PLANNING MEETING ON GRID ESTIMATION OF RUNOFF DATA

IIASA, WMO, IAHS

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Foreword

One of the main objectives of the IIASA Water Resources Project is to improve knowledge of hydrologic and water resource processes within changing environmental situations, and to develop methods needed for relating global climate variability and change to regional water resources. The study is implemented in cooperation with a number of international organisations, including the World Meteorological Organisation (WMO), Unesco, and the International Association of Hydrological Sciences (IAHS).

In the framework of the World Climate Program a meeting was convened by IIASA in cooperation with the Global Runoff Data Centre (Koblenz) to discuss and develop plans for a Pilot Project to Produce Gridded Estimates of Surface Runoff over Selected Regions of the World. Such estimates are needed for transferring catchment-based hydrological data into grid-based data in order to use them for large-scale hydrological modeling and validating atmospheric global circulation models.

This collaborative paper presents the methodological and organisational backgrounds of the Project, which will involve research institutions from Austria, Czechoslovakia, the Federal Republic of Germany, Hungary, Poland and Switzerland. this collaborative paper.

B.R. Döös
Leader
Environment Program

Planning Meeting
on
Grid Estimation of Runoff Data

International Institute for Applied Systems Analysis
Laxenburg, Austria

5–6 March 1990

1. INTRODUCTION

1.1 The Planning Meeting on Grid Estimation of Runoff Data was held at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg on 5 and 6 March 1990.

1.2 The meeting was convened by IIASA in cooperation with the Global Runoff Data Centre (GRDC) of Koblenz with the sponsorship of WMO. The purpose was to discuss and develop plans for the implementation of the project to produce gridded estimates of surface runoff that had first been proposed at the workshop on the Global Runoff Data Set and Grid Estimation (Koblenz, November 1988). The proposal for the project developed in Koblenz is attached as Annex A to this report.

1.3 Annex B lists those who attended the meeting.

1.4 The agenda for the meeting is contained in Annex C.

2. WORLD CLIMATE PROGRAMME

2.1 The meeting reviewed the structure and development of the World Climate Programme (WCP), in particular as regards the water-related activities which form WCP-Water.

2.2 It noted the need for a global set of representative runoff data for the years 1978 to 1980 as a contribution to the data sets of the First GARP Global Experiment (FGGE) and the resulting work which had led to the formal establishment of the GRDC, inaugurated in Koblenz in November 1988.

2.3 The data held by the GRDC were described, as were the operation of the Centre and the services it offered. These are summarized in Annex D.

2.4 It learnt also of the plans for the Global Energy and Water Cycle Experiment (GEWEX) and of the proposals developed by the IAHS/WMO Working Group for GEWEX for a project on macro-scale hydrological modelling. This proposal is attached as Annex E.

2.5 The meeting recognized the need for the hydrological community to develop methodologies for transferring catchment-based hydrological data into grid-based data so they might be used for validating global circulation models (GCMs) as well as for other purposes. It noted the need for data to be used in developing and testing macro-scale hydrological models and endorsed the proposal that the Koblenz proposal (see Annex A) be developed and implemented so as to meet both needs.

2.6 The proposal of the IAHS/WMO working group (see Annex E) had been considered by the JSC Scientific Steering Group for GEWEX at its second meeting (Paris, January 1990). There it had been developed into a much broader proposal incorporating both hydrological and meteorological components with the Mississippi Basin as a suitable candidate for the study area. This proposal was seen as being very important because it reinforced the need for data such as those planned to be collected in the project under review. The meeting felt that the mention of the Mississippi Basin did not affect the plans for a project in Europe.

2.7 During the above discussions, mention was also made of the plans being laid for activities under the International Geosphere-Biosphere Programme (IGBP) of ICSU and of the needs that these gave rise to for hydrological data sets and macro-scale hydrological models.

3. NATIONAL AND REGIONAL ACTIVITIES

3.1 The participants from Austria, Czechoslovakia, the Federal Republic of Germany, the German Democratic Republic, Hungary, Poland and Switzerland outlined their national activities as regards the collection and storage of hydrological and related data and the use of Geographic Information Systems (GISs).

3.2 The information provided by these participants is summarized in Annex F.

3.3 The meeting was informed of the data that had been compiled under the auspices of the FREND (Flow Regimes from Experimental and Network Data) project and of the experience recently gained in studies of the feasibility of using these data to produce grid-based estimates of runoff. Information on the FREND data base is also contained in Annex F.

4. MAJOR ELEMENTS OF THE PROJECT

4.1 The meeting agreed that the project should be implemented in three phases and developed the description of it that is contained in Annex G.

4.2 The geographical region concerned was defined as proposed in Koblenz (see Annex A). It was clear that use of the FREND data would permit the implementation of a similar project in the West and North of Europe. The Steering Group for FREND was therefore invited to consider this possibility.

4.3 A number of specific problems were raised with regard to the implementation of the project which will need to be solved at some stage. In most cases it will be necessary to agree on at least a provisional solution at the next meeting of the group scheduled for May 1991. These problems are summarized below.

4.4 It will be necessary to agree on which grid coordinate system is to be used in the project.

4.5 Phase II will require the exchange of data between three institutions and Phase III will require extensive exchanges of data. Agreement will have to be reached on the data format and transfer mechanism to be used.

4.6 There are considerable advantages in storing and managing the data in association with a GIS. None of the participating institutions are currently using a GIS in their routine work and it is unlikely that, when they do, it will be the same GIS. A decision will have to be made as to whether to select a GIS to apply with the final data set and, if so, which one.

4.7 In Phase III methodologies will be applied to all grid cells. This may be undertaken by:

(a) each institution applying one or more common methodologies

(b) one institution doing the work on behalf of the whole group.

There was seen to be considerable advantages in option (b).

4.8 It was noted that a decision on this was not required for Phase I and it was expected that each institution would be able to undertake the work under this phase on the basis of existing national funding.

4.9 During Phase II the three institutions concerned would be forced to consider this question more closely and a final decision would have to be taken in advance of Phase III. Developments in institutional organisation and funding within Europe during 1990 and 1991 could have a major influence on the project and each institution will need to plan for its participation and funding within this context.

4.10 There was seen to be considerable advantage in identifying one lead institution to which the others could second experts for certain periods of time so that they might work together and hence combine the advantages of options (a) and (b) above.

5. CLOSE OF THE MEETING

At the close of the meeting, the participants thanked Professor Kaczmarek and through him IIASA for hosting the meeting in Laxenburg and for organising it so efficiently.

ANNEXES

A. Proposal for a pilot project to produce gridded estimates of surface runoff over limited regions of the world (Koblenz, November 1988)

B. List of Participants

C. Agenda

D. The Global Runoff Data Centre

E. Plan for IAHS/WMO Project on macro-scale hydrological models in support of GEWEX (St. Moritz, December 1989).

F. National and regional activities

- Austria
- Czechoslovakia
- Federal Republic of Germany
- German Democratic Republic
- Hungary
- Poland
- Switzerland
- FREND data base

G. WMO project for gridded estimates of runoff over Central Europe.

ANNEX A

PROPOSAL FOR A PILOT PROJECT TO PRODUCE GRIDDED ESTIMATES OF SURFACE RUNOFF OVER LIMITED REGIONS OF THE WORLD

(A proposal developed at the workshop
on the Global Runoff Data Set and
Grid Estimation, Koblenz, FRG, November 1988)

1. PURPOSE

The project consists of the collection, processing, analysis and storage of river flow data from dense networks of stations in well-defined limited areas of the world. Gridded estimates of surface runoff over these areas would be made available to climate modellers for use in validating atmospheric General Circulation Model (GCM) outputs.

2. BACKGROUND

Atmospheric GCMs are crucial to the studies of climate variability and the possible impacts of climate change. The ability of these models to produce realistic forecasts of the future climate depends on the availability of powerful supercomputers and the proper formulation of important physical processes. One of the major efforts underway within the World Climate Research Programme (WCRP) is to improve the parameterization of land surface processes in GCMs. Critical to this effort is the availability of reliable data, which could be used to describe the fluxes of sensible and latent heat between the land surface and the atmosphere. Hydrological-Atmospheric Pilot Experiments (HAPEX) are being conducted over various land regions of the globe to improve techniques for parameterizing land surface processes in models. In addition, however, there is a need for reliable global estimates of surface runoff on a regular grid to validate the outputs of GCMs.

The global runoff data set, presently being constructed by the WMO Global Runoff Data Centre (GRDC) in Koblenz, Federal Republic of Germany, should hopefully be sufficient, when used with ancillary information in new analysis models, to produce the global gridded estimates needed for the GCMs. However, any attempt to use the river flow data from the sparse network of stations presently available to the GRDC, with presently-available grid-estimation techniques, would almost certainly result in values with gross errors. Clearly, what is needed is a major effort to develop new analytical techniques, which take into account a substantial amount of ancillary information, in addition to the limited number of river flow observations, to provide gridded estimates of surface runoff.

3. CONSTRUCTION OF PILOT DATA SETS FOR LIMITED REGIONS OF THE WORLD

As a first step in developing a capability to provide reliable estimates of surface runoff on a regular global grid to validate GCM outputs, it is proposed that a project be initiated to construct pilot data sets over certain limited regions of the world, which contain dense networks of river flow stations.

3.1 Areal Extent

The areas under consideration should be fairly homogeneous from both climatic and hyrologic viewpoints and should be of a size roughly equivalent to about 10°–15° latitude × 10°–15° longitude. These areas need not be square or even rectangular but should be in the form of a non-re-entrant polygon, with similar dimensions in the north–south and east–west directions. Data sets should be produced for a minimum of three areas, representing different climatic zones (humid-temperate, semi-arid, humid-tropical).

Each area should be divided into 1° latitude × 1° longitude grid cells and, where possible, 0.5° latitude × 0.5° longitude cells. Within each cell, or groups of cells, one or more gauged catcments would be identified, with areal coverages of between 100–10 000 km^2, such that they provide representative samples of the runoff.

3.2 Requirements for River Flow Data

Daily rive flow measurements for each catchment, for the calendar years from 1978 to 1980, should be obtained. If daily values are not available, then monthly values should be obtained.

If possible, data should be provided by participating countries in computer compatible form to facilitate their processing at a central location. Tabulated values, in documentation form, would also be acceptable. Where the flows are regulated (e.g., by dams) or depleted (e.g., by extractions for water supply purposes), these facts should be noted with the data, in order that the values may be adjusted to represent as far as possible, the natural flow values.

The exact latitude and longitude of each gauging station must be provided, along with maps of the catchment areas on a scale of 1:1 000 to 1:1 000 000.

3.3 Data Analysis

The GRDC will derive monthly and possibly daily runoff estimates for each 0.5° latitude × 0.5° longitude or 1° latitude × 1° longitude grid cell, using a weighted-averaging technique appropriate for each catchment and grid cell.

