Global Terrestrial Observing System

Establishment of a Global Hydrological Observation Network for Climate

Report of the GCOS/GTOS/HWRP Expert Meeting

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Executive Summary

This meeting of experts was organised to consider the establishment of a global hydrological network for climate. The specific objectives of this meeting were to determine user needs for a global hydrological network; identify products to be delivered by such a network and to develop a vision and a strategy for establishing an initial, end-to-end observing ”system”.

Although the focus was on climate-related hydrological variables, the participants fully realised the importance of these variables (and the consequent benefit of a global network) for other subject areas, including water resources monitoring and assessment, monitoring of the global water cycle, biodiversity issues, land-based sources of pollution, as well as coastal and agricultural applications. Among the key groups that are calling for such information are intergovernmental mechanisms such as the international environment conventions and agreements as well as regional bodies. The climate community, scientists involved in research and modelling, and policy analysts frequently cite the need for improved access to hydrological data and information in order to understand key environmental change processes, identify significant trends, assess variability, and develop informed responses.

The meeting identified existing networks, centres and mechanisms that could contribute to an observing network; and proposed an approach to implementation. The meeting was hosted by the Forschungsanstalt Geisenheim and the Deutscher Wetterdienst and attended by representatives of international agencies, organisations and programs active in hydrology observations.

Through presentations and plenary as well as breakout group discussions, the participants synthesised the driving policy and science requirements for global hydrological observations under five themes: improved climate and weather prediction; detection and quantification of climate change; assessment of the impacts of climate change; assessment of fresh water sustainability; and understanding the global water cycle. It was emphasised that these climate-related themes are also relevant to other issues, e.g. water resources management, agriculture and biodiversity, and thus the strategies for observation and data products need to be developed through close collaboration. Following a review of the major hydrological programs and activities as well as the present status in the observation of key hydrological variables1, the participants discussed the need and the strategy for ensuring the ongoing availability of systematic, comprehensive global hydrological observations and data products. An effective global system will consist of satellite and in situ measurements, and both ultimately depend on national implementation and support. Given the existing networks and data product centres, it was agreed that the most desirable approach is linking those currently active to obtain a maximum benefit and as a basis for further improvements. To this end, a Global Terrestrial Network for Hydrology (GTN-H) was proposed to complement terrestrial networks already established for permafrost, glacier and ecological observations. Among the existing hydrology networks and data centres, candidates were identified to address the needs for most of the key

[1] Surface water discharge, surface water storage fluxes, ground water fluxes, biogeochemical transport, isotopic signatures, water use, precipitation, evapotranspiration, atmospheric vapour pressure, soil moisture, snow depth and water equivalent

hydrological variables on a global basis. In addition, the participants defined the need for a scientific panel (Hydrology Observation Panel for Climate, HOPC) that would guide the implementation of GTN-H, advise on the selection of priority products, and ensure linkages with science programs that have observation components and needs. HOPC and GTN-H should be sponsored by the major international organisations with hydrology interests. The governance issues were addressed in a preliminary way. The meeting also defined initial global products for specific variables that are needed now and could be produced in the near future and identified lead agencies for these, and developed a list of early actions and opportunities that should be pursued in the near future.

The following specific recommendations were made:

1. A Global Terrestrial Network for Hydrology (GTN-H) should be established to meet the needs for global hydrological observations for climate. This network should build upon existing hydrology networks and data centres, hence serving as the hydrological complement of existing global terrestrial networks. Recognising, that a GTN-H could meet many other requirements for hydrology and water resources management including i.e. the characterisation of hydrologic processes and systematic regional and global hydrological observations, its terms of reference should address the needs of several regional and global programs in hydrology and water resources in addition to the climate requirements established at this meeting.

2. Potential GTN-H sponsors and participants identified at this meeting should be approached to obtain their endorsement and contributions.

3. A Hydrological Observation Panel for Climate (HOPC) should be established, with its major responsibility being to guide the development and implementation of GTN-H and to ensure its effectiveness.

