).

MODFLOW

MODFLOW is a distributed model using the so-called finite difference technique (McDonald & Harbaugh, 1988). The area is subdivided into rectangular cells. For each cell the basic differential equation is approximated by a finite-difference equation. To solve the whole set of differential equations for the model area boundary conditions have to be introduced; these can either be fixed head or fixed flow at certain cells. The MODFLOW model allows the simulation of more than one layer. In the toplayer the transmissivity depends on the saturated thickness.
In both models leakage to or from the aquifer is allowed to take place as well as abstractions and recharge.
The leakage also represents the interaction of the aquifer with surface waters, which is the most important process in the FRIEND study.
The input data to the numerical model includes time serie records of recharge and stream levels, and groundwater levels on those boundaries which do not coincide with the hydrological water divide. The model also needs spatial data of permeability, storativity and leakage coefficient. In the FRIEND study a time step of 10 days was used. The model was applied to the Noor catchment to explore the effect of groundwater recharge on droughts in terms of low streamflow.

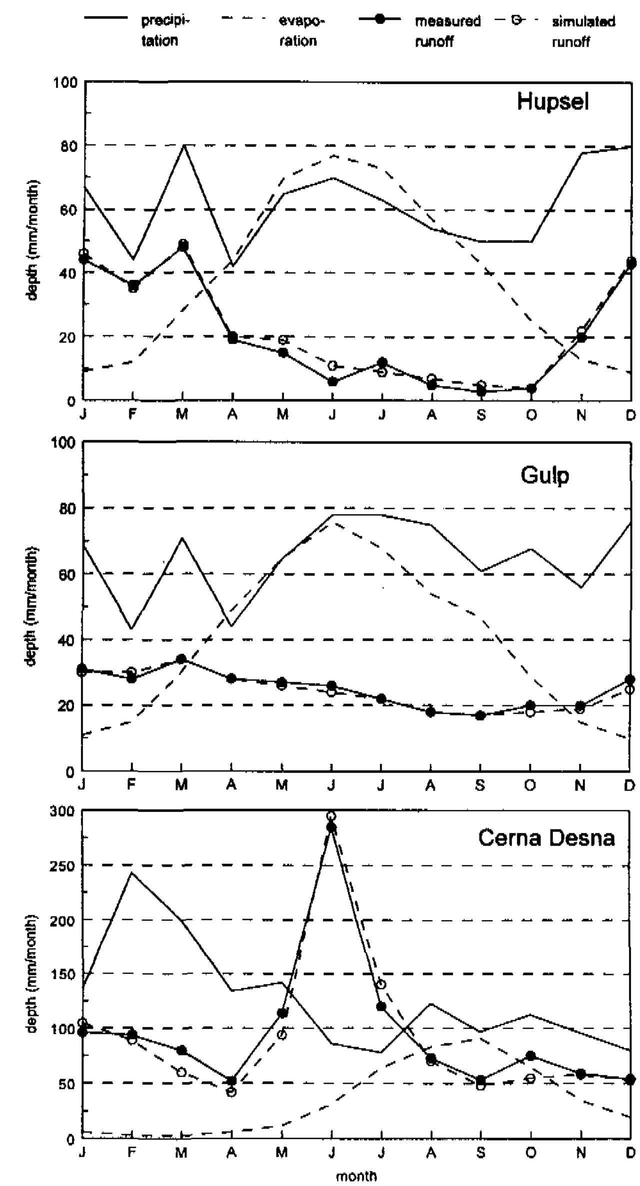


Figure 5. Simulated and observed mean water balance terms for a Czech, a Belgium-Dutch and a Dutch catchment

Simulated streamflow in catchments with different hydrogeology or climate

The model BILAN was applied to the Hupsel, Gulp and Cerná Desná catchments. The mean monthly water balance was computed from the simulated time serie of monthly water balances for 14 to 24 years dependent on the availability of streamflow data. In Figure 5 the mean monthly precipitation, real evapotranspiration and simulated and measured streamflow is given. In all catchments the simulated and measured streamflow show a reasonable agreement.

In the *Hupsel catchment* the precipitation distribution is

regular, i.e. the variation is between 50 and 80 mm/month. The streamflow is high (40-50 mm/month) during the winter period and decreases significantly during the summer period when evapotranspiration exceeds precipitation. The low streamflow during the summer (usually <10 mm/-month) and the the rapid response of the streamflow on precipitation in autumn imply a low groundwater storage. The large variation in streamflow results in a steep FDC (Fig. 4).
The mean monthly precipitation and evapotranspiration in the *Gulp catchment* are about equal to the Hupsel catchment. The distribution of the mean streamflow over the year, however, is completely different. No clear summer minimum flow and maximum winter flow can be distinguished. The streamflow slightly varies between 20 and 30 mm/month. Therefore the FDC has a flat nature (Fig. 4). Large changes of groundwater storage cause the low response to periods with precipitation excess or deficit. The stream never dries up because of the large groundwater storage.

The total annual precipitation (Table 1) and the mean precipitation pattern of the mountaineous *Cerná Nisa and Cerná Desná basins* is completely different to the patterns of the Dutch catchment (Fig. 5). In the period June-December the mean precipitation is relatively constant in the Cerná Desná catchment, i.e. about 100 mm/month. Especially in the months February and March the precipitation is substantially higher (>200-mm/month). The peak discharge, however, does not coincide with the highest precipitation, because the precipitation accumulates as snow. In June the maximum mean streamflow (about 290 mm/month) occurs, because of snow melting. Of course, this maximum monthly discharge simulated by BILAN cannot be used for design purposes. The design discharge is significantly higher, e.g. >10 m3/s for rainfall events longer than 30 minutes and a recurrence time of 100 years. Groundwater storage is not high in these catchments, but the contineous precipitation excess over the year causes the streams not to dry up. The high peak discharge because of snow melting results in FDCs (Fig. 4) which approach the Hupsel one for the high flows. The tail of the FDCs (intermediate position) is determined by the contineous groundwater recharge even during the summer months.

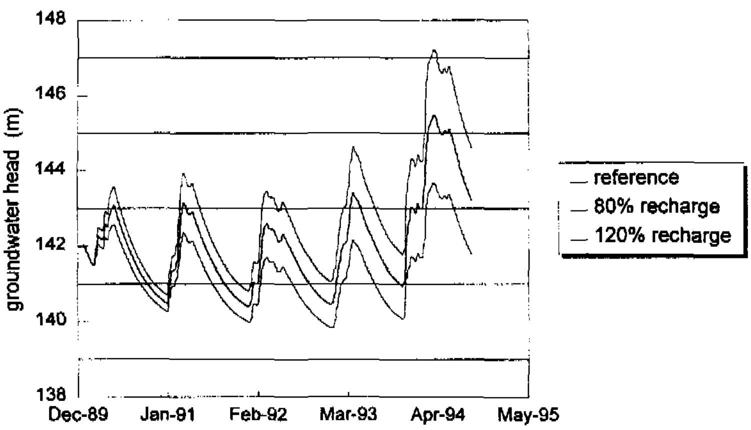


Figure 6. Effect of groundwater recharge on the groundwater heads of the observation well WP98

Impact of groundwater recharge on simulated streamflow

Transient groundwater flow was simulated by MODFLOW in the Noor catchment for the period 1990-1994 (Van Lanen et al., 1995). Effects of groundwater recharge on heads and streamflow were explored. Groundwater recharge derived from meteorological, crop, soil and water-table depth data, amounts 282, 180, 237 and 405 mm/year in the hydrological years 1990-1993 for permanent grassland with deep groundwater levels (63% of model area).

The effects of the natural variation (reference) are clearly reflected in the simulated heads (Fig. 6) for the observation well WP98, which is respresentative for plateau conditions with grassland and very deep water tables (about 30 m below soil surface). In the hydrological years 1990-1992 the rise because of recharge is about 2 m. However, early 1994 (end of hydrological year 1993) the rise is 4 m because of a recharge, which is 120-220 mm/year higher than in the previous years. An adaption of the recharge by 20%, i.e. 80 and 120% recharge, for instance as a consequence of climate change, results on an avarage in about 0.70 m lower or higher groundwater levels, respectively (Fig. 6). In years with a low recharge the head difference is about 0.4-0.5 m (early 1990's) and in years with a high recharge 1.6-1.8 m (early 1994).
The effect of recharge on streamflow of the Noor is presented in Figure 7. Because the Noor is mainly fed by groundwater a strong correlation between the groundwater heads and the streamflow prevails. In years with low recharge, the discharge of the Noor varies between 2000 and 5000 m3/day. In years with high recharge the discharge is significantly higher, i.e. 3000-8000 m3/day. Recharge has a strong effect on streamflow of the Noor and consequently on low flows and associated droughts. An adaption of the recharge by 20% results in dry years in a change of the discharge of 250-500 m3/day, and in wet years in a change of 750-1250 m3/day. So, even small changes in

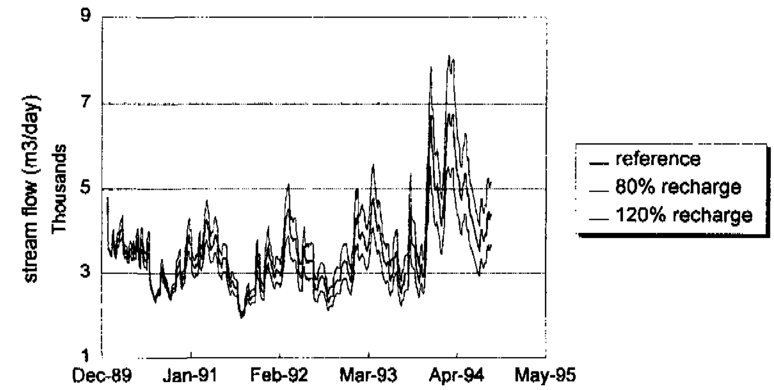


Figure 7. Effects of recharge on streamflow at the outlet of the Noor (M6)

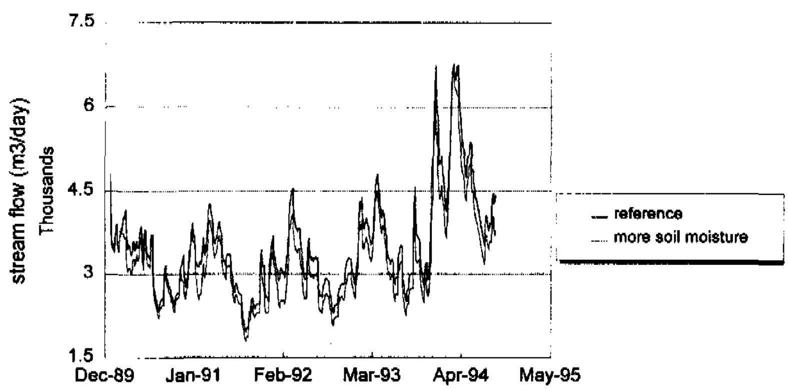


Figure 8. Effects of a change in soil moisture supply capacity on streamflow at the outlet of the Noor (M6)

recharge have a clear effect on the streamflow.
A change in landuse, which results in another potential evapotranspiration and soil moisture supply capacity, affects the real evapotranspiration and consequently the groundwater recharge (Van Lanen, et al., 1996). The effect of an increase of the soil moisture supply capacity for permanent grassland from 75 mm to 125 mm is given in Figure 8. The effect is similar to a reduction of the recharge (Fig. 7). However, the influence of dry and wet years is smaller.
Because of the larger soil moisture capacity the streamflow of the Noor reduces by 100-600 m3/day. Natural variation of streamflow and additional effects of landuse or climate change affect the low flows of the Noor brook and associated droughts. The simulated time series of streamflow were analysed to investigate droughts using EXDEV (_i_ica & Novicky, 1995). A drought occurs when streamflow is below a prescribed threshold discharge. The flow duration curve or ecological criteria can be used to define a threshold discharge. When the streamflow is below the threshold the period is indicated as a deficit period. On the contrary, a excess period occurs when the streamflow is above the threshold discharge. Droughts are defined in terms of deficit duration, deficit volume and deficit magnitude. The deficit volume equals the integrated difference between the threshold discharge and the prevailing streamflow (below the threshold) over the drought period. The magnitude is the deficit volume over the duration. During a prolonged dry period short periods might be observed with a streamflow exceeding the threshold discharge, e.g. a small peak from a thunderstorm, and thereby dividing a large drought in a number of smaller droughts. Usually these smaller droughts are pooled using volume and/or duration criteria (Ricica & Novicky, 1995; Tallaksen et al., subm.). In this study a volume criterion of 0.1 was used, which implies that a drought is independent if the excess volume of the flow in the period following the drought is larger than 0.1 times the deficit volume of the drought. Some results of the analysis of the time series of streamflow data are presented in Figure 9. A threshold discharge of 35 l/s was used, which equals the Q70 (70% percentile of the flow duration curve). In 30 out of 100 years the drought duration for the reference situation is about 50 days (left part of Fig. 9). In 10 out 100 years the duration increases to 125 days. If the recharge decreases by 20% (80% recharge), for instance as a result of climate change, the duration will increase to 210 days in 10 out of 100 years. So, this implies a doubling of the drought duration.

When in this catchment the recharge increases by 20% (120% recharge) in the period 1992-1994, the duration is hardly affected (left part Fig. 9). The difference between the reference and the 120% recharge scenario (middle and lower line) is maximally 25 days. So, drought duration is under these conditions more sensitive to a recharge decrease than an increase by 20%. An increase of the soil moisture supply capacity (125 instead of 75 mm for permanent grassland), for instance as a result of a landuse change, has a similar effect on the drought duration than a recharge reduction (right part of Fig. 9). Conditions with crops having access to more soil moisture result in an increase of the drought duration from 125 to 150 days with occurrence probability of 10%.

Similar to the analysis of drought duration (Fig. 9) deficit

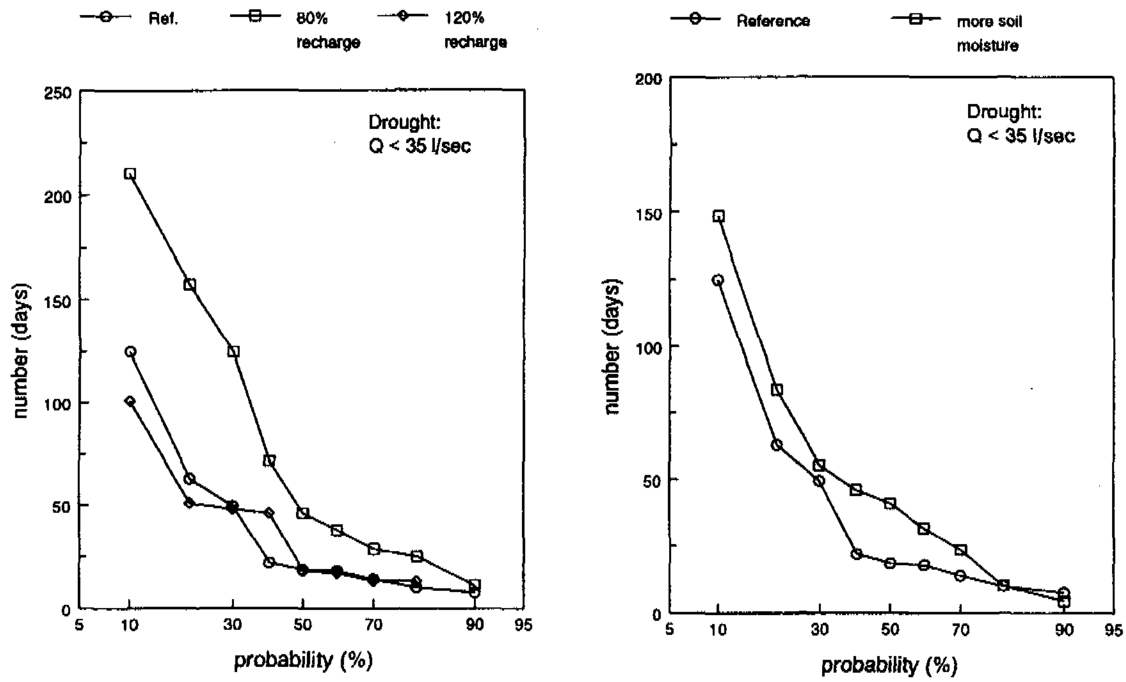


Figure 9. Probability of the drought duration in the Noor catchment derived from simulated streamflow (1992-1994) at the outlet (M6) for different recharge scenarios

volumes and deficit magnitude can be evaluted (e.g. Novicky, 1996; Tallaksen et al., subm.).