4. DISTRIBUTION OF DATA SETS

Each institution, supplying data to the project, will be provided with a copy of the full set of the original data for the entire area in which their catchments are located. In addition, the grid estimates for the area will also be provided.

The derived grid estimates for the entire area will be made available to climate modellers, upon request, in a computer-compatible form.

5. SUGGESTED AREA FOR PILOT PROJECTS

The initial area to be selected is located over Europe, bounded by latitudes 45°–55°N and longitudes 5°–25°E, in view of the dense coverage of river flow stations and the high quality of the data from these stations. It is suggested that the Federal Republic of Germany be approached in taking the lead for this pilot project by having the GRDC collect and process the data set for a smaller area bounded approximately by latitudes 48°–55°N and longitudes 7°–15°E, and then later expanding the coverage to include data from neighbouring countries, which would be approached by WMO to cooperate in this project.

Other areas for which pilot projects should also be implemented are parts of North America (Canada, USA), Australia and well-instrumented developing countries located in the tropics.

6. SCHEDULE

6.1 European Area Gridded Data Sets

JAN 89: Select areas for study
MAR 89: Collect data for inner area
JUN 89: Request data for surrounding areas

JAN 90: Construct data set for European area
APR 90: Derive grid cell values
JUN 90: Distribute results

6.2 Other Areas Gridded Data Sets

MAR 90: Request data for other areas
DEC 90: Construct data set for other areas
JUL 91: Derive grid cell values
DEC 91: Distribute results

7. FOLLOW-ON PROJECT TO INTERCOMPARE MODELLING TECHNIQUES FOR ESTIMATING GRID CELL VALUES OF RUNOFF

The data and information collected for this project would be useful in a future project to develop more sophisticated analysis techniques, which could be used for the estimation of gridded runoff values over the globe, even in areas of poor data coverage. What is needed is a modelling technique which incorporates additional information, such as precipitation amounts, topography, soil types and vegetation cover, with available river flow measurements to estimate the runoff over data-sparse or data-void regions.

The WMO, in coordination with the GRDC, will begin initiating contacts with hydrological and meteorological groups, which might be interested in participating in a project to intercompare techniques for estimating grid cell values of runoff. An augmented pilot data set, consisting of the data described in Section 3 of this document and additional information to be collected at a later date, would be constructed and made available to interested participants. The latter would apply their techniques/models to the same data set, using only a limited number of actual river flow measurements to simulate data-sparse conditions, and the results would be presented at a workshop to evalute the strengths and weaknesses of the various techniques.

ANNEX B

Planning Meeting on Grid Estimation of Runoff Data
International Institute for Applied Systems Analysis,
Laxenburg, March 5–6, 1990

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Water Resources Project

Professor Zdzislaw Kaczmarek
Leader
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ANNEX C

Planning Meeting On Grid Estimation and Runoff Data

**International Institute for Applied Systems Analysis,
Laxenburg, March 5–6, 1990**

PRELIMINARY AGENDA

Monday, 5 March 1990	0900–0915	Opening
	0915–1015	Report on activities of WCP-Water and GRDC Report on ongoing activities in relation to GEWEX
	1015–1045	Coffee Break
	1045–1215	Project on gridding runoff data: – general description of the project – methodology
	1215–1345	Lunch
	1345–1515	Report by participants on existing hydrometric methods, climatic and other maps and GIS within their countries
	1515–1545	Coffee Break
	1545–1715	Proposal on coordination and cooperation of the project
Tuesday, 6 March 1990	0900–1030	General discussion on project implementation
	1030–1045	Coffee Break
	1045–1215	Formulation of the project outline and role of cooperating institutions
	1215–1345	Lunch
	1345–1515	Conclusions
	1515–1530	Coffee Break
	1530–1600	Closing of the meeting

ANNEX D

Global Runoff Data Centre

established by the Federal Republic of Germany under the auspices of the World Meteorological Organization (WMO)

Koblenz, F.R. Germany, May 1990

INTRODUCTION

Knowledge of the river discharge or streamflow is a basic information requirement for all kinds of hydrological investigations. Flow data are also needed for the development and verification of global models of atmospheric circulation. This has led to the collection of such data on a global scale, but it is evident that these data are also of great value for other purposes. In order to ensure that the data are easily obtainable, a central data bank was established. This is maintained by the Global Runoff Data Centre (GRDC) at Koblenz, Federal Republic of Germany, which was officially inaugurated on November 14, 1988. The GRDC now operates with the support of the Federal Republic of Germany under the auspices of the World Meteorological Organization (WMO) for the benefit of WMO members and the international scientific community.

DATA BANK

The GRDC data bank currently consists of daily flows for 1 533 stations from 83 countries and of monthly flows for 1 059 stations from 107 countries (Annex 1). This means that about 2 800 000 daily flows and about 278 000 monthly flows are stored in the computer.

The core of the data bank are the daily flows for 1 217 stations from 67 countries which were collected by the Hydrology and Water Resources (HWR) Department of the WMO Secretariat. The WMO/ICSU Global Atmospheric Research Programme (GARP) presented the first opportunity to collect flow data on a global scale. Within the First GARP Global Experiment (FGGE) climatological data for the years 1978, 1979 and 1980 were collected. The first request for flow data was sent to WMO member countries in August 1982. In this letter, criteria for the selection of stations and instructions for data preparation were given. Because of the needs of general circulation models, the stations were to be selected according to the following criteria:

(1) Uniform distribution consistent with network conditions, with higher densities in areas of rapid variation of flow.

(2) Coverage, to the greatest possible extent, of each type of hydrological homogeneous region of each country.

(3) Relatively small river basins (up to about 5 000 km^2, and in exceptional cases, up to 10 000 km^2).

(4) Flow data should represent natural river flow, i.e. they should be corrected for diversions, abstractions and redistributions by storage.

(5) Availability of good quality data.

The circular letter was answered by 67 countries with the submission of daily flow data for 1207 stations.

After the establishment of the World Climate Programme (WCP), the collection of flow data became part of WCP-Water (Activity Area A.5: Collection of Global Runoff Data Sets) and is now being continued on a long-term basis. A second circular letter was sent to WMO member countries in June 1984 in which they were asked to submit daily flow data for the years 1981 and 1982, and to supply the data for the following years as they became available. This letter was answered by 42 countries with submission of daily flows for 665 stations. Some countries also sent data for the year 1983. Australia has also submitted data for flows from 96 stations for the years 1984 and 1985.

All of these have been entered into a computer and transferred in a standardized format either by the Institute of Bioclimatology and Applied Meteorology, University of Munich, which acted as the data centre from 1983 to 1987, or by the GRDC itself while it was being established in 1987 and 1988.

In order to enlarge the data basis, efforts were started during 1988 and 1989 to enter flow data which were already available in published form. The principal source in this context was the Unesco publication "Discharge of selected rivers of the world". Within the scope of the International Hydrological Decade (IHD) and the International Hydrological Programme (IHP) Unesco has collected monthly flows from 859 stations of 106 countries for the period 1965–1979. For 144 stations the data are available from the start of observations. The longest series is for Göta at Vänesborg from 1807. It should be noted that the Unesco data are mainly for larger basins. So only 49 stations appear with the data both collected by WMO and published by Unesco.

A further source of flow data are hydrological yearbooks. Up to now data for 389 stations from 22 countries (319 with daily flows, 70 with monthly flows) have been stored. A major part of the stored yearbook data results from the entry of data from national yearbooks which were collected by the WMO Secretariat and submitted to GRDC in 1989.

Additional data have been received through direct contact with other institutes. From the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) daily flows for 77 stations from the Niger basin were obtained. This data set comprises flows from the beginning of observations up to 1980. Furthermore, daily flows for long series from three stations were collected by the GRDC itself.

The collection of monthly flows within WCP-Water Project A.2 "Analysis of Long Time Series of Hydrological Data" gave the opportunity to enter monthly flows for 159 stations from 13 countries into the data base.

In addition, GRDC includes monthly flows from 769 stations in 41 countries which have been compiled by Professor T. MacMahon of Australia.

Finally, GRDC also holds flows for 2124 stations from 13 countries of northern and western Europe which were collected within the FREND project and which are available for exchange under the terms of that project.

RETRIEVAL SERVICE

The GRDC has developed a suite of programmes to provide users with a selection of retrieval options so as to make data and information readily accessible.

The following retrieval options are currently available:

(1) Table of daily flows

(2) Table of monthly flows

(3) Hydrograph of daily flows

(4) Hyrograph of monthly flows

(5) Flow duration curve

(6) Flow duration table

(7) Station and catchment information

(8) Creation of data files.

Examples for output are attached in Annex 2. Requests may be made in writing or by personal visit to GRDC. The following information should be specified:

(1) Name and address to which the output should be sent (including telephone, telefax and telex numbers if available).

(2) Hydrometric stations for which data are required.

(3) Title(s) of options requested.

(4) Transfer medium (magnetic tape or diskette or printout).

Charges might be assessed to cover costs of providing services to users (e.g. costs of tapes or diskettes, mailing and handling charges). The charges may be waived if the individual or institution is a contributor of data to GRDC.

Requests should be addressed to:

Global Runoff Data Centre (GRDC)
Bundesanstalt für Gewässerkunde
Kaiserin-Augusta-Anlagen 15–17
D-5400 Koblenz
FRG
Tel: (261) 1306-1
Tlx: 08-62499
Fax: (261) 1306302