4. HOPC should act in close cooperation with its sponsoring agencies, global observing systems (GCOS, GTOS, GOOS, WWW), institutions participating on behalf of the global observing systems, and global research programs (especially IGBP and WCRP); and the HOPC terms of reference should be developed accordingly.

5. HOPC and GTN-H should develop a plan for meeting the data and product requirements by the various application communities. This plan should take advantage of the initial product generation activities and interests of the participants (section 7.6). Early tangible and beneficial results should be an important goal in preparing this plan.

6. Near-future opportunities for the development of GTN-H should be vigorously pursued, including collaboration within CEOP.

7. The implementation of the recommendations should be undertaken by the sponsors of this expert meeting, i.e. GCOS, HWR/WMO and GTOS, with the interim assistance of TOPC.

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1. Introduction

An expert meeting on the establishment of a global hydrological network for climate was held at the Forschungsanstalt Geisenheim in Geisenheim, Germany, from 26 June to 30 June, 2000. The list of participants is given in Annex I. The following goals for the meeting were developed during the planning sessions:

- Establish user needs for a global hydrological network
- Identify deliverables of such a network
- Develop a vision and a strategy for establishing an initial, end-to-end global hydrology observing ”system”, focusing on the hydrological variables identified by the Terrestrial Observation Panel for Climate (TOPC)
- Identify existing networks, centres and mechanisms that could contribute to this strategy.

The expected output of the meeting was an action plan, with an initial observing system to be operational within two years, to be expanded and take advantage of new opportunities. The plan should identify specific actions that can realistically be implemented, propose implementing/responsible groups/agencies, and specify co-ordination mechanisms to facilitate such implementation.

The meeting was opened on Monday, June 26 at 10:45 am with welcome addresses by Dr Vent-Schmidt of the Deutscher Wetterdienst, by Prof. Schaller, Director of the Research Institute of Geisenheim, and by Dr Grabs of the WMO Hydrology and Water Resources (HWR) Department. Dr Schaller introduced Dr Rudolf who was responsible for local arrangements. Dr Vent-Schmidt proposed that Dr Landwehr of the U.S. Geological Survey and member of TOPC, be elected as Chairperson, and this was unanimously accepted.

Dr Landwehr reviewed the provisional agenda. With some minor amendments, the amended agenda was adopted (refer to Annex II).

2. Goals and Expectations

2.1 WMO/HWR

Dr Grabs provided an outline of the position of the Hydrology and Water Department of WMO. He informed the participants that to serve the needs of the United Nations Framework Convention on Climate Change, the fourth Conference of the Parties (COP-4) urged that Parties undertake programmes of systematic observations based on the requirements developed by GCOS. Hydrological data and information are included in the call to support national networks to collect, exchange and preserve terrestrial data. The WMO Commission for Hydrology (CHy) in which 125 countries and their hydrological services are represented, plays a vital role by supporting national and regional hydrological activities as well as global hydrological data collection initiatives.

For many reasons, it has traditionally been difficult to acquire hydrological data and information at regional and global scales on a routine basis for climate and water resources studies. In most countries, routine hydrological observations are made which could be used for climate research and monitoring purposes and for freshwater assessments. However, a comprehensive global hydrological network that serves observational requirements of several programmes and which operates on a set of agreed procedures for data collection, processing, dissemination, analysis and use does not yet exist.

The meeting objectives and agenda (see Annex II) are fully consistent with the expectations of the Hydrology and Water Resources Programme of WMO. The WMO World Climate Programme – Water (WCP-Water), which is jointly implemented with UNESCO, serves as a link between water and climate related issues in research and applications.

In the view of WMO, a global hydrological network is a milestone to advance our understanding of hydrological processes on regional and global scales, especially in the areas of coupled modelling and improved forecasting. The establishment of the network will also meet observational requirements of GCOS and GTOS.

WHYCOS, GRDC and GPCC are flagships of WMO in the collection of global hydrological data. These initiatives, in collaboration with other global projects such as the Continental Scale Experiments of GEWEX, are important pillars in the establishment of the global hydrological network that would produce near real-time data sets for climate users and for others in hydrology and water resources management. As the UN agency responsible for the collection of hydrological and related data, WMO is ready to oversee the establishment of a global hydrological network and to participate actively in the operation of the planned network.