4. Conclusions

Groundwater monitoring and modelling need to be basic and interlinked activities of sound groundwater management The IHP stimulates international cooperative activities in this field, and distinct results were obtained.

Groundwater monitoring should already start prior to significant groundwater exploitation as *background monitoring*. Of course, significant groundwater exploitation must be supported by *specific monitoring* allowing early recognition of over-exploitation. Groundwater managers must be prepared on a regular refinement of the monitoring network because monitoring data improve knowledge about the hydrogeological system and on the stresses imposed by groundwater abstraction. Groundwater monitoring is a long-lasting activity, escpecially in the semi-(arid) environments where the spatial and inter-annual varaibility are extremely high.

In the context of the FRIEND programme natural and man-induced droughts were evaluated in Northwest- and Central Europe using regional statistical and physcially-based modelling approaches. The regional statistical approach was succesful in mapping the evolution of the severity of the 1976' drought. Climatic impact and spatial coherence at the continental scale were shown in terms of a exceedence probability of the measured discharge in a particular area and period in 1976. The underlying hydrological processes of streamflow generation in dry periods were investigated by the physcially-based modelling approach in some of the catchments. The results show that hydrogeology and climate control streamflow generation. An adaption of the recharge, e.g. because of climate or landuse change, has a distinct impact of the drought duration. For instance, in the Noor catchment (Belgium/Netherlands) a particular landuse change affecting the soil moisture capacity result in 20% longer drought periods with an occurrence probability of 10%.

The network of international contacts developed during IHP activities (e.g. the FRIEND programme) is beneficial for scientific research and education.

The UNESCO budget for IHP activities is low. Budgets need to be raised from other sources than UNESCO (e.g. EU, university). Unfortunately these budgests are likely to decrease in the Netherlands.

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Impact of climate change on the discharge regime of the River Rhine - Preliminary results of the CHR project

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1. Introduction

Climate change can influence the water balance of drainage basins and consequently water management in many ways. Precipitation patterns may change and in combination with a higher temperature also the accumulation and melt pattern of snow. Furthermore evapotranspiration may change and as a consequence the runoff processes and discharge regimes. Around the subject of climate change there are a lot of uncertainties. Scientists united in the IPCC agreed very recently that the global increase in temperature over the last hundred years could be explained by the increased greenhouse effect (IPCC, 1995). Further changes can be expected, but especially on a regional scale it is far from clear when, what climate change can be expected. The processes and in particular the many feedback systems are not yet properly understood.
The River Rhine is economically the most important river in Western-Europe. Its drainage basin covers 185.000 square kilometers and is habitat to about 55 million people. It is the most intensively used waterway for inland navigation and supplies water to large economically important areas. For the Netherlands the Rhine is a vital part of the water management system. Changes in the discharge regime affect the user functions of the Rhine like the safe discharge of water, inland navigation, nature and water supply for industry, agriculture and domestic use.

Against this background the International Commission for the Hydrology of the Rhine Basin (CHR) initiated a project with as main purpose the development of a water management model for the Rhine basin (Parmet, 1993). This model should be used to assess effects of climate and land use changes for the discharge regime of the Rhine. Several institutes from the Rhine riparian states cooperate in the project. The Netherlands contribution is provided by RIZA and the University of Utrecht and is incorporated in the Dutch National Research Program on Global Change.

The project is carried out in two phases. In the first phase model development takes place along two lines, a bottom-up and a top-down approach (CHR, 1991). Along the bottom-up line hydrological models are developed for selected sub-basins in characteristic areas throughout the Rhine basin. These models are detailed in time and space. They have a time step of one day and can be used to assess effects of climate change on average and peak discharges. Different modelling concepts are used in the different parts of the Rhine basin, because the relevant hydrological processes are not the same.
For example snow accumulation and melt is very

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important in the Alpine area. In the lowland part groundwater plays an important role.
Along the top-down approach a GIS-based water balance model is developed for the whole Rhine basin. This model is course in time and space. It has a timestep of one month and has been validated on the spatial scale of the Rhine and its main tributaries. With the models developed in this first phase, effects of climate change for average and low flows can be assessed throughout the Rhine basin. For peak flows this is only possible for the selected sub-basins. Therefore the goal of the second phase of the CHR project is to assess the effects on peakflows for the whole Rhine basin. To achieve this the top-down and bottom-up approaches will be combined.

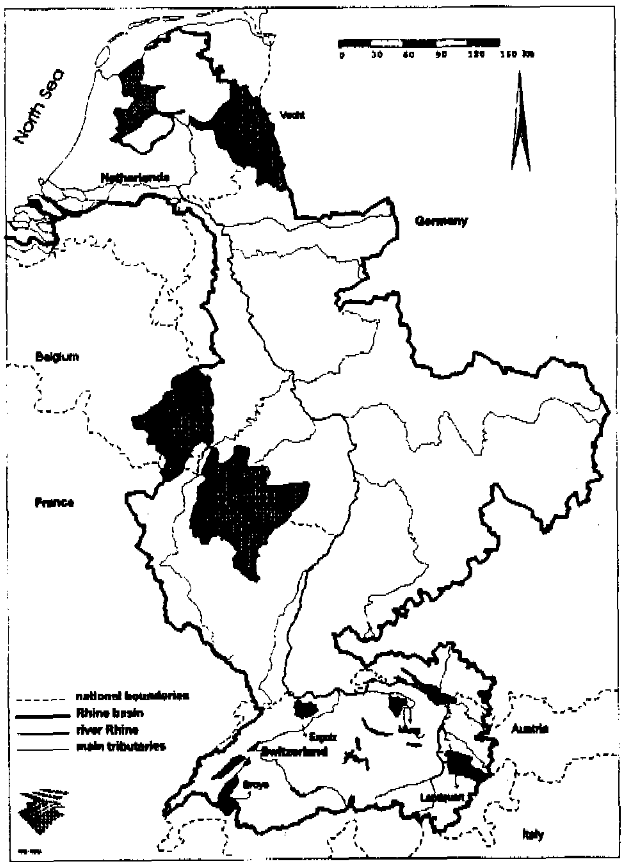

Fig. 1. Drainage basin river Rhine and of the sub-basins that are modelled with detailed hydrological models in the first phase of the CHR-project.

The first phase of the CHR-project is also incorporated in a larger project on European water resources. In this project the hydrological effects of climate change are assessed on three different scales. The sub-basin scale, the regional scale (Rhine basin scale) and the European scale (half by half degree). On all scales the same scenarios as developed by the Climate Research Unit will be used. The CHR-project contributes with the detailed models (bottom-up approach) to the sub-basin scale and with the water balance model (top-down approach) to the regional scale. It is an important part of the project since with the water balance model, it provides the link between the sub-basin and the European scale.

This paper is restricted to the Rhine basin. Some results obtained sofar and an indication of the effects for water management are presented. Furthermore an outlook into the second phase of the project is given.

2. Results of the bottom-up approach

Along the bottom-up approach detailed models have been developed for a number of sub-basins in the alpine area, the middle mountains and the lowland area. The modelled sub-basins are described in figure 1. Results will be given for the alpine and for the lowland area.

Alpine area
In the alpine area a conceptual hydrological model developed at the Royal Belgium Meteorological Institute is used (Bultot et al., 1988). It has been extended with an improved snow module, since snow is the most sensitive part of the water cycle in this part of the Rhine basin with respect to climate change (Schädler, 1992). The IRMB model has been calibrated for three sub-basins; Broye, Murg and Ergolz.

Simulations with a doubled CO2 scenario as described by Bultot et al. (1988) and given in table 1, showed a strong decrease in the number of snow days. This is shown for the Broye catchment in figure 2. Because less precipitation is stored as snow and the snow starts to melt earlier and furthermore an increase in precipitation in winter is assumed, the simulations showed an increase in winter discharge. Summer discharge reduces due to a decrease in the contribution of melt water and an increase in evapotranspiration (Bultot et al, 1992). For Switzerland besides effects for water management, the changes in snow cover also have a direct economic effect through a decrease in the possibilities for wintersport. In the region below 1500 m a.s.l., were about 50% of the ski-lifts start and even about 30% end, climate change might lead to a strong increase in the number of years were the

Table 1. Changes in average temperature (T) and predipitation (P) as applied for the Murg, Ergolz and Broye (based in Schädler, 1992)

Season	DJF	MAM	JJA	SON
T, °C	3.2	3.1	2.5	2.7
P, %	11	7	-2	5

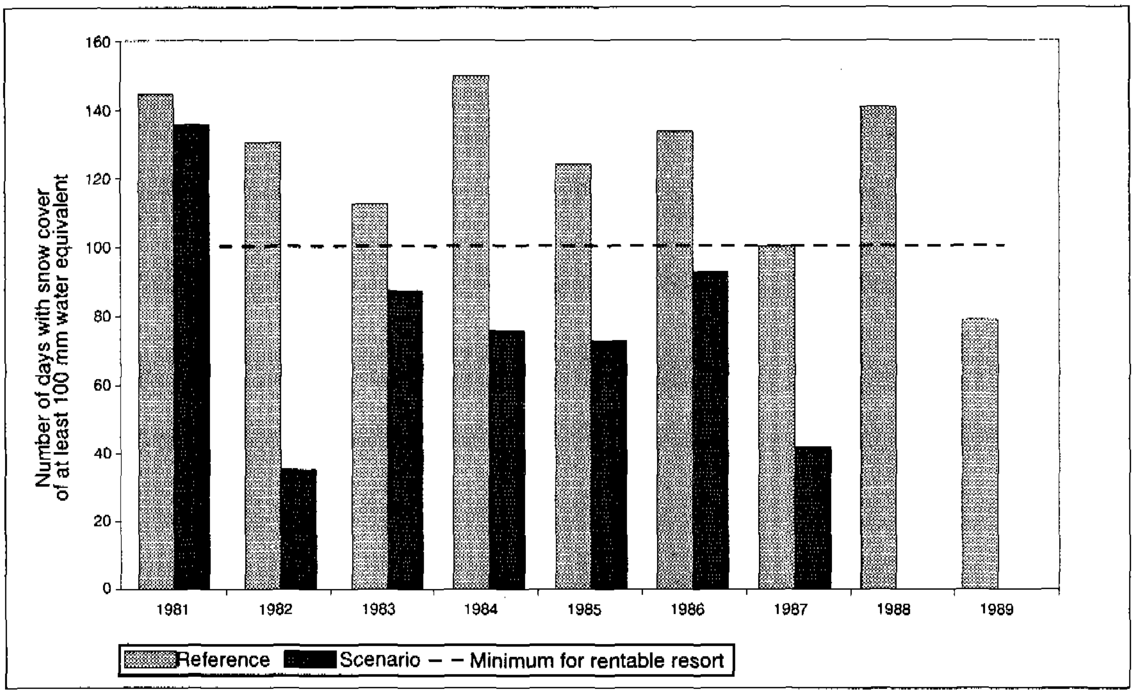

Fig 2. Number of days with snow cover of at least 100 mm water equivalent in the period December to April in altitude zone 1200-1500 m (adapted from Bultot et al., 1994)

duration of the snow cover is not rentable (Bultot et al., 1994).

Lowland area

The model for the lowland area is developed by RIZA for the drainage basin of the Overijsselsche Vecht, which covers an area of about 3800 km2. Several existing model concepts have been combined (Parmet and Raak, 1996). First the basin has been divided in sub-basins. For each sub-basin the hydrological processes are described with the unsaturated zone model MUST (de Laat, 1992), in combination with the rainfall-runoff Wageningen Model (Warmerdam, 1993) and a simple reservoir model describing the sewer system. Discharges of the sub-basins are routed to the mouth of the Vecht basin with the Muskingum method. The lowland model was validated with satisfying results. For gauging station Vechterweerd, near the mouth of the basin, an average model efficiency of 90% was reached for the period of 1980 tot 1983. In figure 3 the observed and simulated hydrographs are given for these years.

In the framework of the Dutch National Research Program simulations were carried out with scenarios developed by the Royal Netherlands Meteorological Institute. They developed a method to generate daily precipitation scenarios, based on a relation between temperature and rainfall (Buishand and Klein-Tank, 1995). Amongst others simulations were carried out with a scenario with a temperature increase of about 3 degrees originating from a double CO2-run of the Canadian Climate Center GCM. This resulted in an increase in precipitation varying per season between 20 and 11 percent (see table 2). The scenario is, except for the precipitation in the summer season, comparable with that presented for the alpine region. Scenario simulations with the lowland model were carried out for the period 1965-1990. Due to the increase in temperature, evapotranspiration increases in all months. Changes in crop parameters were taken into account. The average annual increase in evapotranspiration is 7%. Without taking into account that crops evaporate more effective under increased CO2-conditions, this would be about 10%.

The increase in evapotranspiration does not compensate for the increase in precipitation. Average discharge increases in all months, varying between about 10% in the summer to 25% in the winter season.