Register of GRDC stations

Country	A	B	C	D	E	F
Afghanistan	2	0	0	0	0	0
Albania	0	0	9	0	0	0
Algeria	0	0	12	0	0	0
Argentina	18	0	19	0	0	0
Australia	135	12	10	0	0	2
Austria	3	0	1	0	0	0
Bangladesh	0	0	3	0	0	0
Belgium	2	0	0	0	0	0
Benin	0	0	0	12	9	0
Bolivia	0	0	6	0	0	0
Brazil	116	0	14	0	0	0
Bulgaria	0	0	6	0	0	0
Burkina Faso	7	0	0	43	0	0
Burma	4	0	0	0	0	0
Cameroon	0	0	13	0	0	0
Canada	205	97	76	0	0	0
Central African Rep.	0	0	3	21	0	0
Chad	0	0	2	10	0	0
Chile	0	0	6	0	0	0
China	0	0	9	0	0	0
Columbia	0	0	12	0	0	0
Congo	11	0	12	0	0	0
Costa Rica	0	0	5	42	0	0
Cote d'Ivoire	0	0	0	38	15	0
Cuba	4	0	7	0	0	0
Cyprus	0	0	2	2	0	0
Czechoslovakia	7	0	3	0	0	0
Denmark	0	0	3	0	0	0
Dominican Republic	0	0	5	0	0	0
Ecuador	0	0	14	0	0	0
Egypt	0	0	5	6	0	0
El Salvador	0	0	5	0	0	0
Ethiopia	21	0	10	0	0	0
Fiji	2	0	0	0	0	0
Finland	11	0	3	0	0	0
France	9	0	8	0	0	0
France (Guadeloupe)	1	0	1	0	0	0
France (Martinique)	0	0	1	0	0	0
France (Reunion)	1	0	0	0	0	0
French Guiana	2	0	1	0	0	0
French Polynesia	2	0	1	0	0	0
Gabon	0	0	1	0	0	0
German Dem. Rep.	0	0	2	6	0	0
F.R. Germany	9	6	3	0	0	0
Ghana	0	0	5	0	0	0
Greece	2	0	2	0	0	0
Guinea	5	0	5	0	14	0
Guatemala	0	0	4	0	0	0
Guyana	5	0	2	0	0	0
Honduras	5	0	0	0	0	0
Hongkong	2	0	0	0	0	0
Hungary	8	2	4	0	0	0
Iceland	3	0	4	0	0	0
India	0	0	44	0	0	0
Iran	11	0	10	0	0	0
Iraq	0	0	4	0	0	0
Ireland	0	0	7	0	0	0
Israel	4	0	2	0	0	0
Italy	0	0	5	6	0	0
Jamaica	0	0	3	8	0	0
Japan	8	0	5	24	0	0
Jordan	0	0	2	0	0	0
Kenya	4	0	1	0	0	0
Rep. Korea	0	0	8	0	0	0
Laos				12		
Dem.Peopl.Rep.Korea	0	0	7	0	0	0
Lesotho	3	0	4	0	0	0
Liberia	0	0	7	0	0	0
Libya	46	0	0	0	0	0
Luxembourg	1	0	0	0	0	0
Madagascar	0	0	4	0	0	0
Malawi	4	0	3	24	0	0
Malaysia	4	1	10	0	0	0
Mali	0	5	6	39	29	0
Mauritania	2	0	0	1	0	0
Mauritius	1	0	5	5	0	0
Mexico	28	0	32	0	0	0
Mongolia	7	0	6	0	0	0
Morocco	0	0	2	0	0	0
Mozambique	0	0	8	0	0	0
Netherlands	2	0	1	0	0	0
New Caledonia	2	2	1	0	0	0
New Zealand	6	0	7	0	0	0
Nicaragua	5	0	14	0	0	0
Niger	5	0	4	0	10	0
Nigeria	0	0	3	0	0	0
Norway	10	8	1	0	0	0
Pakistan	24	0	3	0	0	0
Panama	5	0	8	0	0	0
Papua New Guinea	0	0	1	0	0	0
Paraguay	0	0	1	0	0	0
Peru	0	0	4	0	0	0
Philippines	0	5	10	0	0	0
Poland	11	9	4	0	0	0
Portugal	0	0	14	0	0	0
Romania	0	0	4	0	0	0
Senegal	5	0	13	20	0	0
Sierra Leone	0	0	7	0	0	0
Singapore	1	0	1	0	0	0
Spain	14	0	5	0	0	0
South Africa	26	0	0	0	0	0
Sri Lanka	0	2	7	0	0	0
Sudan	0	0	3	18	0	0
Suriname	4	0	4	0	0	0
Sweden	12	3	3	0	0	0
Switzerland	3	0	2	0	0	0
Syria	0	0	4	0	0	0
Tanzania	12	0	2	0	0	0
Thailand	11	7	5	40	0	0
Togo	2	0	1	0	0	0
Tunisia	0	0	6	0	0	0
Turkey	13	0	5	0	0	0
Uganda	0	0	7	3	0	0
United Kingdom	16	0	4	0	0	0
Uruguay	4	0	2	0	0	0
U.S.A.	120	0	90	0	0	0
USA (Pacific Area)				96		
U.S.S.R	164	0	86	0	0	0
Venezuela	0	0	12	0	0	0
Vietnam				12		
Yugoslavia	5	0	4	0	0	0
Zaire	0	0	0	0	0	1
Zambia	10	0	3	0	0	0
Total	1217	159	859	389	77	3

A	=	WMO-Data (GARP/WCP-Water A.5)	daily flows
B	=	WCP-Water A.2-Data	monthly flows
C	=	UNESCO-Data	monthly flows
D	=	Yearbook-Data	daily/monthly flows
E	=	ORSTOM-Data	daily flows
F	=	other sources	daily flows

GLOBAL RUNOFF DATA CENTRE (GRDC)

River : DYLE
Station : SINT-JORIS-WEERT
Country : BELGIUM

Catchment Area : 645.0 km**2
Geographic Location : 50 80 N 4 63 E
WMO Basin No :

1981 RUNOFF (M**3/S) 1981

Day	Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	5.28	7.03	6.89	5.44	5.27	8.14	4.50	5.34	3.38	3.85	7.13	15.3
2	5.81	6.92	5.05	5.35	5.05	10.4	4.83	7.47	3.19	3.84	6.55	8.90
3	12.6	8.32	5.05	5.27	5.19	12.6	5.09	4.88	3.74	4.45	5.94	7.14
4	10.5	9.80	5.63	4.85	5.40	14.5	5.21	4.06	3.34	4.08	5.55	8.84
5	8.11	9.43	4.76	4.34	5.53	7.63	5.16	3.98	3.35	3.78	5.37	13.0
6	8.55	8.53	4.66	3.91	5.27	5.54	5.09	3.81	3.25	4.88	5.26	11.7
7	9.04	7.83	4.95	4.24	4.94	5.18	5.03	4.81	3.23	7.22	4.91	11.4
8	8.03	7.59	4.85	4.79	5.10	4.79	4.95	4.11	3.35	4.80	4.79	14.5
9	7.41	7.32	6.40	4.77	6.86	4.43	4.93	3.83	3.58	4.49	4.42	14.3
10	10.2	7.11	15.2	4.65	6.71	4.09	4.93	4.00	3.47	5.18	4.64	9.88
11	7.45	6.98	11.7	4.56	6.19	3.81	4.88	4.17	3.35	6.32	4.89	11.2
12	6.21	6.89	7.57	4.57	5.69	3.79	4.88	3.90	3.54	5.28	4.98	11.7
13	6.62	6.83	6.50	4.57	5.17	3.77	4.80	3.87	3.93	5.61	4.77	8.52
14	8.36	6.69	10.4	4.57	4.66	3.71	4.74	3.66	4.56	4.64	4.66	9.47
15	21.6	6.50	8.44	4.57	4.43	3.62	4.74	3.72	5.05	5.24	4.66	15.4
16	18.2	6.32	6.40	4.39	4.32	3.26	4.30	3.59	4.39	5.27	4.56	10.1
17	14.2	6.27	6.40	4.21	4.28	2.86	3.80	3.61	3.80	4.47	4.82	7.43
18	11.5	6.22	6.21	4.08	4.21	2.46	3.79	3.54	3.79	6.84	4.71	6.60
19	9.82	6.15	6.60	4.11	4.28	2.62	3.76	3.48	4.44	5.21	7.92	6.17
20	9.30	6.11	5.24	4.19	4.27	2.96	3.73	5.30	7.16	9.80	6.04	5.81
21	8.85	6.05	4.85	4.27	4.37	3.31	3.75	4.61	8.77	9.43	6.34	6.06
22	8.69	5.96	4.85	4.35	5.72	3.50	3.78	3.75	6.25	6.29	6.31	6.21
23	8.64	6.02	5.05	4.34	5.53	3.45	3.70	3.65	5.21	8.33	5.59	6.31
24	8.60	5.92	5.13	4.60	5.53	3.42	3.67	3.41	4.35	6.11	5.69	6.21
25	8.49	5.92	5.17	5.67	5.24	3.41	3.94	3.64	4.20	5.74	5.05	6.12
26	8.24	5.92	5.21	6.80	5.14	3.46	3.78	3.57	4.12	8.15	4.83	5.88
27	8.68	5.92	5.22	7.62	4.74	3.65	3.77	3.46	4.02	7.62	6.76	5.74
28	8.73	6.02	5.23	6.96	4.65	3.67	3.76	3.53	3.81	5.82	11.4	5.57
29	8.21		5.32	6.10	4.57	3.83	3.73	3.50	3.81	8.41	11.2	6.90
30	7.65		5.33	5.63	4.50	4.15	3.62	3.42	3.82	8.77	11.0	7.90
31	7.21		5.39		5.86		3.73	3.36		7.98		13.2
Mean	9.38	6.88	6.31	4.93	5.12	4.87	4.33	4.03	4.21	6.06	6.02	9.14

Mean	Jan.-June	6.25	July-Dec.	5.64	Year	5.94

Option 1 : Table of daily flows

GLOBAL RUNOFF DATA CENTRE (GRDC)

River : DYLE
Station : SINT-JORIS-WEERT
Country : BELGIUM

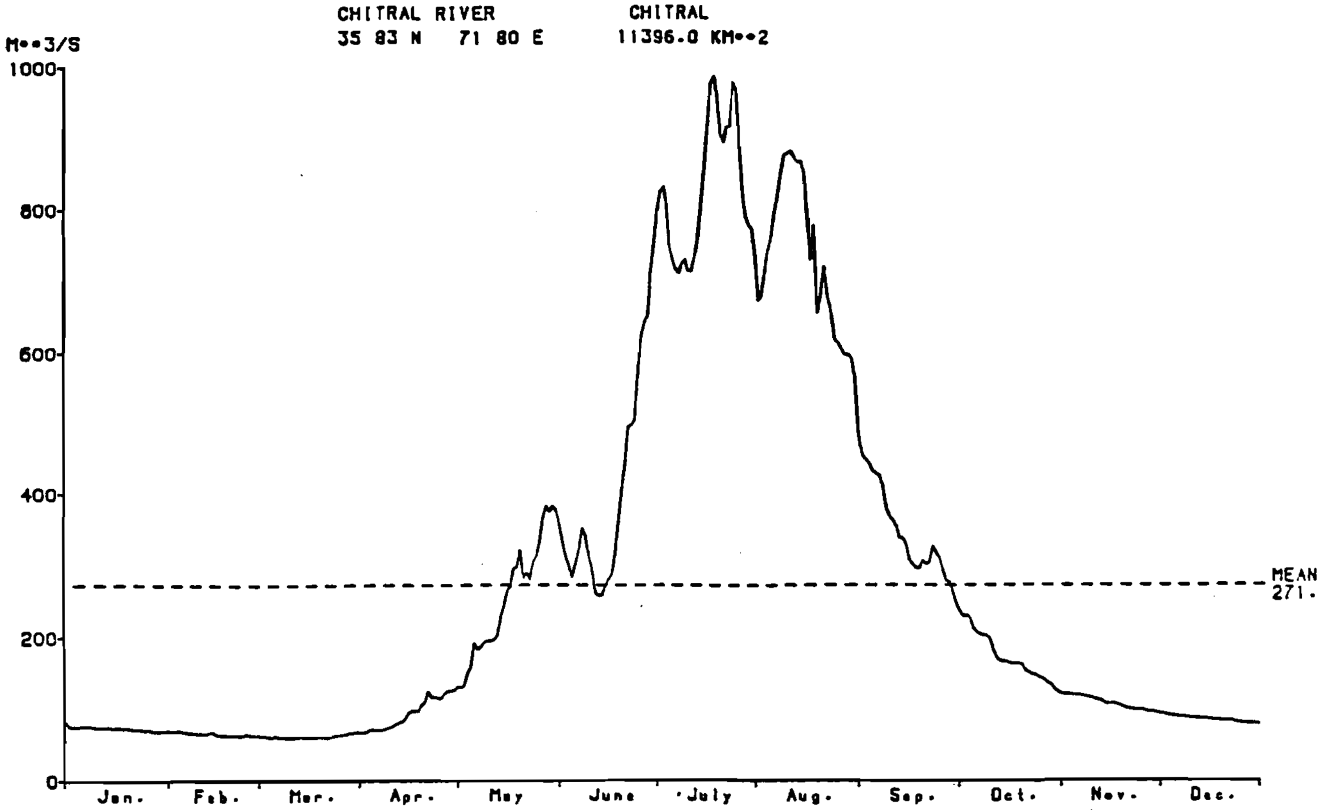
Catchment Area : 645.0 km**2
Geographic Location : 50 80 N 4 63 E
WMO Basin No :