2.2 GCOS

As background to discussing the goals of the meeting, Dr Thomas reviewed the results from COP-5, in particular decision 5/CP.5 on systematic observations. This decision has several important provisions relevant to a global hydrological network for climate:

- Parties are to provide the COP with detailed national reports in accordance with the UNFCCC Reporting Guidelines on global climate observing systems, prepared by GCOS on behalf of its partner programs
- The UNFCCC Secretariat, in conjunction with the GCOS Secretariat, is to develop a process for synthesising and analysing the information in the reports
- COP, recognising the needs of developing countries for capacity building to participate in systematic observations, invited the GCOS Secretariat to organise regional workshops in consultation with international organisations, including the GEF.

Dr Thomas then addressed the implementation activities of GCOS related to these decisions of COP and the need for defining and implementing a global hydrological network for climate. Including a hydrology network in the revision of the UNFCCC Reporting Guidelines in the 2002 time frame should be a priority. The GCOS Steering Committee will be meeting in September 2000 and two issues for discussion should be of direct interest to this workshop: the GCOS Chair is interested in identifying the top priorities for terrestrial observing systems, and the GCOS Steering Committee will be discussing strategies for implementing networks, such as a global hydrological network for climate, based on national (or consortia of national) and agency contributions.

The GCOS view of the goals of the meeting is to:

- Develop a vision and strategy for an initial end-to-end global hydrology observing system for climate
- Define an action plan for an Initial Operational System that can be implemented in the next 2-3 years, including observing networks, production of near real-time data and products; centres/programs for monitoring data availability, quality control and assembly; and centres for data archiving and distribution
- In particular, identify the requirements for satellite observations and for data assimilation techniques.

2.3 FAO

Dr Reichert discussed FAO interests in hydrology issues. Land and water are essential resources for agricultural production. Given that globally a large fraction (~75 percent) of fresh water is consumed by agriculture-related activities, its sustainable management is of vital interest to FAO and its member countries. Water is becoming increasingly scarce in many regions due to growing use for irrigation and the increasing consumption for domestic and industrial purposes, which can also affect the quality of water. Careful management of water resources is therefore imperative. This requires reliable and up-to-date information on its status and changes over time, in terms of quantity and quality.

The Land and Water Development Division of FAO has developed the AQUASTAT database as an information system on water in agriculture and development which produces regional analysis and country profiles on water resources (http://www.fao.org/waicent/faoinfo/agricult/agl/AGLW/AQUASTAT/Aquastat.htm). FAO is also co-operating in the preparation of the World Water Report for the year 2002. Given the importance of water resources to FAO, the Organisation will contribute to the establishment of a global hydrological network for the collection, exchange and analysis of data on hydrology and the preparation of related products.

2.4 GTOS

Dr Reichert provided a brief perspective on GTOS. Availability of freshwater resources is one of the five key issues of GTOS, affecting also the other four (changes in land quality, biodiversity, impact of climate change, and effects of pollution and toxicity). GTOS, in co-operation with GCOS, has generated a list of critical variables to be observed in the assessment and monitoring of freshwater resources which forms part of the database on Terrestrial Ecosystem Monitoring Sites (TEMS). TEMS is presently being re-designed and upgraded with additional features, based on the recommendations of TOPC (see chapter 5.11 and GTOS (2000)).

Within GTOS, the Global Terrestrial Observing Network (GT-Net) has been established as a system of networks with similar thematic objectives (thematic networks) or covering a specific geographical region (regional networks). Thematic networks so far established include the ecology, glaciers and permafrost (see section 2.5). A thematic network for hydrology is envisaged as consisting of networks, institutions and sites that measure, monitor, archive, analyse and exchange hydrological data and products following commonly agreed standards. GTOS would be ready to host a hydrological network, assist in the establishment of a metadata base in the framework of TEMS and provide secretarial assistance including the reparation of meetings, establishment of HOPC and other support as might be required.