Table 2. Changes in average temperature (T) and predipitation (P) as applied for the Overijsselsche Vecht basin

Season	DJF	MAM	JJA	SON
T, °C	3.0	2.3	3.7	3.4
P, %	20	11	11	11

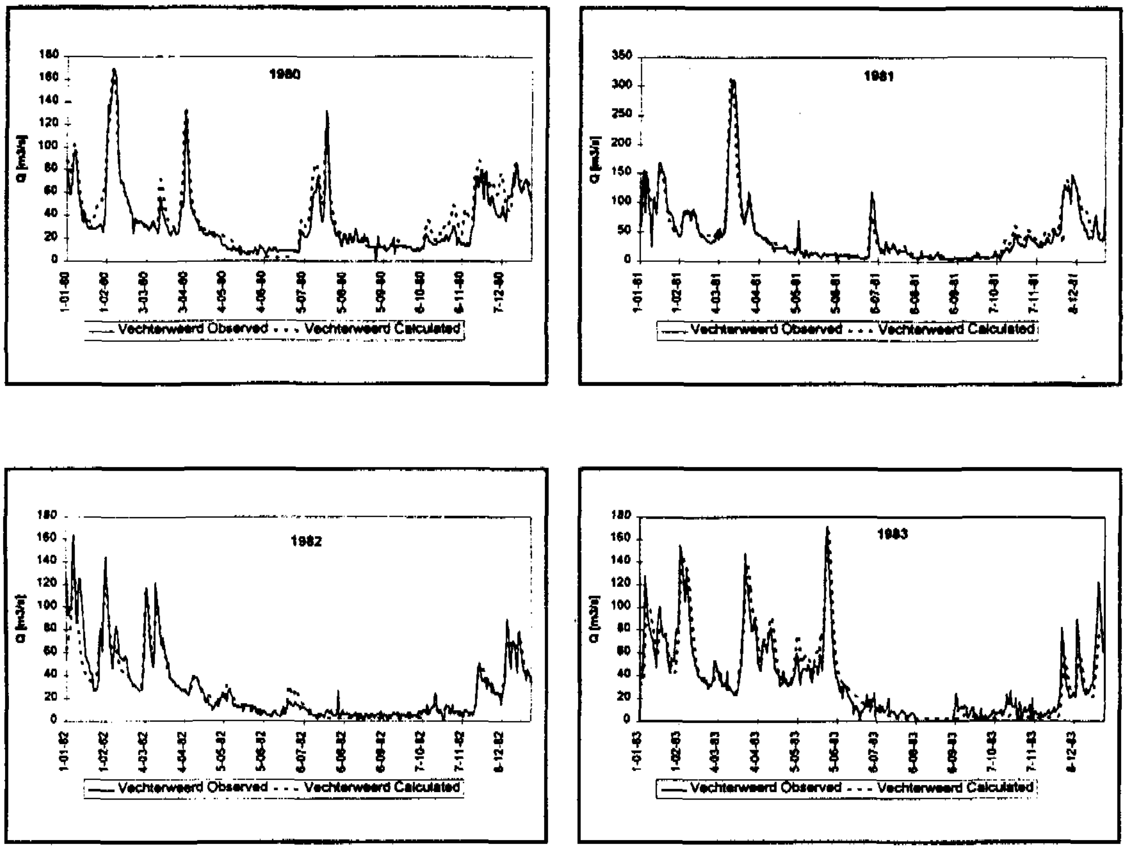

Fig. 3. Observed and computed daily discharge for Vechterweerd (river mouth Vecht basin) for the years 1980, 1981, 192 and 1983, in [m3s-1].

Also the maximum daily flow increases. To indicate what this would mean for safety along the River Vecht, a Gumbel function has been fitted through the simulated series of annual daily maxima. Using this function peak flows with larger recurrence times than the 26 years of the simulation period can be estimated. For example the peak flow with a recurrence time of 1250 years, which is an important parameter in the design of the main river dikes in the Netherlands. The results, visualized in figure 4, indicate that peak flows that are rare under present conditions can be expected to occur a lot more frequent if climate changes according to the applied scenario.
Next it can be seen that the design discharge increases significantly. The increase is in the order of 25%. For a proper analysis of changes in design discharges of course a lot more has to be done, but the results do give an indication about effects of climate change on peak flows in the lowland area of the Rhine basin.

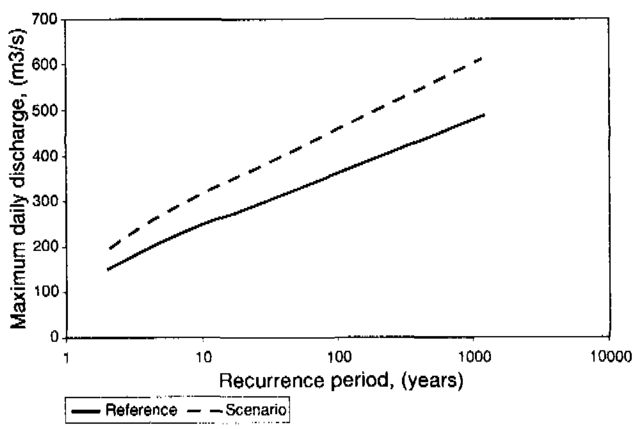

Fig 4. Maximum daily discharges for different recurrence times for reference and scenario conditions as computed with the

3. Results from the top-down approach

Along the top-down approach, a water balance model has been developed. This model called RHINEFLOW, is based on a Geographical Information System and calculates the water balance for grids of 3 by 3 kilometer on a monthly basis (Kwadijk, 1993). The model has been run with a wide range of scenarios, that were based on several GCM experiments, for Business as Usual and Accelarated Policy emissions, for the target period 2100 (Kwadijk and Rotmans, 1995).

In figure 5 the results are given for the gauging point Lobith at the German-Dutch border for business as usual emission scenarios. Since the range in GCM output is large, it is not surprising that also the range in changes in the discharge regime is large. The best guess scenario (see table 3) is comparable with the scenarios presented earlier for the alpine sub-basins, see table 1. Temperature increases with about 3 degrees, precipitation increases in winter and hardly changes in summer. The effect of this scenario on the discharge regime near Lobith is an increase in winter discharge and a decrease in summer discharge. This is for a major part caused by the changes in the alpine area.

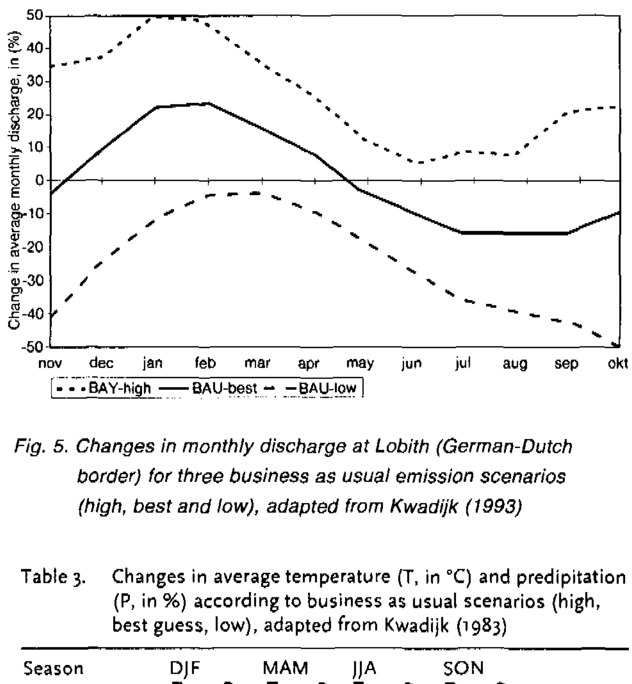

Fig. 5. Changes in monthly discharge at Lobith (German-Dutch border) for three business as usual emission scenarios (high, best and low), adapted from Kwadijk (1993)

Table 3. Changes in average temperature (T, in °C) and predipitation (P, in %) according to business as usual scenarios (high, best guess, low), adapted from Kwadijk (1983)

Season	DJF		MAM		JJA		SON	
	T	P	T	P	T	P	T	P
BAU-high	5.7	35	5	27	4.2	18	5	27
BAU-best	4.2	19	3.6	10	2.9	0	3.6	10
BAU-low	2.7	4	2.2	-9	1.8	-22	2.2	-9

In line with the results of the bottom-up approach for the alpine sub-basins, less precipitation is stored as snow and the snow that falls starts to melt earlier. Next to that, total precipitation is assumed to increase in the winter period. Because of an increase in evapotranspiration and a decrease of the contribution of meltwater in summer, discharge decreases in the summer period. This effect is enforced by changes in the downstream part of the basin.

Mainly as a result of the increase in temperature, the Rhine changes from a combined river, fed by rainfall and snowmelt, towards a more rain-fed river. The discharge regime of the Rhine which is at present very stable over the year, will become more variable. Both the frequency of low and of high flows will increase. For the best guess scenario the period with a discharge below 1000 m3/s increases on average from 3 to 5 weeks per year, which is an increase of 60%. The model RHINEFLOW is due to its monthly timestep, not suitable to analyse effects for peakflows.

However, based on a relationship between average monthly discharges and peak discharges, changes in frequencies of smaller peak flows, with a recurrence time upto about 2 years, can be analyzed. Under best guess scenario conditions the frequency of such peaks increases significantly (Kwadijk and Middelkoop, 1994). Although for larger flows the relation is not very reliable, results do indicate an increased flood probability.

4. Implications for water management in the Netherlands

What do the results of the first phase of the CHR-project implicate for water management in the Netherlands ? Looking at changes in peak flows in relation to safety, well-founded results are not yet available. However, the results of the first phase indicate that an increase is not unlikely. Floods like those of 1993 and 1995 may occur more often if climate will change in the direction as is presently expected. Climate change is one of the reasons that protection against flooding will undoubtly remain a topic of continuous concern for the low lying parts along the Rhine, also in the future.

Next to safe discharge of water, inland navigation is an important function of the river. Both an increase in the frequency of peak and low flows lead to extra costs. During the last flood, ships were not allowed to sail for two weeks, which lead to extra costs. Also an increase in low flows lead to extra costs. Following the business as usual best guess scenario, RHINEFLOW computed an increase in the average number of weeks with a discharge below 1000 m3/s from 3 to 5. Based on a relation between discharge at Lobith and shipping costs the additional costs can be determined (Luiten, 1990). According to this relation the two extra weeks of low flow lead to additional costs of at least 90 million guilders.

The third main function of the river is nature. At the moment plans are developed for nature development

along the rivers. An increased variability of the discharge regime due to climate change influences inundation frequencies in the floodplains and consequently habitats. This is not necesarilly a negative aspect. Independantly from the discharge regime, a higher temperature will lead to larger biological activity in aquatic ecosystems in the floodplains, which could lead to a disturbance of the food chain.
River water is also used for cooling water for industry, mainly in electricity production. A previous study has shown that a reduction in the summer discharge of the Rhine with 7% leads to an increase in production costs of 6 million guilders (ISOS, 1990). According to the business as usual best guess scenario, discharge decreases in summer with about 10%. Consequently the extra costs will be larger.

Although the fraction of the Rhine discharge that is used for agriculture and drinking water is small, more frequent low flows may lead to increased salt intrusion through the surface water, with potential problems with water intake in the Western part of the Netherlands.

5. Outlook into second phase of the CHR-project

The potential effects of changes in the discharge regime due to climate change are large. Not only direct effects are important, but also indirect effects through for example changes in morphology and ecology, which also influence water levels and the river functions.
Furthermore changes in the discharge regime of the Rhine, in combination with changes in climate in the Netherlands and sea level rise, also affect other parts of our water management system, like that of the large inland lake IJsselmeer and of terrestrial areas including groundwater and small surface waters.

Therefore the Netherlands contribution to the second phase of the CHR project is directed towards two aspects. The first is a better assessment of effects of climate change on the river regime, especially for peak flows. For this the RHINEFLOW model will be refined to a grid size of one by one kilometer and a timestep of 10 days. Also methods will be developed to get results on a daily timestep, based on the improved RHINEFLOW model and the already existing detailed sub-basin models. A preliminary study carried out by the Agricultural University showed promising possibilities for this. Next the development of usable climate scenarios should be stimulated.

Another important part of the second phase of the CHR-project is a case study on the assessment of effects of climate change for inland water systems and water management in the Netherlands.
For three sub-systems, the Rhine branches, terrestrial areas and the IJsselmeer, the effects of changes in climate related boundary conditions as river regime, weather and sea level rise, on hydrological, morphological and ecological characteristics will be analyzed.
Based on this, consequences for the user functions and for society will determined and measures to mitigate negative and enhance positive effects will be identified. The base for the analysis will be the modelling tools that RIZA has developed and is developing for policy analysis on the national and sub-national scale.

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The Netherlands contribution to the World Meteorological Organization

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1. Introduction

Within the turbulent United Nations community, the World Meteorological Organization is not the most noisy one. And it should not be, as its major task still is in guarding the continuity and quality of meteorological data flow all over the globe.

Applied meteorology is a real-time activity, and, in particular, weather forecasting, would not be feasible without the standards and procedures developed in the World Weather Watch Programme of WMO. This Programme requires a world-wide co-operation and discipline, which may be unique, even for UN organizations. Also in the years of the cold war, the WMO infrastructure operated perfectly in good harmony.

However, the World Weather Watch is only one of the Programmes of WMO. Also the World Climate Programme is of major importance, with regard to the problem of the influence of human activities on the global climate.

And many other programmes benefit from the constructive co-operating spirit within the WMO organization as well, including the Programme for Hydrology and Water Resources.

But, before turning to the Hydrology subject, I will give some more consideration to the relation between WMO and KNMI.

2. The relation between KNMI and WMO

KNMI contributes to the work of WMO in many ways. 125 Years ago, Buys Ballot, the founder of KNMI and the first President of the International Meteorological Organization, came to the conclusion that progress in meteorology required an international approach. The basis of Meteorology, Climatology and Hydrology is in the availability of data on a larger scale than a national one, for feeding both research and applications.

Therefore, it is quite obvious that each Member of WMO should make available relevant data from its own territory. But observations only from sites on land are inadequate, and therefore Member countries also co-operate in organizing the generation of observations from sea surface and from the upper air.

KNMI is active in programmes for observations on merchant vessels and aircraft, from drifting buoys, from platforms in the North Sea in good co-operation with Rijkswaterstaat, and from the METEOSAT satellites.

But KNMI is also involved in processing the data, in particular in our participation in the European Centre for Medium Range Weather Forecasts. A number of basic products from this centre is made available for the whole meteorological community.

Furthermore, KNMI is contributing expertise in various fields, for example, in the calibration of meteorological instruments and in dispersion models for pollution.

In particular our activities in the Intergovernmental Panel on Climate Change may be mentioned here. KNMI is a co-author of the second scientific evaluation report of working group 1: IPCC's 1995 Assessment. Its publication, last week, received much attention in the press, as a result of the firm statements on the influence of human intervention upon the world climate regime. Next week, this report will also be discussed in the other working groups, culminating in policy directives for the Conference of the Parties in the Climate Convention.

One could question whether the benefits we ever could gain from our involvement in WMO could balance the costs of all these contributions. The answer, however, is clearly positive. And also quite an amount of value is added to our efforts as a result from the many contacts on an international level.

3. The role of KNMI in the field of hydrology

KNMI is involved in hydrology in many ways, generally in good co-operation with other institutions in this country. In particular, the role as data provider for precipitation is of clear importance, and the KNMI rainfall forecast during the critical situation along the main rivers in the last two winters was a substantial one.

Hydrology is not a formal component of the national responsibilities of KNMI, however. In many other countries meteorology and hydrology are combined in one national institute, and also WMO has formal hydrological responsibilities.

And, in a similar way as the threat of climate changes has an enhancing impact on the global co-operation in this discipline, the world wide problems in the field of water resources calls for an enhanced large-scale co-operation in the field of hydrology.

In particular, the limited amount of available fresh-water in the world may become an alarming subject, the more as this amount tends to decrease in a continuously increasing world population.

