WORLD CLIMATE PROGRAMME

RESEARCH

THE GLOBAL WATER RUNOFF DATA PROJECT

Workshop on the

GLOBAL RUNOFF DATA SET AND GRID ESTIMATION

(Koblenz, FRG, 10-15 November 1988)

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The World Climate Programme launched by the World Meteorological Organization (WMO) includes four components:

The World Climate Data Programme
The World Climate Applications Programme
The World Climate Impact Studies Programme
The World Climate Research Programme

The World Climate Research Programme is jointly sponsored by the WMO and the International Council of Scientific Unions.

Report of the

Workshop on the

GLOBAL RUNOFF DATA SET AND GRID ESTIMATION

(Koblenz, FRG, 10-15 November 1988)

Organized by

WMO Hydrology and Water Resources Programme Department

World Climate Research Programme

In Co-operation with

Bundesanstalt für Gewässerkunde

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LIST OF ACRONYMS

FAO - Food and Agriculture Organization of the United Nations
FGGE - First GARP Global Experiment
FINGIS - Finnish Geographic Information System
GARP - Global Atmospheric Research Programme
GCM - General Circulation Model
GEWEX - Global Energy and Water Cycle Experiment
GIS - Geographic Information System
GRDC - Global Runoff Data Centre
GRID - Global Resource Information Database
HAPEX - Hydrological-Atmospheric Pilot Experiment
HWR - Hydrology and Water Resources Department (WMO)
ICSU - International Council of Scientific Unions
MOBILHY - Modélisation du Bilan Hydrique
SAMER - Système Automatique de Mesure de l'Evapotranspiration Réelle
UNEP - United Nations Environment Programme
Unesco - United Nations Educational, Scientific and Cultural Organization
WCP - World Climate Programme
WCRP - World Climate Research Programme
WMO - World Meteorological Organization

1. OPENING OF THE SESSION

The Workshop on the Global Runoff Data Set and Grid Estimation was opened at 9:00 a.m. on 10 November 1988 at the Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde) in Koblenz, Federal Republic of Germany. Dr. H.-J. Liebscher, Director of the WMO Global Runoff Data Centre (GRDC) was elected to chair the meeting.

The purpose of the meeting was to review the work of the GRDC, in producing data sets required by the climate research and hydrological communities, and to discuss the possibilities for the gridding of hydrological data for use in validating climate model outputs.

The names and addresses of the participants are given in Appendix A. The agenda, as approved, is given in Appendix B.

2. NEED FOR GLOBAL WATER RUNOFF INFORMATION

2.1 General

Knowledge of the water discharge at various points within a river catchment is the basic information requirement for all kinds of hydrological investigations and/or applications. Such applications would normally require long time series of river gauge measurements with fairly high spatial and temporal resolutions and are, therefore, primarily focussed on specific river basins within a geographic region. Climate research, on the other hand, requires runoff information to close the groundwater budget over continental areas, placing emphasis on large-scale averages (of the order of the resolution of climate models, e.g. 100 x 100 km^2 and larger), mean monthly values and global coverage. The main climatological applications of global river discharge information are, together with global precipitation data, diagnostic and modelling studies of the global hydrological cycle, assessment of existing water resources in relation to climate events, and assessments of future climate trends with respect to global water balance.

2.2 Climate Research Requirements

2.2.1 First GARP Global Experiment (FGGE)

The initial requirement for the construction of a global runoff observational data set came from the WMO/ICSU Global Atmospheric Research Programme's (GARP) FGGE, whose primary purpose was to collect a unique set of global data to study those physical processes in the troposphere and stratosphere that are essential for a better understanding of the transient behaviour of the atmosphere as manifested in the large-scale fluctuations which control changes in the weather. This would lead to increasing the accuracy of forecasts over periods of one day to several weeks. It was quickly apparent to the planners of the experiment that the FGGE presented an unprecedented opportunity to assemble additional information, such as runoff data, which in conjunction with the atmospheric data could be used to study those factors that determine the statistical properties of the general circulation of the atmosphere, which in turn would lead to a better understanding of the physical basis of climate.

This then led to the formulation of the plan to collect runoff data in the form of discharges from selected river gauging stations and the boundaries of the catchment areas for the water years 1978-1980. The planning and actual collection of data were undertaken by the Hydrology and Water Resources (HWR) Programme of WMO.

2.2.2 World Climate Research Programme (WCRP)

The World Climate Programme (WCP) was formally established in 1979. The research component of the WCP, called the World Climate Research Programme (WCRP), was seen to include many research activities related to the second objective of GARP. The general goals of the WCRP have been formulated in terms of three specific objectives or streams of climate research, each corresponding to different kinds of climate predictability on different time scales, as follows:

(i) First Stream: to establish the physical basis for and feasibility of predicting large-scale weather patterns, on time scales of one to two months.

(ii) Second Stream: to understand and, eventually, to predict the variations in the heat transport by ocean currents and the corresponding variations of the atmospheric general circulation, over periods from several months to several years.

(iii) Third Stream: to understand the causes of long-term climate trends and to assess the potential response of climate to natural or human influences, over periods of several decades.

The development of climate models, in which the elements of the climate system are coupled together, is an essential component of all three streams of climate research. One of the highest scientific priorities of WCRP is to improve the parameterization of processes that control the fluxes of momentum, water, energy and gases between the atmosphere and the ocean and land surface. For this, global climatological data sets are essential not only for the development and testing of parameterization schemes but also for the validation of outputs of climate models.

Thus, there is an on-going need to continue the collection and processing of information on the hydrological cycle, begun during the FGGE. The recent endorsement by WMO and ICSU of the proposal to undertake the preparation of a Global Energy and Water Cycle Experiment (GEWEX) as one of the major projects of the WCRP, beginning in the 1995-2000 time period, is a further clear indication of the need to continue the collection and processing of runoff data.

2.3 Needs of Climate Modellers

P. Rowntree of the U.K. Meteorological Office described the needs of climate modellers for water runoff data. Basically, runoff enters into climate models at two points: first, in the land model which must estimate the amount of runoff for given fluxes between the atmosphere and the land surface, and second, in the ocean component of the model, where the runoff enters the ocean and modifies the water properties. These require different types of runoff data for validation. In the land context, the need is for local grid scale data derivable from observations for small catchments, although integrated data for larger catchments would also be of value. In the ocean context, the need is for data on the input to the oceans, both at major river outlets and from groundwater and small streams, if they are of comparable size.

A brief review of the structure of climate models was presented. A description of the major terms of the land surface water budget was provided. These included the inputs (precipitation and snow melt), infiltration and surface runoff, percolation and deep runoff, and evapotranspiration. It was clear that the role of runoff in the system is a significant one and it is important that the runoff processes are adequately represented in climate models. If the precipitation is realistically simulated, it is possible that observed data could be used to improve the simulations by using the information they provide to adjust the model formulations of runoff on the soil characteristics. First, the hydrological parameterizations would be improved using runoff data for areas where the soil characteristics are relatively well known. Then, the validations would be employed to diagnose soil characteristics in other regions. Given a sufficient quantity of data, for example a multi-year runoff series and a limited number of parameters in the hydrological system, an appropriate mathematical technique could perhaps be devised to determine all parameters for a region or group of grid boxes.

Runoff is of considerable significance for the oceans through the ocean salinity or freshwater budget equation. The importance of runoff to the ocean would be expected to be a maximum in the proximity of major rivers and where the ocean is particularly sensitive to the salinity. However, the sensitivity of the ocean to runoff variations has not been assessed in a systematic way, but some conclusions could be drawn from studies conducted in the past. The runoff from rivers into the Arctic Ocean appears to have a significant effect on the ocean circulation. In the tropics, the effects on the circulation may be small or difficult to detect because of the generally more intense currents, the more important roles of precipitation and evaporation, and the inherently more stable vertical structure.

The needs of climate modellers for runoff data were summarized as follows:

(i) Models could use local runoff data averaged over a gridbox to validate and calibrate several aspects of land surface parameterizations. However, to do this properly requires extensive meteorological and hydrological observations. The WCRP Hydrological-Atmospheric Pilot Experiments (HAPEX's) have been designed to provide these observations. Good quality runoff data sets for specific regions/groups of grid boxes would also be useful for such validation exercises. Ideally, a few regions representing different climates, e.g. temperate (some snow, unfrozen ground), continental (frozen soil in winter), subtropical with dry season, tropical with large runoff, should be analysed. Areas with minimal human interference would be needed.

(ii) Global runoff data sets (monthly/annual means and measures of interannual variability), with indications of reliability, are needed to provide global validation of climate models.

(iii) Monthly data on runoff into the oceans are needed for validation of coupled ocean-atmosphere climate models. These are also likely to be required by ocean modellers, in the context of the World Ocean Circulation Experiment.

A complete text of P. Rowntree's presentation is included in Appendix C.

2.4 Hydrology Requirements

Although the requirements for the construction of global runoff data sets were initially based on the needs of the meteorological and climatological communities, many of those actually involved in the collection and processing of the data recognized the considerable potential value of the information to hydrologists. With time, this value had been recognized more widely and growing interest in the work of the GRDC was shared by both climatologists and hydrologists.

Hydrologists, in common with others working in the geophysical sciences, have a substantial need for field data on which hypotheses could be developed and tested. The Global Water Runoff Data Project was viewed as being particularly valuable, in this regard, because the data being collected came from every region of the world and this would encourage the development of analytical and modelling techniques that would be applicable more widely than those based on data from only a single country or region. This applied to work being done on grid area estimation as well as on techniques for the assessment of water resources or the forecasting of floods and droughts.

It was recognized that interest among hydrologists in the work of the GRDC was also due in large measure to the significant increase in recent years in large-scale, even global, studies of a hydrological nature. The occurrence of widespread droughts and the need for a better understanding of the interdependence of hydrological phenomena over comparatively large distances have led to the undertaking of such studies, which in turn require data on surface water and other hydrological elements on a continental or global scale. The meeting noted that a proposal was made at the recent eighth session of the WMO Commission for Hydrology (Geneva, 24 October-4 November 1988) for the quasi-real-time monitoring of hydrological elements on a global extent, as a basis for detecting variability and change. The GRDC could play a significant role in such an activity.

For the above reasons, the meeting felt that the GRDC should see its role as serving both the climatological and the hydrological communities. Great benefit was seen, therefore, in the GRDC establishing contacts with a broad range of similar institutions, at both national and international levels, so as to ensure that maximum use is made of the facilities and services it offers and to seek wide support for and recognition of the work it has undertaken to do.

3. GLOBAL RUNOFF DATA CENTRE

3.1 Background and Arrangements

The WMO Hydrology and Water Resources Department was entrusted with the task of organizing the collection and processing of surface water runoff data for use in the validation of atmospheric general circulation models (GCMs), as part of the FGGE. In addition, various other projects within the World Climate Programme and the WMO Hydrology and Water Resources Programme need surface water runoff data such as those originally collected for the FGGE. For this reason, the collection and storage of these data are now being continued on a long-term basis.

From 1983 to 1987, the Institute for Bioclimatology and Applied Meteorology of the University of Munich, in the Federal Republic of Germany, served as the WMO Global Runoff Data Centre. During this period, the centre entered daily flow data for over 3,600 stations-years for the period 1978-1980. The Institute also began the digitization of catchment boundaries, which were planned to be archived with the runoff data.

On 1 May 1987, a permanent Global Runoff Data Centre (GRDC) was established at the Federal Institute of Hydrology in Koblenz, Federal Republic of Germany, under the auspices of the WMO. By early 1988, the GRDC had entered data received from about 50 countries for the period 1981-1983. The data processed by the University of Munich had been transferred to the GRDC in Koblenz.

3.2 Responsibilities and Functions of the GRDC

The GRDC operates for the benefit of WMO Members and the international scientific community. It provides a mechanism for the international exchange of data pertaining to river flows and surface water runoff on a continuous long-term basis. The GRDC receives data, through the WMO, from many sources. While every attempt is made to assure reasonable standards for data quality and related documentation, the ultimate responsibility for data reliability lies with the data contributors and not with the GRDC. All data, archived at the GRDC, are available to users upon written request or personal visit.

The GRDC has prepared documentation describing the data bank and retrieval service. This information is being distributed to all countries. Arrangements are being made through the WMO to collect new data from countries which have supplied them in the past and data from 1978 from those countries which did not respond to the original request. The GRDC collaborates with the WMO in a number of projects related to runoff data, such as the development of a methodology for transferring river flow data to grid values. The GRDC plans to issue an annual global runoff monitoring report based on available river flow data.

A detailed description of the responsibilities and functions of the GRDC is provided in Appendix D.

3.3 Data Collection, Checking and Storage

The first request to countries for daily flow data for the FGGE (1978-1980) was circulated in August 1982. The intent was to obtain a global set of flow data for use in validating GCM outputs on a regular horizontal grid (e.g. 2.5° latitude x 2.5° longitude). It was recognized that hydrometric networks were not consistent with a regular grid array. Since interpolation techniques would be necessary, in most cases, to derive runoff values for a regular grid array, hydrometric stations in each country had to be selected according to the following criteria:

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

(ii) Coverage, to the greatest extent possible, in each type of hydrologically homogeneous region of each country.

(iii) Availability of good quality data.

To facilitate data interpolation and to obtain measurements which directly reflect the variation in time of local meteorological conditions, the following were observed in the selection of the river flow stations:

(i) Data should be obtained from relatively small river basins (up to about 5,000 km^2, and in exceptional cases, up to 10,000 km^2). Data from larger river basins would be obtained in regions where the information from small river basins could not be obtained.

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

On the basis of limited information available to the WMO Secretariat on the hydrological conditions in each country, a tentative number of hydrometric stations in each was suggested for consideration. The participating countries revised the lists of stations, suggesting alternative ones in place of those which had been discontinued, those for which measurements were not available for the required period, those for which the data were of questionable quality, and those for which the natural regimes of stream flow could not be calculated.

Sixty-seven countries responded to the request and daily river flow data for 1,200 stations were collected (see Table 3.1). The daily flow data were submitted on magnetic tapes, diskettes or in documentation form (photocopies or printouts of yearbooks or observation forms). In addition, it was required that the data be subjected to an adequate quality control. In most cases, the quality of the data furnished for each station was indicated by attaching one of the following flags to the reported values:

(i) Data considered to be of very good quality, i.e., accurate to within ±5%.

(ii) Data considered to be of good quality, i.e., accurate to within ±5 to ±10%.

(iii) Data considered to be of moderate quality, i.e., accurate to within ±10 to ±20%.

(iv) Data considered to be of poor quality, i.e., accurate to no better than ±20%.

(v) Data amended in light of quality control checks.

(vi) Data derived in order to complete a missing record.

The call for supply of daily flow measurements for the same stations for the years 1981-1982 went out in June 1984. In addition, countries were requested to provide maps of the catchment areas for each station, in order to enable users to interpret the flow data in terms of grid values. About 50 of the 67 participating countries supplied the data and maps for approximately 600 catchments.

Table 3.1. GRDC Summary Register of Hydrometric Stations

Country	Number of stations with archived flow data	
	Daily (WMO Collection)	Monthly (Unesco Pub.)
Afghanistan	2	-
Albania	-	9
Algeria	-	12
Argentina	18	19
Australia	135	10
Austria	3	1
Bangladesh	-	3
Belgium	2	-
Bolivia	-	6
Brazil	116	14
Bulgaria	-	6
Burkina Faso	7	-
Burma	4	-
Cameroon	-	13
Canada	205	78
Central African Republic	-	3
Chad	-	2
Chile	-	6
China	-	8
China (Taiwan)	-	1
Colombia	-	12
Congo	11	12
Costa Rica	-	5
Cuba	4	7
Cyprus	-	2
Czechoslovakia	7	3
Denmark	-	3
Dominican Republic	-	5
Ecuador	-	14
Egypt	-	5
El Salvador	-	5

Country	Number of stations with archived flow data	
	Daily (WMO Collection)	Monthly (Unesco Pub.)
Ethiopia	21	10
Fiji	2	–
Finland	11	3
France	9	8
France (Guadeloupe)	1	1
France (Martinique)	–	1
France (Reunion)	1	–
French Guyana	2	1
French Polynesia	2	1
Gabon	–	1
Germany, Federal Republic of	9	3
German Democratic Republic	–	2
Ghana	–	5
Greece	2	2
Guatemala	–	4
Guinea	5	5
Guyana	5	2
Honduras	5	–
Hongkong	2	–
Hungary	8	4
Iceland	3	4
India	–	44
Ireland	–	7
Iran	11	10
Iraq	–	4
Israel	4	2
Italy	–	5
Jamaica	–	3
Japan	7	5
Jordan	–	2
Kenya	4	1
Korea, Democratic People's Republic	–	7
Korea, Republic of	–	8
Lesotho	3	4
Liberia	–	7
Libya	46	–
Luxembourg	1	–
Madagascar	–	4
Malawi	4	3
Malaysia	4	10
Mali	–	6
Mauritania	2	–
Mauritius	1	5
Mexico	28	32
Mongolia	7	6
Morocco	–	2
Mozambique	–	8

Country	Number of stations with archived flow data	
	Daily (WMO Collection)	Monthly (Unesco Pub.)
Netherlands	2	1
New Caledonia	2	1
New Zealand	6	7
Nicaragua	5	14
Niger	5	4
Nigeria	-	3
Norway	10	1
Pakistan	24	3
Panama	5	10
Papua New Guinea	-	1
Paraguay	-	1
Peru	-	4
Philippines	-	10
Poland	11	4
Portugal	-	14
Romania	-	4
Senegal	5	13
Sierra Leone	-	7
Singapore	1	1
South Africa	26	-
Spain	14	5
Sri Lanka	-	7
Sudan	-	3
Suriname	4	4
Sweden	12	3
Switzerland	3	2
Syria	-	4
Tanzania	12	2
Thailand	11	5
Togo	2	1
Tunisia	-	6
Turkey	13	5
Uganda	-	7
United Kingdom	16	4
Uruguay	4	2
USSR	146	86
USA	120	90
Venezuela	-	12
Yugoslavia	5	4
Zambia	12	3
	1200	864

The GRDC data bank consists of daily flows for 1,200 stations from 67 countries. The first available year is 1978 and there are data for up to 1980 from nearly all of the stations. Data from 40 countries are also available up to 1982-1983 and from Australia up to 1984-1985. In addition, monthly flows for 864 stations in 106 countries, taken from the Unesco publication - Discharge of Selected Rivers of the World (1965-1979) - have also been entered into the GRDC data bank. It should be noted that the length of data records varies from station to station. Finally, information on catchment areas and geographical locations are also available.

3.4 Retrieval Service

The GRDC has developed a suite of programmes to provide users with a selection of retrieval options to make the data and information readily accessible. A list of the currently-available retrieval options is provided in Table 3.2. Examples of typical outputs are provided in Appendix E.

Table 3.2. List of GRDC Retrieval Options

OPTION	TITLE	REMARKS
1	Table of daily mean flows (in m^3/s)	Includes monthly and annual mean flows
2	Table of monthly mean flows (in m^3/s)	Includes annual mean flows
3	Hydrograph of daily mean flows	(Inclusion of mean of period possible)
4	Hydrograph of monthly mean flows	(Inclusion of mean of period possible)
5	Flow duration curve	(Inclusion of maximum and minimum flow duration curve possible)
6	Flow duration table	
7	Station and catchment information	
8	Creations of data files	

In response to user requirements, the GRDC data bank was being continually extended in time and space. It was hoped that the data retrieval facilities would also be upgraded, subject to the availability of resources.

Requests could be made in writing or by a personal visit to the GRDC. The following information should be specified:

(i) Name and address to which output should be sent (include telephone and telex numbers if available).

(ii) Hydrometric stations for which data are required.

(iii) Title(s) of options requested.

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

Requests should be addressed to:

GRDC
Bundesanstalt für Gewässerkunde
Kaiserin-Augusta-Anlagen 15-17
D-5400 KOBLENZ
Federal Republic of Germany

Telephone: 0261-1306-1
Telex: 08-62499

4. DIGITIZATION OF CATCHMENT BOUNDARIES

4.1 Background

In order to convert river flow measurements into runoff values from catchments, it is necessary to know the areal extents of the catchments. Thus, one of the requirements of the Global Water Runoff Data Project is to obtain the necessary geographical information, which describes the catchment boundaries, with the river-flow measurements. About 50 countries have already supplied maps with the geographical co-ordinates of some 600 catchments, but more maps are needed.

4.2 University of Munich Work

G. Schwartzmaier reviewed the work done so far by the University of Munich. Software has been written to digitize the boundaries of catchments, but the programme had not been applied to the map information which had been received from participating countries. Difficulties had been encountered because of the different sizes of the catchments (4 km^2 to 10,000 km^2), the map scales and the map projections.

It was stressed that the University of Munich had the resources (funds and personnel) to take on this task, but needed help from the meeting on how to proceed with the actual digitization.

4.3 Finnish Geographic Information System

Y. Sucksdorff informed the meeting on the Finnish Geographic Information System (FINGIS), which is the main programme for a computer-based hydrologic geographic information system, developed in the National Board of Survey of Finland for managing numerical spatial data. FINGIS has been used to digitize 74 main drainage basins and 7,700 sub-basins (each about 30 km^2) within the Finnish borders. In order to make the drainage basin register as compact as possible, extra digitized points of drainage divides have been filtered. Two digital models have been used to calculate the average height and average slope of river basins.

A complete text of his report is provided in Appendix F.

4.4 Recommendations

The meeting noted the various digitization projects, which have been undertaken on global and regional scales. In particular, the UNEP Global Resource Information Database (GRID) system and the FAO project for Africa were cited as projects which could provide valuable information to the Global Water Runoff Data Project. The meeting agreed that digitization of catchment boundaries was essential and should be undertaken as soon as possible. It was agreed that only catchment areas greater than 100 km^2 should be digitized.

Noting the willingness of the University of Munich to undertake the work of digitizing the catchment boundaries, the meeting recommended the following:

(i) WMO and FAO undertake to determine what information on catchment boundaries was already available and to obtain such information (WMO/HWR has overall responsibility).

(ii) WMO provide the above information to the GRDC.

(iii) GRDC determine what additional information are required and take action, in co-operation with WMO, to obtain them.

(iv) GRDC supply maps and supporting information to the University of Munich, which would then be responsible for accomplishing the digitization.

(v) University of Munich provides digitized catchment boundary data to the GRDC for archiving.

5. GRIDDING OF HYDROLOGICAL DATA

5.1 Background

The stream flow data, being compiled by the GRDC, are for individual river catchments, rather than for grid cells. The problem of transforming catchment data into grid cell estimates of surface water runoff has been discussed over a number of years, particularly within the context of the World Climate Programme - Water (WCP-Water) Projects A.6 and B.3 (WMO, 1986). Although some techniques have been proposed, no generally accepted method has been established.

In areas of dense coverage of gauged catchments, on the order of a few hundreds of square kilometers, estimates of surface water runoff for 0.5° latitude x 0.5° longitude or 1.0° latitude x 1.0° longitude grid cells could be obtained directly from monthly or daily catchment values by taking the averages of those which are most representative of each grid cell. However, the use of such a technique would not be applicable for most areas constituted by developing countries and also many areas of developed countries. In addition, even if adequate data were available, the difficulties to be encountered in the data collection and analysis would make it highly unlikely that such a straight-forward approach could be used on a global scale.

5.2 Consideration of Proposed Techniques

S. Solomon, G. Girard and G. Schwartzmaier informed the meeting of various approaches which have been considered for the computation of grid point and grid area estimates of hydrological variables. Traditionally, hydrologists have performed the spatial interpolation of point or small area values using techniques such as isoline interpolation, Thiessen polygons, weighted averaging and Kriging, but all of these are applicable only when a dense network of observations are available or where there is only a small spatial variation in the parameter of interest. In the case of the GRDC data set, the network of available observations, except in the case of a few localized regions, is much too sparse to permit the use of any of these simple techniques. Clearly, what is needed is information, in addition to stream flow data, which could be used as a basis for the interpolation and spatial distribution of the available data.

One alternative to the simple approaches referred to in the previous paragraph is to use a multiple regression technique, which incorporates additional parameters (e.g., topography, soil type, land use/land cover, geology and estimates of areal precipitation). This approach has already been studied by the Institute of Bioclimatology and Applied Meteorology at the University of Munich. However, the limitations of this approach need to be properly recognized and the independent variables should be properly selected. The technique implies that these variables have a real physical relationship with the dependent variable and are not affected by errors which would make any reduction in estimating variance a practical impossibility. It is well known, for example, that one of the basic assumptions of regression analyses is that the independent variables are free of errors, but this is never possible in practice.

Another alternative is to use the same or similar additional parameters in a water balance model, which could be applied to grid cells in such a way as to obtain values for the balance components, which are internally and hydrologically consistent, and at the same time matches the observed data. S. Solomon has used such a technique in the past, but not on a sparsely-populated global data set such as the one being constructed by the GRDC.