2.5 TOPC

Following a request by the GCOS Steering Committee for a meeting of experts, TOPC was one of the prime organisers for this meeting. In introducing TOPC goals relevant to the meeting, Dr Landwehr presented the following background information.

TOPC was established in 1995 as a scientific advisory panel to both GCOS and GTOS, to advise on issues which fall in both their spheres in the terrestrial domain. The terrestrial hydrologic systems, both continental and coastal, were included in this charge. A major initial concern of TOPC was to identify an over-arching set of terrestrial variables for which observations are needed globally to predict, detect and assess climate change. To this end, TOPC published the GCOS/GTOS Plan for Terrestrial Climate-Related Observations (GCOS, 1997). This report identified 65 variables in 9 terrestrial categories as necessary to establish the aforementioned task, and provided a justification for each variable with a suggestion of the spatial and temporal resolution with which observations are needed. The "Hydrology" category identified seven variables, namely, biogeochemical transport from land to ocean, evapotranspiration, ground water storage fluxes, precipitation accumulated as both solid and liquid, relative humidity, surface water flow as discharge, and surface water storage fluxes. Two additional variables in the list of 65 were also singled out as important for hydrologic purposes, namely snow water equivalent and soil moisture.

Subsequent to the identification of these variables, TOPC members have sought to ascertain the electronic availability of data for these variables. Their findings have been published in the Report of the GCOS/GTOS Terrestrial Observation Panel for Climate, Fourth Session, 1998, Corvallis, USA (TOPC, 1998). An additional variable of global hydrologic concern for terrestrial systems - water use - was identified in the TOPC report of its fifth session (TOPC, 1999). Water use is an untypical variable in the climate context, because it explicitly reflects anthropogenic forcing; however, water use information is critically important to detecting and understanding climate variability and change. These outcomes are also summarised on the Global Observing Systems Information Center (GOSIC) Internet site (http://www.gos.udel.edu/) which serves as an information dissemination point for the GxOS (GCOS, GTOS and GOOS) activities. In brief, some of the variable categories are data rich, but most are not and some are virtually non-existent.

To address the lack of available appropriate data, several global terrestrial networks have been established within GTOS with TOPC initiative. These include: GTN-G (for glaciers) supported by the University of Zurich, GTN-P (permafrost) with support of the International Permafrost Association, and GTN-E (ecology) in association with ILTER. In addition, GCOS had established an observation network for meteorological data based on operational systems and WMO protocols, the GCOS Surface Network (GSN). The major remaining gap is in hydrologic systems and hence, the need for a specialised network. However, hydrologic information poses unique challenges. Where it exists, most hydrologic data is collected for reasons of national and operational interest, rather than for research or scientific purposes, and frequently does not follow a tradition of global availability as with meteorological information as hydrologic observations are frequently limited by unique proprietary concerns. Ideally, the global hydrological network would provide hydrologic observations, either single time series or concurrent sets of information, with appropriate spatial and temporal resolution, and with appropriate quality assurance, in a timely manner that is easily accessible with minimal cost to all requesters.

Consequently, the TOPC objectives for this meeting were:
1. Develop a vision or framework for a global hydrological network
2. Develop a strategy for an end-to-end system, from observer to user
3. Identify existing resources, and
4. Develop an implementation plan.

3. Presentations on Requirements for Hydrologic Data and Information

3.1 Weather and Climate Forecast Modelling

The terrestrial biosphere, atmosphere, and oceans are integrated in an Earth system characterised by variability of controlling parameters at a wide range of time and space scales. The variability and memory in this system are due to, among others, the cycling of water in different phases and storage compartments. Small fluctuations in initial forcing conditions may be amplified by feedback mechanisms. Although the land fraction of the Earth is relatively small (~30 percent), its distribution in large contiguous areas and its distinctive hydrothermal inertia cause significant variations in regional climatic systems.