MEAN FLOW (M**3/S)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	J-J	J-D	Year
1978	4.08	4.14	4.43	3.67	5.30	3.46	3.49	2.75	2.67	2.88	2.96	4.23	4.18	3.16	3.67
1979	4.29	5.34	6.16	4.29	3.93	3.35	2.63	3.14	2.82	3.18	4.59	5.82	4.56	3.70	4.13
1980	5.06	5.42	4.56	4.90	4.10	3.69	7.52	3.56	3.23	3.95	4.15	5.63	4.62	4.67	4.65
1981	9.38	6.88	6.31	4.93	5.12	4.87	4.33	4.03	4.21	6.06	6.02	9.14	6.25	5.63	5.94
1982	M	5.61	6.38	5.42	5.42	4.99	3.99	4.17	3.96	6.48	5.54	7.01	M	5.19	M
1978-1982	M	5.48	5.57	4.64	4.77	4.07	4.39	3.53	3.38	4.51	4.65	6.37	M	4.47	M

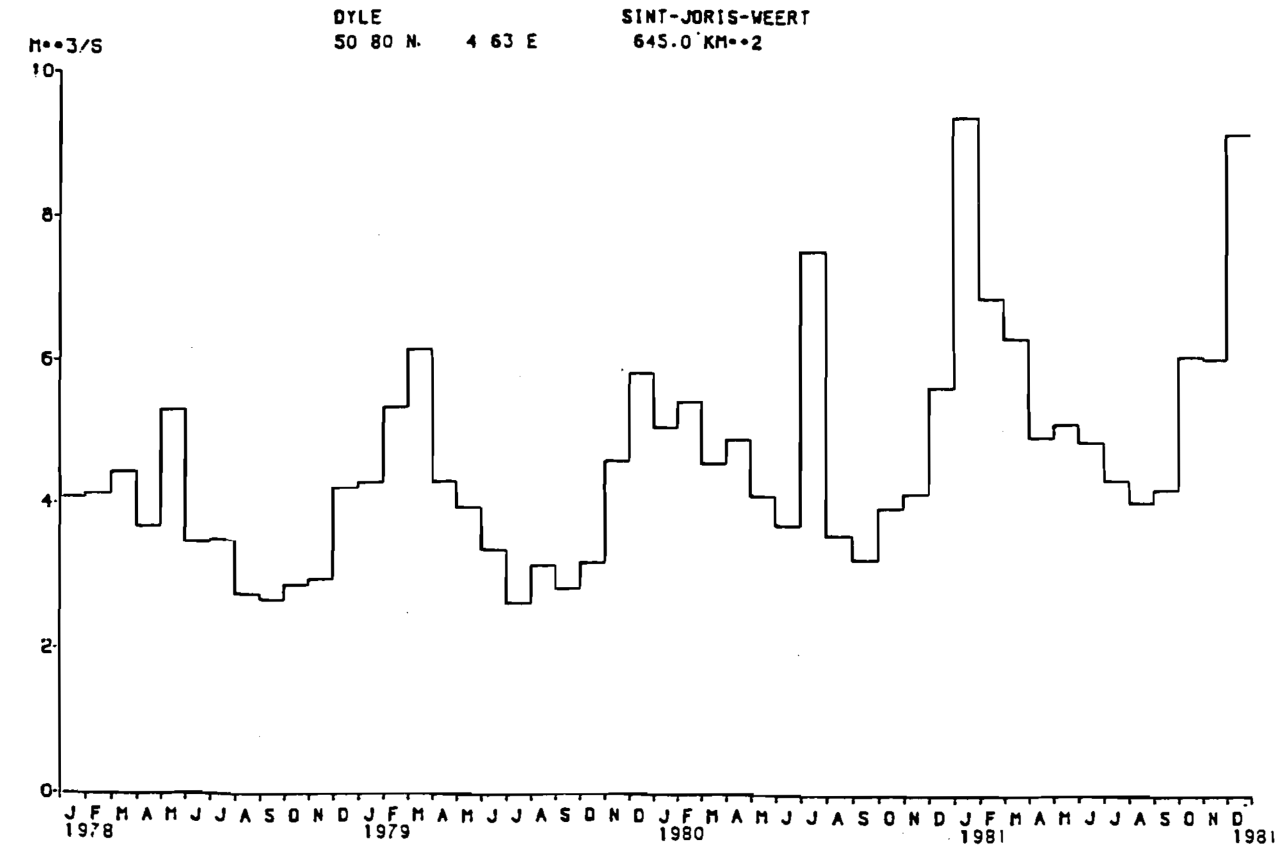
Option 2 : Table of monthly flows

MEAN DAILY DISCHARGE 1981

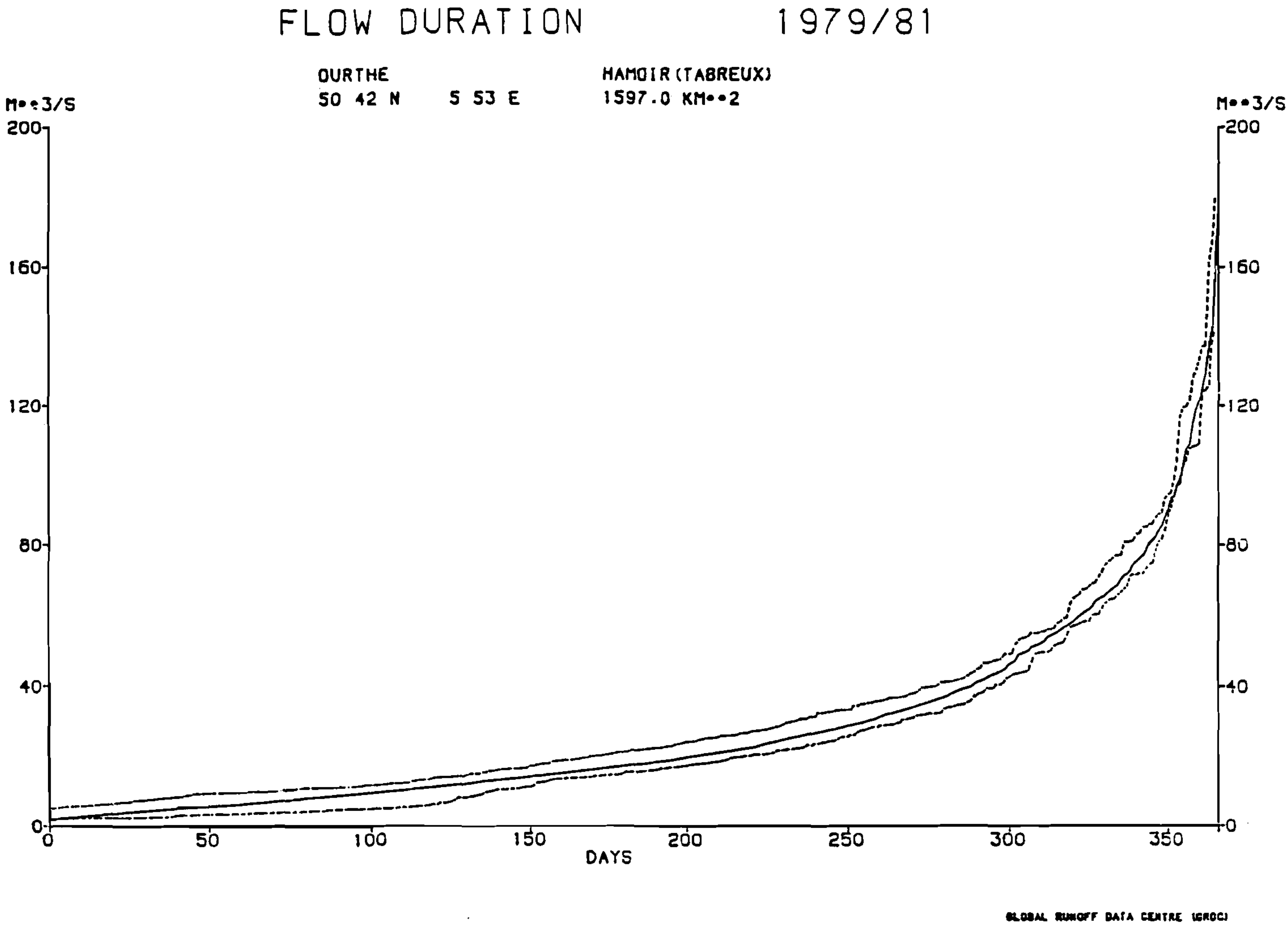


Option 3 : Hydrograph of daily flows

MEAN MONTHLY DISCHARGE 1978/81



Option 4 : Hydrograph of monthly flows



Option 5 : Flow duration curve

GLOBAL RUNOFF DATA CENTRE (GRDC)

River : DYLE
Station : SINT-JORIS-WEERT
Country : BELGIUM

Catchment Area : 645.0 km**2
Geographic Location : 50 80 N 4 63 E
WMO Basin No :

FLOW DURATION TABLE 1981/1983

(1 DAY MEAN FLOW IN M**3/S FOR GIVEN PERCENTAGE OF TIME)