G. Girard described the application of a grid-based hydrological model during the HAPEX-MOBILHY experiment, which took place over a 100 x 100 km^2 region in Southwestern France from April 1985 - January 1987 (see Appendix G). The model was applied on a time scale of 1-30 days for the purpose of evaluating the transfer of water across the atmosphere-land surface interface. This evaluation needed to maintain compatibility with observed values of precipitation, runoff, groundwater levels and soil moisture. A spatially distributed model was used, in order to take into account the spatial as well as the temporal variability of the input information. The model coupled surface and ground water and was based on a 5 x 5 km^2 grid, with 2.5 x 2.5 km^2 or 1.25 x 1.25 km^2 grids where it was necessary to simulate the more linear elements of the drainage basins.

The only inputs for the calibration of the model were daily precipitation measurements from a network of 70-100 raingauge stations and estimates of potential evaporation from 7-8 stations. The output used for the calibration was the daily discharge for the gauged sub-basins, plus groundwater levels for certain locations. The results were presented in the form of estimates for each of the water balance terms for the 10 x 10 km^2 grid squares, for the period 1974-1986. The estimates agreed well with those obtained by other means, in particular those from the Système Automatique de Mesure de l'Evapotranspiration Réelle (SAMER) stations. This confirmed the validity of the model and its results, in terms of the HAPEX-MOBILHY experiment.

Recognizing the shortcomings of using any of the above-mentioned techniques with the GRDC data set, the meeting concluded that what is needed is a modelling technique, which incorporates additional types of information with the available river flow measurements to "extrapolate" the coverage of runoff information to adjacent areas. Some suggestions were offered on how the analysis might be performed and what types of addition data might be required. The use of a Geographic Information System (GIS), in conjunction with the analysis model, was strongly advocated. It was recognized, however, that it would be some time before a GIS, with the appropriate additional information, could be established by the GRDC and an appropriate analysis scheme could be tested for use in producing global gridded fields of runoff data.

The meeting concluded that the Global Water Runoff Data Project should not attempt, at this time, to produce an interim global data set, on the basis of using presently-available simple analysis methods, because the resulting data would, in all likelihood, not be accurate enough for climate research purposes. Thus, it was recommended that in parallel with the development and testing of generally applicable grid estimation techniques under WCP-Water, WMO should undertake a project which would provide a preliminary data set, or data sets, for limited areas of the Earth's land surface in as short a time period as possible.

5.3 Pilot Project to Produce Gridded Estimates of Surface Runoff over Limited Regions of the World

It was recognized that in certain regions of the world, there were sufficiently dense networks of river flow stations which could permit the use of presently-available techniques to produce gridded estimates of runoff over limited areas for use in validating GCM outputs. The collection of high-density measurements from these networks could be useful for this purpose.

A pilot project was proposed for the purpose of constructing data sets over certain dense river flow networks, which could be used in currently-available techniques for estimating runoff over grid cells. The areas under consideration should be fairly homogeneous from both climatic and hydrologic viewpoints. Daily river flow measurements for each catchment, for the calendar years from 1978 to 1980, should be obtained. Where this is not possible, then monthly values should be obtained.

The meeting recommended that the area should be confined initially to latitudes 48°-55°N and longitudes 7°-15°E, and then later expanded to 45°-55°N and 5°-25°E. It was suggested that the Federal Republic of Germany be approached to consider taking the lead for this project by having the GRDC collect and process the data set, with the assistance of WMO in requesting the co-operation of participating countries. The GRDC would be responsible for the construction of the data set and the derivation of runoff estimates for grid cells covering the project area. The data set would then be made available to GCM modellers for validating outputs over the European area. A detailed project plan is given in Appendix H.

5.4 Intercomparison of Techniques for Computing Grid Point and Grid Area Estimates

The river flow data sets to be collected in the pilot project would be of significant value to the development of techniques for estimating grid cell runoff values in areas of limited data coverage. Almost certainly, additional data and information would be required, in conjunction with the river flow data, to arrive at gridded estimates. A suitable model is needed which incorporates all of these information in a hydrologically consistent way.

The meeting proposed that efforts should be made to obtain the additional data and information from available sources, insofar as possible. Certain information included in Geographical Information Systems, such as the UNEP GRID system, would be most valuable for the construction of a GIS to serve the purpose of running a model to produce gridded estimates of runoff data. However, the meeting cautioned that the sources of the information needed should be checked to ensure that the quality of the information is acceptable.

Although no firm recommendations could be made regarding an intercomparison project, the meeting suggested that the WMO Secretariat should begin to initiate contacts with hydrological and meteorological groups, which might be interested in participating in such a project. A pilot data set, consisting of river flow observations plus the additional data and information from a GIS, should be constructed and each participant provided with a copy of the data set. The participants would be asked to apply their techniques/models on the same data set (using only a limited number of actual river flow observations to simulate data-sparse regions over most of the globe) and their results would be presented at a workshop to evaluate the strengths and weaknesses of each technique. It was hoped that by means of such an intercomparison, a practical technique for producing gridded runoff estimates could be obtained for use by the GRDC.

6. ACTION PLAN

The meeting concluded that follow-on activities were essential for the improvement of the completeness of the available data sets, for the collection of geographical information on catchment areas and the digitization of catchment boundaries, and for the development of models and a geographic information system to provide the gridded information required by climate modellers. An action plan was developed to continue the work which had already been accomplished and is given in Appendix I.

The workshop suggested that the plan of activities of the GRDC might be developed in three stages:

(i) First Stage: The finalization of the principal data base of river flow measurements and the establishment of the routine retrieval service to users, along the lines specified in the responsibilities and functions of the GRDC. (This stage should terminate in the first half of 1990.)

(ii) Second Stage: The establishment, through WMO and independently, of contacts with other data centres and organizations with data bases, which are relevant to the task of estimating and validating river flow data, by use of basin information other than actual measurements of river flow, and the inclusion of such information in its own data base. In addition, the establishment of an information base for advising users, upon request, on where such data are archived and how they might be obtained. (This stage should terminate in the second half of 1990 or the first half of 1991.)

(iii) Third Stage: The continuation of the study to provide runoff data on a grid point basis and, in this connection, the consideration of establishing a geographical information system, which could ultimately provide, together with the use of appropriate hydrological models, global data coverage on the hydrology of the earth in a dynamic mode for the purpose of modelling the impacts of climate change on the availability of water resources. A small advisory board, consisting of representatives of the SRDC, WMO and Unesco and possibly some individual scientists, would be constituted for this purpose. (This stage should begin in the second half of 1989 or the first half of 1990.)

7. CLOSURE

The workshop was closed at 12:00 p.m. on 15 November 1988.

8. REFERENCE

WMO, 1986: Co-ordination meeting for Implementation of WCP-Water Projects, Geneva, 10-14 November 1986. World Climate Programme, World Meteorological Organization, WCP-129.

WORKSHOP ON THE

GLOBAL RUNOFF DATA SET AND GRID ESTIMATION

(Koblenz, Federal Republic of Germany, 10-15 November 1988)

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WORKSHOP ON THE GLOBAL RUNOFF DATA SET AND GRID ESTIMATION

(Koblenz, Federal Republic of Germany, 10-15 November 1988)

Agenda

1. OPENING

2. GLOBAL CIRCULATION MODELS AND RELEVANT ACTIVITIES UNDER THE WORLD CLIMATE RESEARCH PROGRAMME

3. THE GLOBAL RUNOFF DATA CENTRE (GRDC)

   3.1 Background to the Establishment of the GRDC
   3.2 Current Techniques and Administrative Arrangements
   3.3 Data Storage, Checking and Analysis
   3.4 Requests for and Inputs of New Data
   3.5 Digitizing of Catchment Boundaries
   3.6 Supply of Data to Users
   3.7 Future Plans for the GRDC

4. GRIDDING OF HYDROLOGICAL DATA

   4.1 Principles and State of the Art
   4.2 Applications to Global Runoff Data
   4.3 Applications to Hydrological Models

5. GRID-BASED HYDROLOGICAL MODELS AND THEIR LINKS WITH GENERAL CIRCULATION MODELS

6. CLOSURE

THE NEEDS OF CLIMATE MODELLERS FOR WATER RUNOFF DATA

By

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1. INTRODUCTION

The objective of this meeting is to discuss the Global Water Runoff Data Project. I have been asked to provide guidance on the needs of numerical modellers for the products of the project. This paper has been written in response to that request.

Runoff enters into climate models at two points. The first is in the land model, which must estimate the amount of runoff for given fluxes, past and present, between the atmosphere and the land surface. The second is in the ocean component of the model, where the runoff enters the ocean and modifies the water properties.

I shall first summarize the structure of a climate model and then describe in more detail the role of runoff in the land surface parameterizations and in ocean models. Finally, I shall present some results from atmospheric models to allow you to assess their present capability for simulating runoff and briefly discuss the inclusion of runoff in ocean models.

2. CLIMATE MODELS

A climate model, as is used at present, typically has 4 components - atmosphere, land, ocean and sea-ice. The atmospheric model represents the two horizontal wind components, temperature and humidity on a three-dimensional array of points and the surface pressure or total mass for each vertical column. In the horizontal, the surface of the globe is divided into a latitude-longitude mesh with north-south gridlengths varying between models from about 8° to 2° of latitude (e.g., the MO model has a 2.5° latitude x 3.75° longitude grid). In the vertical, models have from 2 (a rare exception) to 12 layers. Each of the main variables is given an initial value, which may be from real data or simply a windless isothermal state. The rates of change are then calculated using the relevant physical equations and the state one time step later (10 minutes for the MO model) is computed. This process can be continued indefinitely. This is exactly the same as the method used for a forecast. Even though the predictability of day-to-day features is limited to a few days, a good model should be able to generate a realistic climatology. By modifying aspects of the environment, such as CO_2 content, assessments of expected climate change can then be made.

The model of the ocean is similar in structure, with salinity replacing humidity as a variable. The sea-ice and land surface may be represented with a range of complexities. I shall discuss the land hydrology representations in detail, shortly.

3. RUNOFF DATA REQUIREMENTS

There are two needs of GCMs for runoff data, one associated with each of the contexts where runoff appears in the GCM formulations: surface moisture budget and ocean freshwater input. These require different types of runoff data for validation. In the land context, the need is for local grid scale data derivable from observations for small catchments, though integrated data for larger catchments is of value as will be indicated later. In the ocean context, the need is for data on the input to the oceans, both at major river outlets and also perhaps (if they are of comparable size) from groundwater, and small streams.

3.1 Land Data Requirements

3.1.1 Introduction

Models represent the major terms of the land surface water budget as in the equation:

$$\partial m/\partial t = P - E + M_s - Y \qquad (1)$$

where m is the total soil moisture, t is time, P is rainfall, E is evaporation, M_s is snow melt and Y is the total runoff. The processes included in the runoff parameterization are typically the surface runoff and a deeper runoff. These processes are familiar to hydrologists, but it may be instructive to describe how one of the more sophisticated parameterization schemes, the Biosphere-Atmosphere Transfer Scheme or BATS (Dickinson, 1984; Dickinson et al., 1986) represents them. Reference will also be made to another sophisticated parameterization, the Simple Biosphere model or SiB (Sellers et al., 1986), and to the Meteorological Office scheme (Warrilow et al., 1986, Warrilow, 1986). Figure 1 shows the main components of BATS; the input terms, the transfers into the soil and runoff, and the return of moisture to the atmosphere through evapotranspiration. Clearly, validation of the model with runoff data is capable of providing information on each of these processes and their parameterization. Precipitation is treated here as an external input, but this is somewhat misleading. As has been shown in a number of experiments, including several recently in which the evaporation was reduced over land by allowing for plant stomatal resistances, reduction of evaporation tends to decrease precipitation. A particularly striking demonstration of this was provided by the experiment of Shukla and Mintz (1982) in which the evaporation was eliminated over land (see Figure 2). Precipitation was greatly reduced over land, showing how important local water sources are to the atmospheric water budget.

3.1.2 Input of water to land surface

I consider first the inputs, the first and third terms on the right side of equation (1). The rainfall is simulated by the atmospheric branch of the model as based on the laws of physics; generally, the models separately parameterize convective and large-scale precipitation. In the presence of vegetation, allowance is made for interception of the rainfall by the foliage, and for its evaporation at the potential rate (i.e., with zero surface resistance). When the canopy capacity is reached, any surplus is assumed to drip to the ground. Snow is similarly intercepted and may sublimate or

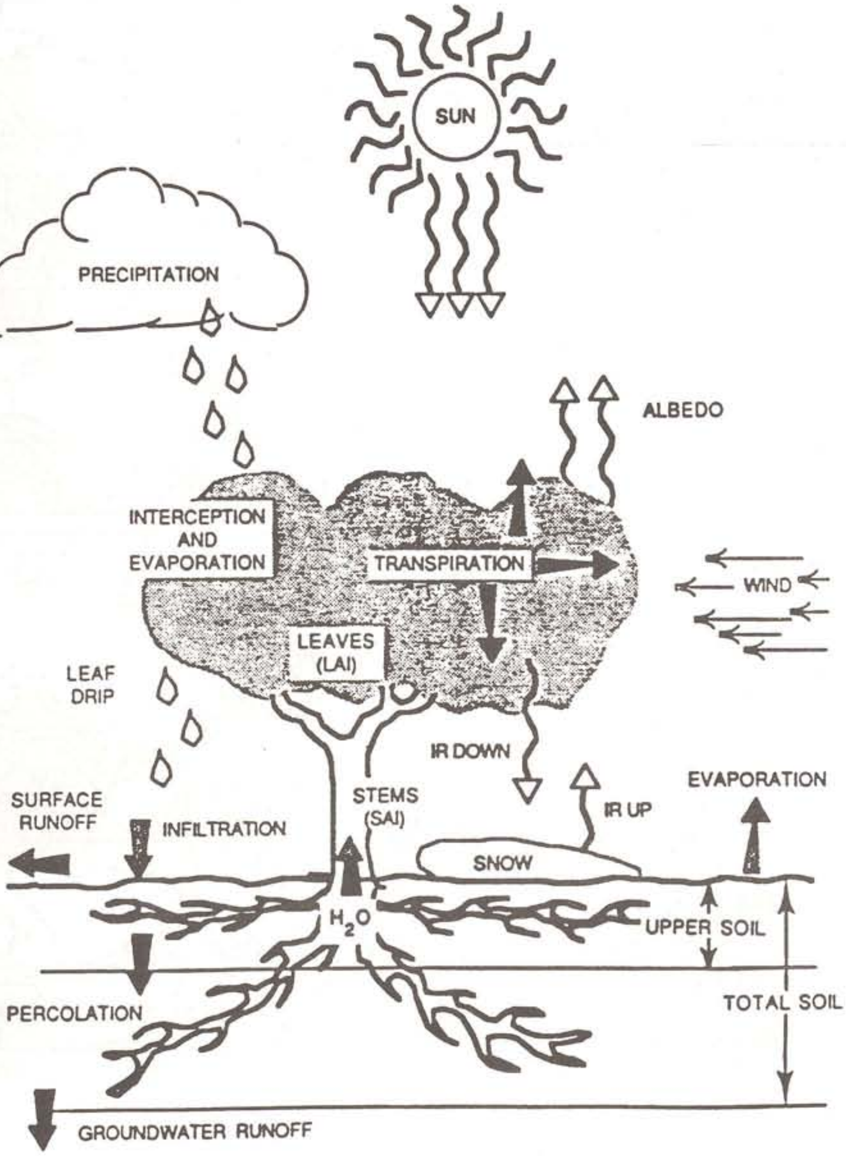


Figure 1. Schematic diagram illustrating the features included in a land-surface parameterization scheme.

fall/blow from the vegetation when the capacity is exceeded. (For the albedo calculation, it is effectively all assumed to blow off). Snowmelt is added to any rainfall occurring at the same time, and infiltrates into the soil provided the input does not exceed the maximum infiltration rate. Determination of this involves the modelling of water in the soil, which is the subject of the next subsection.

3.1.3 Infiltration and surface runoff

For many years, the standard GCM parameterization of soil moisture was the simple "bucket" model (Manabe 1969), based on equation (1). The bucket was of finite depth (m_{max}) and the runoff (Y) was zero until the bucket was

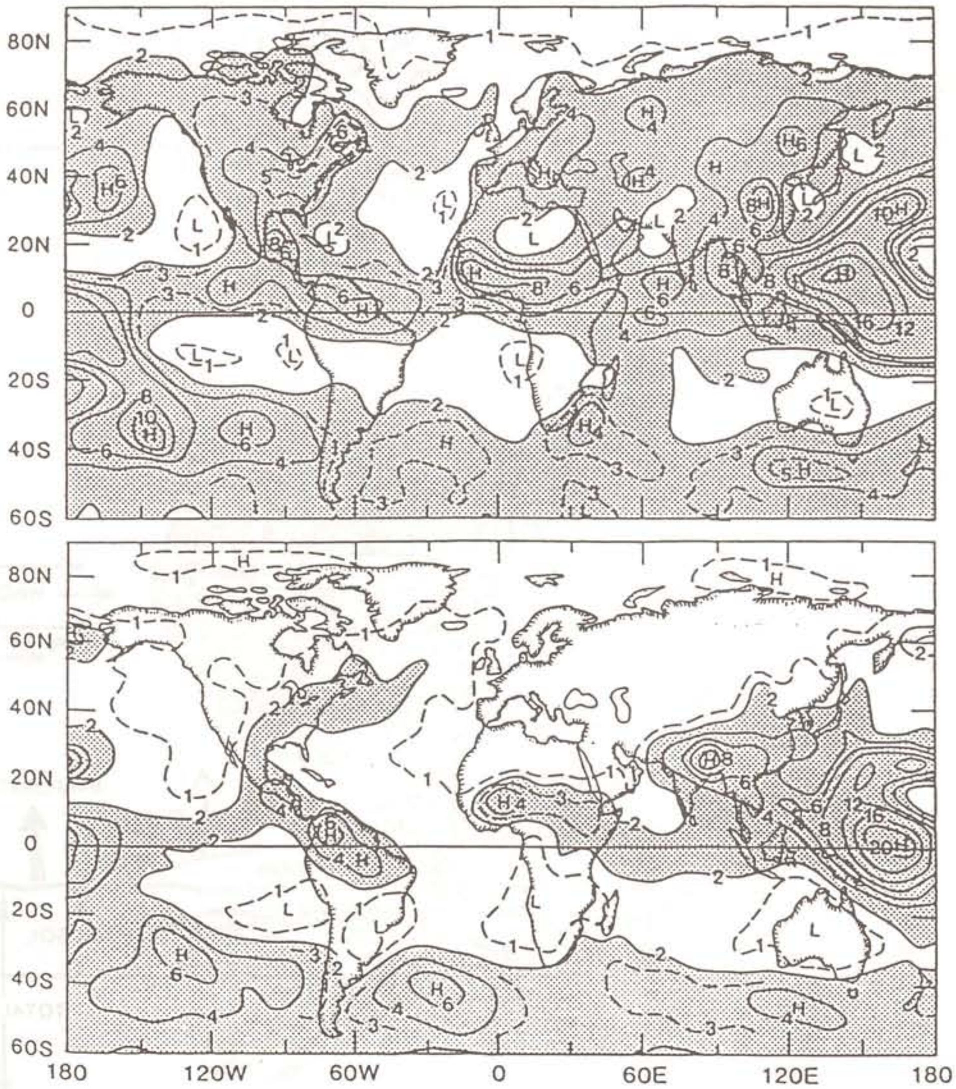


Figure 2. Precipitation (mm/day) in wet-soil case (top) and dry-soil case (bottom), in experiment of Shukla & Mintz (1982). (Precipitation greater than 2 mm/day is shaded).

full, after which Y was sufficient to maintain $m = m_{max}$. More elaborate treatments designed to allow some runoff for $m < m_{max}$ were incorporated into some models. A few models included no hydrology at all. The NCAR Community Climate Model (CCM) simply assumed that evaporation over land was a fixed fraction (0.25) of the potential value. Hansen et al. (1983) relaxed some of the constraints, allowing different field capacities (m_{max}) for different vegetation types, and including two layers with upward diffusion between them, which depended on vegetation and time of year, so effectively representing the transfer of water from the lower layer by roots during the growing season. Runoff from the upper layer was taken as being proportional to its water content and to the rainfall, though with a sudden increase when m reached m_{max}.

The BATS formulation introduced a more physically-based approach to the parameterization of soil moisture. The moisture flux in the soil at depth Z can be described in terms of the soil water suction ($\Phi = Z - \Phi_w$) and the hydraulic conductivity (K):

$$M(z) = -K(z)\ \partial\Phi/\partial z \qquad (2)$$

K is expressed by Dickinson et al. (1986), after Clapp and Hornberger (1978), in terms of the fractional soil water content, s, (ratio of soil water volume to volume of voids in the soil) as

$$K = K_o s^{2B+3} \qquad (3)$$

Similarly, Dickinson assumes

$$\Phi_w = -\ \Phi_o s^{-B} \qquad (4)$$

In these expressions, B is a nondimensional parameter which varies with soil type, from about 3 for sand to 11 for clay, and Φ_o and K_o are values at saturation. Φ_o does not vary with soil type in Dickinson's parameterization, but K_o is greater for sand by two orders of magnitude relative to clay. Water is represented in two layers, the surface layer and the total rooting layer, which includes the surface layer.

The SiB uses a similar parameterization in a 3-layer model. The moisture in the upper layer is directly available for evaporation into the atmosphere, while the second layer's water can be tapped only by roots. Transfer of water in the third layer is by diffusion and gravitational drainage only.

Surface runoff is parameterized in BATS in terms of the fractional saturation b (soil water density/saturated soil water density), as b^4F where F is the net input of water ($P+M_s-E$), unless the second layer soil temperature is below freezing, in which case the larger quantity bF is used to allow for blocking of infiltration by ice. The remainder of the water at the soil surface infiltrates and is added to the upper soil water reservoir. Note that this formulation takes no explicit account of the vegetation type, though the interception of water by the canopy makes some allowance for this. In SiB, the infiltration is zero if the top layer is saturated or the ground surface temperature is below freezing, but otherwise is limited only by the saturated hydraulic conductivity, K_o.

In reality, rainfall is not distributed evenly over a grid square. In the MO model (Warrilow, 1986), an exponential frequency distribution function is assumed for the rainfall in determining the surface runoff caused by the maximum infiltration rate being exceeded, so that:

$$Y(0) = P\ \exp\ (-\varepsilon F/P) \qquad (5)$$

where F is the maximum infiltration rate, Y(0) is the surface runoff, and ε is 1 for large scale rainfall and 0.3 for convective rainfall. The maximum infiltration rate is also a function of vegetation and soil types, with:

$$F = F_s\ (\upsilon\beta_\upsilon + 0.5\ (1-\upsilon)). \qquad (6)$$

Here, υ is the vegetated fraction, F_s is the bare soil infiltration capacity, dependent on soil type, and β_υ is the vegetation infiltration enhancement factor, which varies from 2 for crops to 6 for forest. This allows for the effect of vegetation on ground permeability, e.g. through decayed roots and litter. The factor 0.5 in (6) allows for crusting of bare soil.

3.1.4 Percolation and deep runoff

In the "bucket" formulations, surface and deep runoff were not separated, while in Hansen et al.'s scheme, the lower soil layer could not reach saturation because it received water only when the upper layer was wetter than the lower layer in terms of fractional saturation. Both BATS and SiB parameterize percolation between the layers in terms of the gradient of the soil water potential Φ, defined earlier. Deep runoff is the gravitational drainage term which in BATS is $K_o s^{2B+3}$, giving a large sensitivity to s. For example, for a loam with B=5 and K_o of 1.3×10^{-5} m/s, deep runoff with s=0.5 is about 0.2 mm/day, while with s=0.6 and the same soil, runoff is ten times greater. The SiB formulation is similar to BATS but allowance is made for a mean slope. The drainage is dependent on the water content of the third layer rather than that of the whole soil represented in the model as it is in BATS.

3.1.5 Evapotranspiration

Finally, the evapotranspiration is parameterized in terms of a Penman-Monteith approach with dependence on two resistances; one, the stomatal resistance (r_s) representing the resistance to transfer between the interior and the exterior of the leaf, and the other, the aerodynamic resistance (r_A), the resistance to transfer between the leaf surface and the canopy air space. Here, one is mainly interested in r_s, because it is dependent on the soil moisture. Other dependences are included in the BATS formulation for r_s, for example on temperature, solar radiation and vapour pressure deficit below saturation. The dependence on soil moisture has two components. Firstly, the limit to uptake of water by roots is represented by restricting transpiration to about 0.5 mm/hour. Secondly, this limit is further reduced as the soil moisture approaches the wilting point, E being reduced by multiplication by a term $(1 - W_{LT})$, dependent on soil water potential for each model layer, where:

$$W_{LT} = (s^{-B} - 1)/(s_w^{-B} - 1) \qquad (7)$$

Here s_w is the soil water content for which transpiration becomes zero - some water being unavailable. The value of s_w increases from near 0.1 for sand to over 0.5 for clay. The dependence of W_{LT} on s through (7) is illustrated by the values in Table 1 for a typical value B = 5 with the value of s_w (0.125) suggested by Dickinson (1984).