There is evidence that on weather- and storm event- time scales, initial soil conditions can reinforce the development of precipitating weather systems. At the regional scale, soil moisture availability has substantial influence on elevated mixed layers and on associated “lids” on atmospheric instability that focus the release of convective instability and hence determine the distribution of the regional precipitation in time and space (Clark and Arritt, 1995). For example, using numerical mesoscale atmospheric models, the evolution of summertime weather systems in the Midwestern U.S. was found to be critically dependent on so-called “dryline” conditions where sharp gradients in soil moisture are present (Chang and Wetzel, 1991). Hydrological processes with long memory, such as soil moisture, may serve to integrate past atmospheric forcing and enhance prediction skills for regional climates (e.g., Fennessey and Shukla, 1999). - The presence of feedback mechanisms can enhance land-memory phenomena. Thus, if positive feedback mechanisms are present in the coupled land-atmosphere system, an initial anomaly can persist through reinforcement at both climate and weather time scales. Scott et al. (1997) and others demonstrated the importance of both soil-moisture reservoir size and the recycling of precipitation.

Thus, it is apparent that, in certain conditions, land memory in the form of the soil-moisture storage, perhaps reinforced by positive feedback mechanisms such as recycling of precipitation, has significant effects on atmospheric variability and predictability and can lead to greater persistence of weather and climate anomalies. Delineation of the conditions under which soil-moisture state is important to the evolution of weather and climate, coupled with ways of estimating the initial soil-moisture state based on *in situ* and satellite observations and the realistic simulation of the subsequent evolution of that soil-moisture state, are expected to improve skills in predictive models for weather and climate. Thus, hydrological observations available in a timely fashion can be expected to make a very important contribution to improving the accuracy of regional weather and climate predictions. They are important for medium term weather forecasts but the significance increases significantly with the length of the forecasting period. In addition to soil moisture, freshwater input into the oceans plays an important role in modulating thermohaline circulation and thereby affecting climate variability at longer time scales. It should be noted that observation requirements for short-range weather forecasts to seasonal forecasts are already being considered by the Task Force on the redesign of the global observing systems (CBS-OPAG).

3.2 Climate Diagnostics and Change Detection

Prof. Phil Jones discussed the need for long measurements of climate and hydrologic data for studies of climate variability and change. Gridded fields are easiest to work with in most of these studies, although point measurements are necessary is some applications. New et al. (1999, 2000) have developed fields for many climate fields and it is essential to develop these further and extend them to some hydrological variables such as discharge and runoff, for both climate variability and change studies and climate model validation.

Most studies of changes in climate variability and in climate change detection have focused on temperature, because this field can be well represented by the available network. The temperature field exhibits relatively high correlation decay lengths, allowing grid-box scale (5^o x 5^o) averages to be reliably developed. Both future impacts and those of past events are, however, much more dependent upon changes in precipitation. Changes are not just vital for hydrology, but are also much more important than temperature for many other sectors, for example agriculture and forestry. Studies of large-scale changes in precipitation are hampered by the need to gain access to considerably more precipitation data than is conventionally available. A similar case can also be made for runoff data. Climate change detection studies need to be undertaken on a global scale, and both the available networks of precipitation and runoff data are inadequate. At present, the best that can be achieved are studies on regional and catchment scales.

3.3 Water Availability Modelling

Dr Döll presented data requirements for the global modelling of water availability and use, the aim of which to derive scenarios of the future water situation in river basins. She listed the following types of data which, too a large extent, relate to the human interference with the natural water cycle and are necessary for an integrated water assessment:

Gridded data (spatial resolution 0.5° or higher):

- Meteorological data, in particular precipitation (preferably daily, and including correction factors for measurement errors) and extent/depth of snow cover
- Land cover

Point data:

- River discharge directly upstream and downstream of (large) lakes and reservoirs
- Evapotranspiration
- Soil moisture
- Water quality parameters (in particular nutrients)
- Naturalised flows
- Location, volume-area function and management of reservoirs
- Location and other data of hydropower plants
- Location and other data of wastewater treatment plants
- Area (and volume) of lakes and wetlands (time series)

Polygon data (for administrative units):

- Withdrawals and consumptive water use differentiated according to source (groundwater, surface water) and user sector (agriculture, households, manufacturing, cooling etc.), similar to water use data for all the counties of the USA (collected by United States Geological Survey)
- Water quality: source emissions of relevant substances.