Also the impacts of changes in the global climate should be mentioned in this context. Such changes may generate regional effects on precipitation amounts, and consequently on hydrological cycles.

Under these circumstances, the many indications for a growth of interest from the hydrological community in the Netherlands for the international co-operation are not surprising:

- The national committee for the UNESCO IHP and the WMO OHP shows an increasing activity;
- As a follow-up to the recommendations of the committee, I hope to inform WMO soon on the formal appointment of a Hydrological Adviser for the Netherlands;
- After a number of years, we could inform WMO that a National Reference Centre for WMO Hydrological Operational Multipurpose Subprogramme HOMS has been established at the Institute for Hydraulic Engineering in Delft;
- And also the organization of this symposium may be regarded as such an indication.

In this context, I welcome this opportunity to stress KNMI's preparedness to intermediate between the Netherlands hydrological community and WMO with a view to a closer co-operation. I am convinced that this would benefit both global and national purposes.

Water related activities of WMO

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1. Introduction - the need for water resources assessment

Water resources assessment: the determination of the distribution and characteristics of surface water and groundwater, including their quantity and quality, remains an essential prerequisite to the sustainable development and management of water resources. Water resources assessment is fundamental to virtually every use of water; for drinking water supply and irrigation, for hydropower production, and for the dilution and carriage of wastes. In addition, the data produced contain signals of the sustainability of the different activities being carried out within the basins being sampled. Yet, at this time when demands for water are rising rapidly and the need for sustainability is gaining increasing recognition, national Hydrological Services, particularly in the developing countries, are becoming less capable of assessing national water resources.

Water resources assessment constituted one of the cornerstones of the Mar del Plata Action Plan of the UN Water Conference (1977) [1]. It was also one of the key issues addressed by the International Conference on Water and the Environment (ICWE) (Dublin, January 1992) [2] and by the UN Conference on Environment and Development (UNCED) (Rio de Janeiro, June 1992) [3]. It is currently a concern of the United Nations Commission for Sustainable Development (CSD).

2. Purpose and scope of WMO water-related activities

As set out in Article 2(e) of the WMO Convention, one of the major purposes of WMO is *"to promote activities in operational hydrology and to further close co-operation between Meteorological and Hydrological Services"* [4]. This commitment is exercised through WMO's Hydrology and Water Resources Programme (HWRP). The HWRP assists the Hydrological Services of the Members of the Organization to meet the increasing demands for the assessment and development of water resources, on the one hand, and for protection against natural disasters on the other, all in support of the sustainable development of water resources and of environmental management. The Programme also promotes co-operation between countries at regional and sub-regional levels, especially where there are shared basins.

The HWRP embraces operational hydrology, which comprises the *"measurement of key hydrological elements from networks of meteorological and hydrological stations: collection, transmission, processing, storage, retrieval and*

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publication of basic hydrological data" ... and the *"supply of meteorological and hydrological data for design purposes"* [4]. Of course hydrological data and the products derived from them by the skills of the hydrologist include the variations in space and time of both surface water and groundwater. Thus operational hydrology is the essential tool for water resources assessment.
The overall objective of the HWRP as given in the WMO Fourth Long-term Plan (1996-2005) [5] is:

> *"To apply hydrology to meet the needs for sustainable development and use of water and related resources; to the mitigation of water-related disasters; and to effective environmental management at national and international levels.".*

This objective accords with the recommendations of the UN Water Conference [1], with the aspirations of ICWE [2] and with those expressed in AGENDA 21 of UNCED [3].

Other WMO programmes have important hydrological components which contribute to WMO's water related activities, in particular the Tropical Cyclone Programme (TCP), the World Climate Programme (WCP), the Instruments and Methods of Observation Programme and the Regional Programme.
The HWRP also incorporates activities for education and training in hydrology. Furthermore, WMO's technical co-operation activities include a major hydrological component.
The HWRP is closely linked to the programmes of other international organizations, in particular those of UNESCO, UNEP, FAO, and the UN Regional Economic Commissions. These links give the HWRP an added dimension.
Because of the leading role the Organization plays in countering tropical cyclones, floods and droughts, the UN has called for a significant input from WMO to the International Decade for Natural Disaster Reduction (IDNDR, 1990-2000) [6].

3. Programme organization

The International Meteorological Organization (IMO), the predecessor of WMO, was involved in water-related activities in the 1930s and even established a Commission for Hydrology. WMO inherited IMO's responsibilities in 1950 and in 1959 it established a commission to oversee its work in hydrology. WMO worked with UNESCO and other UN agencies in support of the International Hydrological Decade from 1965 to 1974, after which WMO's principal hydrological activities were grouped under its Operational Hydrology Programme (OHP).
The HWRP has three components:

Operational Hydrology Programme (OHP) — Basic Systems
This component concentrates on the basic organization, operation, and development of Hydrological Services. It includes the development, comparison, standardization, and improvement of hydrological instruments and methods for the collection and archiving of water-resources information and human-resource development. The transfer of technology is facilitated by the Hydrological Operational Multipurpose System (HOMS).

Operational Hydrology Programme - Applications and Environment
This component brings together hydrological activities in support of water-resource development and management, including hydrological modelling and forecasting, and the provision of products for a range of projects, including those for environmental protection.

Programme on Water-related Issues
This component contributes to the international programmes of other bodies within the UN family, and to those of intergovernmental and non-governmental organizations (NGOs) through inter-agency co-ordination and collaboration in water-related activities, including regional projects associated with large international river basins.

The future Hydrology and Water Resources Programme (HWRP) is set out in WMO's Long-Term Plan [5] as agreed by the Congress of WMO which also establishes the budget for successive four-year periods. For the period 1996 to 1999 this budget amounts to something over 11 million Swiss Francs. These funds are for use in support of the various meetings and publications, which form part of the Programme, and for the maintenance of the work of the Secretariat in Geneva. They are therefore only a part of the resources available to the HWRP as a whole.

4. Programme implementation

The OHP is planned and executed through the WMO Commission for Hydrology (CHy). Implementation is principally by elected working groups and individual rapporteurs, who address specific aspects of hydrology appropriate to their expertise, through the convening of technical meetings and symposia, and organizing training courses and by the production of reports on these activities.
Specific projects are designed to investigate and compare instruments, network-design techniques and forecasting models. Project results are published in the series of *WMO Operational Hydrology Reports and Technical Reports*

in Hydrology and Water Resources. The essence of these and other activities is summarized in the Guide to *Hydrological Practices*, now in its fifth edition [7]. Agreed standard practices are published in *Volume III (Hydrology)* of the *WMO Technical Regulations* [8]. Working groups on hydrology in the six WMO Regional Associations address topics relevant to the hydrological problems of their Regions. The Working Group on Hydrology of Regional Association VI - Europe was re-established at the Association's eleventh session (Oslo, 1994) and includes rapporteurs on the following topics:

- hydrological networks
- weather radar data for hydrology and water resources
- water quality monitoring, forecasting and control
- climate and water
- operational hydrological research basins
- sediment transport.

The reports of these rapporteurs will be discussed at a session of the Working Group, which will be held in 1997, and subsequently submitted to the twelfth session of Regional Association VI, which is currently expected to be held in Israel in mid-1998.
The *Hydrological Operational Multipurpose System (HOMS)* is a technology transfer system which provides hydrologists with access to technology developed by hydrological services in other countries. Since it was started in 1981, HOMS has achieved nearly 3500 transfers.

5. International data bases

Two global data bases have been established as part of the HWRP:
The *Hydrological Information Referral Service (INFOHYDRO)* contains information on national and regional hydrological agencies, and the networks and data banks they operate [9].

The *Global Runoff Data Centre (GRDC)* at the Federal Institute of Hydrology, Koblenz, Germany, holds daily and monthly flow records for selected river gauging stations from over 140 countries.

6. World Climate Programme

This Programme, with its four themes: data and monitoring, applications and services, impacts and responses and research, and the associated *Global Climate Observing System (GCOS)*, are important to WMO's water related activities. Amongst these activities those of most concern to hydrologists are grouped under *WCP-Water* where the likely impact of climate change on water resources is addressed.

WCP-Water, the management of which is shared with UNESCO, brings together more than 30 projects undertaken by national and international institutions. Analysis of long time series to distinguish trends and changes, the connexions with "El Niño" and the sensitivity of different water systems to climate change are among the topics being addressed. The GRDC was launched as a WCP-Water project.

GCOS was established to provide observations to monitor the climate system and to detect climate change, as well as for improved understanding and prediction of the climate system [10]. GCOS is being built upon the WWW Global Observing System and contains both space-based and surface-based observing components. The hydrological aspects of GCOS contribute to the water-related activities of WMO.

7. Co-operation with other international organizations in projects related to hydrology and water resources

In the field of hydrology and water resources, WMO's closest links are with UNESCO. A handbook for the national evaluation of water-resource assessment activities was prepared jointly by the two organizations [11] and published in English in 1988 and more recently in French and Spanish. The second edition of the WMO/UNESCO International Glossary of Hydrology was published in December 1992 as the culmination of many years of co-operation and this work will continue under a new joint standing committee.

A WMO/UNESCO report on "Water Resources Assessment - Progress in the implementation of the 1977 Mar del Plata Action Plan and a strategy for the 1990s" was published in 1991 [12]. It was prepared under the aegis of the former *UN Administrative Committee on Co-ordination - Intersecretariat Group for Water Resources (ACC ISGWR)*. Along with several other reports by different agencies, it was one of the basic inputs to the ICWE.

International conferences on hydrology are organized jointly with UNESCO every few years. The fourth such conference was held in Paris in March 1993. It had a less formal structure than in the past, and for the first time ICSU was associated with WMO and UNESCO as a co-convener of the Conference. The opening coincided with the celebration of the first *World Water Day* (22 March 1993). Building on the results of ICWE and UNCED, the meeting made a number of recommendations for action in four areas: hydrological research, operational hydrology, interdisciplinary studies and capacity building, and training and education. The Conference also adopted a "Paris Statement".

Inter-agency coordination is also important to the WMO Plan of Action for the IDNDR [10]. It includes two special projects related to hydrology and water resources. The first, the *Comprehensive Risk Assessment Project (CRASH)* is promoting the effectiveness of risk assessment in efforts to reduce loss of life and damage caused by flooding, by violent storms and by earthquakes. The second is a system for *Technology Exchange for Natural Disasters (STEND)*, which is modelled on HOMS but for a broader range of geophysical sciences. STEND is collecting information on technology and advising potential users on what is available to answer their particular needs, initially for seismology and volcanology as well as hydrology. The first edition of the STEND Reference Manual should be issued in the first half of the 1996 and will be available from the WMO Secretariat in Geneva.

With IAEA and several bodies within ICSU, WMO has concern for the use of natural isotopes in understanding past climates to improve understanding of the hydrological cycle today and the impact of future climate changes on water resources. WMO has expanded its co-operation in GEMS-Water, the inter-agency programme on water quality monitoring, where UNEP, UNESCO and FAO are also involved.
In January 1992 WMO convened in Dublin, on behalf of the 24 agencies with membership in the former ISGWR (see paragraph 7.2 above) the *International Conference on Water and the Environment (ICWE).*
The recommendations of the Conference and their means of implementation were embodied in the Dublin Statement and in the Report of the Conference [2]. Many of the matters they addressed were incorporated in the fresh-water document which went to *UNCED* in Rio de Janeiro, to emerge as Chapter 18 of AGENDA 21.

8. Human-resource development and technical co-operation

Training in hydrology consists of a number of different approaches, including in-service training, training in educational institutions, workshops, seminars, and short-term residency of experts. WMO grants fellowships for study in hydrology and organizes training courses. It also prepares and publishes related guidance and training material.
The objective of *WMO's Technical Co-operation Programme* is to assist Members in developing their capabilities in hydrology. Presently there are three major sources of support, namely: (a) the United Nations Development Programme (UNDP); (b) WMO's Voluntary Co-operation Programme (VCP); and (c) Trust Fund arrangements by means of which assistance is provided by donor countries to specific projects. On average, 40 percent of WMO's total technical-assistance expenditure over the years has been in the field of hydrology.

9. Sessions of the WMO Commission for Hydrology

The Commission, at its ninth session in Geneva in January 1993 [13], made a number of proposals for work under the HWRP, such as on the hydrological aspects of disaster mitigation and transboundary water issues; on the application of business practices such as water pricing and cost-benefit analyses; on advances in science and technology especially in the area of information processing; and on the effects of climate change and sea-level rise on water resources, in line with concerns expressed in UNCED'S AGENDA 21.

The Commission adopted the "Statement of the Ninth Session of the Commission for Hydrology". Noting the improvements required to water resources assessment, amongst the actions proposed in the statement is the promotion of a global hydrological network covering the continents and the oceans and including the principal components of the water cycle, both for quantity and quality. The main objectives of such a global network, the World Hydrological Cycle Observing System (WHYCOS) (see 10. below) are to ensure the availability of hydrological information at the global scale in near real time, in support of international investigations of the global water cycle and climate systems and to improve the performance of Hydrological Services.
The tenth session of the Commission is currently expected to be held in December 1996.

10. World Hydrological Cycle Observation System (WHYCOS)

Both ICWE and UNCED brought in fresh concepts and requirements from Members, laying increasing emphasis on the sustainable development of water resources, the problems of natural hazards and on the furtherance of sound environmental management. Consequently, the emphasis and direction of the HWRP has been changed to respond to the concerns of these two conferences in order to provide an appropriate follow-up in the fresh water area. The WHYCOS initiative is aimed particularly at the follow up to UNCED.

This major long term initiative seeks to improve knowledge of the hydrological cycle and respond directly to the need expressed by ICWE for an improved knowledge base in terms of quantity and quality, the same sentiments being expressed in Chapter 18 of Agenda 21. The initial idea was to establish a global network of about 1000 stations on the major rivers to monitor flow and water quality and to transmit the data through geostationary satellites to global, regional and national centres. WHYCOS will upgrade networks, facilitate the exchange of data, establish or enhance data bases, assist the processing of data and provide for the assimilation of remotely-sensed data. WHYCOS will apply on the national, regional and global scales. WHYCOS will employ the existing WMO World Weather Watch (WWW) system and will, in turn, contribute data to WWW and to GCOS as well as to the Global Terrestrial Observing System (GTOS).
Within WHYCOS a number of regional components, called Hydrological Cycle Observing Systems (HYCOS), have been promoted. The status of these projects is as follows:

-MED-HYCOS: Mediterranean Hydrological Cycle Observing System is funded by the World Bank and implementation started in 1995.

-SADC-HYCOS: HYCOS for the Southern African Development Community was appraised by the European Union in late 1995.

-ARAL-HYCOS: HYCOS for the Aral Sea is expected to form one of the components in the World Bank/UNDP project which has been initiated recently. Switzerland has already appraised this component of the project and is expected to launch activities in early 1996.

Africa is the focus of attention for developing other regional components of WHYCOS because the situation of African Hydrological Services is the most serious. However, the concept is also being developed for Latin America and the Caribbean. The main impediment to progress on WHYCOS is lack of funding- - some $14 million is needed for WHYCOS-Africa for the first 6 years of the 20-year programme which is proposed.