Table 1: Variation of W_{LT} with soil moisture s for B = 5, s_w = 0.125

s	1	.8	.6	.4	.3	.2	.175	.15	.14	.13	.125
W_{LT}	0	.0001	.0004	.003	.013	.095	.19	.40	.57	.82	1

Note the small effect of variations in s for s > 0.3. The abrupt decrease in water availability over a small range of s is consistent with the observations summarized by Priestley and Taylor (1972). However, it may not be appropriate to apply such a sharp cutoff to a model grid box of scale 100 km or more with considerable inhomogeneity in several respects (rainfall, soil and vegetation type, slope, etc.).

3.1.6 Discussion

The role of runoff in this system is clearly a significant one and it is important that the runoff processes are adequately represented. If the precipitation is realistically simulated, it is possible that observed data could be used to improve the simulations by using the information they provide to adjust the model formulations of runoff or the soil characteristics. One might envisage two stages in the use of such data. First, the hydrological parameterizations would be improved using runoff data for areas where the soil characteristics are relatively well known. Then the validations would be employed to diagnose soil characteristics in other regions. This would be of particular value because satellite data are likely to be of limited use in the specification of soil characteristics. Given a sufficient quantity of data, for example a multiyear runoff series and a limited number of parameters in the hydrological system, an appropriate mathematical technique could perhaps be devised to determine all the parameters for a region or group of grid boxes. One problem with the above proposal is that the sum of surface runoff and percolation to groundwater (the usual modelled quantities) approximates river runoff (the observed quantity) only in a long period mean.

3.2 Ocean Data Requirements

Runoff is of considerable significance for the oceans through the ocean salinity or freshwater budget equation:

$$\rho_w Z dS/dt = S(E - P - I) \qquad (8)$$

where I is the input of water from the land per unit area of the ocean surface, ρ_w is the density of the seawater, Z is the ocean depth and S is the salinity or salt content per unit mass. This is derived by defining S as (mass of salt)/(mass of water) or W_s/W_w and differentiating it with respect to time t, assuming W_s fixed, to obtain:

$$dS/dt = -(W_s/W_w{}^2)\, dW_w/dt = -(S/W_w) dW_w/dt \qquad (9)$$

The importance of runoff to the ocean would be expected to be a maximum in the proximity of major rivers and where the ocean is particularly sensitive to the salinity. Comparison of the runoff for each ocean as a fraction of the total mass of the ocean (Table 2) is instructive in this context. Points of interest in Table 2 include the large inflow of runoff into the Atlantic, the much larger inflow for its size into the Arctic than the other oceans, and the large imbalance between evaporation and precipitation in the Atlantic. The first two points are a consequence of the geography - the positions of watersheds well away from the Atlantic and Arctic, and close to the Pacific and Indian Oceans. The last is probably mainly due to the presence of the Sahara Desert upwind of the Atlantic, leading to advection of dry air, with a large potential for evaporation across the subtropical Atlantic. The greater observed salinity of the Atlantic compared with the Pacific can be attributed to this.

Table 2. Components of fresh water mass balance for oceans
(from Korzun et al. (1974))

Ocean	Area (10^6 km²)	Volume (10^6 km³)	Inflow	Precip.	Evap.	Balance	I/V 0/00/yr
			------------(10^3 km³/year)-----------				
Pacific	178.7	707.1	14.8	260.0	269.7	+5.1	0.02
Atlantic	91.7	330.1	20.8	92.7	124.4	-10.9	0.06
Indian	76.2	284.6	6.1	100.4	108.0	-1.5	0.02
Arctic	14.7	16.7	5.2	5.3	3.2	+7.3	0.31
Total	361.3	1338.5	47.0	458.0	505.0	0	0.035

The sensitivity of the ocean to runoff variations has mostly not been assessed in any systematic way. Possible sensitivities may be grouped under the following headings:

(i) Tropical river inputs. Examination of ocean salinity charts reveals marked minima in salinity near the entrances to major rivers, in particular the Amazon, which provides the largest input of freshwater to the world's oceans. The effects of salinity on the tropical ocean circulation have been discussed by Cooper (1988). He calculated the effects of salinity on the density distribution and noted the important role of salinity in the Atlantic and northern Indian Oceans. Generally, gradients were larger if the effects of salinity were ignored. This indicates that the effects of temperature and salinity tend to cancel, warm water being generally more saline in the tropics. (This is as expected in the absence of rainfall, since evaporation tends to be greater over warm water; also, the clear skies of the subtropical high pressure regions allow strong solar warming and are associated with a lack of rainfall). The input of low salinity water by rivers such as the Amazon generate large salinity gradients and associated density gradients. However, these are confined to layers near the surface (e.g., the Levitus (1982) atlas gives the mean salinities for 0°-5°N, 50-55°W as 25.4, 33.4 and 35.7 o/oo at 0, 10 and 20m depth respectively) and have little effect on the pressure gradients in the tropical ocean. They have been generally disregarded by tropical oceanographers. Some appreciation of the reasons may be gained from the figures in Table 2 and by comparing the mass transport of the Amazon, about 0.2 x 10^6 m^3/s at its seasonal peak in May, to that of the offshore Brazilian coastal current, about 20 x 10^6 m^3/s.

(ii) High latitude river inputs. Salinity maps also show low values in the Arctic Ocean, where a number of major rivers enter the ocean, as is evident from Table 2. Two possible consequences need to be considered. The first is that the circulation may be directly affected by the salinity change.

Note that at the temperatures typical of high latitude oceans, the ocean density is little affected by temperature differences (Figure 3). The second is that there may be effects on sea-ice because river runoff of fresh water contributes to the formation of a shallow halocline, favourable for ice development. A matter of considerable interest is whether the elimination of input from Russian rivers through their diversion for irrigation purposes would have a significant effect on the extent of Arctic ice, and so on climate. Semtner (1984, 1987) has modelled the Arctic Ocean circulation and perturbed the inflow from Russian rivers to provide some preliminary assessment of the possible effects of diversions of Russian rivers, and thus also of the effects of river runoff per se.

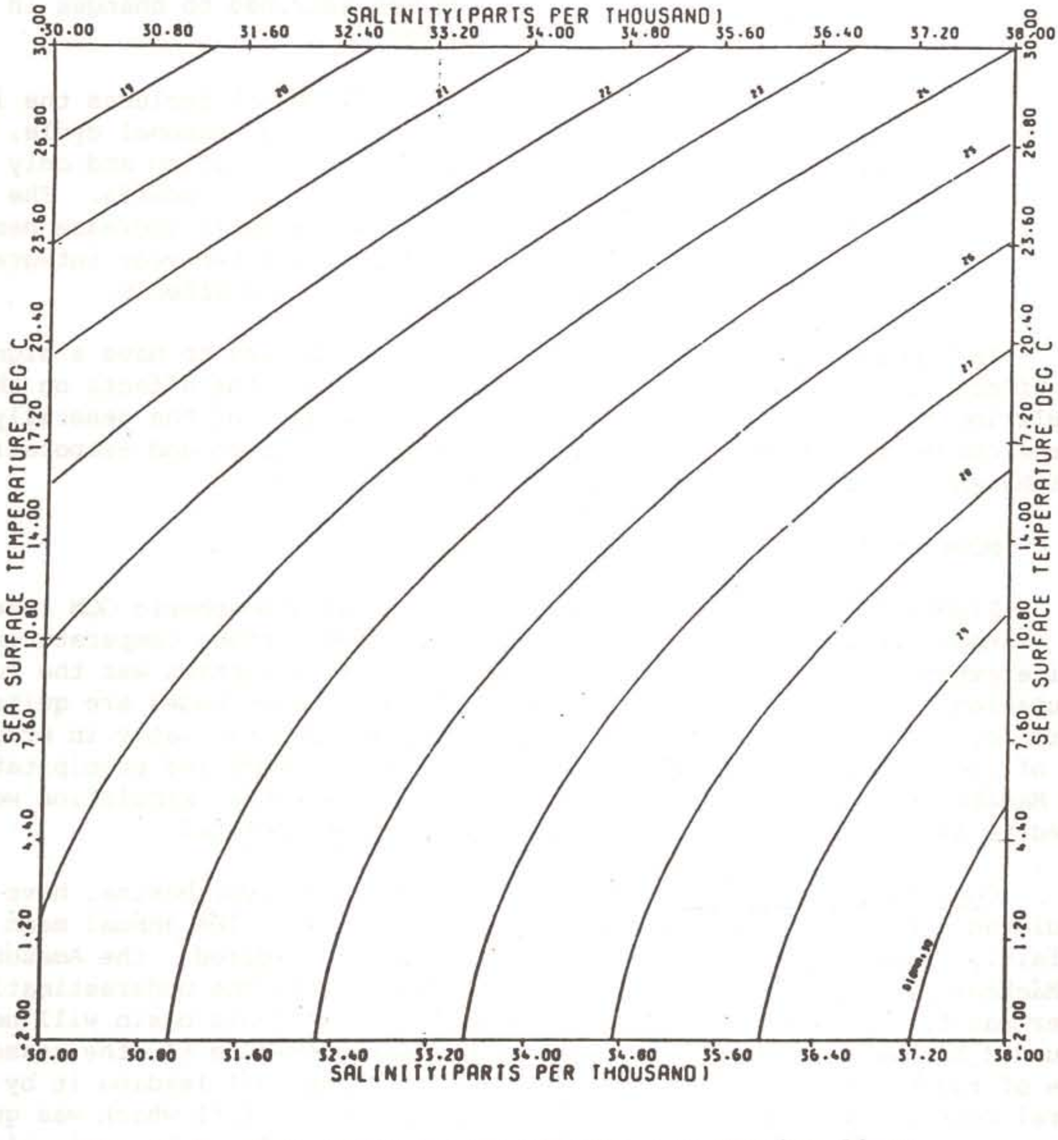


Figure 3. Temperature-salinity diagram showing lines of constant density. Unit for density is 1000 (density^{-1}).

In his first paper, the ice processes were only simply modelled, with the ice extent estimated from the surface temperature and no seasonal cycle. Experiments were run to 80 years to provide an equilibrium solution for different runoff inputs from Russian rivers. Though the mixed layer became less stable in the marginal seas adjacent to the affected rivers, the halocline of the central Arctic Ocean was nearly unaffected. However, there were substantial changes in salinity distribution (Figure 4) and surface currents. In particular, the net surface outflow from the Kara and Barents Seas was halved, with the total diversion of the rivers flowing to these seas, a large area having flow changes of about 1 cm/s. In this case, maximum temperature and salinity changes occurred near the edge of the shelf, with surface salinities increased by nearly 2 °/oo, a surface warming of 0.4K and cooling near 560 m of over 1K; the cooling was ascribed to changes in advection of warm Atlantic water.

In his second paper (Semtner, 1987), which includes the ice dynamics and thermodynamics and also the seasonal cycle, the emphasis is on the modelling of the circulation and only a two year experiment was run with reduced river runoffs. The only effect on ice cover in this time was a small increase near the ice edge in the Barents Sea. Arguably a two year integration is not a very good guide to the long term effects.

In summary, the runoff from Arctic rivers appears to have a significant effect on the ocean circulation. In the tropics, the effects on the circulation may be small or difficult to detect because of the generally more intense currents, the more important role of precipitation and evaporation and the inherently more stable vertical structure.

4. MODEL ESTIMATES OF RUNOFF OVER CONTINENTS

Figure 5 shows the runoff as modelled in an atmospheric GCM integration (Manabe and Holloway, 1975) in which the ocean surface temperatures and sea ice extents were specified. The surface parameterization was the bucket formulation described earlier. Generally the model magnitudes are quite realistic, but the details of the distribution are substantially in error. Most of the errors can be explained by errors in the modelled precipitation (see Manabe and Holloway, 1975); it is clear that a better simulation would be needed to allow other causes of discrepancies to be isolated.

Comparisons of runoff, modelled for specific river basins, have been calculated for a recent integration with the MO model. The annual mean runoff was fairly realistic for two of the three basins considered: the Amazon and the Mackenzie. For the third, the Ganges/Brahmaputra, the underestimation of summer rainfall prevented any useful comparisons, and this basin will not be discussed further here. In the case of the Amazon (Figure 6), the seasonal cycle of runoff was badly out of phase with the observed, leading it by several months. This was not due to errors in the rainfall which was quite realistically modelled; the evaporation is also unlikely to be seriously in

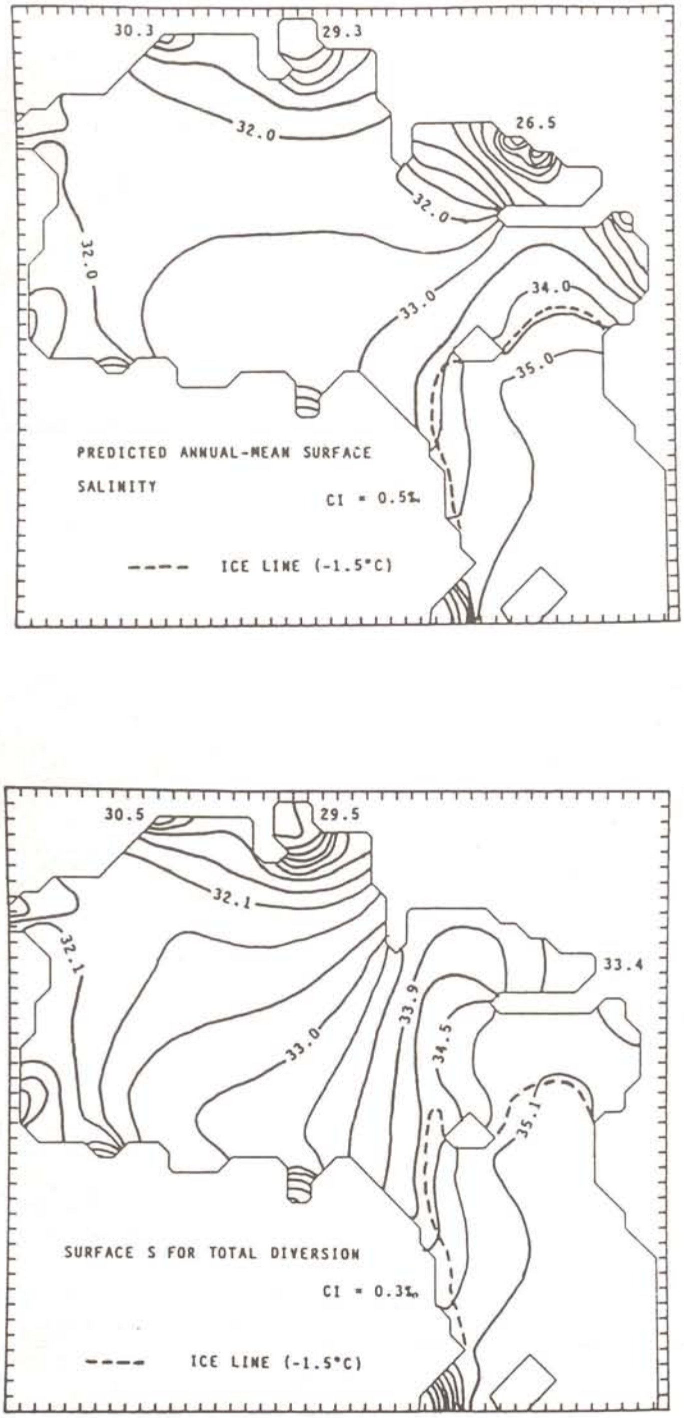


Figure 4. Surface salinity (o/oo) for control experiment (upper) and with total diversion of indicated Soviet rivers (lower), from experiment by Semtner (1984).

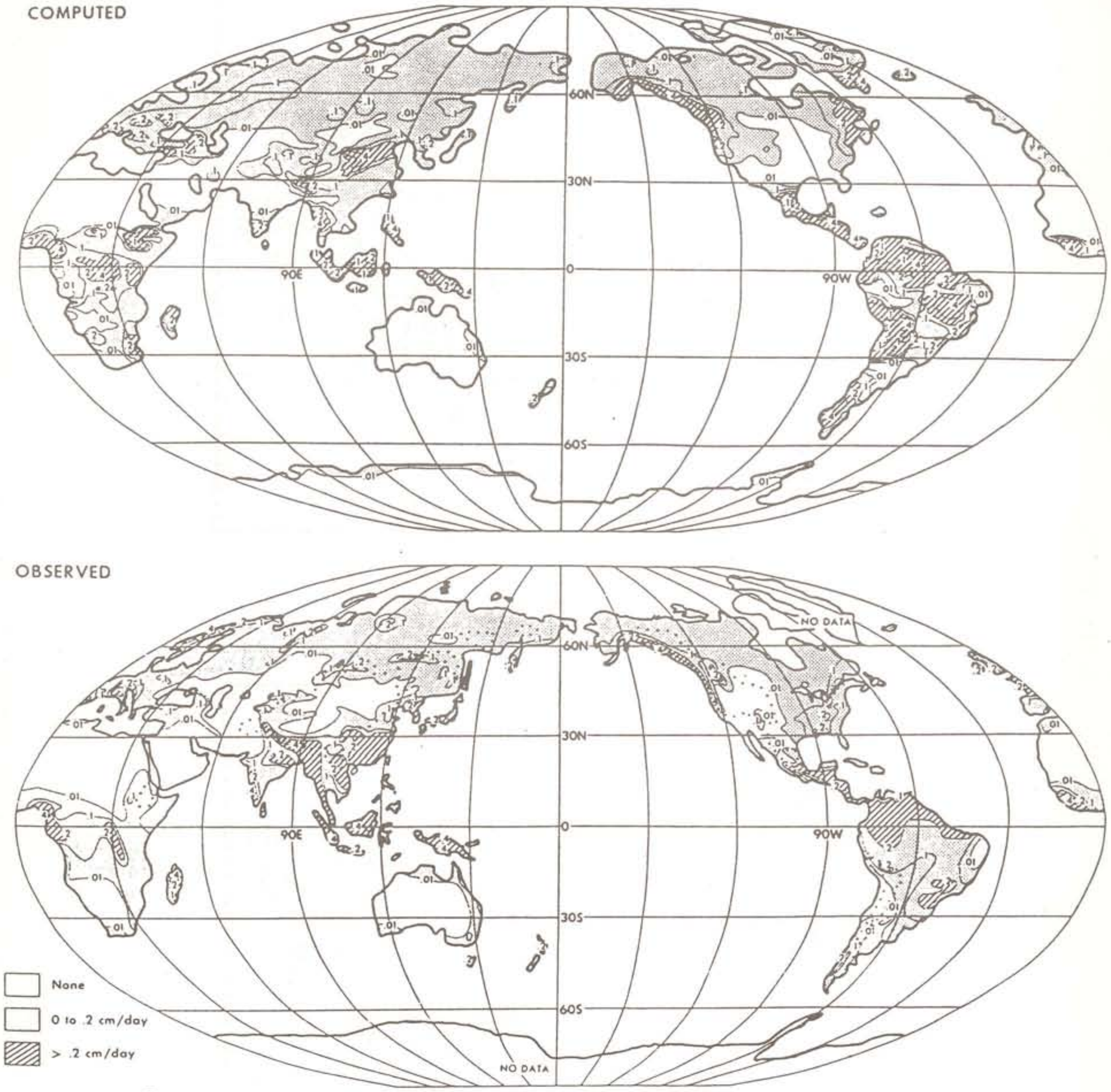


Figure 5. Global distribution of annual mean rate of runoff simulated by GFDL model (top) compared with an observed distribution (bottom). (From Manabe and Holloway, 1975.)

error, being near to the potential most of the year. Presumably the error lies in the absence of any representation of the lag which must result from the distance the water must travel from the region where the runoff is generated to the mouth of the river where gauging occurs.

In the case of the Mackenzie (Figure 7), the total runoff is again quite well modelled, and the maximum model runoff occurs in summer as observed. There is a phase lag of about one month as one might expect from

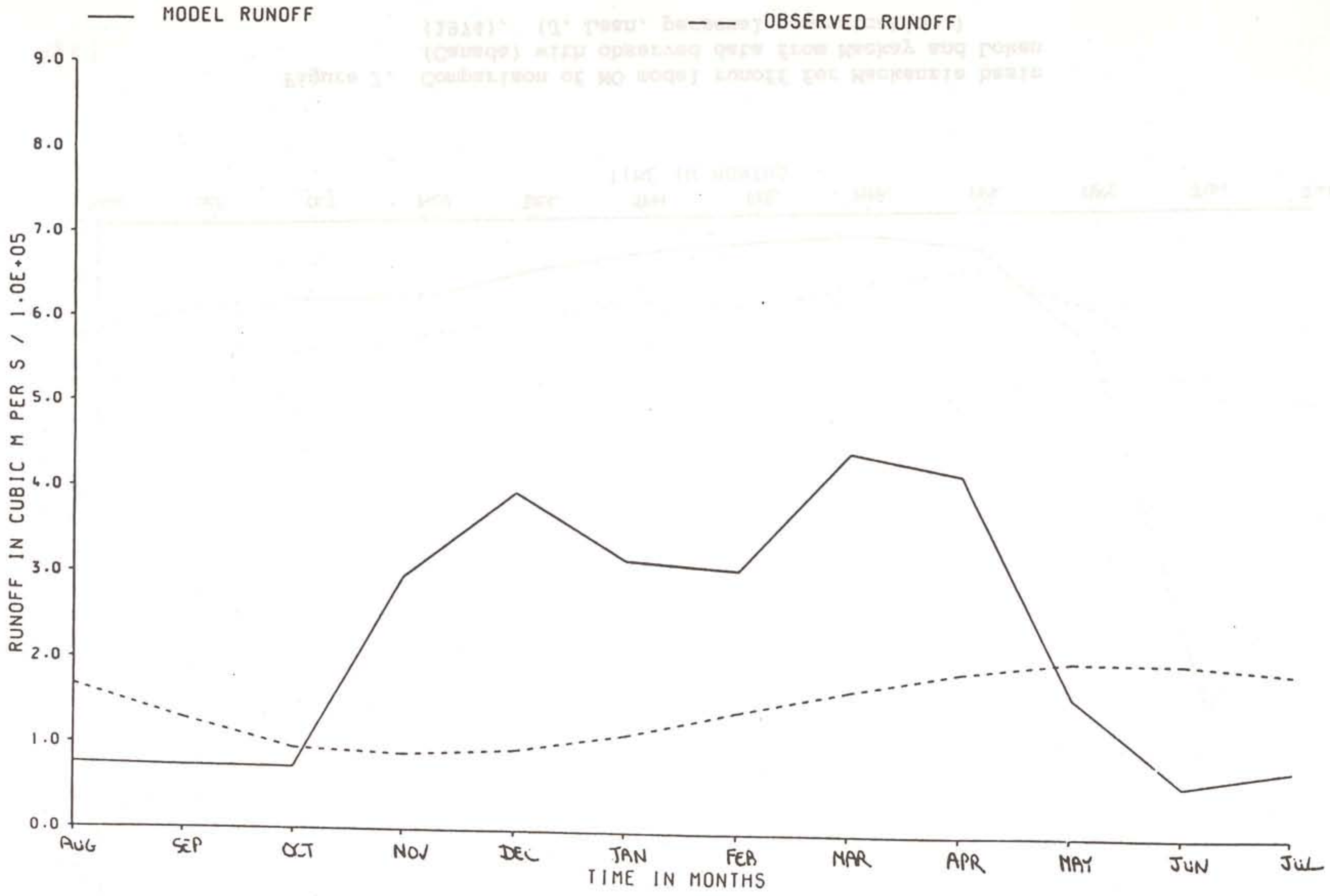


Figure 6. Comparison of MO model runoff for Amazon basin with observed data for 1928-1947 from Unesco (1971). (J. Lean, personal communication)

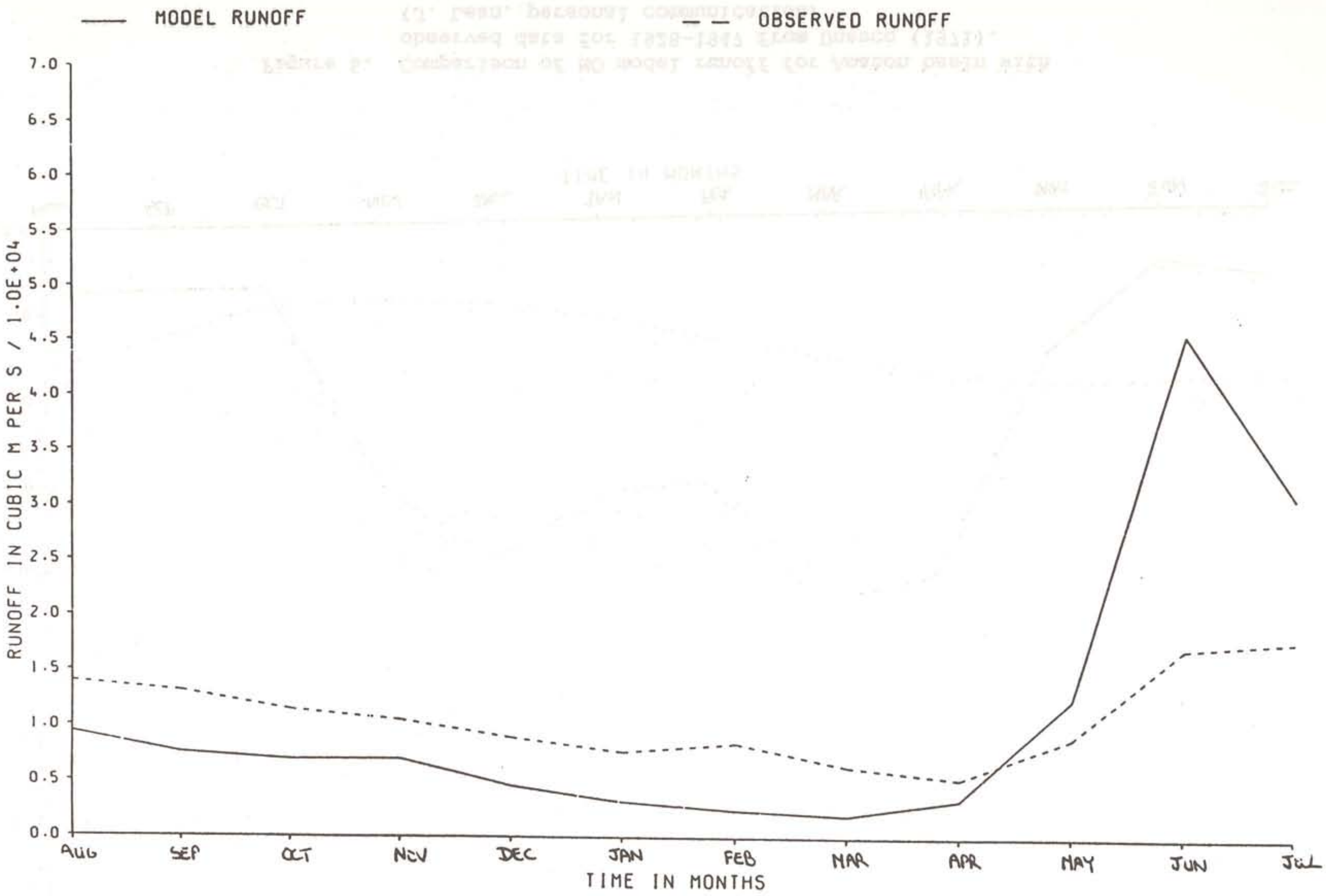


Figure 7. Comparison of MO model runoff for Mackenzie basin (Canada) with observed data from Mackay and Loken (1974). (J. Lean, personal communication.)

the previous discussion. However, the intensity of the peak is far too great. This may be due to smoothing of the flow by storage in lakes and swamps. It is interesting that the runoff from some Russian rivers displays a much more peaked flow than from the Mackenzie (Figure 8). The model simulates this much better, though the total flow is too large by nearly 50%.