Preferably, the data should be global and represent a long time series. They should include information on how the data set was derived, and on the uncertainty of the data.

Dr Fröhlich presented the methodology and results of a case study for a GIS-related balance of water availability and water demands in large river basins by using published generally accessible data and information. The core of that balance calculation is the location- and time-related comparison of available resources with sectoral water demands in the river basin, while the underlying methodology is an in-depth balancing by means of a long-term water management model on the basis of the Monte-Carlo technique. It allows to take into account diverse water uses and demands in their temporal and spatial variability. Thus, demand functions may be adapted individually, and qualitative or economic parameters, interactions with groundwater or flow-times in the river system may be considered. The monthly balancing step makes it possible to evaluate the satisfaction of demands both in the annual averages and in the variations during the year. The outputs of the balancing procedure may be exceedance probabilities of events at any point along the river course, duration of events, mean values and mean minima and maxima of monthly streamflow. Among others, the study yielded a method that is applicable on large river basins, provided that plausible and reliable data can be obtained that describe the anthropogenic impacts on the hydrological system.

3.4 Precipitation Assessment

Precipitation links the global water and energy cycle, and simultaneously belongs to the scientific disciplines of meteorology and climatology as well as to hydrology.

The variable of interest is first the precipitation depth (measured in mm = ltrs.m^{-2} of water fallen during a defined time-interval as hourly daily, weekly or monthly).

Other variables of interest are the precipitation rate or intensity during short time-intervals, number of days with precipitation per month or year, or the fraction of liquid, solid and mixed of the total precipitation depth.

3.4.1 Precipitation Data Sources:

a) Point data

Conventionally and during most time of the past, daily and monthly precipitation depth is locally but directly observed using gauges, called raingauges or precipitation gauges) at stations operated in national or local meteorological, climatological or hydrological networks. The number of raingauges being operated is estimated to be about 200,000 world-wide. Recording raingauges operated at some of the stations also deliver short-time precipitation rates or intensities. The systematic measuring error due to evaporation losses and wind drift is a problem to be considered.

An operational global exchange of a limited number of data (about 8,000 stations) is established within the World Weather Watch co-ordinated by the WMO. For climatology purposes, data from a subset of these stations (about 1,000) are monitored and collected within the GCOS Surface Network (GSN). Additional data are bilaterally exchanged between countries or provided by the originators to regional or global research projects, or have been collected by individual institutes from more or less official sources.

b) Gridded data

Gridded precipitation data represent the area-averaged precipitation depth for grid-boxes defined by metric or geographical co-ordinates. There are three different types of gridded data sources:

- Area-mean respectively grid-box precipitation can be derived from locally observed point data using interpolation methods as kriging, objective analysis or empirical algorithms. The accuracy of the resulting area-means respectively the sampling error strongly depends on the number of data points (stations), but also on the grid or area size, the temporal resolution and the regional climate variability.

- Remote-sensing techniques, being available since the seventies, as radar and satellites provide information on precipitation rates based on volume-integrated observed radiation using radiation-cloud-rainfall models or empirical relationships. Advantage of these data is the equal and complete area-coverage. But the indirectly gained results need to be adjusted to corresponding data derived from direct (in situ) observations. Time-series of satellite-based data are heterogeneous since the techniques have continuously been improved during the last 20 years and there is still a development long-term going on.

- Numerical weather prediction models also deliver area-mean precipitation data corresponding to the spatial model resolution. But even in the NWP model re-analyses of ECMWF or NCEP the precipitation results are fully predicted and not based on analysed observed precipitation data and need be verified.

3.4.2 Requirements

The requirements for precipitation data depend on the purpose and way of application. For statistical analysis and climatological diagnosis of temporal variability and trends, observation-based climate change studies, long-term homogeneous time series are required, which are available from a smaller number of stations only. A full area-coverage is not given by the available data, but seems to be not necessary.