	0	1	2	3	4	5	6	7	8	9
0		3.33	3.43	3.50	3.55	3.61	3.65	3.69	3.72	3.75
10	3.78	3.81	3.84	3.88	3.91	3.95	3.99	4.03	4.06	4.10
20	4.14	4.19	4.22	4.25	4.27	4.30	4.34	4.37	4.40	4.44
30	4.49	4.52	4.55	4.58	4.61	4.65	4.69	4.73	4.76	4.80
40	4.83	4.85	4.88	4.91	4.95	4.99	5.02	5.05	5.09	5.13
50	5.17	5.21	5.24	5.27	5.30	5.35	5.40	5.45	5.50	5.54
60	5.59	5.63	5.66	5.70	5.76	5.82	5.87	5.92	5.96	6.01
70	6.06	6.11	6.15	6.19	6.24	6.30	6.37	6.49	6.61	6.68
80	6.76	6.85	6.97	7.07	7.17	7.31	7.47	7.62	7.77	7.94
90	8.16	8.33	8.55	8.77	8.97	9.45	9.92	10.4	11.6	14.3

NUMBER OF VALUES USED : 1095

FIRST MONTH USED: 1

Option 6 : Flow duration table

```
GLOBAL RUNOFF DATA CENTRE (GRDC)

Name of station             : WADOWICE
Name of river               : SKAWA
Country                     : POLAND
WMO basin no                :
Latitude                    :          +4981
Longitude                   :          1950E
Catchment area   (km**2)    :           836.
Station elevation    (m)    :            255
Accuracy of measurement     :              C
Internal station no         :       02840040
GRDC station no             :           6021
Begin of observation        :

Name of station             : NOWY SACZ
Name of river               : DUNAJEC
Country                     : POLAND
WMO basin no                :
Latitude                    :          +4962
Longitude                   :          2068E
Catchment area   (km**2)    :          4341.
Station elevation    (m)    :            275
Accuracy of measurement     :              B
Internal station no         :       06560006
GRDC station no             :           6022
Begin of observation        :

Name of station             : KRASNYSTAW
Name of river               : WIEPRZ
Country                     : POLAND
WMO basin no                :
Latitude                    :          +5098
Longitude                   :          2317E
Catchment area   (km**2)    :          3001.
Station elevation    (m)    :            173
Accuracy of measurement     :              B
Internal station no         :       18480017
GRDC station no             :           6023
Begin of observation        :

Name of station             : PRZEDBORZ
Name of river               : PILICA
Country                     : POLAND
WMO basin no                :
Latitude                    :          +5108
Longitude                   :          1975E
Catchment area   (km**2)    :          2535.
Station elevation    (m)    :            187
Accuracy of measurement     :              B
Internal station no         :       20920011
GROC station no             :           6024
Begin of observation        :
```

Option 7 : Station and catchment inforamtion

```
DYLE                                                  SINT-JORIS-WEERT
 5.278 5.81012.58810.497 8.109 8.546 9.038 8.026 7.41310.193 9999.   XXXX 1 11981
 7.455 6.206 6.619 8.36021.56518.24214.20311.478 9.818 9.295 9999.   XXXX 2 11981
 8.853 8.686 8.643 8.605 8.491 8.244 8.678 8.734 8.212 7.654 7.213   XXXX 3 11981
 7.028 6.919 8.321 9.800 9.428 8.531 7.827 7.591 7.317 7.108 9999.   XXXX 1 21981
 6.980 6.887 6.828 6.687 6.499 6.325 6.267 6.217 6.149 6.108 9999.   XXXX 2 21981
 6.050 5.964 6.020 5.920 5.920 5.920 5.920 6.020 9999. 9999. 9999.   XXXX 3 21981
 6.890 5.050 5.050 5.630 4.760 4.660 4.950 4.850 6.40015.200 9999.   XXXX 1 31981
11.700 7.570 6.50010.400 8.440 6.400 6.400 6.210 6.600 5.240 9999.   XXXX 2 31981
 4.850 4.850 5.050 5.132 5.172 5.211 5.216 5.229 5.321 5.327 5.388   XXXX 3 31981
 5.438 5.345 5.273 4.851 4.344 3.915 4.243 4.792 4.765 4.654 9999.   XXXX 1 41981
 4.560 4.574 4.575 4.574 4.572 4.391 4.208 4.083 4.113 4.191 9999.   XXXX 2 41981
 4.271 4.353 4.342 4.600 5.666 6.796 7.620 6.957 6.104 5.628 9999.   XXXX 3 41981
 5.270 5.048 5.185 5.396 5.532 5.265 4.937 5.103 6.859 6.707 9999.   XXXX 1 51981
 6.192 5.694 5.172 4.664 4.428 4.318 4.277 4.213 4.280 4.270 9999.   XXXX 2 51981
 4.370 5.720 5.530 5.530 5.240 5.140 4.744 4.652 4.570 4.496 5.863   XXXX 3 51981
 8.14410.35712.60514.512 7.628 5.542 5.180 4.794 4.427 4.093 9999.   XXXX 1 61981
 3.808 3.789 3.774 3.714 3.622 3.263 2.856 2.456 2.619 2.960 9999.   XXXX 2 61981
 3.309 3.502 3.448 3.420 3.413 3.456 3.653 3.668 3.829 4.155 9999.   XXXX 3 61981
 4.501 4.829 5.090 5.211 5.161 5.094 5.030 4.955 4.930 4.928 9999.   XXXX 1 71981
 4.879 4.880 4.798 4.739 4.739 4.302 3.803 3.794 3.758 3.726 9999.   XXXX 2 71981
 3.748 3.777 3.701 3.673 3.944 3.781 3.771 3.758 3.729 3.622 3.729   XXXX 3 71981
 5.338 7.474 4.876 4.057 3.978 3.806 4.809 4.107 3.833 3.999 9999.   XXXX 1 81981
 4.172 3.902 3.868 3.665 3.721 3.593 3.607 3.542 3.481 5.298 9999.   XXXX 2 81981
 4.611 3.746 3.648 3.406 3.637 3.566 3.460 3.530 3.504 3.419 3.364   XXXX 3 81981
 3.383 3.189 3.739 3.339 3.346 3.252 3.229 3.347 3.582 3.471 9999.   XXXX 1 91981
 3.352 3.536 3.929 4.560 5.050 4.391 3.795 3.789 4.440 7.162 9999.   XXXX 2 91981
 8.765 6.252 5.211 4.350 4.197 4.116 4.019 3.805 3.811 3.816 9999.   XXXX 3 91981
 3.853 3.838 4.452 4.076 3.785 4.880 7.219 4.800 4.487 5.177 9999.   XXXX 1101981
 6.322 5.283 5.613 4.642 5.238 5.267 4.469 6.842 5.206 9.803 9999.   XXXX 2101981
 9.431 6.293 8.332 6.115 5.737 8.148 7.619 5.819 8.410 8.766 7.978   XXXX 3101981
 7.134 6.552 5.942 5.546 5.373 5.262 4.907 4.787 4.419 4.641 9999.   XXXX 1111981
 4.892 4.979 4.772 4.660 4.660 4.560 4.821 4.714 7.921 6.037 9999.   XXXX 2111981
 6.338 6.311 5.593 5.686 5.053 4.831 6.76011.39111.20210.953 9999.   XXXX 3111981
 5.292 8.898 7.139 8.84212.97511.67311.39914.50314.317 9.883 9999.   XXXX 1121981
11.24711.699 8.523 9.46515.37110.111 7.427 6.603 6.172 5.815 9999.   XXXX 2121981
 6.062 6.210 6.310 6.210 6.118 5.875 5.738 5.575 6.901 7.89713.235   XXXX 3121981
```

Daily flows

```
DANUBE                                     ORSOVA
19615540.04650.04780.04650.06840.06540.04140.03360.02530.02120.03690.03820.0XXXX
19624870.05310.07600.012140.9150.06800.05650.03740.02550.02100.03220.04460.0XXXX
19634400.04720.07150.09050.06390.05180.04160.02270.04110.03490.03060.03650.0XXXX
19642350.03030.04850.07890.06340.04520.04390.03170.02960.04370.07220.06870.0XXXX
19656280.05960.06670.08800.011000.12200.10360.6190.05060.03840.03190.07010.0XXXX
19665570.08280.08300.07190.07370.06280.06310.07220.06910.03450.05570.08100.0XXXX
19676190.06334.08368.010758.9732.08065.06012.03685.03520.03156.02845.03067.0XXXX
19685785.06452.06277.06456.04867.04930.03652.04652.04716.05254.04104.04693.0XXXX
19693800.05800.08690.07270.06820.06430.05860.03490.04810.02610.02530.04760.0XXXX
19706720.08740.09500.012560.12600.11460.8130.06340.05300.03800.04200.04450.0XXXX
Year  Jan.  ...                                                        ...  Dec.
```

Monthly flows

Option 8 : Creation of data files

ANNEX E

PROJECT ON MACROSCALE HYDROLOGICAL MODELS IN SUPPORT OF GEWEX

(A proposal developed by the IAHS/WMO
Working Group for GEWEX at its
meeting in St. Moritz, Switzerland, December 1989)

Hydrologic models account for the storage and flow of water on the continents, including exchanges of water and energy with the atmosphere and oceans. During the past three decades, hydrologists developed a large number of hydrologic models ranging in sophistication and complexity. Essentially all this work applies to geographical areas smaller than the area represented by a typical GCM grid square, although some basin-scale hydrologic models have been applied to areas as large as 10^4 km^2. Hydrologic models that would be appropriate to use at the scale of a GCM grid square (e.g. 10^5 km^2) and that could accept atmospheric model data as input are "macroscale" hydrologic models.

Preparing macroscale hydrological models for GEWEX is a major undertaking that will require a cooperative effort of hydrologists and other geoscientists throughout the world. The challenge is to extend existing knowledge of hydrologic processes, as they occur at a point location and on the scale of small basins or catchments, to the macroscale. Macroscale hydrologic models for GEWEX must be able to exchange information with atmospheric models. Processes that occur at subgrid scale must be accounted for internally in the hydrologic models. Ultimately, it must be possible to apply the model globally. Sufficient data do not exist to calibrate macroscale hydrologic models in the same way that hydrologists usually calibrate catchment models. Therefore, the required macroscale models must account for the water balance of "ungaged areas", and model parameters must be estimated *a priori* using limited climate, soils and vegetation data.

To help define the work to be done and to stimulate some of the required collaboration, a joint working group on GEWEX was formed by IAHS/WMO Working Group for GEWEX at Baltimore, USA, 15 May 1989 that a "Pilot study of large-scale hydrological modelling" be undertaken. This project would support the broad objective of development, validation and use of large-scale hydrological models spanning a hierarchy of scales, possibly coupled with GCM's, and making use of data from space observing systems. The working group established an *ad hoc* steering group to develop a detailed proposal.