The runoff of snowmelt is a difficult parameterization problem. It is also important, as shown by a recent experiment with the MO model (Mitchell and Warrilow, 1987), in which the usual parameterization of adding snowmelt to soil moisture was replaced by one allowing for the effects of frozen ground acting as a barrier to infiltration. A CO_2 doubling experiment previously run with the standard model was repeated; a common feature of such experiments has been that the soil moisture deficits are increased in summer with increased CO_2. Because the soil no longer reached saturation with the revised parameterization, the model's memory of the increased fall rains was not lost as previously and though soil moisture declined faster through spring and summer with increased CO_2, it still remained larger on average for most of the summer.

5. RUNOFF IN OCEAN MODELS

The inclusion of runoff into the ocean in climate models has been limited as yet. A recent GFDL model with an idealized geography (half land, half ocean) included runoff from the eastern half of continents into the east coastal waters, and similarly for the west. In the Meteorological Office, we have been considering a realistic input for our climate model. Clearly, to do the job at all requires a dataset of the ocean inflow point for each catchment, while to do it properly, allowing for delays due to the time taken to reach the ocean, is a significant task, both conceptually and in programming and data organization terms.

6. SUMMARY

(i) Models can use local runoff data averaged over a grid box to validate and calibrate several aspects of land surface parameterizations. However, to do this properly requires extensive meteorological and hydrological observations. The WCRP Hydrological-Atmospheric Pilot Experiments (HAPEX's) have been designed with this objective. Good quality runoff data sets for specific regions/groups of grid boxes should also be useful for such validation purposes. Ideally, a few regions representing different climates should be analysed, e.g., temperate (some snow, unfrozen ground), continental (frozen soil in winter), subtropical with dry season, tropical with large runoff. Areas with minimal human interference are needed.

(ii) Data sets of runoff (monthly, annual means and measures of interannual variability) are needed to provide global validation of climate models.

(iii) Monthly data on runoff into the oceans are needed for validation of coupled ocean-atmosphere climate models. These are also likely to be required by ocean modellers, in the context of the World Ocean Circulation Experiment.

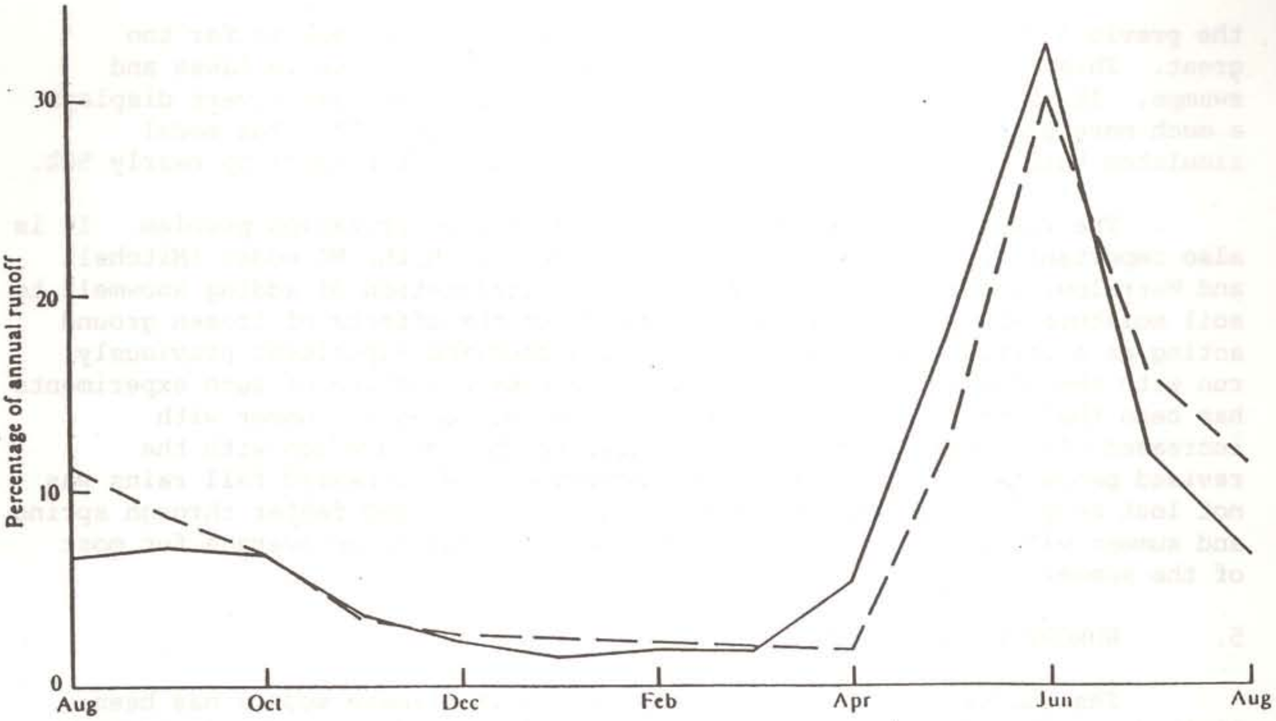


Figure 8. Comparison of MO model runoff for region 50°N to north coast of Asia, 60°-105°E, with observed data for Ob-Irtysh and Yenisai basins, from Mackay and Loken (1974).

(iv) The Global Energy and Water Cycle Experiment will also require global runoff data to allow water budget calculations, etc.

(v) The importance of estimating runoff realistically is clearly shown by the CO_2 experiments with modified representations of runoff from snow melt.

LIST OF REFERENCES

Clapp, R.B. and G.M. Hornberger, 1978: Empirical equations for some soil hydraulic properties. Water Resources Research, 14, 601-604.

Cooper, N.S., 1988: The effect of salinity on tropical ocean models. J. Phys. Ocean, 18, 697-707.

Dickinson, R.E., 1984: Modelling evapotranspiration for three-dimensional global climate models. Geophysical Monograph, 29, A.G.U.

Dickinson, R.E., A. Henderson-Sellers, P.J. Kennedy and M.F. Wilson, 1986: Biosphere-Atmosphere Transfer Scheme (BATS) for the NCAR Community Climate Model. NCAR Tech. Note NCAR/TN-275+STR.

Hansen, J. and others, 1983: Efficient three-dimensional global models for climate studies: Models I and II. Mon. Wea. Rev., 111, 609-662.

Korzun, V.I. and others (Editors), 1974: World water balance and water resources of the earth. USSR Committee for the International Hydrological Decade, Leningrad. (English translation, Unesco, 1978).

Levitus, S., 1982: Climatological atlas of the world ocean. NOAA Prof. Paper 13, U.S. Dept. of Commerce.

Mackay, D.K. and O.H. Loken, 1974: Arctic hydrology. In: Ives, K.D. and R.G. Barry (editors), Arctic and alpine environments. London. Methuen, pp. 111-132.

Manabe, S., 1969: Climate and the ocean circulation-I, The atmospheric circulation and the hydrology of the earth's surface. Mon. Wea. Rev., 97, 739-774.

Manabe, S. and J.L. Holloway, Jr., 1975: The seasonal variation of the hydrologic cycle as simulated by a global model of the atmosphere. J. Geophys. Res., 80, 1617-1649.

Mitchell, J.F.B. and Warrilow, D.A., 1987, Summer dryness in northern midlatitudes due to increased CO_2. Nature, 330, 238-240.

Priestly, C.H.B. and R.J. Taylor, 1972: On the assessment of surface heat flux and evaporation using large scale parameters. Mon. Wea. Rev., 100, 81-92.

Sellers, P.J., Y. Mintz, Y.C. Sud and A. Dalcher, 1986: A simple biosphere model (SiB) for use within general circulation models. J. Atmos. Sci., 43, 505-531.

Semtner, A.J. Jr., 1984: The climate response of the Arctic Ocean to Soviet river diversions. Climate Change, 6, 109-130.

Semtner, A.J. Jr., 1987: A numerical study of sea ice and ocean circulation in the Arctic. J. Phys. Ocean., 17, 1077-1099.

Shukla, J. and Y. Mintz, 1982: Influence of land surface evapotranspiration on the earth's climate. Science, 215, 1498-1501.

Unesco, 1971: Discharge of selected rivers of the world. Volume 2. Unesco, Paris.

Warrilow, D.A., 1986: Indications of the sensitivity of European climate to land use variations using a one dimensional model. In Proceedings of ISLSCP Conference, Rome, 2-6 December 1985, European Space Agency, ESA SP-248, pp. 159-166.

Warrilow, D.A., A.B., Sangster and A. Slingo, 1986: Modelling of land surface processes and their influence on European climate. Meteorological Office. Met O. 20 Tech. Note DCTN 38.

RESPONSIBILITIES AND FUNCTIONS OF THE GLOBAL RUNOFF DATA CENTRE

1. GENERAL

1.1 The Global Runoff Data Centre (GRDC), established at the Federal Institute of Hydrology in Koblenz, Federal Republic of Germany, operates under the auspices of the World Meteorological Organization (WMO) for the benefit of WMO Members and of the international scientific community. It provides a mechanism for the international exchange of data pertaining to river flows and surface water runoff on a continuous long-term basis.

1.2 All data held by the GRDC will be made available to all institutions and scientists, upon written request or personal visit. Charges may be made to cover the costs of providing services to users. This charge may be waived if the individual or institution is a contributor to the GRDC.

1.3 The resources required to support the activities of the GRDC are the responsibility of the host country or institution.

1.4 The co-ordination of GRDC activities within the host country is the responsibility of the Federal Institute of Hydrology.

1.5 If for some reason, the host country is unable at some stage to continue these activities and services, it will make its holdings, records and associated computer software available to another GRDC to be designated by the WMO.

1.6 The GRDC receives data through the WMO from many sources. While every attempt will be made to assure reasonable standards of data quality and related documentation, ultimate responsibility for data reliability lies with the data contributor and not with the GRDC.

1.7 The GRDC will, in general, function on the basis of principles enunciated in the "Guide to the World Data Center System", Part 1, issued by the International Council of Scientific Unions (ICSU).

2. DATA

The GRDC will:

2.1 Receive flow data for selected stations collected by the WMO from Member countries.

2.2 Collect, with the assistance of the WMO, flow data from yearbooks and from other sources, such as Unesco.

2.3 Establish a computerized data base and control the quality of data by agreed-upon procedures.

2.4 Refer all queries with respect to missing or incorrect data to the WMO Secretariat who will then seek clarification and confirmation from data suppliers.

2.5 Provide for the storage and maintenance of daily and monthly flow data in a compatible form and ensure that data copies are subject to adequate standards of accuracy, clarity and durability.

2.6 Provide (i) specifications of the data retrieval service, in consultation with the WMO, (ii) data to users in formats agreed upon with the WMO, and (iii) facilities for on-line data retrieval, if possible.

2.7 Supply data to the WMO Secretariat and the World Data Centres (WDCs) for Meteorology.

3. OTHER INFORMATION

The GRDC will:

3.1 Include in the data base all available digitized catchment boundaries for all stations.

3.2 Assist the WMO in defining requirements for the collection of flow data from additional stations, as needed.

3.3 Prepare annual global runoff analyses and long-time series analyses.

4. COLLABORATION

The GRDC will:

4.1 Collaborate with the WMO in:

(i) Studying the adequacy of available data to provide global coverage to satisfy the needs of the relevant WMO programmes, such as the World Climate Programme, and the Hydrology and Water Resources Programme;

(ii) Preparing a detailed programme of activities of the GRDC, which should be updated at appropriate intervals on the basis of bilateral discussions.

4.2 Co-operate with other governmental and non-governmental international organizations such as Unesco and ICSU.

4.3 Collaborate with the WMO in developing a methodology for transferring runoff data to grid values.

4.4 Collaborate with the Global Precipitation Climatology Centre (GPCC), so that a co-ordinated approach can be taken, where appropriate, with respect to precipitation and runoff data, in particular as regards 4.3 above.

5. REPORTING

The GRDC will:

5.1 Produce yearly status reports which should include information on the following:

(i) Progress of the Centre with respect to the development of the data base and any subsequent updates/changes;

(ii) Assessment of data coverage;

(iii) Description of problems encountered with data handling (e.g. missing data);

(iv) Indication of possible discrepancies in data acquired from different sources and actions taken to resolve them;

(v) Number of requests received for data.

5.2 Provide for the distribution of the status reports (distribution list to be determined in consultation with the WMO.

5.3 Nominate one person, who would be responsible for liaison with the WMO and actively participate in negotiations, as necessary, for acquiring flow data not available through normal WMO data collection channels.

5.4 Participate in relevant workshops and studies organized by the WMO, within WCP-Water and WCRP, for the purpose of assessing the quality and quantity of runoff data required for various purposes.

THE GLOBAL RUNOFF DATA CENTRE

Examples of Typical Computer Outputs

of

Stream Flow Data

and

Supporting Information

TABLE OF DAILY MEAN FLOWS (Option 1)

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	

TABLE OF MONTHLY MEAN FLOWS (Option 2)
(Taken from WMO data collection)

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

TABLE OF MONTHLY MEAN FLOWS (Option 2)

(Taken from Unesco Pub. Data)

GLOBAL RUNOFF DATA CENTRE (GRDC)

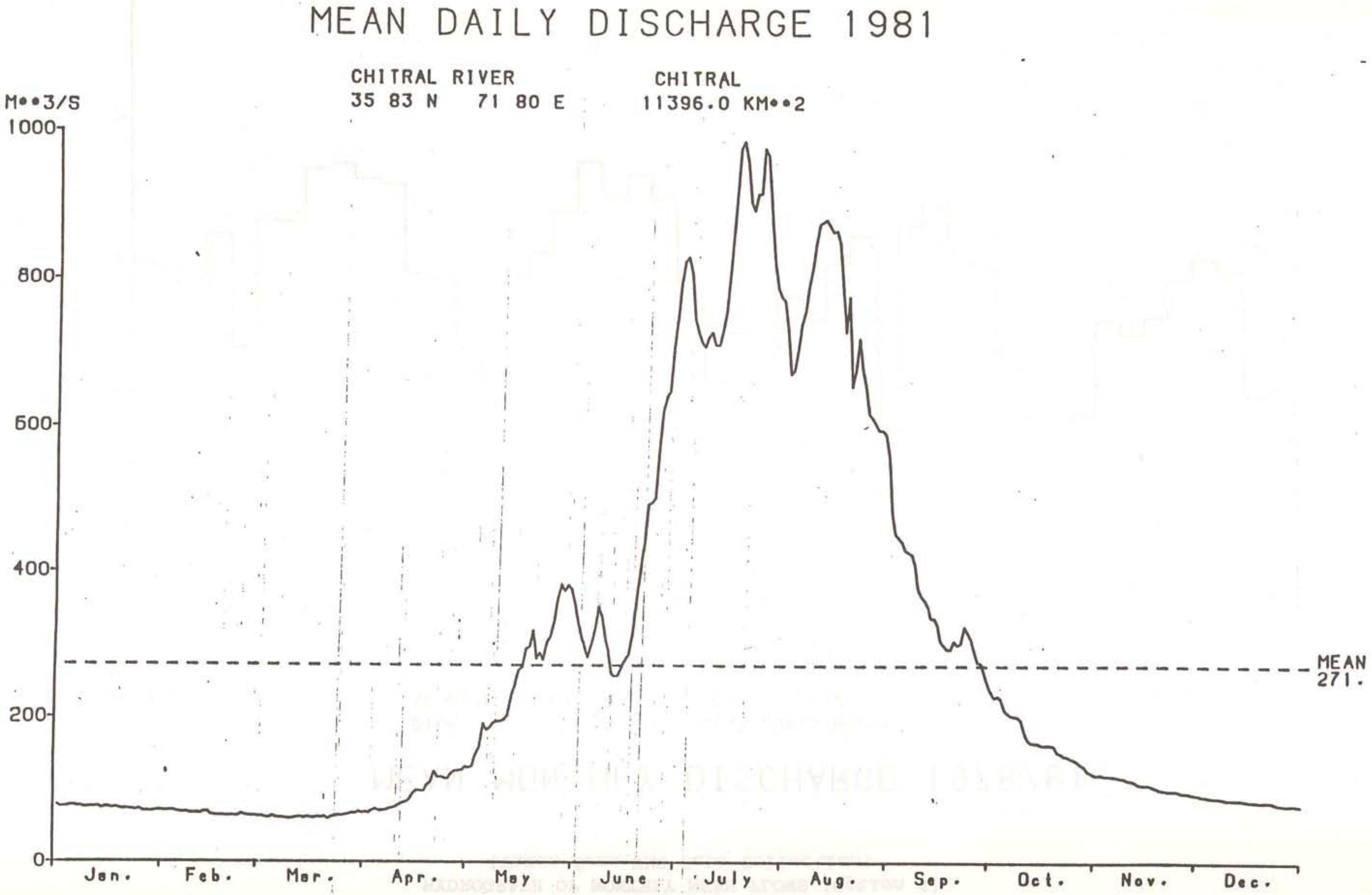
River : DANUBE
Station : ORSOVA
Country : ROMANIA

Catchment Area : 576232. km**2
Geographic Location : 44 42 N 22 25 E
WMO Basin No :

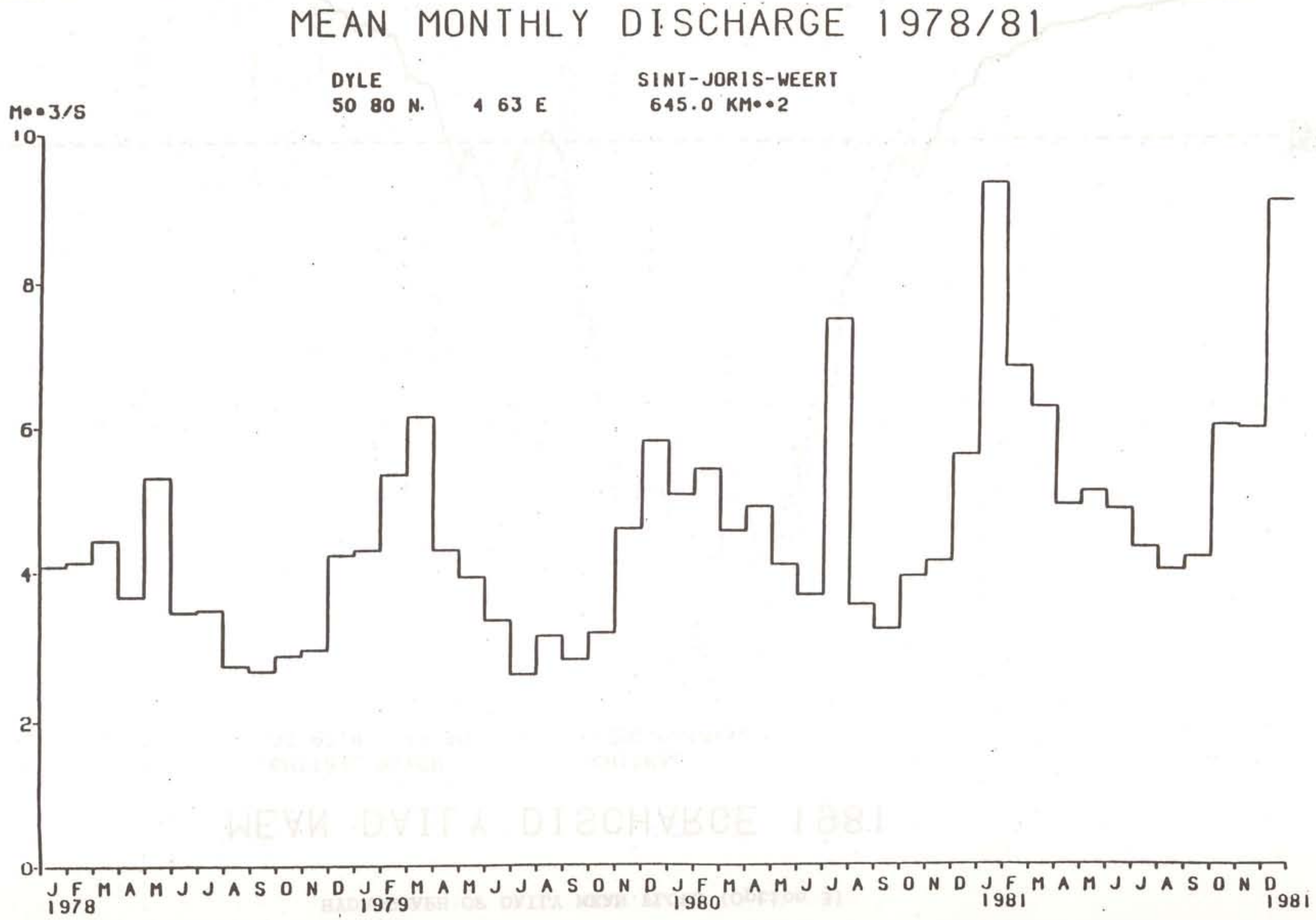
MEAN FLOW (M**3/S)

.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	J-J	J-D	Year
1950	3660.	4940.	6260.	4790.	4950.	3540.	2560.	2540.	2310.	2420.	4690.	7100.	4690.	3603.	4147.
1951	5350.	5700.	7560.	8600.	7820.	7400.	5320.	4210.	2660.	2730.	3420.	3790.	7072.	3688.	5380.
1952	3810.	4650.	5470.	9250.	6440.	4560.	3400.	2240.	2720.	3830.	6430.	8490.	5697.	4518.	5107.
1953	8430.	5540.	5380.	5800.	5470.	6790.	5670.	4150.	3100.	2430.	2520.	1780.	6235.	3275.	4755.
1954	1470.	2120.	6090.	5580.	8690.	7720.	6750.	4910.	3020.	4090.	4540.	4770.	5278.	4680.	4979.
1955	6550.	7180.	8170.	11000.	7750.	5860.	6970.	7790.	5050.	5960.	7100.	6180.	7752.	6508.	7130.
1956	6940.	3320.	7950.	9420.	9640.	7620.	6930.	3980.	3780.	2750.	3720.	4850.	7482.	4335.	5908.
1957	3240.	5650.	6460.	6200.	6820.	7250.	4700.	5210.	4370.	4240.	3350.	3850.	5937.	4287.	5112.
1958	4080.	5000.	9420.	10100.	9280.	4950.	5420.	3660.	2810.	3500.	4860.	4460.	7138.	4118.	5628.
1959	6080.	4040.	4760.	5040.	5210.	6210.	6770.	6000.	3880.	2310.	3890.	4570.	5223.	4570.	4897.
1960	5560.	6290.	7100.	6000.	5580.	5150.	4680.	5640.	4160.	4910.	6350.	6420.	5947.	5360.	5653.
1961	5540.	4650.	4780.	4650.	6840.	6540.	4140.	3360.	2530.	2120.	3690.	3820.	5500.	3277.	4388.
1962	4870.	5310.	7600.	12140.	9150.	6800.	5650.	3740.	2550.	2100.	3220.	4460.	7645.	3620.	5633.
1963	4400.	4720.	7150.	9050.	6390.	5180.	4160.	2270.	4110.	3490.	3060.	3650.	6148.	3457.	4802.
1964	2350.	3030.	4850.	7890.	6340.	4520.	4390.	3170.	2960.	4370.	7220.	6870.	4830.	4830.	4830.
1965	6280.	5960.	6670.	8800.	11000.	12200.	10360.	6190.	5060.	3840.	3190.	7010.	8485.	5942.	7213.
1966	5570.	8280.	8300.	7190.	7370.	6280.	6310.	7220.	6910.	3450.	5570.	8100.	7165.	6260.	6713.
1967	6190.	6334.	8368.	10758.	9732.	8065.	6012.	3685.	3520.	3156.	2845.	3067.	8241.	3714.	5978.
1968	5785.	6452.	6277.	6456.	4867.	4930.	3652.	4652.	4716.	5254.	4104.	4693.	5795.	4512.	5153.
1969	3800.	5800.	8690.	7270.	6820.	6430.	5860.	3490.	4810.	2610.	2530.	4760.	6468.	4010.	5239.
1970	6720.	8740.	9500.	12560.	12600.	11460.	8130.	6340.	5300.	3800.	4200.	4450.	10263.	5370.	7817.
1971	5200.	6340.	4940.	7600.	5670.	4400.	3990.	2770.	2590.	2280.	2040.	3230.	5692.	2817.	4254.
1972	2420.	3030.	3810.	4680.	6580.	5530.	5490.	6000.	4510.	4760.	5280.	6030.	4342.	5345.	4843.
1973	2910.	4440.	4690.	7460.	7700.	5630.	5080.	3500.	2610.	4070.	3410.	4290.	5472.	3827.	4649.
1974	5340.	5530.	4780.	4620.	6300.	7660.	7550.	5250.	3830.	7800.	8660.	8660.	5705.	6958.	6332.
1975	7330.	4990.	5240.	8280.	8060.	8390.	10070.	6060.	5540.	4320.	4120.	4350.	7048.	5743.	6396.
1976	4310.	4230.	5100.	7340.	6450.	7060.	2980.	4220.	4440.	4030.	4740.	7450.	5748.	4643.	5196.
1977	5540.	10050.	10510.	9440.	7420.	4750.	4250.	4820.	4170.	3300.	3920.	4730.	7952.	4198.	6075.
1978	4410.	6040.	8950.	7440.	9320.	8180.	6830.	4110.	4200.	4820.	3170.	4010.	7390.	4523.	5957.
1979	6370.	9910.	7610.	8380.	7640.	6220.	6250.	4600.	3360.	3510.	5980.	6850.	7688.	5092.	6390.
1950-1959	4961.	4814.	6752.	7578.	7207.	6190.	5449.	4469.	3370.	3426.	4452.	4984.	6250.	4358.	5304.
1960-1969	5035.	5683.	6979.	8020.	7409.	6610.	5521.	4342.	4133.	3530.	4178.	5285.	6622.	4498.	5560.
1970-1979	5055.	6330.	6513.	7780.	7774.	6928.	6062.	4767.	4055.	4269.	4552.	5405.	6730.	4852.	5791.