Studies on the global climate system and the global energy and water cycle, on global and regional interactions between atmosphere, ocean and land surface, on the mechanisms and structure of quasi-periodic climate variations (as El Nino), but also the verification of model results and validation of remotely sensed data require gridded precipitation data sets of best possible accuracy and of a suitable spatial-temporal resolution. Hydrological studies generally require area-mean precipitation data. Partitioning of solid and liquid precipitation is required for run-off modelling.

Specific requirements for the assessment of area mean precipitation (gridded data) based on raingauge observations are sufficient data density (about 10 stations per grid-box), performance of quality-control for the data used, assessment of systematic measuring errors and corresponding data correction, and delivery of the estimated total error on the individual grid-box with the product.

3.4.3 Limitations

The major constraint is data availability. Under real conditions a full global (land surface) coverage by gridded precipitation data of sufficient accuracy can be reached so far for the scales 1.0° by 1.0° spatial and monthly temporal resolution. For certain regions such as West and Central Europe, North America or Australia as well as for a number of smaller regions (individual countries), continuous daily analyses on a 0.5° or smaller grid could also be produced and made available for international programmes. Progress might be possible in future based on satellite observations.

3.5 Water Balance Modelling

Understanding the terrestrial energy and water cycle over a range of spatial and temporal scales is a primary focus of the Global Energy and Water Cycle Experiment (GEWEX) and its Continental Scale Experiments (CSEs) such as GCIP, BALTEX, GAME, LBA, MAGS, etc.). The development of coupled hydrological and atmospheric models and their verification over a number of catchments is an integral part of these projects. The transfer of methodologies to other continental areas and different climate regimes is anticipated in order to finally improve global climate models and regional scale weather forecast models. In these and similar studies, hydrological data form the basis for:

- The development and validation of parameterisation schemes for surface and soil hydrological processes
- The verification of the description of surface hydrological processes in climate and weather forecast models
- The assimilation of hydrological variables in real time into weather forecast models
- The real-time validation of the hydrological cycle in weather forecast models.

To meet the requirements of atmospheric models, hydrological data provided by a global network should be reported as point data with the highest possible temporal resolution. The spatial resolution of atmospheric models varies from some km to a few hundred km with a temporal resolution of minutes to hours.

A hydrological network should include real-time variables as well as long time series to allow the verification of operational weather forecast models and the investigation into climate variability and trends. A global network with an increased density of the observing stations over particular regional areas should be anticipated as the regionalisation of climate change predictions is of utmost importance.

The key variables to be included are precipitation –liquid and solid- (3 or 6 hourly), discharge (naturalised flow, i.e. streamflow corrected for manmade storage; daily), lakes and reservoir levels, soil moisture, snow water equivalent, snow cover area, snow depth, and evapotranspiration.

4. Synthesis of Information and Observation Requirements

Workshop participants identified five major reasons for requiring hydrological information, described briefly in sections 4.1 to 4.5 below.

4.1 Improved Climate and Weather Prediction

Main objectives of climate and weather prediction are to improve the accuracy of weather predictions with the most detailed spatial resolution feasible and to substantially improve the capability for seasonal forecasting at regional scales. Energy exchange between the ocean, land surface and the atmosphere is the major driver of the weather engine. Therefore hydrological observations on the highest possible spatial and temporal resolution are required to feed and validate next generation forecasting and prediction models. The following observations would greatly improve the reliability of NWP and climate model predictions (refer also to section 3.1):

- Near real time measurements of river runoff near to the mouth of major world rivers for coupled climate model input, and for the testing of global thermohaline circulation in these coupled models.
- Atmospheric observations such as precipitation. The technical definition of near real time hydrological observations needs to be fitted to meet the actual data requirement of specific numerical models and anticipated products, such as forecasts
- River water sampling for the off-line determination of the isotopic composition as a test of coupled models to reproduce the water cycle on land. The GNIP network is a natural starting point for these activities
- Soil moisture fields as starting fields for weather forecasting (especially medium range) and climate variability predictions, distributed via GTS to forecast centres
- Start to develop satellite remote sensing of hydrological variables, e.g. soil moisture and river runoff. Use existing satellite data (e.g. from SSMI) on snow cover and snow water equivalent.