A proposal was developed by the steering group and presented to the second meeting of the IAHS/WMO Working Group for GEWEX at St. Moritz, 12 December, 1989. It was proposed the project should draw on the expertise of several national groups already involved in this area. The IAHS/WMO working group requested the steering group to identify specific groups and contributions they are prepared to make during the interim period of GEWEX.

Several areas of work are needed to prepare macroscale hydrologic models for use in GEWEX. These are:

(i) Develop alternative macroscale hydrologic models.

(ii) Intercompare and evaluate alternative models through large scale hydrologic experiments.

(iii) Assess data requirements.

(iv) Develop data assimilation systems and databases.

(v) Estimate model parameters on a global scale.

(vi) Incorporate macroscale hydrologic models in GCM's and evaluate results.

Following is a brief description of these areas of work.

Macroscale hydrologic model development

The following general requirements to be met by developers of hydrologic models were suggested by Kleměs (1985) who investigated the suitability of hydrologic models to assess the sensitivity of water resources to climate processes:

(i) They must be geographically transferable and this has to be validated in the real world;

(ii) Their structure must have a sound physical foundation and each of the structural components must permit its separate validation;

(iii) The accounting of evapotranspiration must stand on its own and should not be a byproduct of the runoff accounting. Precipitation and potential evapotranspiration usually form the independent variables.

Several strategies for modeling water and energy transfers on scales ranging from continental to global have been suggested. These are not unique strategies, some include variations of elements of others. The approach taken seems to vary depending on the objective of the investigator. Eagleson (1986), notes that "there is much need for improvement in the formulation of GCM's, particularly the parameterization of subgrid-scale hydrologic processes, but there is also need for additional basic understanding of some critical hydrological phenomena". For example, in understanding the potential problems of environmental change, it is important to develop and use in GCM's vegetation models in which the vegetation and its role in water and energy transfer is determined internally within the GCM. To achieve this goal it will be important to understand to what extent vegetation and soils depend on climate and to what extent soils and vegetation vary among places with the same climate. Accordingly, Eagleson (1982a, 1982b, 1986) has reviewed the scientific basis for modeling the soil, climate, vegetation system and suggested some of the improvements needed, including need for improved measurements.

Dickenson (1989) observes "An optimum approach to water and energy exchange at the land surface involves combining several kinds of observations within an appropriate modelling framework". He presents a general conceptual framework but notes that:

> Progress up to now has been limited for several reasons: the current sensing systems are probably inadequate for the task, the information content of potential future systems has not been adequately characterized by modeling sensitivity studies, and the linked remote sensing and modeling infrastructure has not yet been developed that is needed to carry out this activity.

The parts of Dickinson's conceptual framework include "Skin temperature method" (an energy balance approach), "Rainfall approach" (a water balance approach), "Atmospheric water vapor divergence method", "Vegetation index approach", "Direct measurements of soil moisture", and "Use of soil and terrain information and spatial variability". He proposed to combine these into an extension of the data assimilation systems that are used for numerical weather forecasting. He notes that the ***complete*** global system he visualizes could not be provided by small individual research groups because of the intensive data transfers and model computing required. He suggests it most logically would eventually be implemented by extension of the data assimilation systems of current operational weather services (e.g. NMC or ECMWF) who would need such a system in any case to exploit the improved scientific understanding and observational capabilities of the hydrological cycle expected to emerge over the next decade.

A good summary of the problem at hand was formulated by the organizers of the AGU 1989 Fall Meeting Symposium H03 on "Evaporation and Runoff from Large Land Areas:

> An incomplete understanding of the processes of regional evaporation (or evapotranspiration) and runoff from the continents hinders future developments in our understandings of the global water cycle through such activities as general circulation modelling.
> At present there is no clear consensus among geophysicists on the dynamic interaction of atmospheric, lithospheric, and biospheric processes determining evaporation from large (characteristic length 100 km and up) areas of continental surfaces.
> Observational data are scarce and uncertain, and interdisciplinary boundaries impede fully coupled theoretical analyses of the problem.
> As for runoff, large scale measurements are available in the form of discharges, so operational conceptual models can at least be calibrated and employed with some reliability.
> However, the physical relationship between large scale runoff coefficients and the type and variability of precipitation, soils, topography, and vegetation is unknown.
> A full theoretical picture of the controlling processes and their spatial variability has yet to emerge.

In view of the complexity and limited understanding of water and energy transfers over the continents, it is essential that the macroscale modelling activity has a clear focus on a few well-chosen, specific objectives or questions. Some of these are:

(i) What is the relationship between model accuracy, model complexity and data availability?

(ii) What is the relationship between microscale elements and processes that govern the vertical fluxes of the hydrologic cycle to the aggregate behaviour of these processes at the macroscale?

(iii) How do model parameters depend on climate, soil, vegetation, topography and geology?

(iv) How can macroscale models be formulated to make use of remotely sensed data to improve model parameter estimates and model performance.

(v) How can hydrologic models be formulated for use as part of a data assimilation system to produce "improved" estimates of precipitation, soil moisture and evapotranspiration that would be physically consistent with model and data, and that could be used as input to atmospheric model development or operation?

(vi) How should the information available from atmospheric models be used to specify the inputs to macroscale hydrologic models? Conversely, how should the outputs from such macroscale hydrologic models be used as inputs to the atmospheric models?

Several approaches are possible to search for answers to these questions. A general theme to be addressed is how to handle subscale spatial variability and heterogeneity. One approach is to ignore it and represent aggregate behaviour directly. Another is to use distribution theory to treat spatial distribution analytically. A third is to use a grid approach to represent spatial variability explicitly.

Examples of grid square approaches are those suggested by Girard (1984) or Solomon *et al.* (1968). Nemec and Becker (1987) suggested how a grid approach could be organized into two levels: the first accounting for vertical flux exchanges with the atmosphere; the second, for river basin processes.

In a recent study of 52 watersheds from climates ranging from semi-arid to humid in the US, Schaake and Liu (1989) showed that basic relationships between runoff and climate could be explained by a very simple water balance model with constant parameters for all basins. This model used a distribution theory approach to account for spatial variability in precipitation and infiltration. If the parameters of such simple models could be related to climate, soil, vegetation, geology, land-use, and geomorphology, it should be possible to make *a priori* estimates of runoff for ungaged areas. Most importantly, this also would give a physical basis for estimating the macroscale hydrologic effects of anthropogenic changes to watersheds such as diversions, consumptive use, land-use changes, and reservoir regulation.

Although the initial models may not include formulations of soil moisture flux much more complex than a simple Budyko or Thornthwaite "bucket" approach, they could be organized to permit future investigation of, say, an interactive biosphere (Sellers *et al.*, 1986; Dickenson *et al.*, 1986) as these parameterizations are validated through experiments such as HAPEX and FIFE 1.

Some of the problem areas to be expected are:

Orographic Effects – most large basins have mountainous terrain. For example, it is not possible to study the water balance of the western US without some type of orographic precipitation model or analysis. This is a significant data problem that must be resolved if GCM's are to represent the regional hydrologic processes. In addition, improved parameterizations of atmospheric model estimates of orographic precipitation will be needed.

Leaky Rivers – rivers draining large semi-arid lands loose or exchange water with the underlying soils.

Scale Problems – moisture and energy flux processes are non-linear. Total or average fluxes over a large area are not the same as given by point process models with average values of parameters and spatially averaged inputs. Areal models will depend on point processes but will have different functional form.

Parameter variability – parameters are unknown functions of climate, soil, vegetation, geology, land-use, and geomorphology. These vary spatially in all catchments, but over wider ranges in larger basins.

Anthropogenic changes – no large basin in the world is free of anthropogenic changes to watersheds such as diversions, consumptive use, land-use changes, and reservoir regulation.

Vegetation type – vegetation depends on climate. Therefore, types of vegetation vary with climate. The fact that vegetation types may be supported over a range of climate also means vegetation may switch when the range is exceeded. This introduces a stochastic component into the modelling.

Data availability – perhaps the greatest single problem will be acquiring and managing data sets. Certain types of spatial data such as land use or satellite imagery require well organized data assimilation capability.

Ice, Snow and Frozen Ground – ice, snow and frozen ground processes add significant complexity.

Field experiment to intercompare and evaluate alternative models

It is necessary to validate models through comparison of model predicted results with *in situ* and satellite measurements. Large scale hydrologic experiments are needed to intercompare and assess the characteristics of various algorithms and would strengthen involvement in the study of the water cycle on regional and continental scales.

Such large scale experiments also could be used to calibrate the suite of sensors planned to be flown on the Tropical Rainfall Mission (TRMM), international earth observing polar platforms, and Tropical System Energy Budget Mission (BEST), and validate their algorithms and data products.

The GEWEX macroscale hydrologic experiment described here would systematically test models developed in support of the GEWEX program. This would be done on selected river basins on a long-term basis (minimum of 3–5 years). This would provide the opportunity to intercompare the detailed performances of the various models under realistic time-dependent conditions to ascertain their sensitivity to various possible estimates of forcing fluxes and determine the degree of similarity with observed hydrologic quantities (e.g. river runoff data).

The experimental areas must be large enough so that hydrologic processes important to global climate models and large scale meteorological models are apparent (in the tropics, precipitation cloud "clusters" can be several hundred kilometers in horizontal dimension). The area should encompass a wide range of soil moisture conditions, vegetation types, and surface topographies. Candidate regions would include the major river basins of the United States, Canada, large basins in Europe and eastern Asia, one or more basins in the USSR, Amazon and Nile.

Some of these regions have denser networks of in situ observations. These regions will be important to assess the effect of data limitations in the other regions.

This macroscale hydrologic experiment is envisaged to be conducted in phases as follows:

Phase	*Description*
1	Planning
2	Intercomparison with historical data
3	Initial field experiment
4	Field experiment

The planning phase would start in 1990 and would continue until the full field experiment is started. The field experiment would develop an extensive data base of meteorological and hydrological observations. This would require the coordination of simultaneous acquisition of atmospheric and surface data from satellite, balloon, aircraft and ground measurements. This field experiment would occur in the 1997 time frame.

In preparation for this field experiment, substantial testing can be done in some parts of the world using historical in situ data. Results of such testing would contribute to the detailed planning for the field experiment. The initial field experiment would be a short transition period to bring the data acquisition and assimilation systems to operational status for the field experiment.

The field experiment should last for a period of about five years to monitor seasonal changes and inter-annual variations in soil moisture. It would include short periods of intensive observations in addition to a background program of continuous observation.

These intense observation periods would occur at intervals of a year or longer and could lead to modifications in the experiment if necessary. Throughout the experimental period, data analysis and model development would continue. This would contribute to data quality control and would lead to improvements in data assimilation techniques throughout the experiment. The field experiment would be planned in such a way as to support GEWEX objectives as well as the calibration of TRMM and BEST and other instruments on the international polar orbiting platforms of ESA, Japan and NASA.