HYDROGRAPH OF DAILY MEAN FLOWS (Option 3)

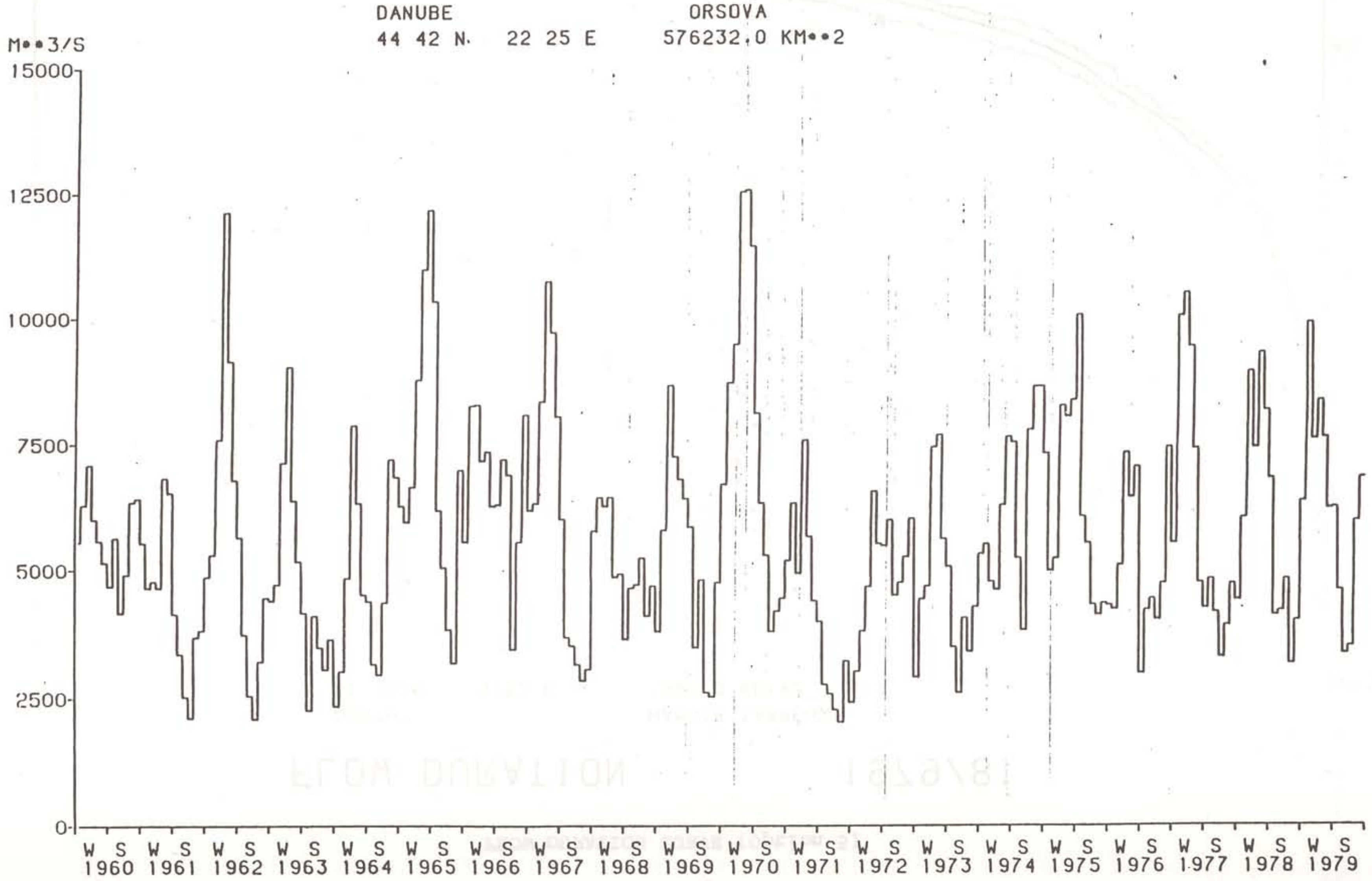


HYDROGRAPH OF MONTHLY MEAN FLOWS (Option 4)
(Taken from WMO Data Collection)



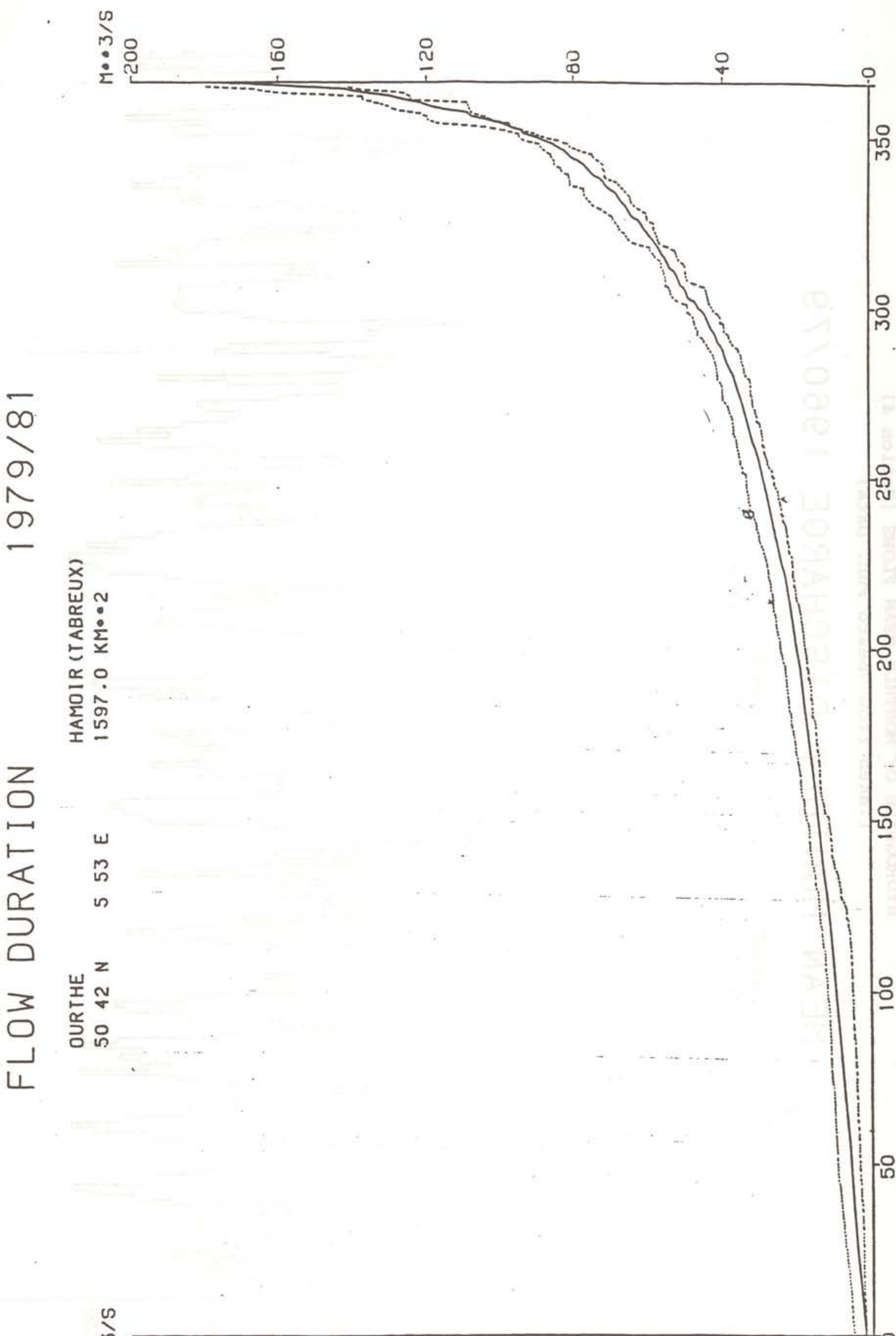
HYDROGRAPH OF MONTHLY MEAN FLOWS (Option 4)
(Taken from Unesco Pub. Data)

MEAN MONTHLY DISCHARGE 1960/79



GLOBAL RUNOFF DATA CENTRE (GRDC)

FLOW DURATION CURVE (Option 5)



FLOW DURATION TABLE (Option 6)

```
                         GLOBAL RUNOFF DATA CENTRE (GRDC)

River   : DYLE                                  Catchment Area      :     645.0 km**2
Station : SINT-JORIS-WEERT                      Geographic Location : 50 80 N    4 63 E
Country : BELGIUM                               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
```

STATION AND CATCHMENT INFORMATION (Option 7)

```
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
GRDC station no            :           6024
Begin of observation       :
```

CREATIONS OF DATA FILES (Option 8)

```
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

THE HYDROLOGIC GEOGRAPHIC INFORMATION SYSTEM IN FINLAND

By Y. Suksdorff

1. INTRODUCTION

A computer-based hydrologic geographic information system (GIS) has been developed at the National Board of Waters and the Environment (NBWE) in Finland. This system is one part of an environmental data system which contains all registers used in NBWE. The information system contains hydrological, water quality, some meteorological, land use, planning and management data from waters, watercourses and drainage basins. It is also compatible with different environmental file systems, provided that these include geographical co-ordinates or drainage basin numbers as co-ordinating entities.

2. GENERAL DESCRIPTION OF THE SYSTEM

The main programme for the hydrologic GIS system is called the Finnish Geographic Information System (FINGIS), which is a software programme for the management of numerical spatial data developed in the National Board of Survey in Finland. The entire GIS system will consist of several databases, each having several levels, as shown in Figure 1. Some of the databases, covering all of Finland, are very large and, thus, have been divided into smaller databases bordering each other. It is possible to combine the smaller databases or to use 2-4 databases at the same time. It is also possible to combine data digitized from maps having different scales, but it is the original scale which determines the accuracy of the database. Wide use of the system is expected since basic data for hydrological models can be obtained, changes in the environment can be monitored and thematical maps can be produced.

3. THE GIS PROGRAMME (FINGIS) USED IN THE SYSTEM

FINGIS is a geographic information system for the management of numerical spatial data. The system supplies the spatial information which permits:

- formation of polygons from line data,
- preparation of inventories of the current situation,
- collection of thematic information,
- overlaying of planning data on the current situation, and
- generalization of the data to a convenient mapping scale.

The user manages the system through interfacing software, which takes care of data input and output, generates graphic symbolisms for map data, drives peripheral units and works interactive graphics. The database management system supports database files, situation indexes and database dictionaries.

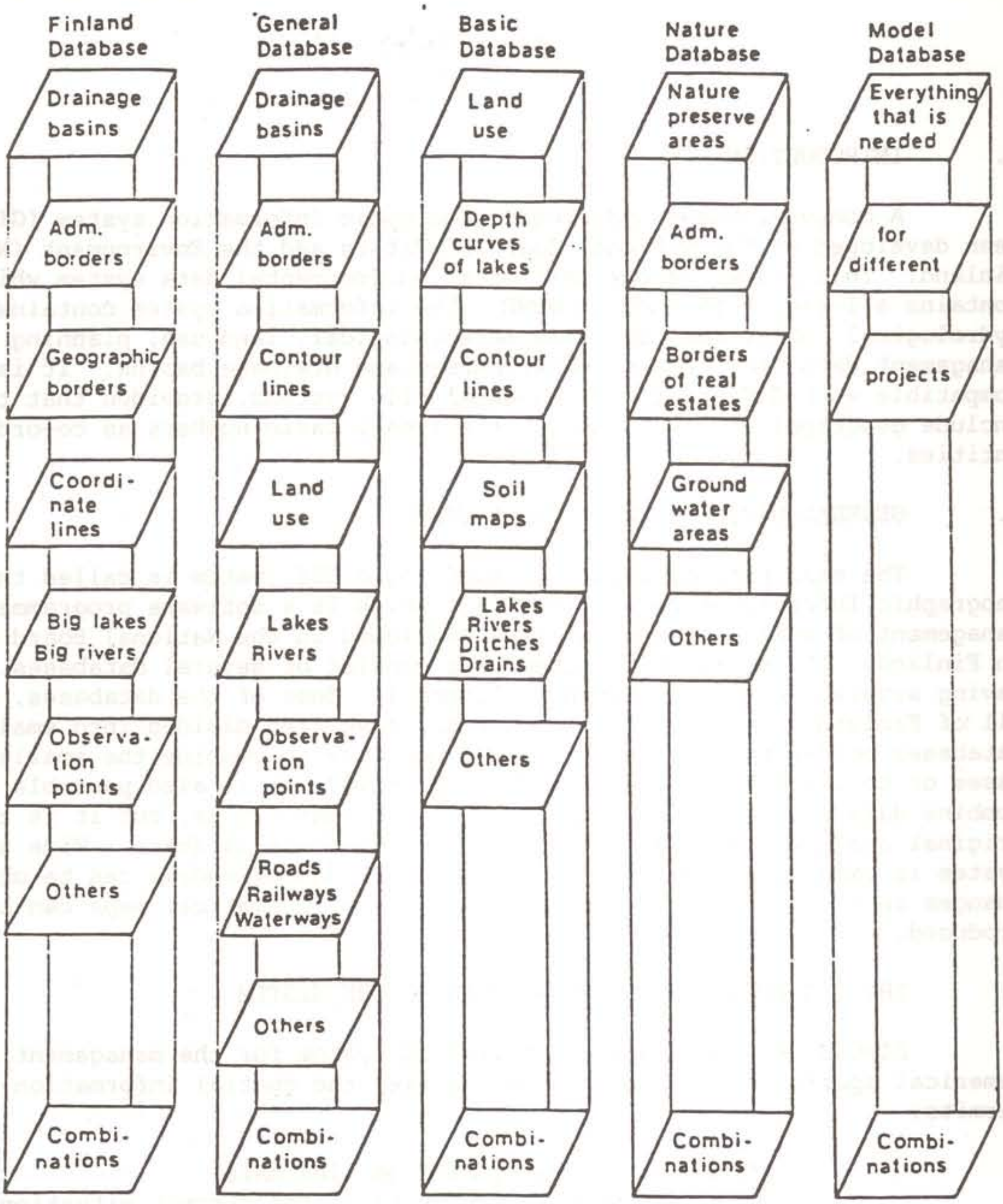


Figure 1. A shortened description of the levels in different databases of the Geographical Information System.

The subsystems of FINGIS (Figure 2) are:

(i) Data input: Numerical spatial data can be input to the database by digitizing or converting geographic data files from other systems. The digitizing unit is a digitizing table, a stereo plotter or a scanner. Interactive and non-interactive digitizing, and the transferring of geographic data files from other systems can be accomplished. Raster (satellite) data can be read in and vectorized.

(ii) Updating of data: The system updates the database in real time at a graphics workstation. All updates can be seen on the monitor.

(iii) Analysis: The geographic database system provides all kinds of data manipulation: data overlay, data inventory and data selection. The system automatically calculates areas and perimeters of polygons, lengths, numbers of objects, volumes etc.

(iv) Data display and output: The data are output in graphic displays, alphanumeric lists and files and standard digital files. The software has been programmed using Fortran 77 in a VAX/VMS system. Peripheral hardware for graphics operation is still required.

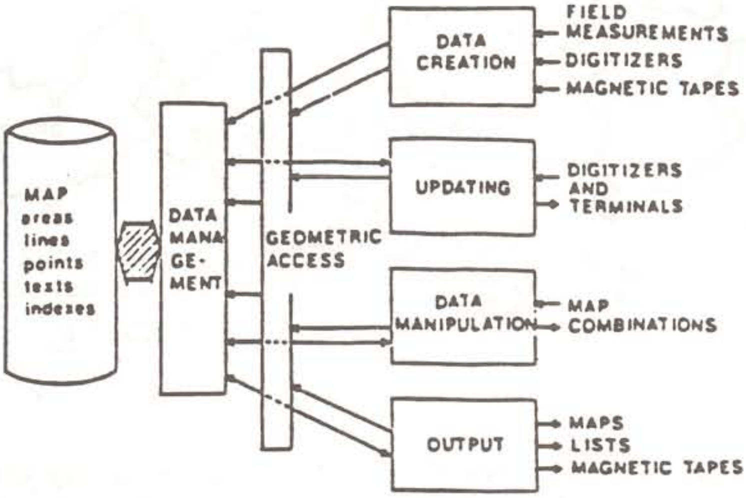


Figure 2. The main functions of the FINGIS-programme.

4. DRAINAGE BASIN DIVIDES AND OBSERVATION POINTS

Finland is divided into 74 main drainage basins and these are further divided into 7,700 sub-basins, with a mean area of about 30 km^2. The divides of the drainage basins are drawn onto maps having a scale of 1:50,000, with the aid of contour lines and flow directions. A five-digit hierarchic number is assigned to each sub-basin and the outlets of each are also marked on the maps. All of these are digitized for all of Finland. Figure 3 shows an example of a drainage basin map with some additional hydrological observation point data. These are collected from the environmental data system with the aid of a link between the GIS-system and the observation register-system in the NBWE, which uses a programme called INGRES. In order to make the drainage basin register as compact as possible, extra digitized points of drainage divides are filtered. The number of points is reduced from 9.2 points/km to 2.5 points/km, on an average, when a tolerance of 50 m is used. This was also the tested digitizing accuracy, when 1:50,000 maps were used.

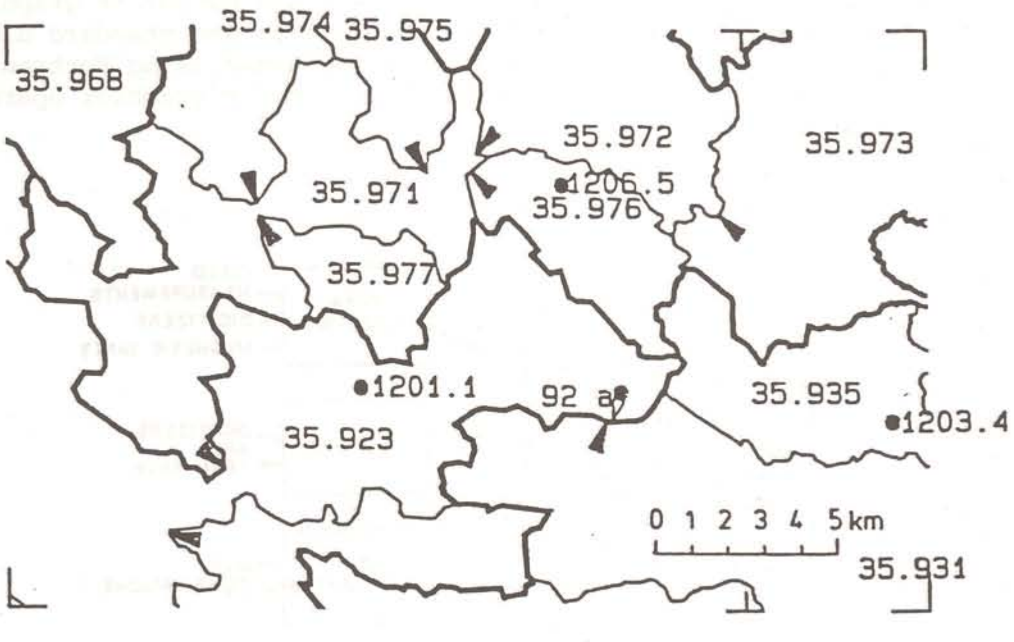


Figure 3. An example of a drainage basin map with some additional data. Explanations: ◢; outlet of a drainage basin; 35.977, a hierarchic number (for each sub-basin); △●92 a, a water level station and its number; ●1203.4, a meteorological station, its number and type.

5. BASIN CHARACTERISTICS FROM SATELLITE IMAGES

During 1988-1990, basin characteristics, such as cultivated lands, bogs, lakes, forests, forest types and the amounts of growing stock, will be interpreted for all of Finland from Landsat TM images. This work will be done in co-operation with the NBWE, the National Board of Survey and two other public institutions in Finland. The total number of interpreted classes will be about 50. A detailed description of the interpreting procedure can be found in Kuittinen and Sucksdorff (1987).

The interpreted satellite images (in raster form) are combined with FINGIS vector data, and inventories inside different areas can be made, as shown in Table 1. Raster images can also be vectorized, so that they can be stored as an ordinary FINGIS file.

Table 1. An example of satellite inventory. Land-use classes are interpreted from a SPOT image, the results are read by the FINGIS-programme, the area of each land-use class inside a drainage basin (number 35.977) is calculated from the amount of pixels and the result is printed.

```
**************************************
** POLYGON: 35.977 AREA (M-2):    10377580.855
**************************************

CODE:     247 AREA:                 910282.
CODE:     248 AREA:                1705631.
CODE:     245 AREA:                 213375.
CODE:     246 AREA:                 323775.
CODE:     251 AREA:                4524694.
CODE:     250 AREA:                1639404.
CODE:     249 AREA:                 384131.
CODE:     244 AREA:                 280566.
CODE:     252 AREA:                 349993.
CODE:     243 AREA:                  34941.