11. Global Water Resources Assessment

During its 1994 session, the UN Commission on Sustainable Development considered fresh-water and requested the preparation of a comprehensive assessment of global water resources for consideration by the General Assembly in 1997. This request is being met by the appropriate UN bodies and agencies with the support of several national institutes. The report they are preparing will have four chapters, the second entitled "A synthesis of the availability and variability of fresh-water resources, use and quality including relevant land use, soils and environmental data" being the responsibility of WMO and UNESCO. Inputs to this chapter will come from a number of sources, but principally from the State Hydrological Institute in St. Petersburg. A first draft is expected by the end of 1995.

12. The Netherlands contribution to WMO's work in hydrology and water resources

As indicated by Dr H.M. Fijnaut in his presentation to this symposium, the Netherlands has long been one of the major supporters of the work of WMO. This has been so in hydrology as well as meteorology; experts from the country have served as members of the Commission for Hydrology and of the RA VI Working Group on Hydrology, and as rapporteurs of these two bodies.

The untimely death of Dr J.W. Van der Made in 1991 and recent changes in personnel and administrative structures within the country have led to a certain hiatus in this link.

Dr H.M. Fijnaut, as Permanent Representative of the Netherlands with WMO, has recently appointed Mr P.M.M. Warmerdam of the Landbouwuniversiteit in Wageningen as his Hydrological Adviser and Dr P.J.M. de Laat of IHE, Delft as the focal point for HOMS within the country. The current symposium has been very valuable in re-establishing links between WMO and the hydrological community in the Netherlands which augers well for future co-operation between the two, in particular in areas such as the monitoring of the quantity and quality of surface and ground water resources, flood forecasting and the development and exchange of operational technology.

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Meteorological observations in the Netherlands in relation to hydrology

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1. Introduction

In the hydrological cycle rainfall and evaporation play an important role. Both elements are also key elements in meteorology.
The Royal Netherlands Meteorological Institute (KNMI) activities, except seismology, are all related to the atmosphere and the interaction with the boundaries. Of great importance are the interactions between soil <-> atmosphere and ocean <-> atmosphere. The latter is the most important for meteorology, since 70 % of the earth is covered with water and because the water vapour transport over the oceans is six times the aqueous vapour transport over land area. In KNMI a notable part of research is devoted to this interesting part of the hydrological and energy cycle.
Since oceanography is not the scope of IHP/OHP I will restrict myself mainly to the meteorological elements: precipitation, evaporation and the processes near the land surface.

History
Already before the foundation of the KNMI in Utrecht in 1854, measurements and registrations were made regarding rainfall and evaporation from pans. Zwanenburg, a location between Amsterdam and Haarlem, has a long history with precipitation measurements since 1735.
Knowledge of rainfall and evapotranspiration in the Netherlands has always been of importance with regard to water management. Already during the 19th century measurements on a large scale were made. The first description of precipitation in the Netherlands is from Engelenburg in 1891 (1). A more comprehensive publication on the precipitation appeared 20 years later in 1913 by Hartman (2). The most popular publications were 2 volumes on rainfall by Braak in 1933 (3) and 1934 (4). Braak already had data from automatic recording rain gauges. In his books he gave a description of the length of precipitation periods, the daily variation and the precipitation characteristics. He also described the dependence on the wind direction.
Regarding evaporation, Braak published in 1936 a comprehensive work: "Evaporation". The publication (5) was based on measurements with evaporation pans.
In the years around 1950 a lot of work was done in calculating frequencies of rainfall amounts in various periods.
From rainfall charts at De Bilt a twelve year series of 5 minute sums was composed. Together with series of other stations these datasets are still in use for calculating the dimensions of drainage systems. Much of this work was published by Levert and incorporated in his book "Rains/a statistical study", issued by KNMI in 1954, (6).

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Finally, Buishand and Velds published in 1980 "Precipitation and evaporation", the first book in the series "Climate of the Netherlands", (7). It gives a clear and widely used review of the available information and data on rainfall and evaporation.

In the early fifties the evaporation calculation according to Penman came into use. His method makes use of four elements: sunshine, wind velocity, temperature and relative humidity. Kramer published in 1957 (8) a comprehensive study on free water evaporation in different parts of the Netherlands. A follow-up was given in 1979 by De Bruin, (9).
Since 1956 the evaporation according to Penman was published in the Monthly Bulletin of the Weather, an issue of KNMI. In the course of the years several improvements were introduced. It gave rise to the confusing fact that in the seventies different versions of the Penman formula existed.

After consultation of users it was decided to make a change to the Makkink formula, because:

1. its behaviour is very similar to that of the Penman formula
2. it is remarkably simple: it requires only air temperature and global radiation as input. Both can be measured directly and very accurately
3. under dry conditions Makkink's formula appears to have even a better performance

De Bruin, Feddes and Lablans presented the new method on a Technical Meeting of the TNO-Committee on Hydrological Research. This resulted in the publication of Proceedings No 39: "Evaporation and weather", (10).

During the last 20 years climate models and general circulation models were developed. Research also started on the effects of climate change on rainfall amounts and rainfall distribution. With the progress in the quality of computer climate models and the use of parametrization schemes the interest in rainfall and evapotranspiration is growing.

2. Observations

The quality of observations is to a high degree determined by *standardization* and *continuity*.
Precise formulation of requirements should be given for:

- representativeness of the station location;
- exposure of instruments;
- description of observation site;
- accuracy and type of instrument;
- time of observation;
- data handling;
- publication and exchange of information.

During many years the instructions and the type of instrument for measuring rainfall remained unchanged. Each day at 08.00 local time the amount of rainfall was measured. At the end of the month the data were mailed to KNMI.
The height of the gauge was 1.50m. Braak already found that due to wind-effects around the rim not all the rain was collected in the gauge. Around 1950 the height of the gauge was lowered to 40 cm in order to reduce the wind error. Since 1962 a new type of raingauge has been introduced with an orifice of 200 cm2 instead of 400 cm2. This new type is still in use.
In recent years daily measurements are made on 325 stations evenly distributed over the country (Figure 1).

For weather forecasting and for climatological purposes 40 stations exist (Figure 2). They should preferably continue for many more years on the same location. Most of the measurements and observations are automatic. Every 10 minutes a meteorological message is generated with means, totals or point measurements of global radiation, temperature, humidity, wind direction and wind speed, amount and duration of rainfall. Other measurements and observations performed on main stations are 10-cm temperature, visibility, soil temperatures, weather, type and height of clouds. From the 10 minute values the hourly and daily values are calculated. The daily potential evaporation is calculated from the global radiation and the mean temperature.

3. Products

For hydrological purposes KNMI can deliver to consulting agencies and water authorities 325 daily values and 40 hourly and 10 minute values of rainfall and 30 daily values of potential evaporation.
All the meteorological data are stored in a database. Hourly data of the last three year-period and daily data are directly available in the relational INGRES-database. The older information since 1900 is stored in a mass-storage system and is accessible through the database within a few minutes.
For standard graphs and tables routine programs are written. Standard products are e.g. the Monthly Bulletin of the Weather and the Monthly Bulletin of Rainfall and Evaporation. They contain daily data of rainfall totals, duration of rainfall, evapotranspiration, frequencies of raindays and monthly totals.
Data are easily selected by using a query language and tables and graphs are rapidly produced. It makes the provision of information very flexible.