A Scientific Steering Group will be needed to develop the field experiment plan and to organize an effective method of project management. The project management would negotiate the location of specific sites for experimental activities with host nations. The IAHS/WMO Committee on GEWEX could form the nucleus for the Scientific Steering Group and could be called upon to coordinate activities in support of this experiment.

It is envisaged that there would be an international joint solicitation and selection of experiment proposals from individual experiment groups for participation in the field campaigns.

Assess Data Requirements

To develop, test and apply macroscale hydrological models on a global scale, a large amount of data will be needed. It is essential that the quality of these data be considered as well as the quantity. In the case of discharge data, it is essential not only to have good quality data in the sense of minimum measurement errors or gaps in observation periods, but the watersheds need to be relatively free of anthropogenic influences. In the case of precipitation measurements, corrections can be made to account for certain measurement errors, but installation of additional gages according to the recommendations of WMO is needed as well.

To satisfy the requirements suggested by Kleměs for model development, at least limited observations of soil moisture and ground water levels will be needed. Systematic observations of soil moisture to meet the needs of macroscale hydrologic model development has not been done. The implication of having inadequate soil moisture data needs to be assessed. Remote sensing techniques using airborne gamma radiation sensors or satellite microwave sensors should be used to reduce the costs of soil moisture data.

Develop Data Assimilation systems and databases

A wide range of data types are needed to develop and use macroscale hydrologic models. These include: in situ observations, remotely sensed information, geographic information, and derived information from analysis. To make use of remotely sensed information about hydrologic processes requires close coupling through data assimilation techniques with the models in which the data are to be used. In addition, observation may be possible of variables normally considered to be "outputs" from the models. By appropriate coupling of data assimilation techniques (e.g. Kalman–Bucy filter theory) with models, information about model outputs can be used as input to the model to improve estimates of the outputs. Therefore, it is essential for developers of macroscale hydrologic modelers to work closely with those developing methods of remotely sensed data to develop data assimilation methods.

The data sets needed for model intercomparison and global estimation of model parameters would be supplied by the institutions participating in the project. The following are suggested as additional sources of data:

(a) World WCP Data Centers for Runoff and Precipitation (Koblenz and Offenbach)
(b) UNEP GRID (Geneva)
(c) FAO, GIS, Division of Land and Water (Rome)
(d) WMO data sets from Amazon and Nile projects, WMO Secretariat (Geneva)

A pilot project to develop data sets of gridded runoff data has been initiated by the GRDC-Koblenz for an area covering several large European river basins 45–55°N latitude, 5–25°E longitude). This is being done in cooperation with WMO, IIASA and concerned national institutions. It also is an activity of the IAHS/WMO Macroscale Modeling project.

Estimate Model Parameters on a Global Scale

The requirement that model parameters be estimated on the basis of available climate, soils, vegetation, topography and geology information will have significant implications for the type of model that can be used and for hydrological research, as well, over the next decade. Another implication of this requirement is that all of the data must be related through a Geographical Information System (GIS). The GIS must be able to extract available information for the area represented by any GCM grid point or set of points. In addition, because of the large number of grid points, an automated system for parameter initialization is needed. This automated system will likely need access to information generated by the GCM to be used with the model.

Incorporate Macroscale Hydrologyic Models in GCM's

Implementation in a GCM will require development of interdisciplinary cooperation between the hydrological entities and atmospheric research institutions. Some possibilities include:

(a) UK Meteorological Service
(b) US National Weather Service
(c) GFDL (Princeton, USA)
(d) NCAR (Boulder, USA, including UCAR universities)
(e) GISS (New York, USA)

This task will require significant additional planning, once the above tasks are in an advanced stage. It is likely that some form of interactive use of the automatic parameter estimation techniques will be required to allow for the effect of feedback from the terrestrial hydrological processes within the GCM to affect the local climate variables used to set the hydrological model parameters.

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ANNEX F

NATIONAL AND REGIONAL ACTIVITIES

Czechoslovakia

Federal Republic of Germany

German Democratic Republic

Hungary

Poland

Switzerland

The "FREND" Project

Country: Czechoslovakia

Area: 126 000 km^2 from Labe (Elbe) river basin 56 000 km^2

Number of stations:

- hydrometric stations:860 (330 in the Labe basin)
- precipitation stations: 1 800 (800 in the Labe basin)
- climatological stations: 400 (130 in the Labe basin)

Yearbook: No information

Monographs:

1. Atlas of Climate in Czechoslovakia
   SZN, 1960, Praha
2. Hydrological conditions of Czechoslovakia
   CHMU, 1966, Praha
3. Changes of climate and water regime in Czechoslovakia
   SZN, 1986, Praha
4. Second long-term plan for water economy of Czech Republi
   MLVH CSR, 1978, Praha
5. Second long-term plan for water economy of Slovak Republic
   MLVM SSR, 1978, Bratislava

Maps:

1. Geological maps 1:500 000
2. Maps of hydrogeological structures 1:200 000
3. Maps of second long-term plan for water economy 1:200 000
4. Maps of climate in Czechoslovakia 1:500 000
5. Maps of hydrological conditions of Czechoslavikia 1:150 000
6. Map of groundwater runoff in Czechoslovakia 1:1 000 000
7. Basic maps for water economy 1:50 000

GIS: Not used for water resources planning

Institute interested in cooperation:

Czech Hydrometeorological Institute, Praha

Country: Federal Republic of Germany
Area: 246 000 km^2
Number of stations:

- hydrometric stations: 2 000
- precipitation stations: 3 000
- climatological stations: 200

Yearbooks:

1. IHP Yearbook (since 1965)
2. Special yearbooks for large rivers: Elbe and coastal areas, Weser and Ems, Upper Rhine, Lower Rhine, Main, Danube
3. Meteorological yearbook

Monographs:

1. Textbook for the Hydrological Atlas
2. Monograph for the river Rhine
3. Monograph for the river Danube

Maps:

1. Hydrological Atlas
2. Climatological maps for the provinces
3. EC-map on soils: 1:3 000 000
4. Hydrological maps

Data Bank: HYDABA at Bundesanstalt für Gewässekunde, Koblenz
GIS:

1. Topography: 20–50 m
2. Land-use: 50 m
3. Soil (in development)

Institute interested in cooperation:

Bundesanstalt für Gewässerkunde
D-5400 Koblenz
Kaiserin-Augusta-Anlagen 15–17

Country: German Democratic Republic
Area: 107 800 km^2
Number of stations:

- hydrometric stations: 300
- precipitation stations: 1 510
- climatological stations: 69

Yearbooks:

1. Hydrological yearbook of the GDR – water quantity: 1956–1987
2. Hydrological 5-year-book: 1975, 1980, 1985
3. Year-books of the GDR for IHD: 1965–1984
4. Hydrological year-books of the GDR – water quality: 1985–1987
5. Hydrological year-books of regional water authorities
6. Meteorological year-book

Monographs:

National report of the GDR for IHD, 1973

Maps:

1. Hydrographical maps 1:200 000
2. Water balance maps 1:200 000
3. Hydrogeological maps 1:50 000
4. Climate Atlas 1:1 000 000
5. Atlas of GDR

GIS: No country-wide GIS available; experimental GIS for test region
Institute interested in cooperation:

Institute for Water Management
Schnellerstr. 140
DDR-1190 Berlin

Country: Hungary

Area: 93 000 km^2

Number of stations:

- hydrometric stations: 120
- precipitation stations: 1 200

Yearbook: Hydrographical Year-book of Hungary (includes precipitation data)

Monographs:

1. Hydrological Atlas of Hungary
2. Monograph of the Danube basin

Maps: No information

GIS: Not used operationally for water resources planning

Institute interested in cooperation:

Research Center for Water Resources
Development (VITUKI)
Kvassay Jeno ut. 1
H-1095 Budapest

Country: Poland

Area: 314 000 km^2

Number of stations:

- hydrometric stations: 1 100 (800 in database)
- precipitation stations: 2 500 (500 in database)
- climatological:250
- groundwater: 1 400

Yearbooks:

1. Hydrological yearbook (separate volumes for the Vistula river basin and Odra river basin)
2. Yearbook of hydrometric measurements
3. Yearbook of precipitation values
4. Meteorological yearbook

Monographs: several for some river basins

Maps:

1. Hydrological Atlas of Poland
2. Catchment maps
3. Soil maps

GIS: Not used for hydrological purpose

Institute interested in cooperation:

1. Institute of Environmental Engineering, Warsaw Technical University
2. Institute of Meteorology and Water Management, Warsaw

Country: Switzerland

Area: 34 550 km^2 for the Rhine river basin

Number of stations:

- hydrometric stations: 100
- precipitation stations: 300
- climatological stations: 90

Yearbook: Hydrological Yearbook of Switzerland

Monographs: Der Wasserhaushalt der Schweiz
Landeshydrlogie, Mitteilung Nr. 6, Bern, 1985

Maps: Landeskarte der Schweiz: 1:500 000, 1:300 000, ...

GIS: ARC/INFO

Institutes interested in cooperation:

1. Swiss Federal Institute of Technology,
Department of Geography, Hydrology Section
2. Swiss Hydrological Service, Bern

Region: The "FREND" Project area
(Austria, Belgium, Switzerland, Denmark, Finland, France, Federal Republic of Germany (FRG), Ireland, Luxembourg, Netherlands, Norway, Sweden, United Kingdom (UK))

Number of stations:

- Catchments with daily flow data: 1350
- Daily precipitation data: 73

Monographs: FREND reports

Maps:

1. Digital data at 1.25 × 1.25 km on:
   - average annual rainfall
   - 10-year, 2-day rainfall
   - forest, urban, lake cover
   - 5-class soil

   covering Belgium, Denmark, France, FRG, Luxembourg, Netherlands, UK
2. Catchment boundaries and thematic data for approximately 1 400 catchments

GIS: Water Information System (WIS)

Institute interested in cooperation:

Institute of Hydrology
Maclean Building
Crowmarsh Gifford
Wallingford
Oxon OX10 8BB

ANNEX G

WMO PROJECT FOR GRIDDED ESTIMATES OF RUNOFF OVER CENTRAL EUROPE

Purpose

1. The overall objective of the project is to provide an avenue for the international hydrological community to advance the science of hydrology and to contribute to the improvement of the prediction of climate change in terms that can be used to estimate the subsequent impact on hydrology and water resources.

2. The specific purpose of the project is to collect, process, analyse and store runoff data from a dense network of streamflow stations in Europe, and to develop grid-based estimates of runoff from these data, for use in:

   (a) completing the FGGE Level IIc data set (1978–1980)

   (b) validating GCMs

   (c) developing and testing macro-scale hydrological models as a basis for linking GCMs with catchment models

   (d) developing and testing other macro-scale models requiring such data.