*** TOTAL AREA:                   10366793.

CODES:
252  ; Water                  247  ; Spruce-dominated forest
251  ; Cultivated land        246  ; Clear cuttings
250  ; Degiduous trees        245  ; Open bog
249  ; Mixed forest           244  ; Open area
248  ; Pine-dominated forest  243  ; Peat land
```

6. HEIGHT AND SLOPE OF THE RIVER BASINS

Two digital models were used to calculate the average height and slope of river basins. The first model was digitized from maps having a scale of 1:10,000 and a vertical distance between contour lines of 2.5 m. The model was then applied to a grid net having a horizontal distance between height points of 100 m. The corresponding values for the second model are: scale 1:200,000, vertical distance between contour lines 20 m and horizontal distance between height points 200 m. The models were tested in seven river basins with areas from 11 km^2 to 40 km^2. The difference in the average height of a river basin between the two models was 1.7 m and the standard deviation was 1.5 m. The slope of a river basin was calculated from the distance weighted mean of the slopes from every divide point to the outlet point. The differences between slope values of the two models varied in three areas from 8 to 13%. When all points were used, the differences were somewhat smaller. In conclusion, both models are accurate enough to calculate the average height or mean slope for river basins having an area over 10 km^2.

7. OTHER NUMERICAL SPATIAL DATA USED

In addition to the previously mentioned databases, some additional data are or will be connected to the system in the near future. These are administrative borders (from maps of scale 1:200,000) grid networks (this means a programme which generates different grids; for instance different map grids or co-ordinate lines used in Finland could be produced), roads (1:200,000) and shorelines (lakes, rivers and ditches scanned from maps 1:10,000). In addition to the above mentioned registers, there are, in Finland, over 200 computer-based registers which consist of spatial data and are maintained in other organizations of the public administration. In order to heighten the effectiveness of data use and to rationalize data production, an attempt has been made to create a system for spatial data exchange in Finland. The test period for this system began in 1988 and the NBWE is among its first users with the river basin register.

8. REQUIREMENTS FOR A HYDROLOGIC GIS-SYSTEM

(i) The system must be easy to use, otherwise it requires too many personnel to run it. Most large systems need (in spite of user-friendly connections) at least 1-2 experts to run them effectively.

(ii) The system must be ready to use. Further programme development always takes more time and money.

(iii) Good peripheral hardware is needed.

(iv) The system must be able to easily use use different co-ordinate-systems.

(v) The system must be able to easily use or produce data from other GIS-systems.

(vi) The simultaneous use of raster (for instance, interpreted satellite images) and vector data must be possible.

(vii) Three-dimensional calculations must be possible.

(viii) All other "normal" GIS-functions (data combinations, inventories, isoline-generation, drawing routines etc.) must be possible.

(ix) Interactive work must be possible, also without a digitizer (for instance manual drawing and correction of isolines on the screen having some basic map data and hydrological point data on it).

(x) A connection to data registers is often necessary.

9. REFERENCES

Keisteri, T. (1988): FINGIS presentation. Nordisk hydrologisk konferens, Finland 1-3 August 1988. NHP-rapport nr. 22, del. 2.

Kuittinen, R. and Y. Sucksdorff (1987): Inventory of river basin characteristics in Finnish conditions using satellite imagery. Aqua Fennica 17, 2, Helsinki, Finland.

Lemmela, R. and Y. Sucksdorff (1985): An Information system for water resources. International workshop on hydrologic applications of space technology, 18-23 August 1985, Cocoa Beach, Florida, U.S.A.

Sucksdorff, Y. R. Lemmela and T. Keisteri (1989): The environmental geographic information system in Finland. (To be presented to the IAHS third scientific assembly, May 1989, Baltimore, U.S.A.).

RESUME DE LA PRESENTATION CONCERNANT LA SIMULATION HYDROLOGIQUE DANS LE CADRE DU PROJET HAPEX-MOBILHY

faite par

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Rappelons que l'étude générale menée par le groupe d'étude HAPEX MOBILHY a pour objectif de contrôler le bilan hydrique régional et d'estimer le flux d'évaporation intervenant comme terme du bilan en eau d'un cube atmosphérique de 100x100x3 km sur l'emprise de la zone d'étude (appelée M100, comme maille de 100 kmx100 km de côté), située dans le sud-ouest de la France (fig.1).

Notre objectif particulier est d'évaluer, sur des pas de temps s'étendant de la journée à une durée maximale de 30 jours, les échanges d'eau à l'interface sol-atmosphère, c'est-à-dire les flux d'évapotranspiration, compatibles avec les apports pluviométriques observés, les écoulements observés dans les cours d'eau et les niveaux d'eau observés dans les nappes tout en respectant les états moyens d'humidité d'eau dans les divers sols constituant la zone.

Pour atteindre cet objectif et prendre en compte aussi bien les variations spatiales que temporelles des entrées, nous avons choisi le modèle couplé*, c'est-à-dire un modèle à discrétisation spatiale couplant les écoulements de surface et les écoulements souterrains et leur interaction. Ce modèle a permis de réaliser cette évaluation et de suivre la dynamique de l'eau dans les bassins versants constituant cette zone, tout en chiffrant l'évolution des fluctuations moyennes des réserves en eau.

1. RAPPELS SUR LA MODELISATION

Le modèle couplé s'articule ici sur trois parties principales concernant:

- la définition de la structure avec son réseau hydrologique composé du domaine superficiel avec son réseau hydrographique et du domaine souterrain, avec l'extension de la ou des couches perméables qui le constituent;
- le bilan hydrique sur chaque élément de surface au pas de temps journalier selon le rythme des précipitations, de l'évapotranspiration potentielle, des caractéristiques de la végétation et la répartition entre ruissellement (direct et retardé) et infiltration à la nappe selon les caractéristiques du sous-sol;

---

*développé conjointement par le Centre d'Informatique Géologique de l'Ecole des Mines de Paris, l'ORSTOM et l'INRS-Eau du Québec.

- les transferts conjoints, superficiels et souterrains et les échanges entre ces écoulements avec prise en compte des caractéristiques hydrodynamiques du milieu souterrain, des prélèvements d'eau aussi bien sur le domaine superficiel que dans le domaine souterrain (à destination de l'irrigation de l'alimentation humaine, industrielle de l'eau) et des transferts artificiels d'eau entre bassins versants.

Nous avons admis, pour la période d'utilisation du modèle (1974-1986), des caractéristiques physiographiques de la zone d'étude inchangées et, par contre, une évolution de l'utilisation de l'eau dans le temps comme dans l'espace.

2. LA GEOMETRIE DU MODELE

Lors de la mise en oeuvre du modèle, le surdécoupage des mailles carrées de 5x5 km de côté en mailles de 2,5x2,5 km et en mailles de 1,25x1,25 km de côté, le long de nombreux affluents, s'est imposé pour représenter plus correctement la forme filiforme des sous-bassins versants drainant les côteaux gersois (fig.2).

Par ailleurs, la présence de la nappe d'eau des Sables des Landes a rendu obligatoire l'extension de la couche souterraine représentant cet aquifère dans les parties nord-nord-ouest de la maille M100 (carré d'étude de 100x100 km), de manière à préciser les écoulements aux limites de cette maille M100 (fig.3).

Les entrées superficielles d'eau provenant de différents sous-bassins versants sur les parties sud et sud-est de cette maille ont été simulées en l'absence de mesures, ce qui a nécessité une extension du maillage superficiel vers l'amont.

Afin de se dispenser d'avoir à utiliser un modèle de fonte de neige sur cette maille M100, les apports d'eau par l'Adour, au sud de cette maille, seront considérés comme des entrées bien définies par la station hydrométrique d'Estirac.

En ce qui concerne le domaine souterrain, seul l'aquifère des Sables des Landes a été pris en compte. Il couvre environ 45% de la partie nord-nord-ouest de la maille d'étude.

Les nombreux autres aquifères, plus profonds, n'ont pas été modélisés car une étude antérieure, faite en 1974-1978, considérant l'ensemble des aquifères du bassin aquitain, a montré qu'un maximum de 10% du débit d'alimentation de la nappe des Sables pouvait transiter par les aquifères profonds.

3. LES ENTREES/SORTIES DU MODELE ET LE CALAGE

Les seules entrées du modèle sont:

. les précipitations journalières mesurées par le réseau d'observation de la Météorologie Nationale (postes climatologiques et postes pluviométriques bénévoles) en un certain nombre de points, variable chaque année, et compris entre 70 et 106 (y compris les postes en deçà des limites de la zone d'étude);

. les évaporations potentielles décadaires Penman calculées par ce même service en 7 à 8 stations (fig.4).

Les sorties du modèle sont:

. les débits calculés aux exutoires naturels des bassins versants et aux emplacements des stations hydrométriques, pour des pas de temps allant du mois à un jour (fig.5);

. les niveaux calculés de la nappe en un certain nombre de points.

Pour permettre l'exploitation du modèle en phase de calage et pour éviter toute confusion, il est clair que ces données climatologiques d'entrée du modèle sont indispensables à son fonctionnement et que les données de sortie permettent d'assurer le réglage des paramètres du modèle dans la phase de mise au point.

En phase de prévision, seules les données d'entrée sont nécessaires.

Il existe également pour ce type d'étude des données importantes et indispensables au fonctionnement du modèle, dites données de fonctionnement. Ce sont les connaissances exactes dans le temps et dans l'espace des diverses utilisations de l'eau (irrigation, alimentation en eau potable ou en eau industrielle), les transferts d'eau, les rejets, les prélèvements dans les nappes, etc... Pour notre cas, les entrées d'eau superficielles au sud de la maille (Adour à Estirac et canal du Bouès) sont indispensables pour la modélisation des débits le long de l'Adour et du Bouès.

En dehors de ces sorties et de toutes les indications fournies sur le déroulement de la simulation, il est aisé d'extraire des données évaluées lors des calculs concernant par exemple l'évolution de la réserve en eau du réservoir sol sur chacune des mailles élémentaires. Ainsi, on a pu évaluer sur des mailles carrées de 10x10 km les divers termes du bilan hydrique au cours du calcul journalier.

La phase calage du modèle consiste à comparer les débits calculés aux débits observés et la piézométrie calculée à la piézométrie observée et à ajuster les paramètres des fonctions productions (zone de mêmes caractéristiques physiographiques sol et sous-sol) de manière à améliorer les résultats spatiaux et temporels de la modélisation. (Ces zones zones sont définies sur la fig.6).