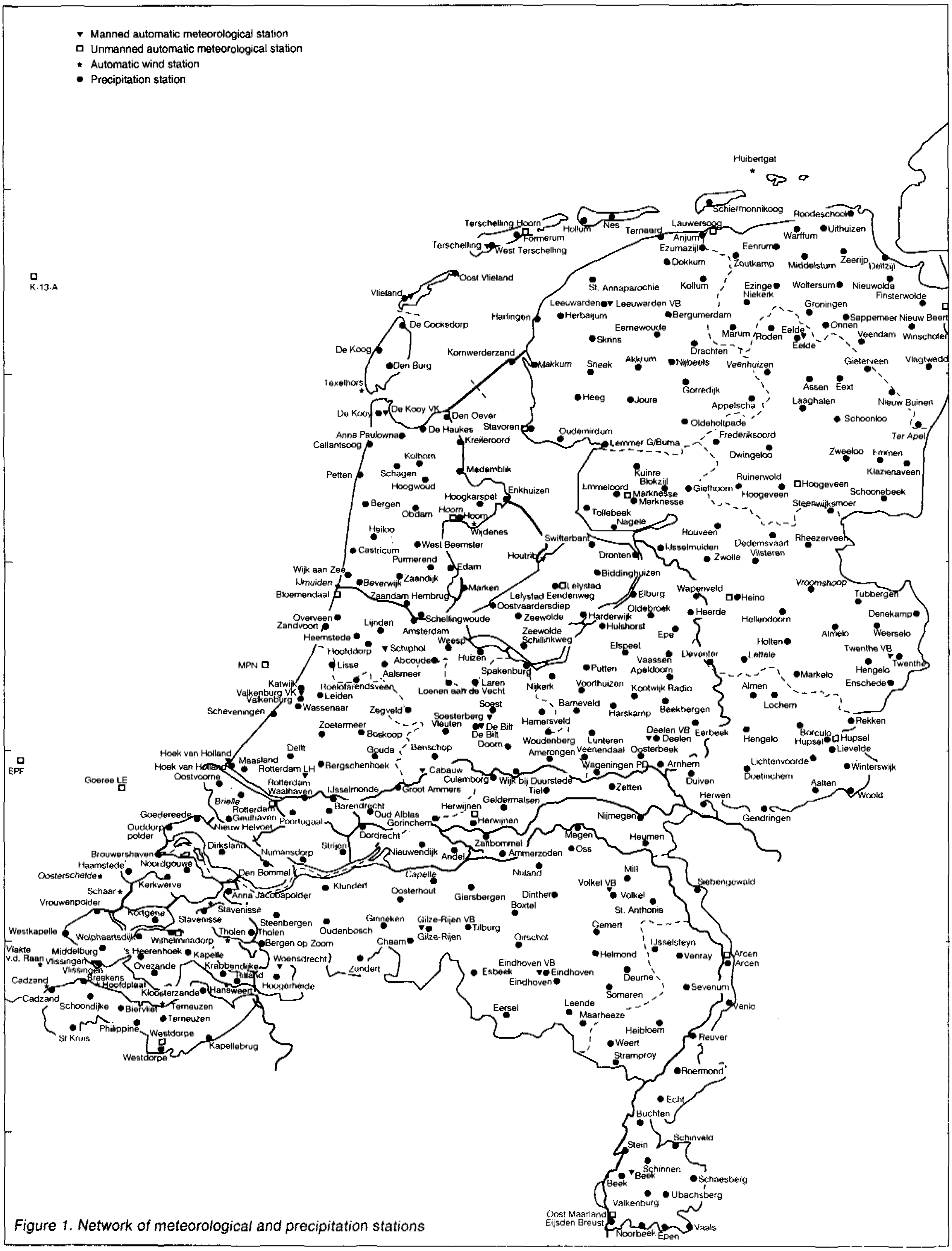


Figure 1. Network of meteorological and precipitation stations

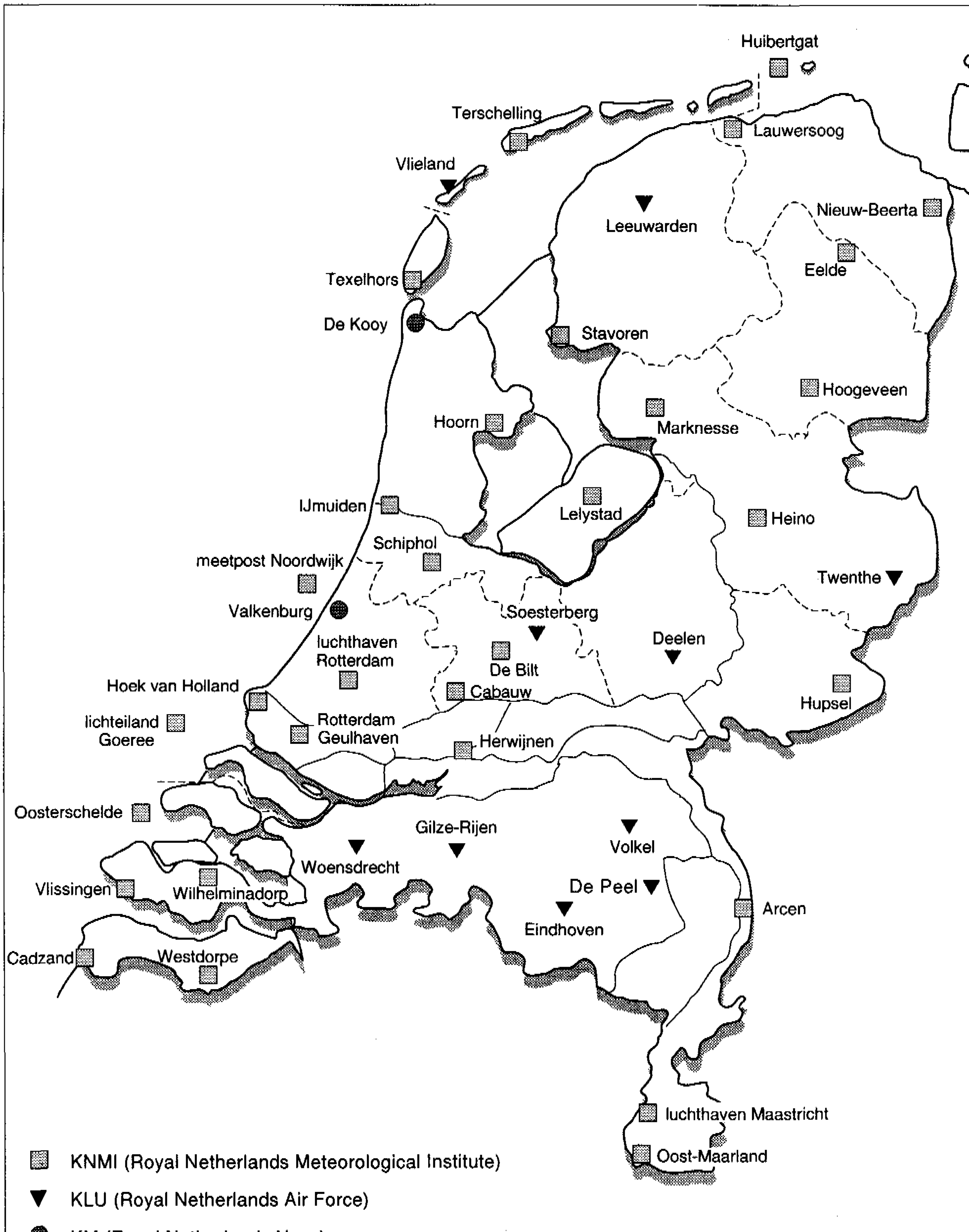


Figure 2. Main meteorological stations

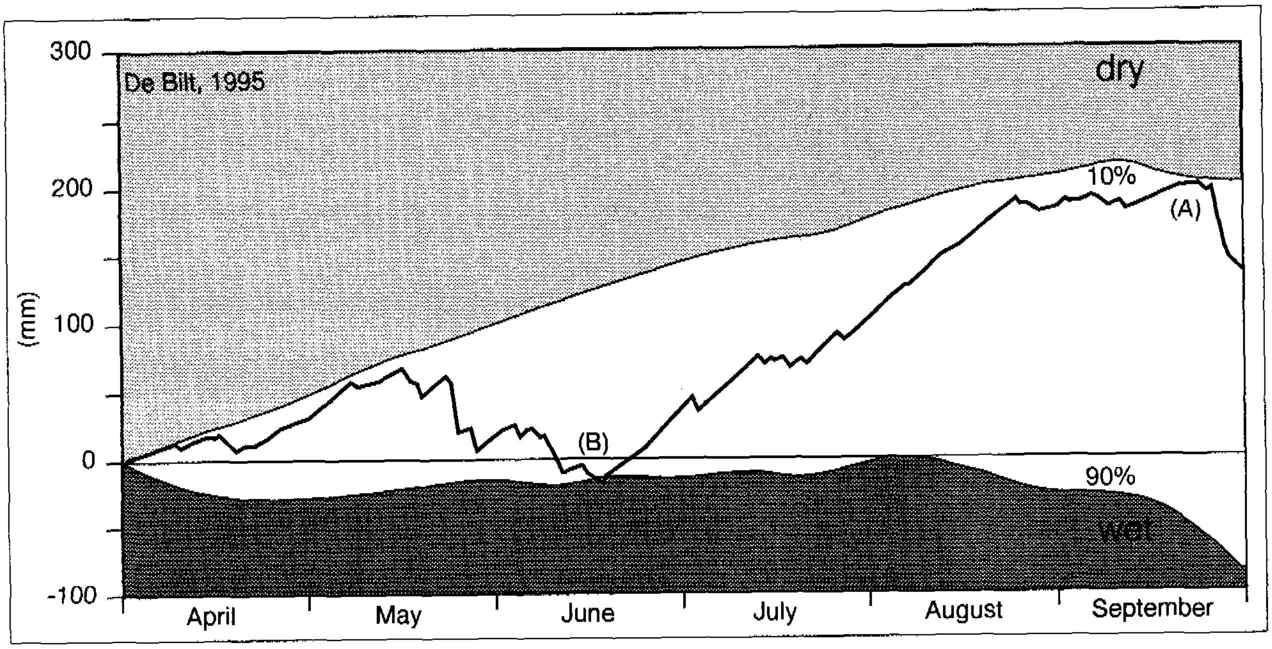


Figure 3. Cumulative potential precipitation deficit the growing season of 1995 at De Bilt.
The 10% and 90% lines give for each date the values that are exceeded in 10% and 90% of the years

Many users of rainfall data, especially farmers and water authorities, are interested in the difference between rainfall and potential evapotranspiration in the growing season. With the help of the database and a computer-program, continuous graphs like Figure 3 are produced for several stations and delivered to users.
Of interest is the maximum precipitation deficit in the growing season. As one can see in the graph of 1995, De Bilt was rather dry with a maximum rainfall deficit of 200 mm in September.
The differences, even in a flat country like the Netherlands, are still large (Figure 4). De Peel was very dry, whereas in the north, in Groningen and Friesland, the difference between evaporation and rainfall was much smaller.
From year to year there is a large variation in the maximum precipitation deficits. The data from the years since 1911 are worked out in a frequency curve, Figure 5. The probability on the horizontal axis corresponds with a certain deficit on the vertical axis. A number of years are mentioned: the sixties were quite wet, while the nineties are mainly found in the middle part.

4. Modern tools

Technical developments allow new measuring techniques, faster exchange of information and complexer calculations.

Since 1 December, 1995 the observers of rainfall stations send their daily rainfall information directly to a KNMI computer by using a toll free telephone-number (06-number). IRIS (which stands for Interactive Rain Collection System) has proven to be a success and makes the rainfall data of nearly all 325 stations the same day available in the database for use in the description of present weather.

Radar pictures of rainfall over the Netherlands and surroundings are continuously available for the meteorologists. Routinely the radarpictures of Schiphol (in the near future Den Helder) and De Bilt are combined into one picture. Radar information exists already more than 30 years. But now with modern communication through computer networks and telephone lines interested customers have the opportunity to use the information on line, Figure 6.
The next day the radar information can be compared with the observed daily rainfall totals.

Information on rainfall and evaporation calculated from satellite data is up to now used in a limited number of projects. An example is the project ASMODE - ASsessment and MOnitoring of DEsertification in the Mediterranean region.
In this project KNMI works together with Wageningen Agricultural University, ITC (International Institute for Aerial Survey and Earth Sciences) and a few Spanish and Dutch consulting firms. Results are e.g. maps with detailed information on total evaporation in Spain for different periods.

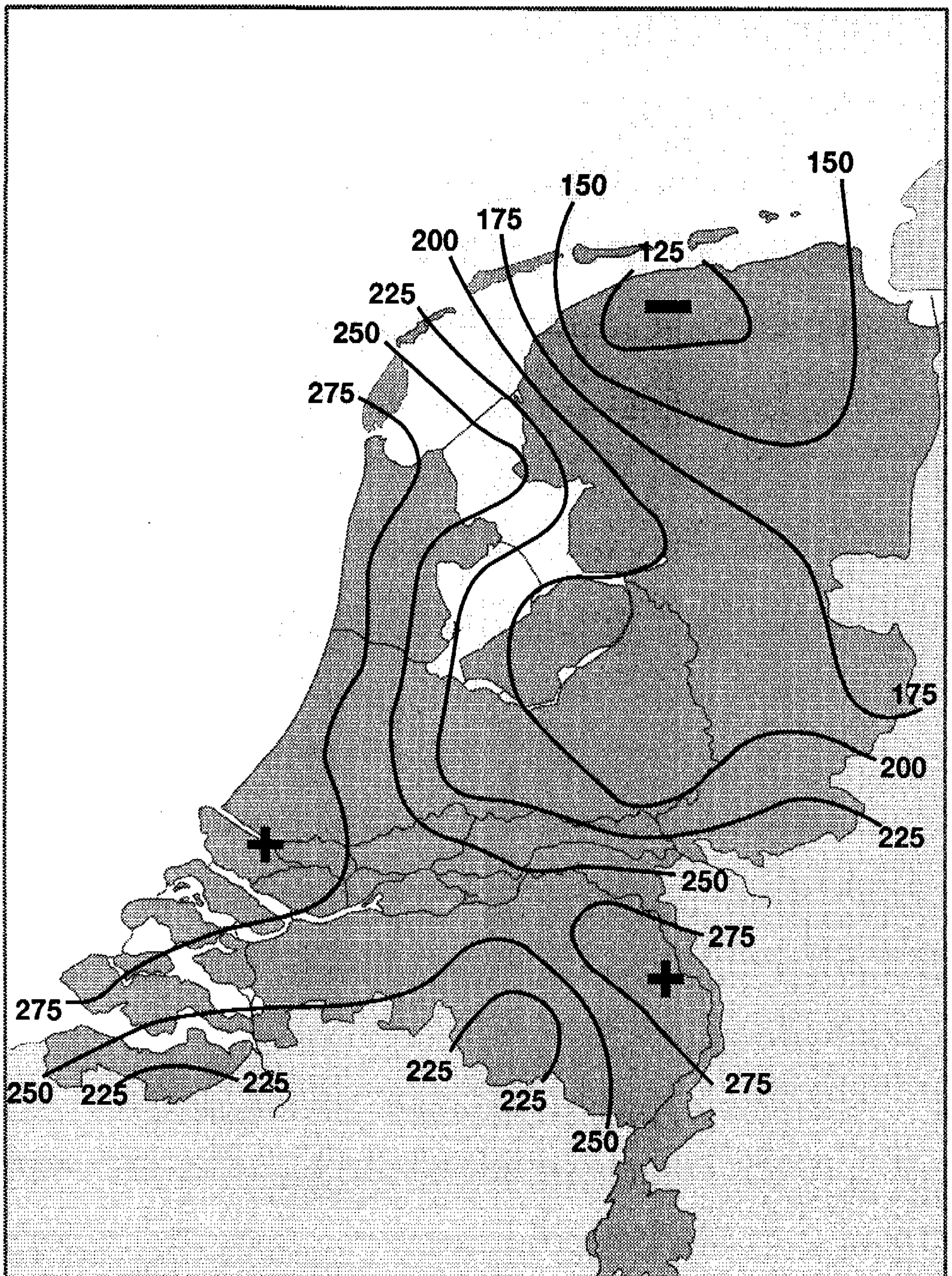


Figure 4. Maximum increase in potential precipitation deficit in mm during the growing season of 1995 (maximum (A) - preceding minimum (B) in figure 3)

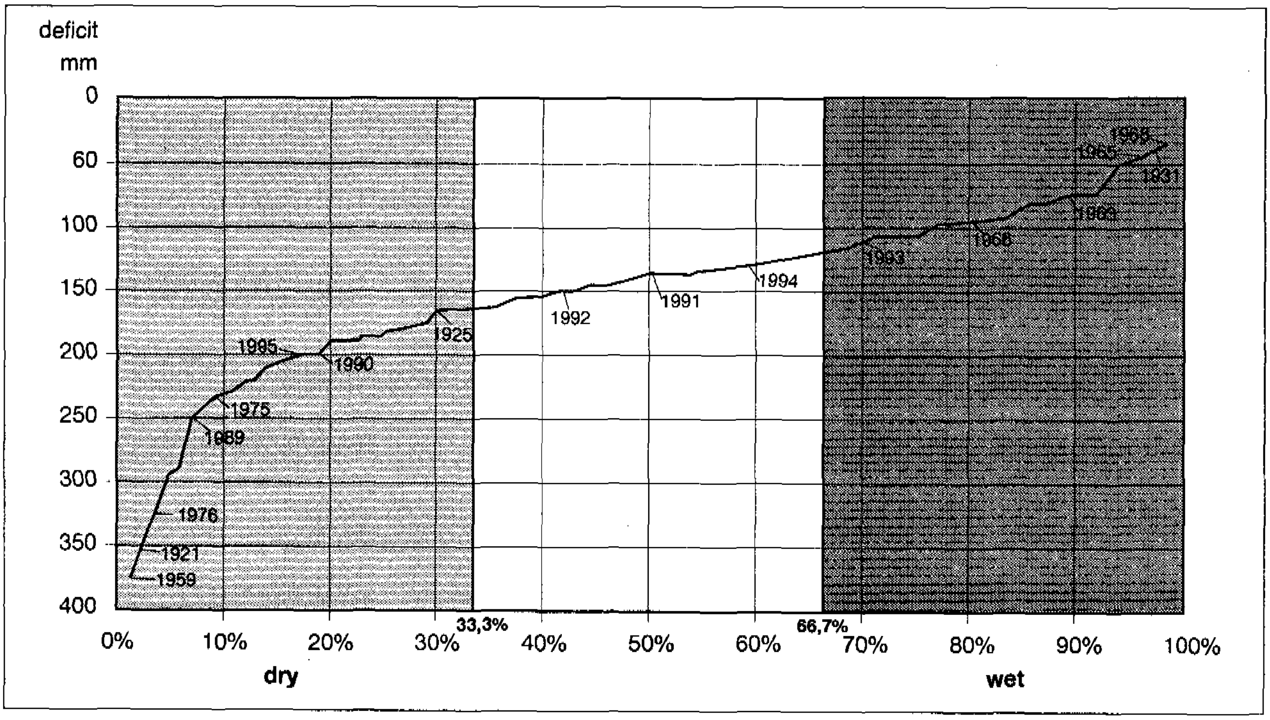


Figure 5. Frequency of exceedance of maximum potential precipitation deficit per year

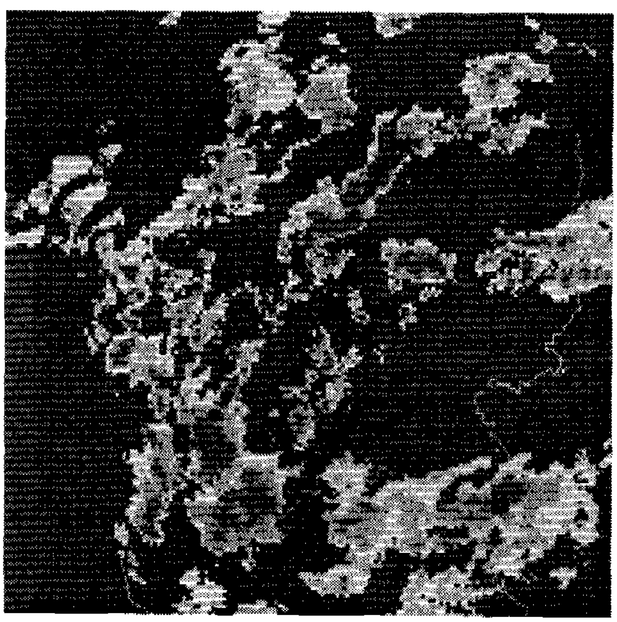


Figure 6. Radar picture of 17 november 1995, 11.45
A, B, C and D: high clouds with tops of 22000 feet, 14000 feet etc.

5. Research

Different branches of two divisions of KNMI are involved in research on the hydrological cycle.

The goals of research related to hydrology are:

1. Understanding and describing the physical processes of water and water vapour transport in the atmosphere and near the surface
2. Applying the results in weather and climate models in order to
   a. produce accurate weather forecasts
   b. develope Global Climate Models (GCM) and Climate Scenarios of climate change

For this research KNMI runs 2 experimental sites.

The first is Cabauw, perfectly situated near Schoonhoven, 20 kms W of Utrecht, Figure 7. The site is situated in rural grassland area. The facilities include a 200-meter-high tower. Mean profiles of wind, temperature and visibility are measured, as well as turbulent fluxes, precipitation and various components of radiation. An Acoustic Sounder, a Windprofiler-RASS system and a Cloud-Detection system complete the site. Since 1985 by these observations the actual evaporation is measured. Figure 8 presents the corresponding water balance for 1987.
The second site Speulderbos is situated near Garderen in the centre of the Veluwe. Mean profiles and various fluxes of energy and water vapour are measured.
In 1989 detailed measurements were made in collaboration with the University of Amsterdam and

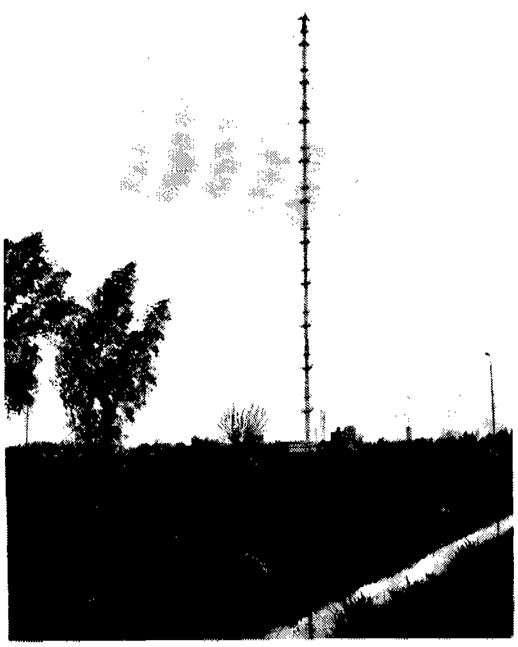


Figure 7. Meteorological and experimental station Cabauw

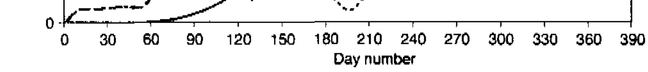


Figure 8. Accumulated waterbudget for Cabauw in 1987

other research institutes. One of the results was a transpiration model developed on measurements performed within the project ACIFORN (*ACI*dification research on douglas fir *FOR*ests in the *N*etherlands). Evaporation measurements are also used for the TEBEX experiment (Tropospheric Energy Budget EXperiment) that started in 1994.