Region.

3. The region within which the data are to be collected and for which the grid-based estimates are to be derived is bounded approximately by latitudes 45° and 55° N and longitudes 5° and 25° E.

4. As the collection and analysis of the data are based on river basins, the region is better defined in terms of the following basins:

   Rhine
   Danube – basin defined by the point where it flows out of Hungary
   Weser
   Elbe–Labe
   Vistula
   Oder

   plus the contiguous areas draining directly to seas.

Grid size

5. Estimates of runoff will be developed for a 1/2° by 1/2° grid. In practice this will be the set of 1/2° by 1/2° grid cells which lie wholly or largely within the river basins and contiguous areas listed in 4 above.

Time period and step

6. In view of purpose (a), under 2 above, attention will focus on the period 1978 to 1980, but the final period is expected to run to 1990 and even beyond.

7. Daily values will be collected and used as the basis for the work.

Methodology

8. A methodology for transferring catchment-based runoff data to grid-based data has to be developed. Because the data sets will be used later on for several purposes, they should incorporate considerable flexibility. This means that the grid-based runoff data should be developed, if possible, only from measured discharges.

Methods based on correlations with precipitation, air temperature and other data related to runoff should be avoided for grid value computations in this project, so that these runoff data are "clean" and not effected by variables representing other elements in the hydrological cycle.

9. The methodologies to be used could be put in different categories, depending on the hydrometric network data available.

10. **Methodology for case I:**

At least one entire catchment lies within the grid cell (Fig. 1). In this case the grid-based runoff can be calculated directly as a weighted average from the measured runoff data. The calculation is as follows:

(1) Selection of suitable stations being representative for the grid cell stations

(2) For estimation of grid-based runoff, Q_G, the following equation is used

$$Q_G = \frac{1}{A_G} \sum_{i=1}^{n} a_i A_{Ci} Q_{Ci} \qquad (1)$$

where Q_{Ci} is the catchment based runoff for basin i, A_{Ci} is the relevant catchment area(s) entirely within the grid, A_G is the area of the grid cell and n is the number of catchments within the grid. The weighting factor a_i, depends on the influence which basin i has in relation to the grid.

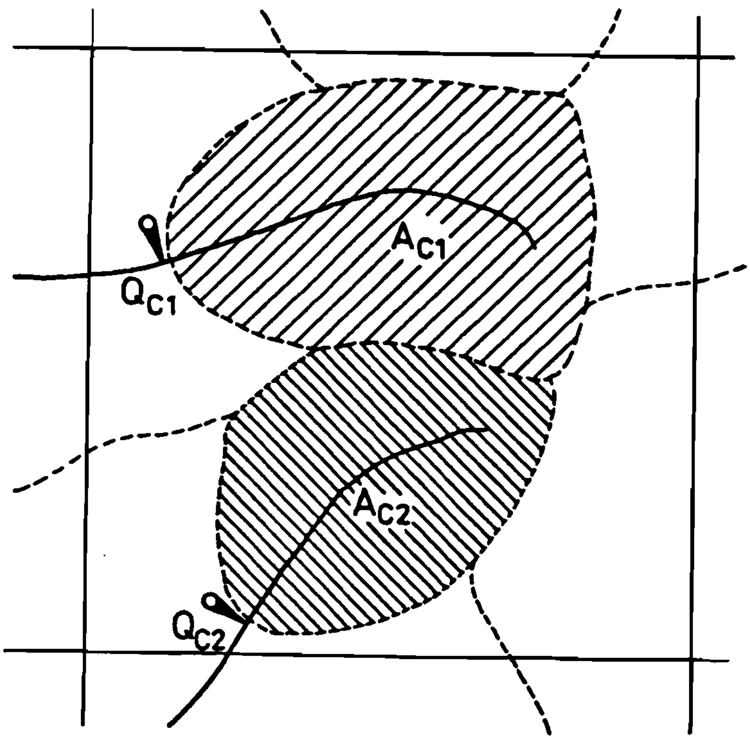

Figure 1. Case I

The following constraint must be satisfied

$$A_G = \sum_{i=1}^{n} a_i A_{Ci} \qquad (2)$$

11. Methodology for case II:

One catchment covers more than one grid cell (Fig. 2). In this case a disaggregation of the catchment-based runoff has to be made. The calculation is as follows:

(1) Selection of the station based on the network available

(2) Stud of the topographic and other characteristics of the catchment

(3) For estimation of the grid-based runoff, Q_{Gj}, the following equation is used

$$Q_{Gj} = a_j \frac{A_{Gj}}{A_C} Q_C \tag{3}$$

Where Q_C is the catchment-based runoff, A_C the relevant catchment area Q_{Gj}, the runoff for grid cell j, A_{Gj} is this part of the grid cell area which contributes to W_C. a_j is a weighting factor, which is a function of the catchment's and cell's characteristics $a_j = f(h \cdots)$. In flatland areas the factor a_j can be assumed to be 1. In mountainous or mixed regions the weighting factor has to be estimated from studies of runoff from small research basins, lysimeters, etc. in comparison with downstream measurements on larger water courses. If such measurements are not available, then use may be made of the results obtained using the case I methodology for grid cells nearby in conjunction with an estimation similar to case II. Grid value estimatation should be computed at a first step for average yearly values and for average seasonal monthly values so as to obtain the coefficients a_j.

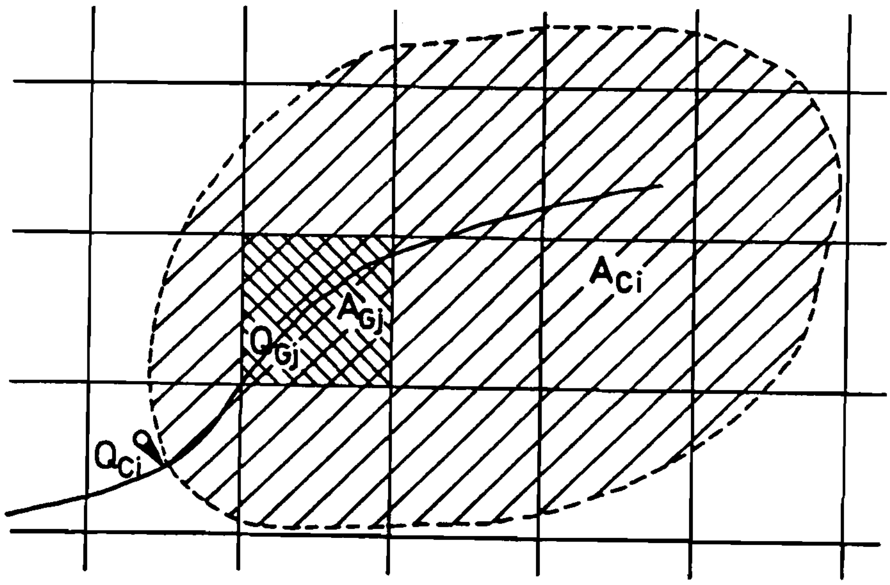

Figure 2. Case II

The final time step used for estimating of the coefficients a_j should be based on the results obtained. The actual grid-based runoff for the individual month k can be calculated by the simple equation

$$Q_{Gjk} = \frac{Q_{Ck}}{\bar{Q}_C} \bar{Q}_{Gj} \tag{4}$$

where $\bar{Q}_C$ is the average runoff of the catchment and $\bar{Q}_{Gj}$ the average grid-based runoff estimated by equation (3) for an observation period longer than 10 years. Q_{Ck} is the catchment based runoff for the individual month k and Q_{Gjk} is the relevant grid based runoff.

If this methodology does not give good results, the catchment area should be split into a system for smaller grid cells for which characteristics such as elevation, slope, soil, vegetation, etc. can be determined and a correlation function between runoff and these characteristics should be found for example by using multiregression.

12. In both cases I and II a check on estimates of the weighting factors a_j should be undertaken by aggregating the individual grid-based runoff data Q_{Gj} over a large river basin to yield a value for basin runoff Q'_B by using the formula

$$Q'_B = \sum_{j=1}^{m} Q_{Gj} \tag{5}$$

where m is the total number of grid cells contributing to the river basin. This can then be compared with measured runoff Q_B for the large river basin and an adjustment made for all a_j. For this reason a correction factor, Δa_j, for each grid cell has to be estimated. This factor should take into account the percentage coverage of catchment based runoff data within the individual grid cell.

$$\Delta a_j = \frac{Q'_B - Q_B}{Q_B} \frac{A_{Gj} + \sum_{i=1}^{n} A_{Ci}}{A_B + A_{BC}} \tag{6}$$

where the following constraints must be satisfied

$$A_B = \sum_{j=1}^{m} A_{Gj} \tag{7}$$

and

$$A_{BC} = \sum_{j=1}^{m} \sum_{i=1}^{n} A_{Cij} \quad . \tag{8}$$

A_B is the total area of the larger river basin. A_{BC} is the total area of the larger river basin which is covered by measured runoff data. In case II where a total grid cell may lie within a catchment there is $A_{Ci} = A_{Gj}$. In this case is $n = 1$.

The corrected weighting factor a'_j is given by

$$a'_j = a_j - \Delta a_j \tag{9}$$

13. After the correction, the estimate for a sum of grid cells should be repeated, and if necessary an iteration should be used.

14. After the selection of stations for the whole region and after the estimates of all parameters A_G, A_C, a_j have been made, a system can be developed, for the automatic calculation of the weighting factors and their application to the catchment-based runoff data. Such a methodology should be capable of computing grid-based runoff for any time step.

Implementation

1.5 The project is currently planned to be implemented in three phases:

Phase I Each participating institution will apply and test the various methodologies described above to a series of grid cells within their national territory. This will include, as far as possible, examples of cases A, B and C grid cells covering alpine, mountainous and flat lands. This will provide a basis for further planning of the project and for the selection of methodologies.

Phase II This will be undertaken as a joint venture between BfG (Federal Republic of Germany), IfW (German Democratic Republic) and HMI (Czechoslovakia). The agreed methodologies will be applied to the entire basins of the Weser and Elbe/Labe.

Phase III On the basis of the experience obtained during Phases I and II, the finally agreed methodologies will be applied throughout the project region.

Schedule

1.6 Phase I of the project will last from March 1990 to March 1991.

1.7 By the end of March 1991 all participating institutions will send to IIASA technical notes or scientific papers summarizing the results of their work during Phase I. IIASA will circulate these widely to all institutions and agencies concerned.

1.8 The second meeting on the project will be convened by IIASA in cooperation with GRDC in May 1991 at a date yet to be fixed. It will be held in Laxenburg over a period of three days, the first day being devoted to presentations of the results of Phase I, the other two days being taken up with planning the further implementation of the project.

1.9 A more detailed time schedule will be developed at the second meeting, bearing in mind the aim of producing substantial results before 1995.