Signalons que la durée du temps de calage est fortement influencée par le nombre d'anomalies contenues dans les données d'observations hydrologiques et météorologiques. Nous avons constaté que les données météorologiques présentaient très peu d'anomalies comparativement aux données hydrologiques, et nous avons dû mettre en évidence les plus grosses d'entre elles afin d'obtenir un meilleur ajustement des paramètres du modèle en utilisant les périodes hors anomalies détectées de toutes les stations hydrométriques de la période 1974-1982.

4. LES UTILISATIONS SUCCESSIVES DU MODELE

Les paramètres du modèle ainsi calés ont permis d'utiliser le modèle en simulation pour les périodes successives suivantes:

- 1983-84 (simulation appelée SIM 83-84)
- 1985 (simulation appelée SIM 85)
- 1986 (simulation appelée SIM 86).

L'exploitation du modèle, pour la période 1983-1984 (SIM 83-84), impose deux conditions essentielles:

- s'affranchir des conditions initiales de remplissage des réserves en eau du sol en assurant la simulation des bilans hydriques sur l'année précédant immédiatement la période d'exploitation du modèle. Le fichier des données d'entrée des précipitations et des évapotranspirations doit être élaboré sur les années 1982-1983 et 1984. Le changement du nombre et de la localisation des postes d'observations pluviométriques entre 1982 et la période 1983-1984 oblige à faire quelques approximations dues aux différentes affectations des postes aux mailles de la couche de surface;
- mémoriser l'état de la nappe (niveau d'eau au 31 Décembre de l'année 1982) lors de la simulation de calage 1974-1982, de manière à pouvoir initialiser les calculs sur la période ultérieure.

Une telle procédure a été employée pour les deux autres périodes successives:

. 1985, avec un fichier 1984-1985,
. 1986, avec un fichier 1985-1986.

L'avantage de cette procédure est de pouvoir utiliser le maximum d'informations pluviométriques au cours des périodes successives et de mieux en appréhender la variabilité spatiale en faisant évoluer, au cours du temps, le nombre et l'emplacement des postes pluviométriques.

Remarquons que, sans avoir recours à une reconstitution du champ pluviométrique à chaque pas de temps comme dans un modèle hydrologique de prévision de crue, le modèle utilisé prend toutefois en compte une distribution spatiale assez fine des précipitations journalières (fig.7).

la simulation de la période 1983-1984 (SIM 83-84) a été considérée comme une vérification du modèle couplé calé sur la période 1974-1982, et nous avons vu que les résultats obtenus, même sur des stations hydrométriques non utilisées pour la phase calage, permettaient de considérer la validité du modèle comme parfaitement acceptable.

Les deux autres simulations, SIM 85 et SIM 86, avaient pour objet de fournir des données particulières utilisables par divers membres du groupe de travail telles que les cartes d'isovaleurs mensuelles du terme ruissellement + infiltration et du terme variation de la réserve, établies à partir des sommations ou moyennes pondérées sur les mailles de 10x10 km et formées par un regroupement des mailles de 5x5 - 2,5x2,5 et 1,25x1,25 du modèle couplé (fig.8).

Le regroupement des mailles de tailles variables du modèle hydrologique est assuré automatiquement par un programme.

C'est à partir de ces bases et des résultats de la simulation des bilans hydrologiques sur chaque maille du modèle que nous pouvons évaluer les termes de ces bilans sur chaque maille de 10x10 km par sommation de chacun d'eux au prorata des superficies de chacune des fonctions production soumise à un régime pluviométrique associé à la maille et pour le pas de temps journalier.

Bilan annuel

Les différents termes du bilan hydrologique (pluie - évapotranspiration - (ruissellement + infiltration) - variation de la réserve) pour chacune des mailles 10x10 km au cours de l'année 1986 sont présentés sur les figures 9 et 10.

Il est à noter la très grande fluctuation des précipitations annuelles de 1986 sur le carré HAPEX MOBILHY, de 641 à 1.286 mm en moyenne sur 100 km². L'écoulement varie de 108 à 740 mm, et l'évaporation de 428 à 702 mm.

La variation de la réserve en eau du sol pour cette année faisant suite à une année sèche montre un stockage important de 10 à 90 mm.

5. RESULTATS DE L'EERM/CNRM

Dans le cadre des applications du modèle couplé surface-souterrain pour la connaissance du bilan en eau sur le carré HAPEX-MOBILHY de 100x100 km, nous avons vu précédemment les estimations prévues pour chacun des éléments de ce bilan pour l'année 1986 à l'aide de ce modèle.

Il était intéressant de comparer les données concernant les évapotranspirations "réelles déduites du modèle aux mesures des évapotranspirations réelles effectivement mesurées lors de la période intensive d'observation.

Données d'évapotranspiration mesurée

L'Atlas des Données SAMER publié par l'EERM/CNRM en Juillet 1987 présente sous forme de graphiques de variation les valeurs mesurées de l'évapotranspiration journalière réelle au cours de la Période Intensive d'Observation (POI) du 7 Mai 1986 au 15 Juillet 19876 à chacune des Stations Automatiques de Mesure de l'Evapotranspiration Réelle (SAMER).

Nous avons extrait directement les valeurs de l'évapotranspiration réelle mesurée chaque jour du graphique présenté, et ce pour chacune des 12 stations SAMER. Notre souci était de connaître les fluctuations spatiales et les fluctuations temporelles afin de tenter des rapprochements avec les valeurs de l'ETR déduites du modèle couplé pour l'année 1986 dont nous venons de présenter les résultats de la simulation.

Nous donnons, pour les 10 premières stations SAMER du 7 Mai au 15 Juillet 1986, les valeurs journalières extraites de ces graphiques sous forme de courbe de variations (fig.11). Sur cette figure, nous avons porté également les valeurs maximales, médianes et minimales des précipitations journalières observées à proximité des stations automatiques SAMER.

A l'examen visuel de cette figure, nous faisons les remarques suivantes:

- les fluctuations spatiales sont d'autant plus faibles que les valeurs sont faibles,
- l'existence fréquente de valeurs inférieures à 1 mm/j de l'ETR,
- l'existence de valeurs supérieures à 6 mm/jour,
- l'existence d'une plus grande dispersion spatiale au cours des mois de Mai et Juillet qu'au cours du mois de Juin.

Nous avons noté par ailleurs que les fluctuations journalières des valeurs médianes d'ETR SAMER sont très importantes et varient dans le rapport 1 à 5. La moyenne brute des valeurs SAMER, observées sur la période intensive d'observation, fluctue par ordre croissant pour les 12 stations de 2,37 à 3,60 mm/jour (2,37-2,38-2,41-2,43-2,57-2,64-2,74-2,90-3,06-3,23-3,39-3,60).

Cette moyenne générale de 2,82 mm/jour reste nettement plus faible que la moyenne des médianes journalières établies à partir des données mesurées de 2,96 mm/jour.

La comparaison (fig.12) entre l'ETP moyenne décadaire Penman (aux 6 stations synoptiques), l'ETR (SAMER médiane décadaire) et l'ETR (SAMER minimale journalière) permet de remarquer qu'à compter du 35ième jour après le début de la POI (soit le 11 Juin), les valeurs ETR s'écartent des valeurs ETP et que les valeurs minimales restent nettement plus faibles après le 50ième jour.

COMPARAISON DES RESULTATS "MODELE" ET DES MESURES SAMER

Cette comparaison a été réalisée très sommairement entre les données d'ETR déduites du modèle pour chacun des mois de Mai-Juin et Juillet 1986, les données médianes SAMER pour la période du 7 Mai au 15 Juillet 1986 et les données ETP décadaires PENMAN moyennes des 6 stations.

Sur la figure 13, les valeurs portées pour chaque mois se rapportent à la période effectuée de 70 jours de la P.O.I. Il est intéressant de constater que le quotient SAMER/modèle présente une certaine constante sur les trois mois. Toutefois, nous ne pouvons pas expliquer la valeur plutôt faible de ce quotient qui devrait rester voisin de l'unité. Le quotient SAMER/ETP respecte l'effet du dessèchement du sol au cours du mois de Juillet.

Il est certain qu'un fonctionnement en continu sur 18 mois de trois stations SAMER aurait permis d'évaluer les fluctuations mensuelles de ces évapotranspirations réelles mesurées et de les comparer efficacement à celles déduites du modèle hydrologique à partir des données climatologiques d'entrée.

6. CONCLUSION

Le modèle hydrologique (modèle couplé) utilisé s'attache à simuler les écoulements des cours d'eau et les états de la nappe. L'évapotranspiration réelle est constituée essentiellement par un terme résidu.

Ces simulations ont été atteintes pour toute la période 1974-1986 à partir des données hydropluviométriques sur la maille carrée de 100x100 km HAPEX MOBILHY et sur les différents bassins qui la drainent.

Les différents postes du bilan hydrologique sur les sous-mailles de 10x10 km sont évalués. Ils montrent l'extrême variabilité dans l'espace des précipitations tout comme l'importance des écoulements directs et différés.

Si, à la l'échelle journalière, les écoulements sont bien représentés et si les valeurs d'évapotranspiration réelle sont seulement approchées en période longue et très sèche, nous devons reconnaître qu'à long terme il n'existe aucune dérive, ni tendance.

Les essais de comparaison entre résultats obtenus à partir des mesures SAMER (Station Automatique de Mesure de l'Evapotranspiration Réelle) et les résultats issus du modèle pour la Période Intensive d'Observation de Mai à Juillet 1986 montrent, en moyenne, une relative concordance entre eux.

La variabilité spatiale et temporelle des évapotranspirations réelles mesurées par SAMER, bien que se situant très au-dessus du terme précipitation, montre également les difficultés prévisibles pour la modélisation régionale de ce terme très important.

LISTE DES FIGURES

Plan de situation du
site MOBILHY

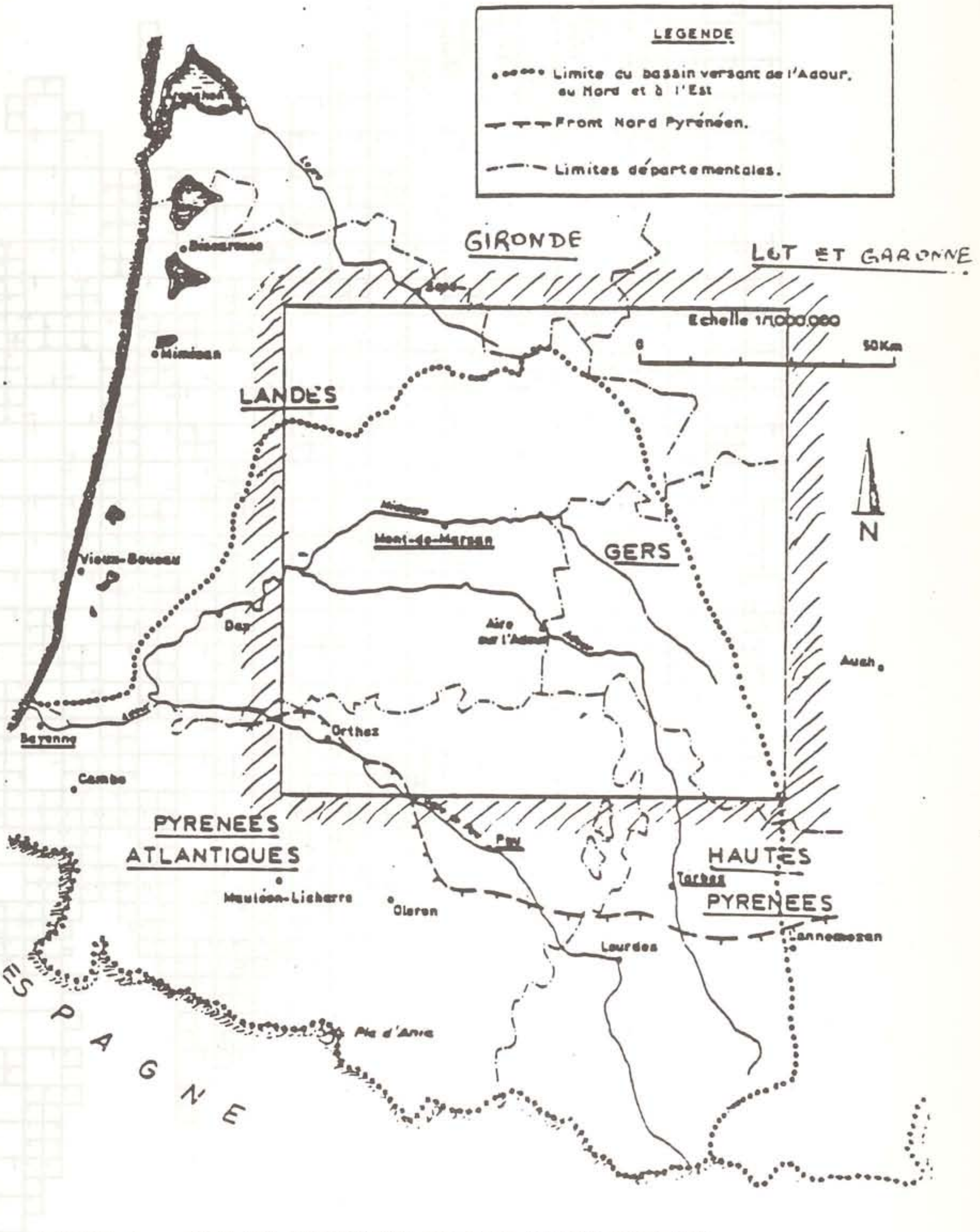


FIGURE 1 - PLAN DE SITUATION DU SITE HAPEX-MOBILHY

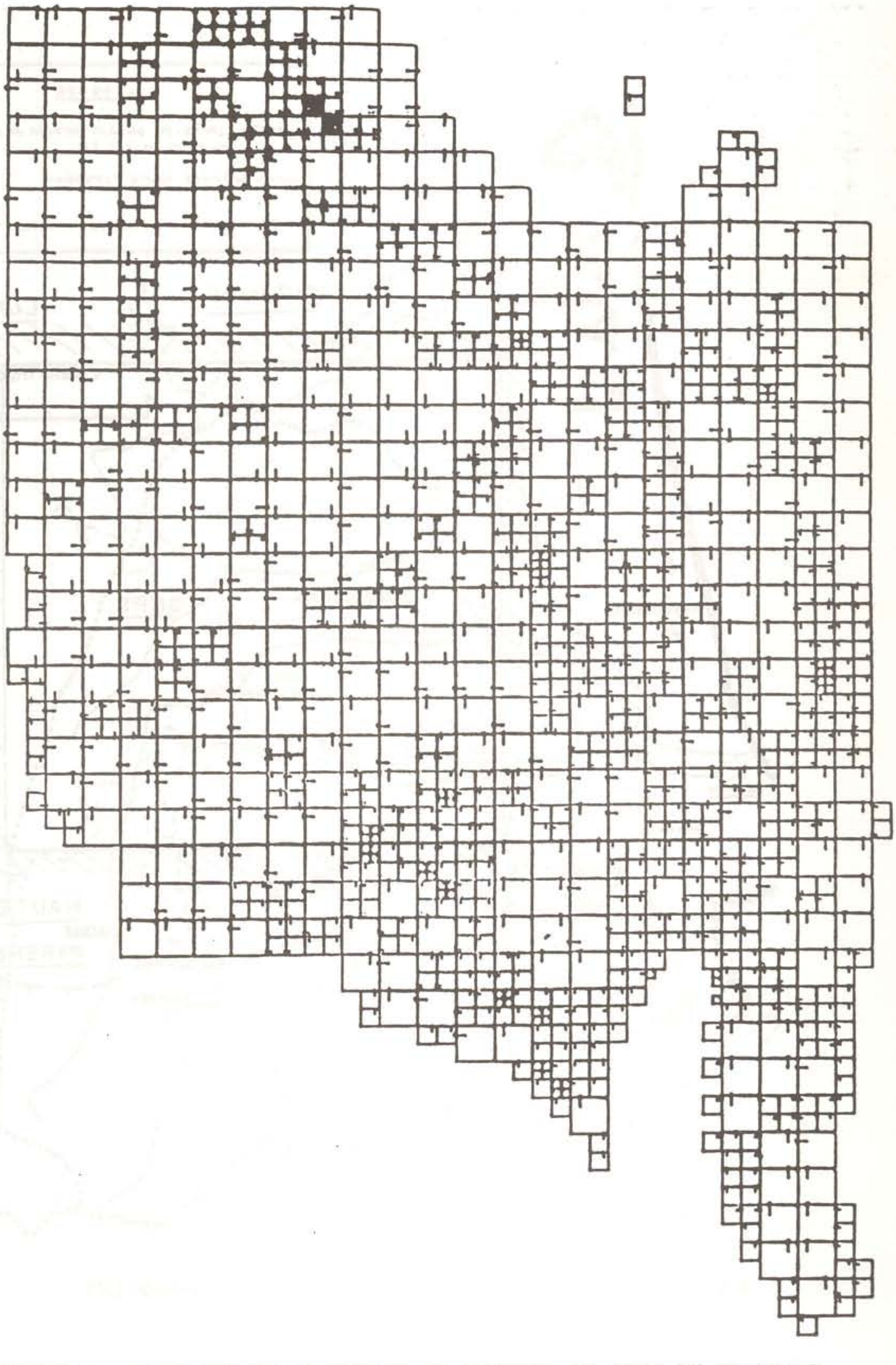
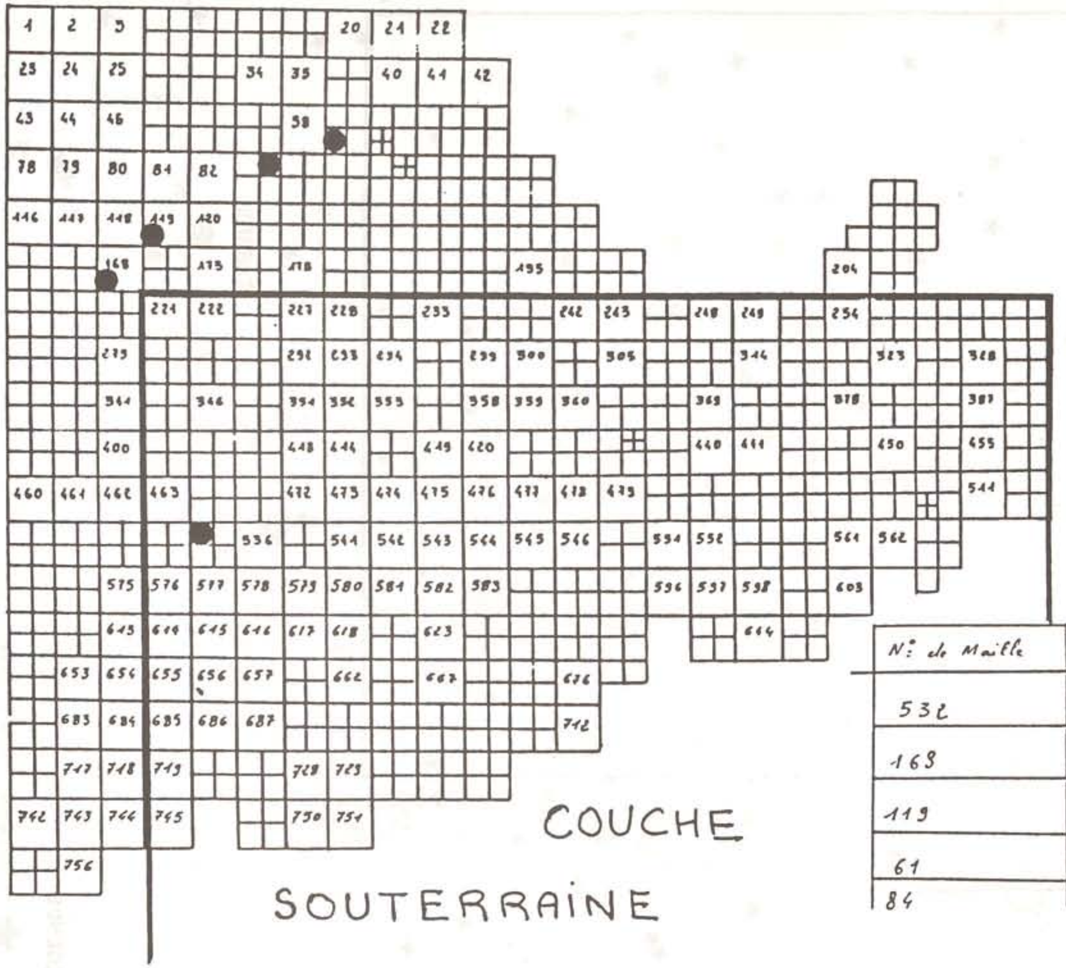


FIGURE 2 - MAILLAGE DE LA COUCHE DE SURFACE ET SENS DU DRAINAGE



N° de Maille	PIEZOMETRE
532	PLATIET
168	MALET
119	BIREDIS
61	BALÈGE
84	BOUTOX

FIGURE 3 - MAILLAGE DE LA COUCHE SOUTERRAINE ET SITUATION DES PIEZOMETRES

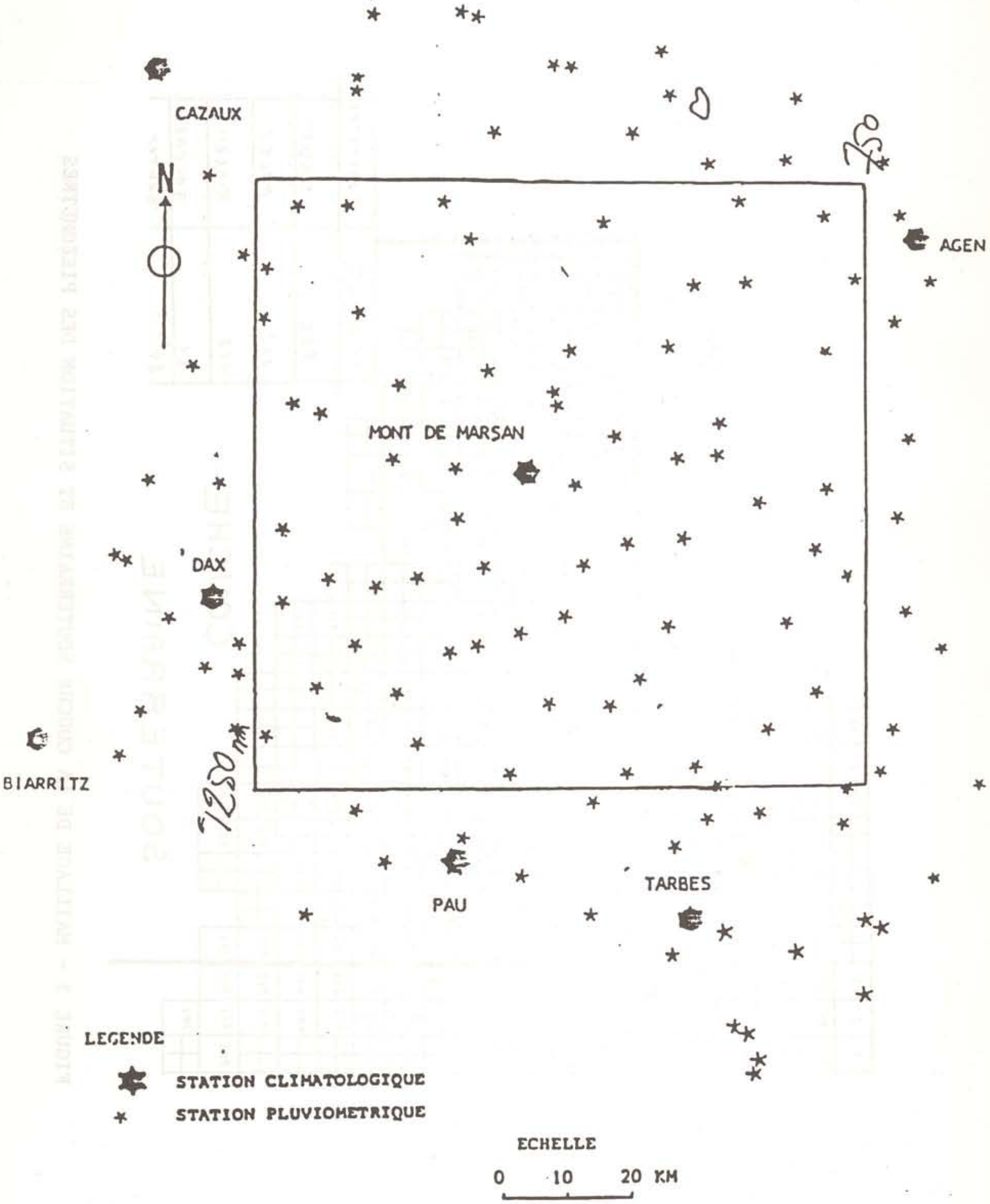


FIGURE 4 - **PLAN DE SITUATION DES STATIONS PLUVIOMETRIQUES ET DES STATIONS CLIMATOLOGIQUES**

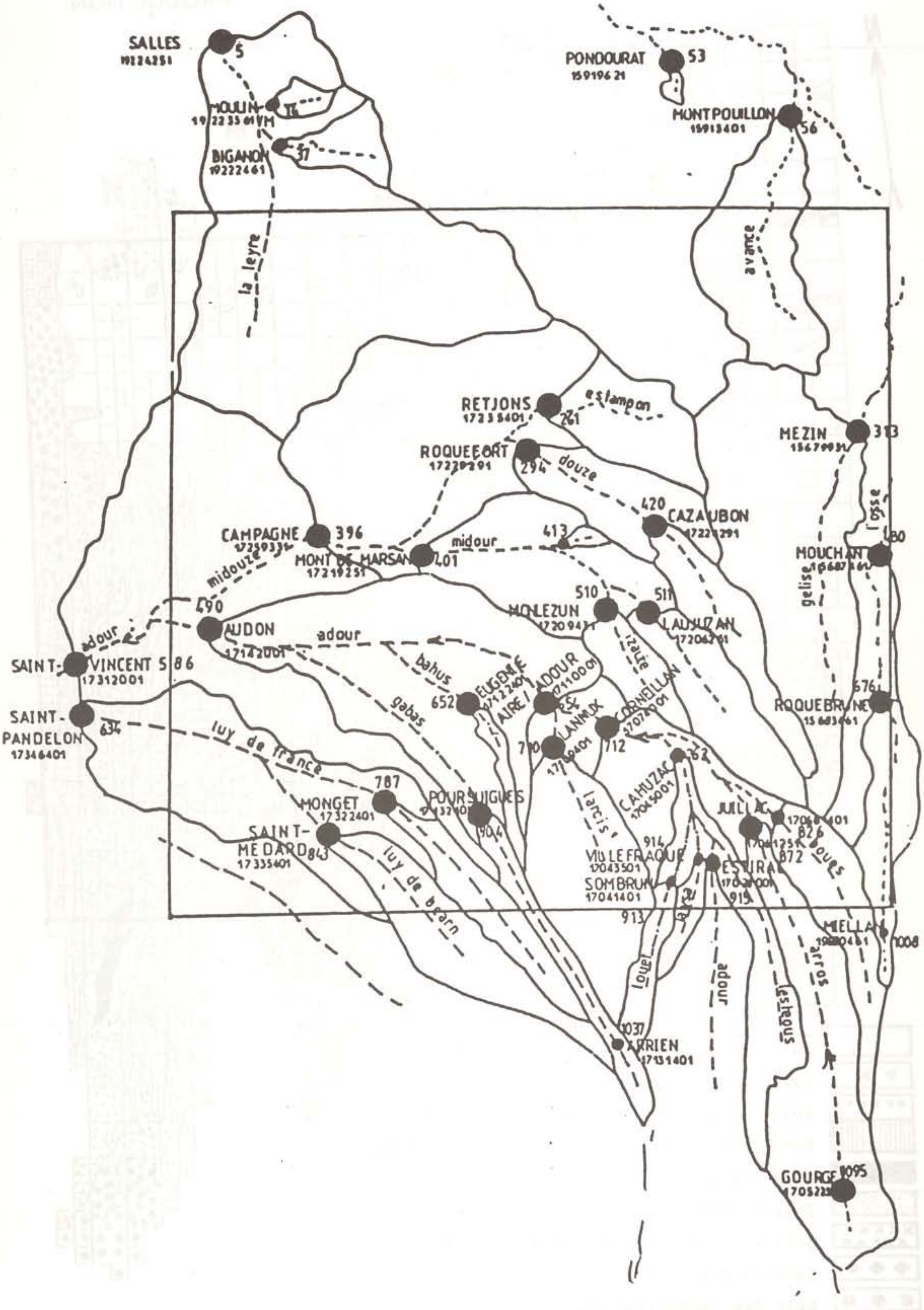


FIGURE 5 - PLAN DES STATIONS HYDROMETRIQUES
ET DES BASSINS VERSANTS CONTROLES

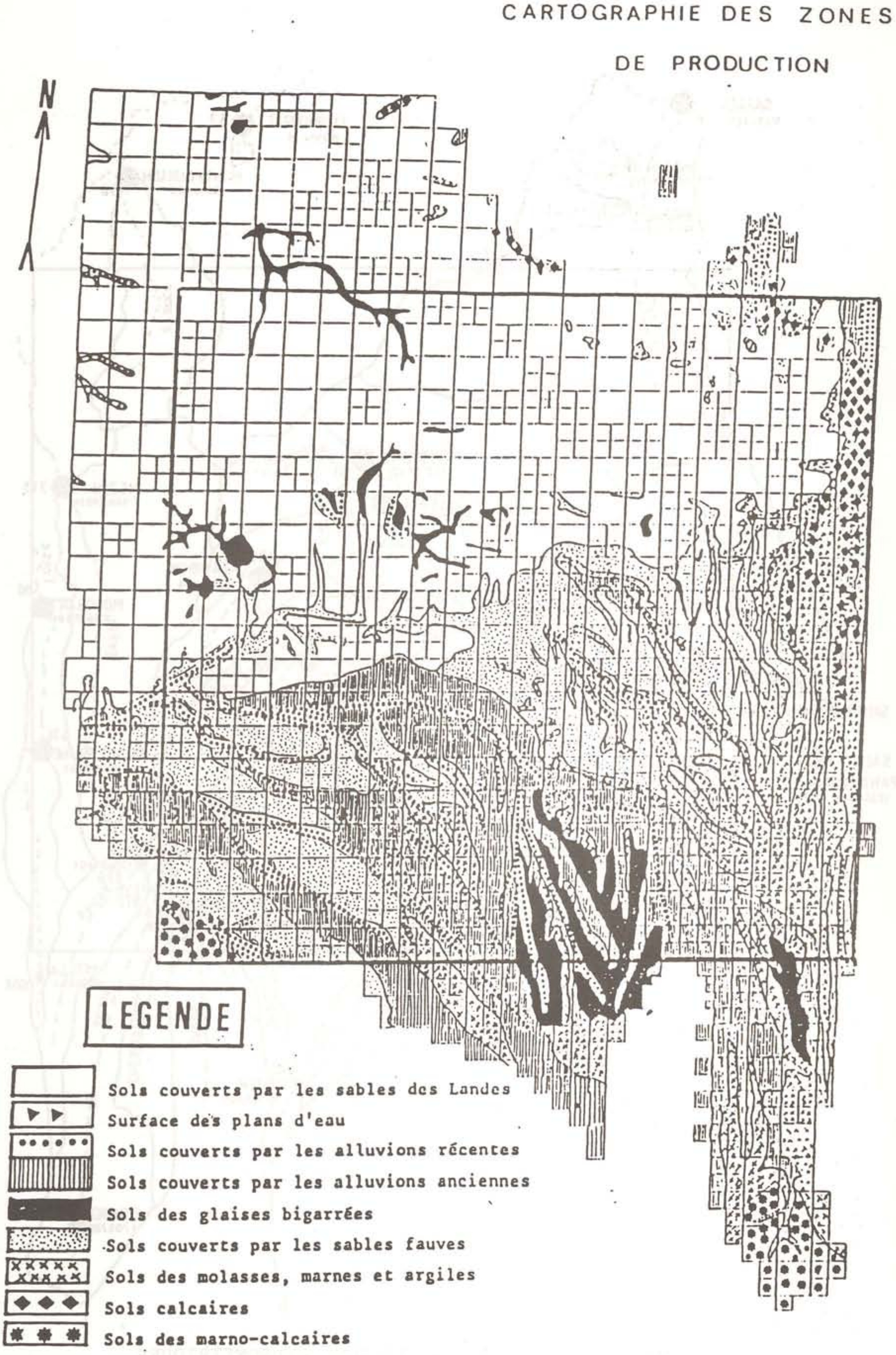
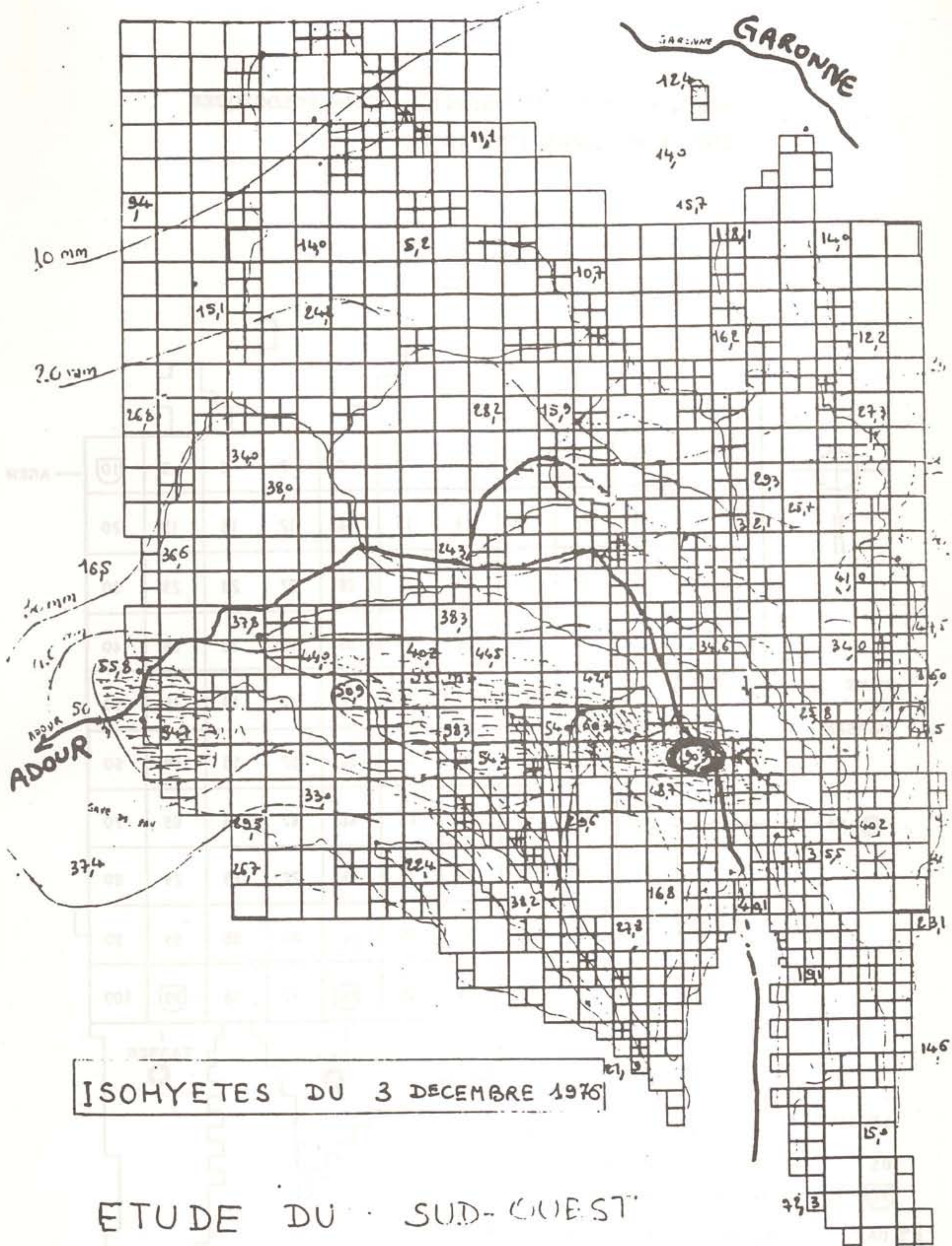


FIGURE 6 - CARTOGRAPHIE DES ZONES DE PRODUCTION



ETUDE DU SUD-OUEST
(HAPEX-MOBILHY)

FIGURE 7 - VARIABILITE DES PRECIPITATIONS JOURNALIERES AU 3 DECEMBRE 1986

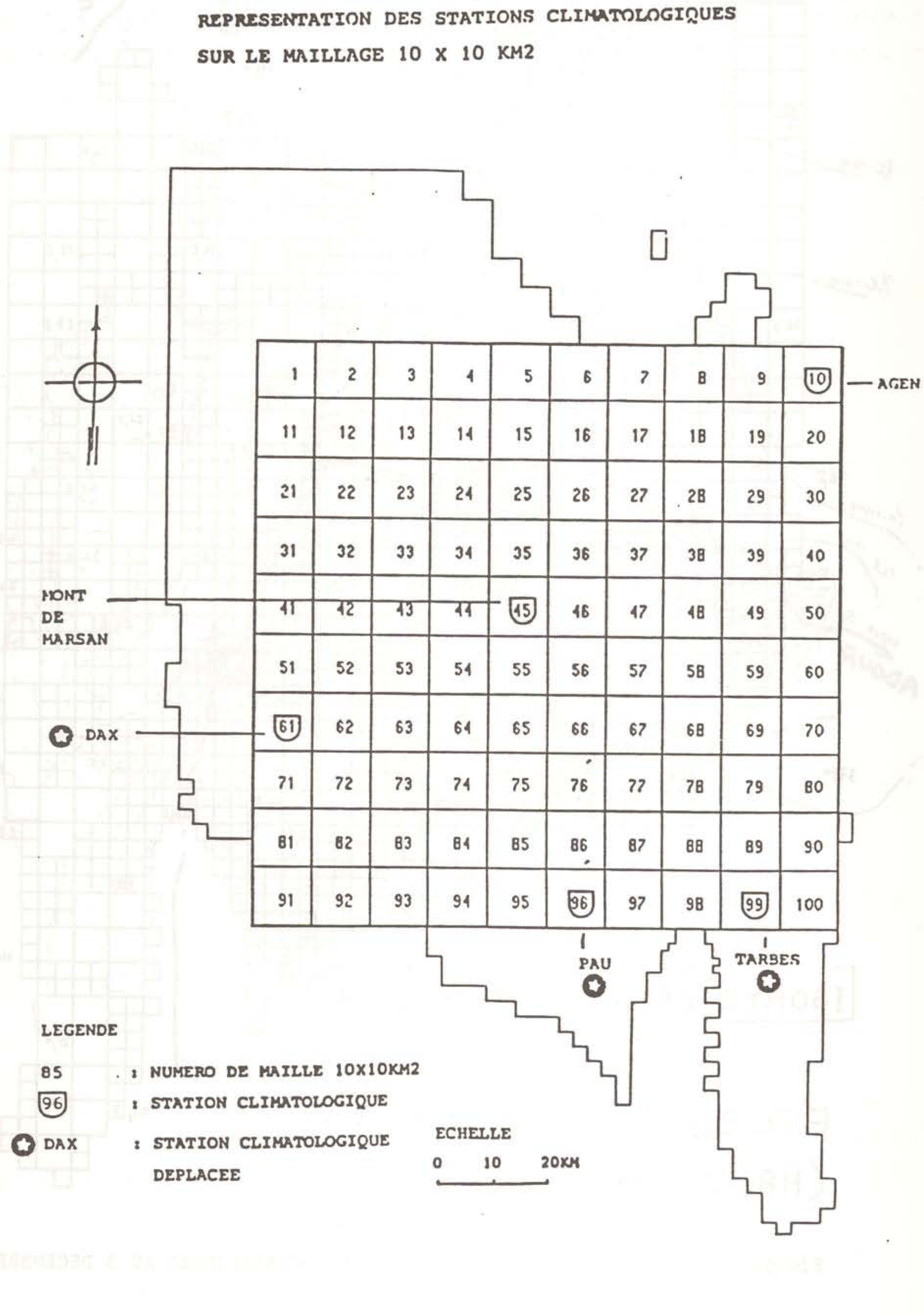


FIGURE 8 - MAILLAGE DU BILAN HYDROLOGIQUE

Figure 9.b : Bilan d'écoulement en surface en 1986
10^6 m^3

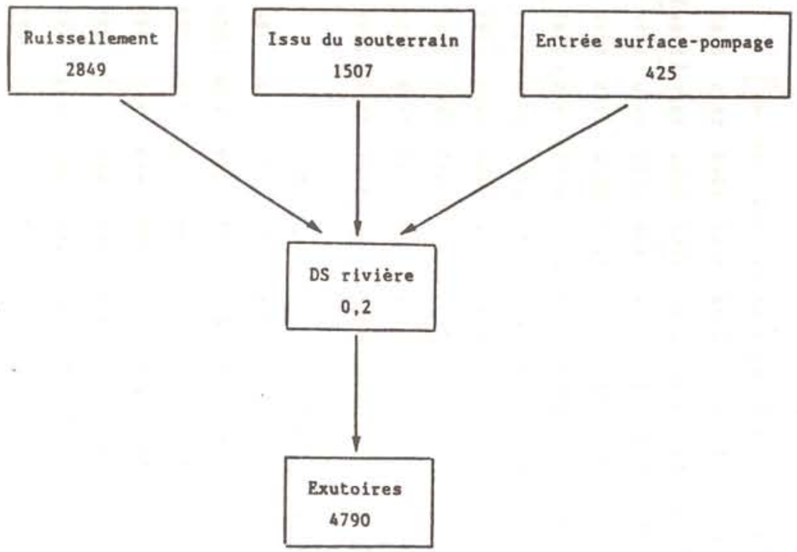


Figure 9.a : Bilan de la nappe en 1986
en 10^6 m^3

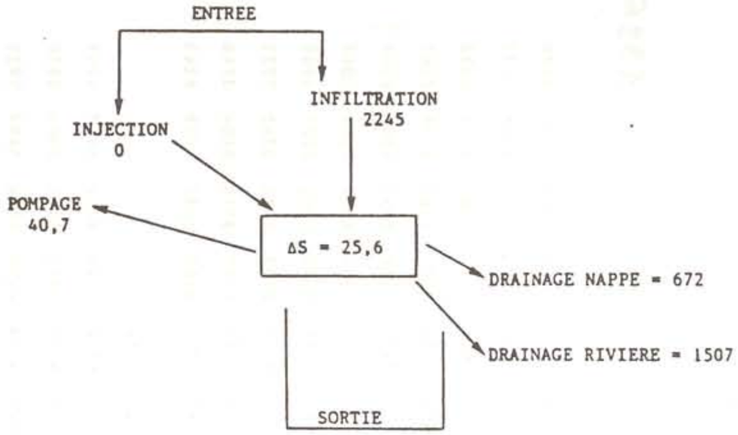


FIGURE 9 - BILAN D'ECOULEMENT ET BILAN DE NAPPE EN 1986

PLUIE ETR RUIS DRAIN DE JT= 366 A JT= 730 1986

PLUIE EN 1/10 DE MM

10762	10120	10177	10123	9044	8409	8338	6384	8375	7479
12131	12038	10587	10104	9192	8596	8134	8482	8025	7232