From both sites very extensive and unique datasets are compiled by Beljaars and Bosveld (11) for improving parametrization. They are also used for the validation of model representations of landsurface processes and the hydrological cycle.

Climate change

Since serious floodings and near floodings occurred in the winters of 93/94 and 94/95, there is a growing interest to investigate possible changes in the rainfall regime and in the discharge of rivers due to climate change. The branch - Climate Scenarios - is strongly involved in this study and in related international projects. An example is the EU-project POPSICLE (*P*roduction *O*f *P*recipitation *S*cenarios for *I*mpact Assessments of *CL*imate Change in *E*urope), in which six international institutes and universities co-operate.
The maximum moisture content increases with higher temperatures. Under the assumption that the weather patterns and other circumstances don't change, a warmer climate will therefore result in an increased rainfall. This was known already, but is now used to describe the consequenses of a warmer climate. In Figure 9 the relation between mean precipitation and daily mean temperature is shown for the rainy days in The Netherlands (12). The relationship is used to transform the existing precipitation distribution into a distribution for a warmer climate. Both the transformed and the untransformed series will be used in a hydrological rainfall/runoff model. Afterwards the outcome will be used to assess the impact of climate change.
In Figure 10 the 7-day rainfall distributions for the present climate and scenario's with a temperature rise of 2°C and 4°C respectively are given. The probability that an amount of 100 mm in 7 days is exceeded increases exponential with the temperature rise (13).
The consequences of a 1 to 4 degree temperature change are shown in Figure 11.

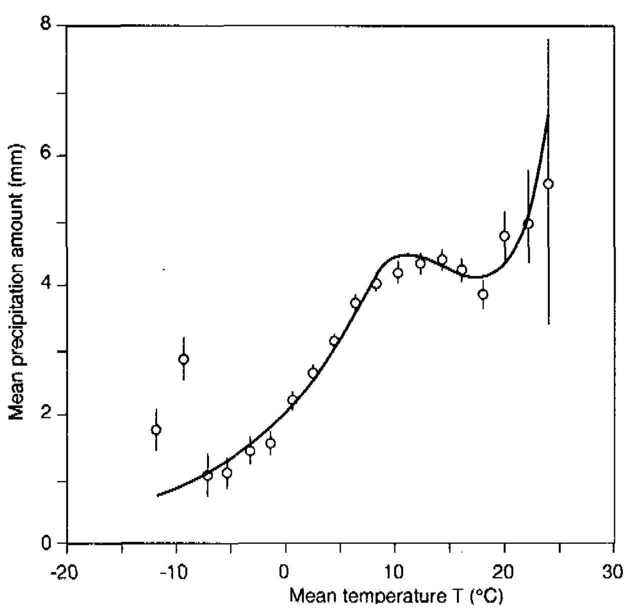


Figure 9. Example of relation between mean precipitation and daily mean temperature

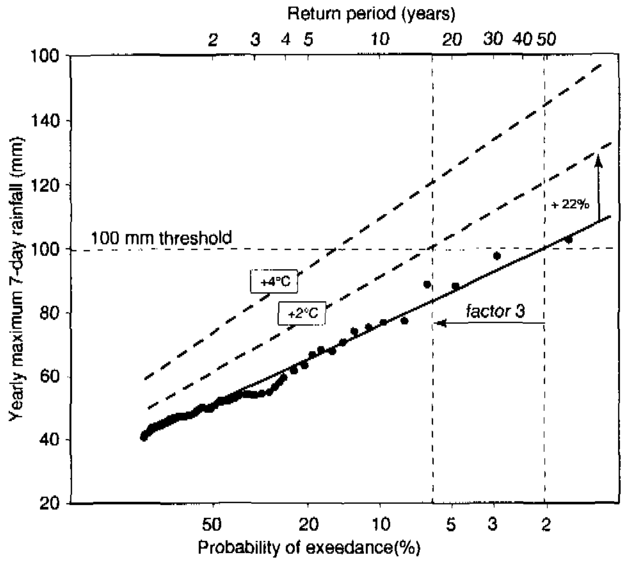


Figure 10. 7-day rainfall distribution for present climate and scenarios with a temperature rise of 2°C and 4°C respectively.Calculated from De Bilt data (1906-1994)

	now (1990)	± 2050			
temperature rise	0°C	1°C	2°C	3°C	4°C
rainfall increase	0°C	11%	22%	33%	44%
return period T of 7-day rainfall>100mm	49y	30y	17y	11y	6y
probability 1/T of 7-day rainfall>100mm	2%	3%	6%	9%	17%

Figure 11. Consequences of a temperature rise for the return period of a certain rainfall amount

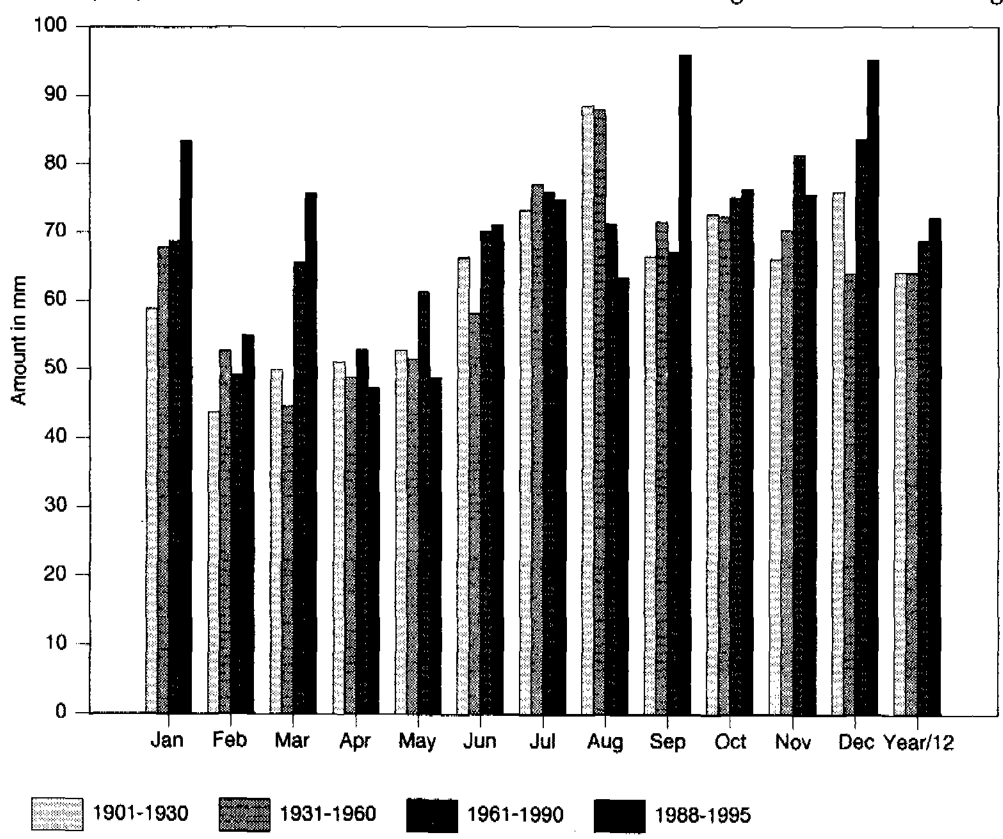
From 1910 up to now the amount of rainfall in the Netherlands indicates a small increase, especially during the winter half year (14).

From the individual months of De Bilt (Figure 12) the conclusion is that only the increase of rainfall in March is statistically significant (Buishand). August is a little drier than in the first half of the century.

During and after the floodings of December 1993/January 1994 and January/February 1995 a good co-operation existed with RIZA (the Institute for Inland Water Management en Waste Water Treatment) and the Royal Meteorological Institute of Belgium.

Daily rainfall totals of several stations in France, Belgium and the Netherlands were used to calculate the expected discharge and waterlevel at Borgharen (15). Figure 13 showes the calculated spatial precipitation in the Meuse basin and discharge at Borgharen during the last flooding.

Figure 12. Trend in mean monthly and yearly totals of precipitation for De Bilt



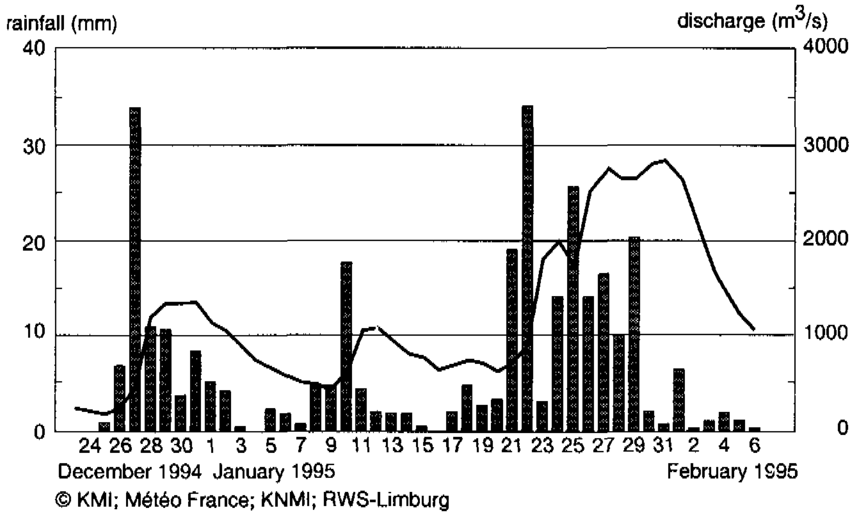


Figure 13. Daily rainfall in the Meuse basin and discharge at Borgharen in December 1994 - January 1995

6. Conclusions

In the coming years hydrology has the ability to make a large step ahead, due to the following reasons:

1. Better process descriptions and models of sub-systems with regard to the interactions of the atmospheric boundary layer and the earth surface are being developed.
2. More detailed information on present rainfall is now on-line available for operational hydrology.
3. A distinct progress in the forecasting of rainfall.
4. Increasing national and international co-operation.

These four points may improve the interaction between hydrology and meteorology.

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The CHR-25th anniversary: Steps towards extended co-operation.

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Netherlands Representative, respectively Secretary to the Commission for the Hydrology of the Rhine basin (CHR)

1. Introduction

The Commission for the Hydrology of the Rhine basin (CHR) was founded in 1970 as part of UNESCO's International Hydrological Decade. Since 1975 it has continued under the umbrella of UNESCO's International Hydrological Programme and the WMO's Operational Hydrology Programme. The tasks of the CHR, as defined at its creation, were:

- to promote co-operation between hydrological institutes and offices in the Rhine catchment area;
- to carry out hydrological studies in the Rhine basin and to exchange the results of research work carried out;
- to promote the exchange of hydrological data and information in the Rhine basin;
- to develop standard methods for the collection and processing of hydrological data in the Rhine's riparian states.

These tasks still apply today. At the time the CHR was created, river research work had a strong mono-disciplinary bias. Hydrology and discharge forecasting in particular formed the central focus of attention which because of their cross-border character made them excellent candidates for international co-operation. Now, 25 years later, significant changes have occurred to the background of research work. The scope and complexity of the future management of the Rhine have come more to the forefront.

2. A world-wide view of the status of surface water

The World Bank is an organisation which provides help in combating poverty in the world by supporting economically and ecologically feasible projects that contribute to social equality. Most of these projects concentrate on the management and utilisation of that most important source of prosperity: water. In particular, the projects at issue are drinking water projects, projects concerning the installation of waste-water systems, irrigation and drainage projects, hydroelectric plants, and of course the construction of dikes as a defence against flooding. Based on the experience gained, the World Bank has reached the conclusion that the way in which mankind handles its water reserves must drastically change and that we must realise that water is a very limited natural resource to be treated with the greatest of care.

At the United Nations world conference held three years ago in Rio de Janeiro, the concern for our water reserves

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was high on the list of priorities. As the water cycle is a continuous one, in theory water can be utilised over and over again. This cycle is a unique combination of distillation and movement processes. The sun evaporates the water in the sea and on land.
Water vapour then rises in the air to later fall by some means or other back to earth. Water collects in and on the ground, flows through a system of rivers off the land and thus returns to the sea. This at least is the usual pattern.

A development towards a new meaning of the term hydrology can also be seen in the latest draft of the International Hydrology Programme.

To quote from this programme:
In general, IHP-V should stimulate a stronger interrelation between scientific research, application and education. The emphasis should be on environmentally sound, integrated water resources management and planning, supported by a scientifically proven methodology.

Specifically for rivers, this can be clearly seen in one of the IHP V projects:
This project bearing the name "Interactions between river systems, flood plains and wetlands" has the following objectives:
- to contribute to the understanding of the role of the hydrological cycle in different ecosystems;
- to identify links between abiotic and biotic indicators in order to maintain the filtering capacities of flood plains and wetland, with respect to sediment nutrients and pollutants, and the buffering capacity against extreme hydrological events.

There is an increasing need for interdisciplinary co-operation in the area of river research work, with a number of different river functions playing an important part.
That is why it is quite legitimate to ask in which direction the CHR can develop as a co-operational body with hydrological objectives in research as its primary focus in the decades to come.

3. Field of study

In recent years, three major trends have become noticeable in river research work:

1). Increase in scale.
2). Integrated approach, i.e. hydrology in a broader context.
3). A strive for greater efficiency.

Re. 1).: An increase in scale
Thanks to the latest developments in information technology, a river management approach embracing the entire Rhine catchment area, which has been acknowledged as a requirement for many years, has now come within reach.
The need for such an approach is illustrated by the examples listed below, where a national approach is either impossible or would lead to unsatisfactory results:
- Changes in climate are occurring throughout the catchment area and the consequences are already noticeable. Ongoing climatological studies carried out by the CHR are already international in nature; only in this way will it be possible to obtain useful results.
- The relative proportion of diffuse sources in surface water pollution is increasing. The need to restrict these emissions makes it imperative that completely new political areas be involved (agriculture, production policy, air pollution, etc.). The joint development of new knowledge and parallel information models and methodologies in participating states can form a productive basis for common policy implementation.
- The river's hydrology and morphology are influential factors, for instance, for the river's navigational and ecological functions and for protection against floods. Changes in the upper reaches have their effect in the lower reaches, and vice versa (especially morphological changes). Quantitative studies of these areas of interaction must form the basis for future river management measures. An international consensus on methods and models will encourage a joint approach.
- Restoration of the river landscape and a reinforcement of the river's dynamics are basic requirements if the flora and fauna typically found in the river are to make it their habitat once again. The spatial distribution of habitats is a prerequisite if the river's ecosystem is to develop as an integral unit (the "eco-network" concept). Internationally co-ordinated research work would greatly benefit the Rhine's ecological function.

Re. 2).: Integrated approach, i.e. hydrology in a broader context
At the end of the 1970s and during the early 1980s there was a complete reversal in the way people thought about the river. The concept of sustainable use came to the fore, and greater attention was focused on the function of nature. The realisation that the river's various functions are intricately interrelated resulted in wide-reaching changes in river management policy. This led to ever-increasing demands being placed on river management. Running hand-in-hand with this development an increasing need for information and methodology arose

in order to improve management control functions. It is not just the number of questions which has increased, but their complexity too. Many matters are of an interdisciplinary nature, especially when the question of vulnerability in the Rhine catchment area is raised.
This also applies to hydrology, the CHR's central discipline. Hydrology is not only important for discharge forecasting, but also for the river's morphological development, for ecological development in the summer bed, and for the development of nature in flood plains. More and more often, research questions of a hydrological nature are being asked within a broader research context, yet almost always form the basis for further research work.

Re. 3).: A strive for greater efficiency
The main drift of politics is to achieve the same goal by spending less money. Improved efficiency has become a key concept, in research work too. An international exchange of information and the joint development of methods, technology and models offer opportunities for paying greater service to this call for improved efficiency.
The projects carried out by the CHR increasingly need to be in tune with the tasks and objectives set by the participating bodies. These institutes continue to be the ones who instigate the studies, as it is they who provide the necessary staffing and finance. Consequently, they expect to see themselves reflected in the CHR's products. It was recently agreed that the logos of the participating institutes should in future be printed on the front cover of CHR reports.
There is an increasing tendency for the tasks of the institutes in the Rhine region to be determined by the International Commission for the protection of the Rhine against pollution (IRC). The institutes work together on the preparation of reports for the International Commission. There is also a growing bilateral co-operation between international government offices.
What role can the CHR play in this context?
First it has to be said that over the past years the CHR has performed a wide range of useful work. The Rhine monograph was the first objective, followed by reports on the movement of water and sediment; together with the IRC the Rhine alarm model was drawn up; studies on floods and changes in the climate are underway. Use has also been made of modern information technology, with the CHR currently compiling a comprehensive GIS for the Rhine basin. Its unique position as a working party of riparian states has made it possible for the CHR to obtain large sets of geographical data without financial cost and to compile this data into a standard data set for the entire Rhine catchment area. This GIS will in future serve as the basis for further studies.

4. Discussion on social context

At the present time the CHR is fulfilling a unique role in international co-operation in the Rhine catchment area. It is the only working party to have research work and the exchange of information as its main objectives. The CHR aims to be a knowledge base for common problems in the Rhine catchment area. However, we must ask if the CHR's activities adequately meet social considerations.

Figure 1 shows the CHR's current organisation.
The CHR is made up of permanent representatives and a

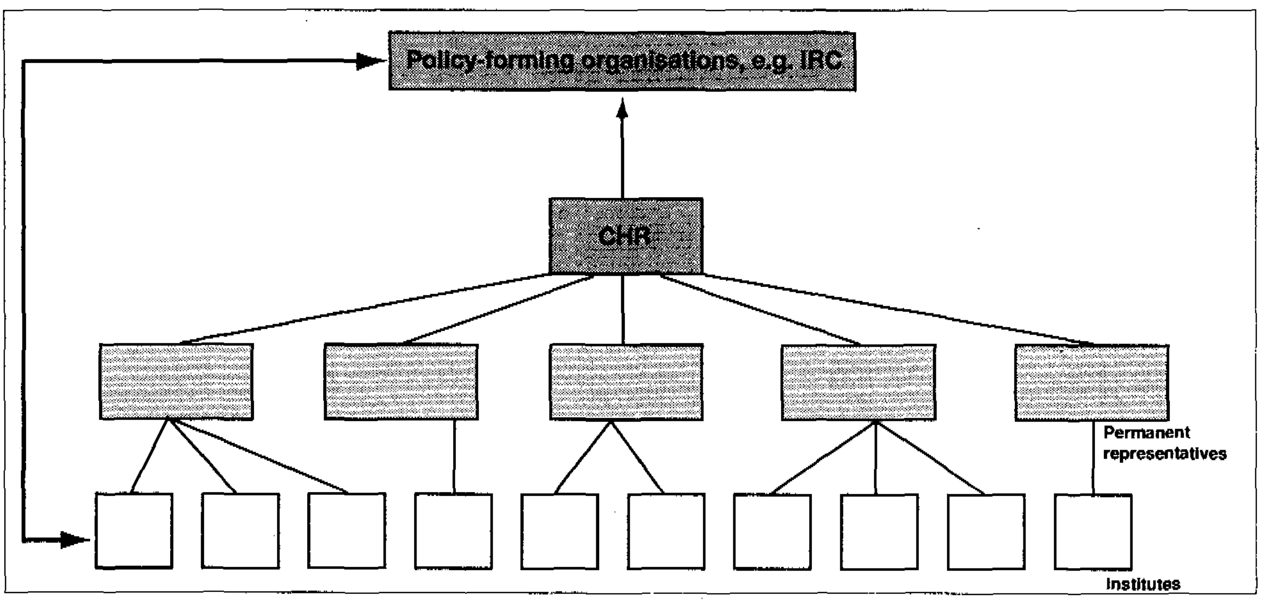

Figure 1. Current organization of CHR

secretariat. These representatives, or "co-ordinators", represent their national state. Reporting back to their national delegations is organised differently from country to country.

To start the discussion I would like to summarise the situation as it is today:
The relationship between the CHR and the national representatives is clearly defined. The relationship between the national representatives and the leading national research institutes is less clearly defined. One might ask whether the leading research institutes have sufficient abilities to harvest the fruits of the CHR's function as a knowledge base, and if the institutes find they are adequately reflected in the CHR and able to make their voices heard.

Policy-forming bodies such as the IRC will generally turn to the leading national research institutes in scientific matters. Because the relationship between the CHR and these institutes has not been sufficiently well defined, the CHR does not function at all, or at best not directly, as a knowledge base. There is some justification for describing the flow of information between the policy-forming bodies and the CHR as one-way traffic.

If we consider this summary to be accurate, it would be a logical step to incorporate the leading national research institutes in the Rhine catchment area more profoundly into the CHR (alternative 1, figure 2). This is quite feasible from an organisational point of view, if representatives of the most important government institutes and offices are included in the CHR as well as national representatives. The institutes and offices would then see themselves reflected more clearly in the work of the CHR, and the work of these institutes would be carried out more effectively.

However, in this case there is still the question of whether the CHR wishes to be merely a knowledge base for the research institutes, or whether it also wishes to be approached by social bodies when problems of a joint, cross-border nature are at issue. If the CHR is a working party made up of the leading research institutes, this question is of less relevance. These institutes are the first to be approached and can benefit from the support of their CHR, even deciding to implement joint research work within the CHR framework.

A more radical alternative would be to alter the structure of the CHR in such a way that it much more expressly becomes a working party of national research institutes in the Rhine basin (alternative 2, figure 3). This would also mean departing from the principle of national representatives, with representatives of participating institutes assuming the co-ordination of the CHR instead. But in this case the CHR would also work for the policy-forming national and international committees.

5. 25 years of CHR

A reason to celebrate, and to stop and reflect for a moment. A time to look back with satisfaction and to consider what shape the future might take.
No matter how the CHR may be organised in future, the tasks set 25 years ago remain fully relevant and are becoming more and more important.
Co-operation between the various state institutes and government offices in the entire Rhine catchment area can only increase in significance. The entire Rhine will be affected, with its tributaries and riparian land. The CHR has a task to fulfil in the development of new concepts if it is to answer the questions that are likely to be

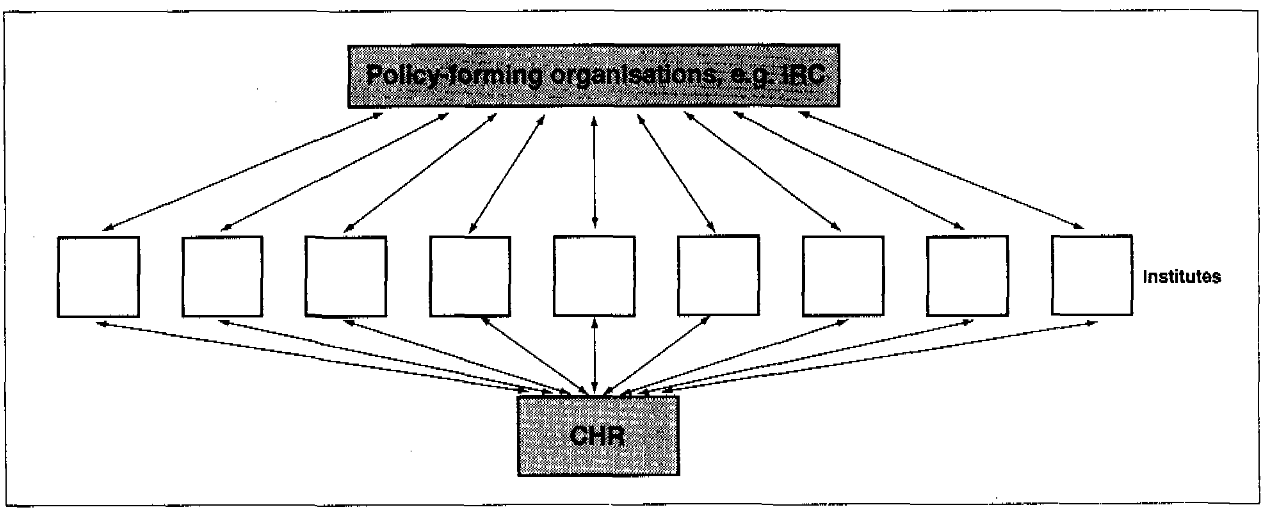

Figure 2. Proposed future organization: alternative 1

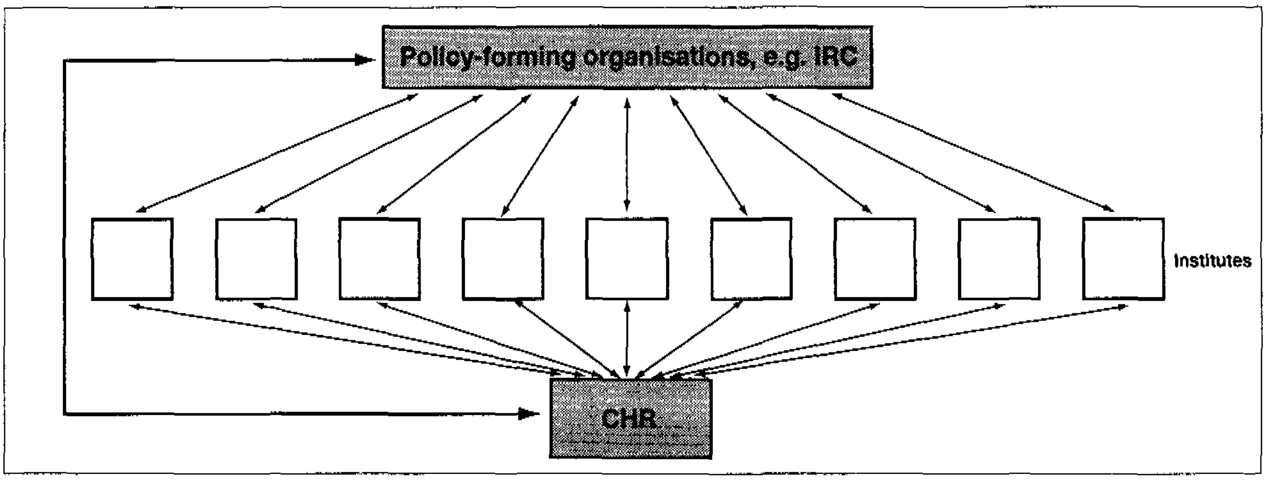

Figure 3. Proposed future organization: alternative 2

confronting us in a few years' time - a "pioneer thinker" function.
An informal exchange of information about which research work should be carried out, and exactly where in the Rhine catchment area; a science-technological exchange of information and the creation of a generally recognised basic package of data and models is also desirable from a political viewpoint. These are the issues with which the CHR has been and should be occupied. Issues, embedded within an ever-changing society.

In my opinion, the topics of current relevance, i.e.
- the movement of water and sediment;
- the changing climate and
- GIS

could be supplemented by
- diffuse pollution
- ecological rehabiliation of flood plains and
- the management and forecasting of floods.

It is my hope that in this way the CHR will long continue to work for the benefit of all those living within the Rhine catchment area and beyond.

Forum discussion: The importance of international co-operation

Chairman: Justus J. de Visser
Secretary: Floris C. Zuidema

At the end of the Symposium a successful forum discussion on international co-operation was held.
At first it was stated that there is hardly doubt on the interest of international co-operation, however up to now verbal statements have been rendered too little into actions. A continuous commitment is required to be sure that international items acquire the same priority as national issues, where research can support in finding solutions. In the discussion it proved that under fixed conditions (steering, budgeting, well defined mission) a structural basis for international co-operation (e.g. at European or riverbasin level) might be given a fair chance.
A second statement concerned the fact that hydrology and meteorology are more and more thrown on each other. They have to benefit from each other more than happens at this moment. The representatives of UNESCO and WMO informed the audience that both organizations have their own responsibility, e.g. WMO to collection and standardization of data and UNESCO to stimulate studies on hydrological processes. However, they recognize that adequate common presentations of the key objectives of both programmes will stimulate further co-operation between hydrologists and meteorologists, at national as well as at international level. Moreover, such an approach might enlarge the chance to win interventions for a higher budget.
Finally the surplus-value of participation in the IHP- and OHP-programmes was discussed. Professor A. Volker emphasized that IHP has given us the opportunity to learn from colleagues abroad and from experiences in other countries. And still it does. In his opinion basic hydrological knowledge is still a prerequisite for good watermanagement. Professor R.A. Feddes stressed the spin-off of both programmes for science and applications, even if there are only limited funds available. His statement was that scientists and other experts, as well as their institutions have the opportunity to bring in their specialized knowledge and expertise. In that way they subscribe to the key objectives of the international programmes. Mr. H.J. Colenbrander and other participants underlined that the networks of UNESCO and WMO, as well as IAHS and EGS favour the personal communication. In the view of Professor J. Leentvaar international co-operation is very stimulating. However, in the present situation of limited research funds at national level, the scientific curiosity cannot fully bear responsibility for its development. International co-operation also needs authorization and some financial stimulus from international as well as national agencies.
Finally Dr. A. Szöllösi-Nagy mentioned three essential points concerning the execution of IHP-V: steering of the programme, execution of the various projects via working groups and (regional) co-operation, and special attention to get the younger scientists involved.

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Adequate planning and clear presentation of goals and foreseen activities are needed to create successful products.
At the end of the day Professor Feddes expressed special thanks of the National Committee to Mr. K. Matthijsse for his valuable and highly appreciated work as Secretary of the National Committee during more than 25 years.

Annex 1

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