11387	11856	11151	10435	10436	9452	9412	8680	8126	7696
10705	11043	11055	10435	10022	8782	9021	8383	8198	7647
10443	10477	9561	9661	9221	8782	8306	8953	8804	6414
10427	10949	10367	10181	10267	9835	8544	9038	8506	7047
11462	12017	11340	10585	10285	9315	9593	9160	7779	6905
12457	12013	12032	11351	10568	9677	9553	8935	8365	7723
12601	12007	12305	11765	9525	9515	9970	8910	8404	8748
12782	12865	12536	12462	11749	9341	9409	8362	7959	8343

EVAPOTRANSPIRATION EN 1/10 DE MM

6937	6735	6242	6350	6245	6132	6168	6266	6407	5201
7021	6492	6493	6484	6275	6228	6094	5966	6066	5830
6490	6444	6264	6395	6403	6568	6630	6056	5692	5931
6002	6159	6014	6254	6282	5357	6214	5865	5595	5380
5878	6139	6011	5914	5980	5911	5342	5805	5467	5054
5655	6227	6029	5724	6465	6228	5582	5629	5206	5052
6123	6359	6235	5944	5253	5988	5745	5519	5120	5095
5860	6334	5980	5631	5379	5249	5117	5285	5517	5411
6063	5857	6125	5350	4312	4717	4725	4699	5477	5372
5095	5444	5527	5316	4341	4759	4396	4285	4378	5044

(RUISSELLEMENT PLUS INFILTRATION) EN 1/10 DE MM

3343	3047	3244	3185	2464	2112	1947	1846	1871	2185
4393	4605	3445	3047	2569	2145	1752	2006	1565	1086
4130	4557	4170	3465	3453	2435	2366	2136	1995	1375
4021	4149	4378	3653	3165	2363	2343	2018	2175	1917
3781	3387	2959	3076	2607	2345	2578	2453	2325	1085
4102	3912	3593	3597	2905	2663	2472	2792	2784	1501
4697	5146	4517	4066	4472	2987	2844	2836	1963	1495
6229	5233	5405	5098	4432	3908	3753	2319	1955	1727
6082	5581	5263	5350	4205	4266	4609	3637	2119	2558
7405	6625	6246	6494	6413	4502	4582	3665	2542	2526

VARIATION DE LA RESERVE EN 1/10 DE MM

403	300	515	542	300	165	222	270	96	86
577	738	583	529	327	222	287	497	408	306
640	722	630	533	535	426	414	480	429	384
586	639	595	490	542	345	457	494	411	325
701	673	545	626	610	504	361	645	460	264
576	727	589	480	839	386	456	565	463	461
546	418	495	473	426	762	907	721	625	291
302	385	560	516	603	507	661	717	793	521
397	245	759	447	413	442	529	449	708	682
176	522	581	516	364	483	360	319	451	641

FIGURE 10 - BILAN HYDROLOGIQUE PAR MAILLE DE 10x10 KM - ANNEE 1986

Evapotranspirations réelles journalières SAMER à 10 stations
du 7 Mai au 15 Juillet 1986

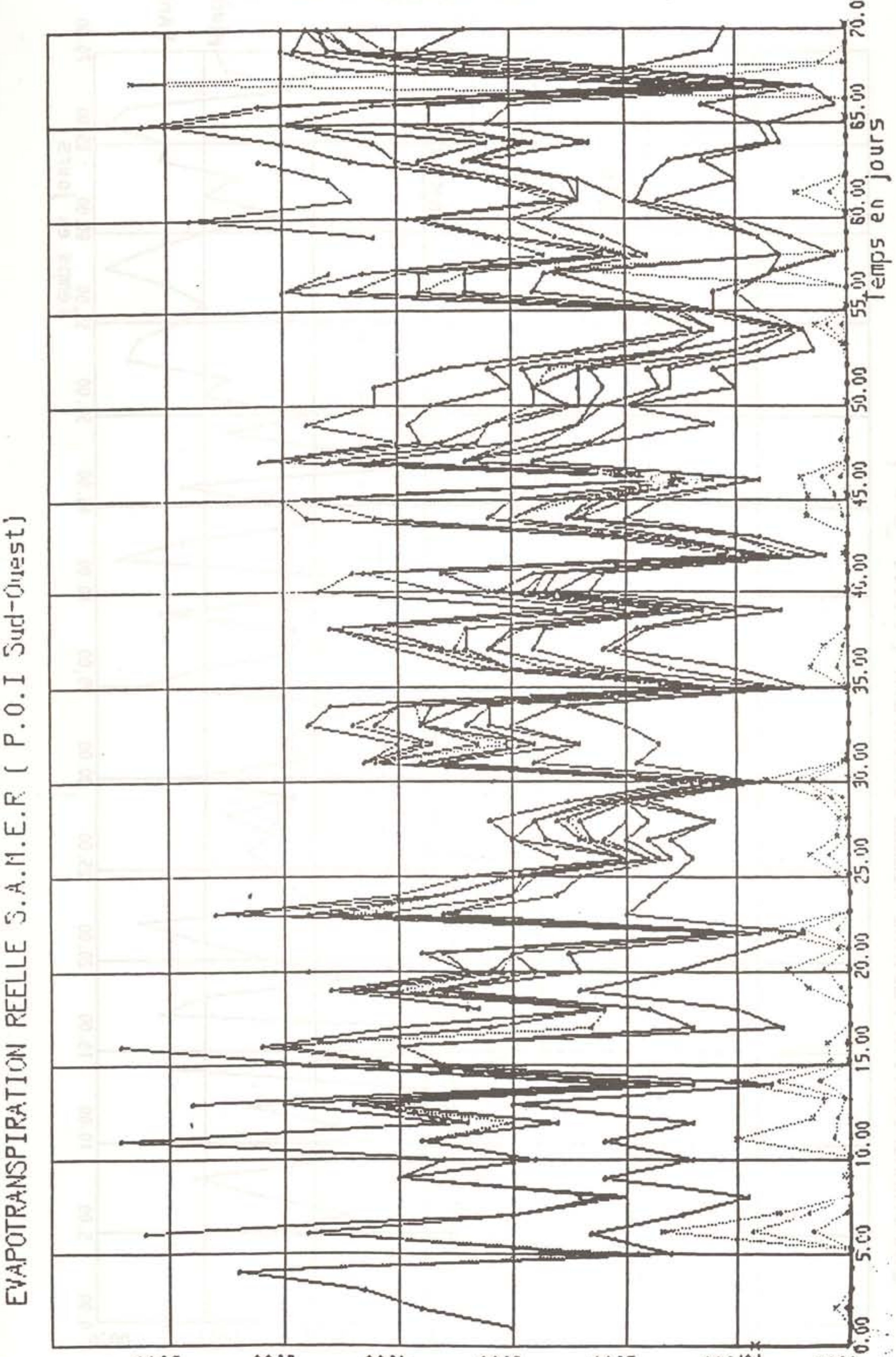


FIGURE 11 - EVAPOTRANSPIRATION JOURNALIERE RELLE (S.A.M.E.R.) ET PRECIPITATION DU 7 MAI AU 15 JUILLET 1986

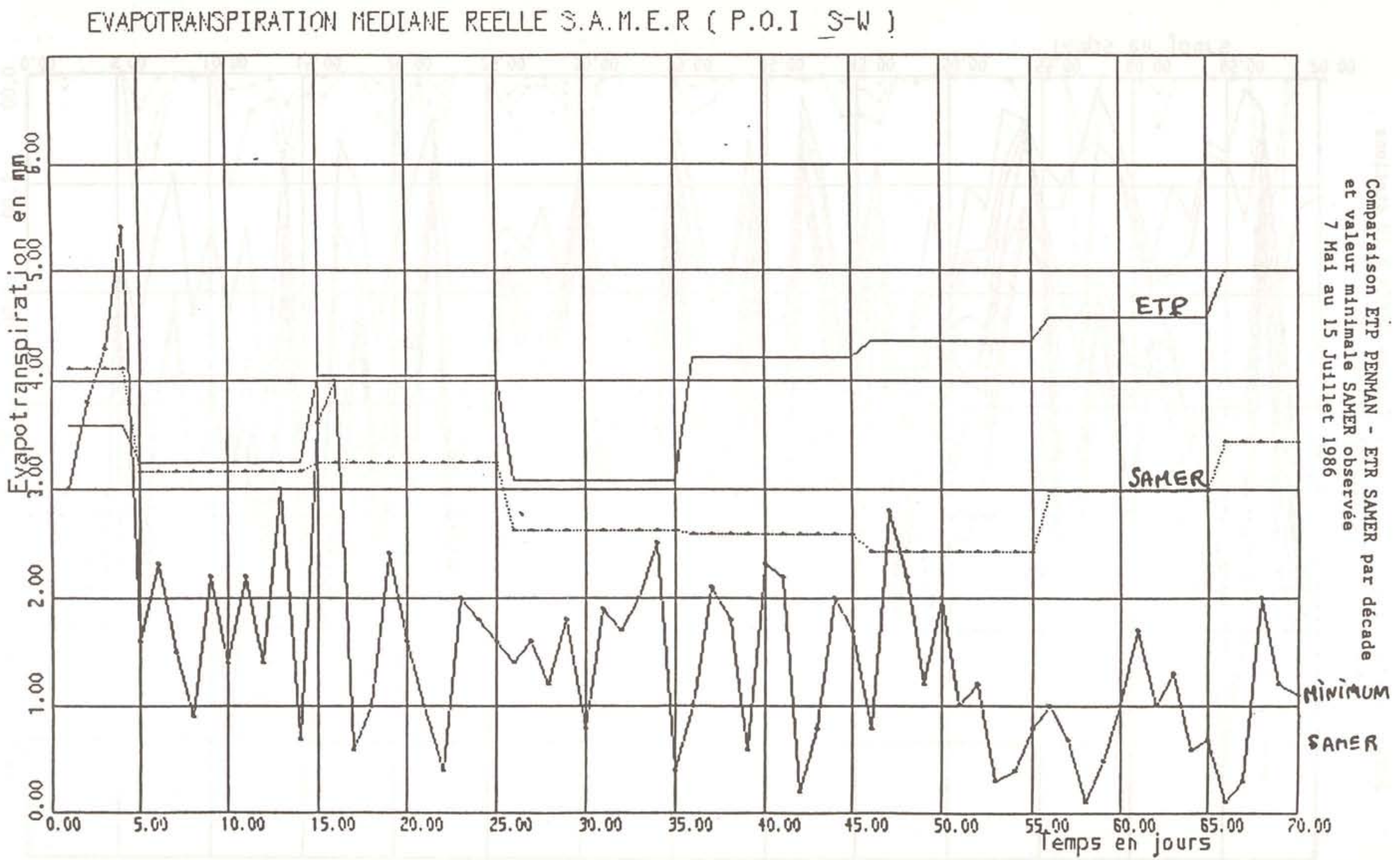


FIGURE 12 - EVAPOTRANSPIRATION MEDIANE REELLE (S.A.M.E.R.) ET ETP PENMAN ET MINIMUM (S.A.M.E.R.)

COMPARAISON MODELE - SAMER - ETP POUR LA PERIODE P.O.I

7 Mai 1986 - 15 juillet 1986

Mois	samer	ETP	modele	samer/ETP	samer/modele
Mai	83,7	111,0	103,5	0,745	0,809
Juin	76,5	100,0	95,9	0,765	0,782
Juillet	47,0	89,0	62,2	0,528	0,756

FIGURE 13 - COMPARAISON EVAPOTRANSPIRATION MODELE-SAMER-ETP (EN MM)

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

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 hydrologic viewpoints and should be of a size roughly equivalent to about 10°-15° latitude x 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 x 1° longitude grid cells and, where possible, 0.5° latitude x 0.5° longitude cells. Within each cell, or groups of cells, one or more gauged catchments 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 river 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 x 0.5° longitude or 1° latitude x 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 co-operate 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 co-ordination 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 evaluate the strengths and weaknesses of the various techniques.

APPENDIX I

ACTION PLAN FOR The Global Water Runoff Data Project

(as proposed by the WMO Workshop on the Global Runoff Data Set and Grid Estimation, November 1988)

	Actions	Responsibility	Target date	Remarks
1.	ANNOUNCEMENT OF GRDC			
1.1	Prepare description and functions of GRDC and distribute to WMO, Unesco, FAO	GRDC	DEC 1988	
1.2	Prepare article for WMO Bulletin	WMO	JAN 1989	
1.3	Circulate letters through WMO channels	WMO	JAN 1989	
1.4	Prepare article for IHP Bulletin	Unesco	JAN 1989	
1.5	Prepare article for FAO Land and Water Bulletin	FAO	JAN 1989	
1.6	Prepare article for IAHS Journal of Hydrological Sciences	GRDC	JAN 1989	
1.7	Approach Institute of Hydrology (UK), ORSTOM (France), etc. to invite collaboration	GRDC/WMO	1989	
1.8	Prepare leaflet on GRDC	GRDC	1989	With a logo
2.	GLOBAL DATA SET			
2.1	Prepare maps and lists showing present status of data availability	GRDC	DEC 1988	
2.2	Prepare summary of current status on map holdings and digitization	GRDC/Munich	DEC 1988	

Actions	Responsibility	Target date	Remarks
2.3 Request past donors to complete, augment data sets and map holdings	WMO	JAN 1989	Send back listings and plots of their own data, for checking
2.4 Request past donors to confirm "natural flows", data quality and availability of digitized maps	WMO	JAN 1989	
2.5 Request past donors to provide data for 1983 et seq.	WMO	JUN 1989	
2.6 Request non-donors to provide data and maps	WMO	MAR 1989	
2.7 Provide data for large rivers, for 1980-85	Unesco	JUN 1989	
2.8 Collect data from yearbooks	GRDC/WMO	1989	Seek from WMO, USGS, ORSTOM, etc.
2.9 Digitize catchment boundaries for small basins	Munich	DEC 1989	
2.10 Digitize catchment boundaries for large basins	?	?	Remains to be decided
2.11 Submit FGGE Level II-c data set to WDCs	GRDC	JAN 1990	
3. LIMITED AREA DATA SET			
3.1 Select areas for study	WMO/GRDC	JAN 1989	Review in Dec. 1989
3.2 Prepare first part of data set for pilot area	GRDC*	MAR 1989	
3.3 Request data for pilot area	WMO	JUN 1989	

Actions	Responsibility	Target date	Remarks
3.4 Compile data for pilot area	GRDC*	JAN 1990	
3.5 Derive grid cell values for pilot area	GRDC*	APR 1990	
3.6 Distribute results for pilot area:	GRDC*/WMO	JUN 1990	
- to climate modellers			Grid cell values only
- to data suppliers			All data and results
3.7 Request data for other areas	WMO	MAR 1990	
3.8 Compile data from other areas	GRDC*	DEC 1990	
3.9 Derive grid cell values for other areas	GRDC*	JUL 1991	
3.10 Distribute results	GRDC*/WMO	DEC 1991	
4. GLOBAL RUNOFF GRID CELL DATA			
4.1 Describe current and planned GRDC-GIS	GRDC	DEC 1988	
4.2 Seek information on GIS data available from:		JUN 1989	Catchment maps (scales), data (formats), software (formats), conditions (costs)
- UNEP/GRID	WMO		
- FAO	FAO		
- USGS	WMO/GRDC		
- Environment Canada	WMO/GRDC		
4.3 Invite "grid modellers" to participate in intercomparison of grid estimation techniques	WMO	APR 1990	
4.4 Plan grid estimation intercomparison and obtain additional data (see 4.2)	WMO	JUL 1990	

Actions	Responsibility	Target date	Remarks
4.5 Intercomparison of grid estimation techniques using pilot area data (see 3.6) and additional data (see 4.4)	WMO/GRDC*	JUN 1991	
4.6 Select grid estimation technique(s) to apply to global data set and define additional data required	WMO/GRDC*	SEP 1991	
4.7 Collect additional data	GRDC/WMO	MAR 1992	
4.8 Implement grid cell estimation on global basis	GRDC*	DEC 1992	
5. GRDC PLANNING AND MANAGEMENT			
5.1 Regular review of GRDC activities and plans	GRDC	Continuous	At national level
5.2 Consider future role of Centre, e.g. regarding:	GRDC/WMO	JUN 1989	
- intercomparison of grid estimation			
- further analysis of global runoff data set			e.g. monthly flow statistics
- storage and analysis of long time series			WCP-Water Project A.2
- quasi-real-time global monitoring of hydrological elements			Possibly with UK Institute of Hydrology
5.3 Convene workshop to review and advise on GRDC activities	WMO/GRDC	1991-1992	

* NOTE: It should be understood that these activities can be undertaken only if the GRDC is able to obtain the necessary resources from its government.

LIST OF REPORTS

WCRP-1 VALIDATION OF SATELLITE PRECIPITATION MEASUREMENTS FOR THE GLOBAL PRECIPITATION CLIMATOLOGY PROJECT (Report of an International Workshop, Washington, D.C., 17-21 November 1986) (WMO/TD-No. 203)

WCRP-2 WOCE CORE PROJECT 1 PLANNING MEETING ON THE GLOBAL DESCRIPTION (Washington, D.C., USA, 10-14 November 1986) (WMO/TD-No. 205)

WCRP-3 INTERNATIONAL SATELLITE CLOUD CLIMATOLOGY PROJECT (ISCCP) WORKING GROUP ON DATA MANAGEMENT - SIXTH SESSION (Ft. Collins, USA, 16-18 June 1987) (WMO/TD-No. 210)

WCRP-4 JSC/CCCO TOGA NUMERICAL EXPERIMENTATION GROUP - FIRST SESSION (Unesco, Paris, France, 25-26 June 1987) (WMO/TD No. 204)

WCRP-5 CONCEPT OF THE GLOBAL ENERGY AND WATER CYCLE EXPERIMENT (Report of the JSC Study Group on GEWEX, Montreal, Canada, 8-12 June 1987 and Pasadena, USA, 5-9 January 1988) (WMO/TD-No. 215)

WCRP-6 INTERNATIONAL WORKING GROUP ON DATA MANAGEMENT FOR THE GLOBAL PRECIPITATION CLIMATOLOGY PROJECT, (Second Session, Madison, USA, 9-11 September 1988) (WMO/TD-No. 221) (out of print)

WCRP-7 CAS GROUP OF RAPPORTEURS ON CLIMATE, (Final Report, Leningrad, USSR, 28 October-1 November 1985) (WMO/TD-No. 226)

WCRP-8 JSC WORKING GROUP ON LAND SURFACE PROCESSES AND CLIMATE, (Final Report, Third Session, Manhattan, USA, 29 June-3 July 1987) (WMO/TD-No. 232)

WCRP-9 AEROSOLS, CLOUDS AND OTHER CLIMATICALLY IMPORTANT PARAMETERS: LIDAR APPLICATIONS AND NETWORKS, (Final Report, Meeting of Experts, Geneva, Switzerland, 10-12 December 1985) (WMO/TD-No. 233)

WCRP-10 RADIATION AND CLIMATE: (Report of the First Session, JSC Working Group on Radiative Fluxes (Greenbelt, USA, 14-17 December 1987) (WMO/TD-No. 235)

WCRP-11 WORLD OCEAN CIRCULATION EXPERIMENT - IMPLEMENTATION PLAN - DETAILED REQUIREMENTS (Volume I) (WMO/TD-No. 242)

WCRP-12 WORLD OCEAN CIRCULATION EXPERIMENT - IMPLEMENTATION PLAN - SCIENTIFIC BACKGROUND (Volume II) (WMO/TD-No. 243)

WCRP-13 RADIATION AND CLIMATE - Report of the Seventh Session of the International Satellite Cloud Climatology Project (ISCCP) Working Group on Data Management (Banff, Canada, 6-8 July 1988) (WMO/TD-No. 252)

WCRP-14 AN EXPERIMENTAL CLOUD LIDAR PILOT STUDY (ECLIPS) (Report of the WCRP/CSIRO Workshop on Cloud Base Measurement, CSIRO, Mordialloc, Victoria, Australia, 29 February-3 March 1988) (WMO/TD-No. 251)

WCRP-15 MODELLING THE SENSITIVITY AND VARIATIONS OF THE OCEAN-ATMOSPHERE SYSTEM - Report of a Workshop at the European Centre for Medium-Range Weather Forecasts (11-13 May 1988) (WMO/TD-No. 254)

WCRP-16	GLOBAL DATA ASSIMILATION PROGRAMME FOR AIR-SEA FLUXES (JSC/CCCO Working Group on Air-Sea Fluxes), October 1988 (WMO/TD-No. 257)
WCRP-17	JSC/CCCO TOGA SCIENTIFIC STEERING GROUP (Report of the Seventh Session, Cairns, Queensland, Australia, 11-15 July 1988) (WMO/TD-No. 259)
WCRP-18	SEA ICE AND CLIMATE (Report of the Third Session of the Working Group on Sea Ice and Climate, Oslo, 31 May-3 June 1988) (WMO/TD-No. 272)
WCRP-19	THE GLOBAL PRECIPITATION CLIMATOLOGY PROJECT (Report of the Third Session of the International Working Group on Data Management, Darmstadt, FRG, 13-15 July 1988) (WMO/TD-No. 274)
WCRP-20	RADIATION AND CLIMATE (Report of the Second Session of the WCRP Working Group on Radiative Fluxes, Geneva, Switzerland, 19-21 October 1988) (WMO/TD No. 291)
WCRP-21	INTERNATIONAL WOCE SCIENTIFIC CONFERENCE (Report of the International WOCE Scientific Conference, Unesco, Paris, 28 November to 2 December 1988) (WMO/TD No. 295)
WCRP-22	THE GLOBAL WATER RUNOFF DATA PROJECT, Workshop on the Global Runoff Data Set and Grid estimation (Koblenz, FRG, 10-15 November 1988) (WMO/TD No. 302)

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