4.2 Characterising Hydrological Variability to Detect Climate Change

The workshop participants noted the need to understand and to characterise the variation of hydrologic variables in response to climatic variations in order to be able to detect trends, that is, changes in the fundamental nature of the climatic status quo. However, such changes are not just ones of anthropogenic origin, as is clearly highlighted by the existence of past ice ages as well as more moderate climatic excursions such as the medieval warm period which could not have a human origin. The ability to discern trends in the context of expectable variations is necessary not only for reasons of scientific knowledge, but also for long term infrastructure planning. Thus, the one primary user of such information would be the UNFCC through the IPCC process and its contributing scientific collaborators, national and regional governments, and international decision and risk takers such as insurance companies.

The following observations are particularly important for climate variability studies:

- Monthly runoff series for the top few hundred catchments (in size) around the world, if possible with naturalised flows
- Daily runoff series for a few hundred smaller natural catchments (~1000 km^2 in size) used for research spread over the globe
- Long time series of hydrological records
- Comprehensive catalogues of metadata that explain the data sets within a global hydrological network.

An important current science issue concerns the causes of the increased frequency and intensity of ENSO events during recent decades: do they represent a long-term natural fluctuation or are they of anthropogenic origin? The answer cannot be given yet. However, it may be possible to obtain it by using measurements of the isotopic composition of the water molecules in annual natural deposits like ice-cores, lake varves, corals and tree rings. Because these data can extend the records back in time into the pre-instrumental period, if circulation anomalies like ENSO or the North Atlantic Oscillation (NAO) leave any imprint on isotope patterns. First exploratory measurements to the GNIP database and using the GNIP database point to the El Nino patterns in South American isotope data. For improved transfer functions between conventional hydrological data and isotope patterns derived from point measurements of both data types we need more monthly mean isotope data at more precipitation stations and also isotopic composition of river water, preferably at gauging stations. In addition, isotopic composition during precipitation events has to be measured to test the reliability of the mean monthly data.

4.3 Developing the Ability to Predict the Impacts of Change

The goal is to understand the process of change, both for scientific purposes and to establish the capability for implementing mitigation measures as necessary. Indeed, some argue that change can and does occur and that its consequences need not be catastrophic (e.g., von Storch and Stehr, 2000), so that an ability to assess the need for mitigation or lack thereof is critical.

A major product to be derived from a global hydrological network will be information on water availability and distribution. Climate variation has the potential to significantly alter the natural distribution of water-resources world-wide. Changes in precipitation and shifting patterns of water distribution can lead to increase of floods, water shortages and drought. In addition to water quantity, water quality aspects are an important issue , both from societal perspective and to maintain healthy ecosystems. Indeed, freshwater limnological ecosystems are known to be responsive to climate change impacts, but the magnitude of effects on these systems is just beginning to be quantified (McNight et al., 1996).

An important component of climate impact assessment concerns the transport of materials (surface and subsurface) from land to oceans. The movement of carbon and nutrients has potential impacts on coastal margins as well as in sensitive ocean regions.

The following observations are particularly important for change impact studies:

- Daily runoff series for a few hundred smaller natural catchments (~1000 km^2 in size) distributed over the globe, together with precipitation and other data permitting the study of hydrological processes in specific regions
- Monthly or seasonal information on biogeochemical materials transported from land to the ocean with appropriate spatial and temporal resolution to characterise global as well as regional impacts
- Multiyear ground water, surface water and water use time series to characterise water availability
- SW flux values to anticipate change in storage in natural and artificial reservoirs.

4.4 Assessing Water Sustainability as a Function of Water Use Versus Water Availability

The concept of sustainability implies that a resource is used in such a way as to remain available to that use for an unlimited time period with no detrimental environmental, economic or social consequences.

In order to assess sustainability of human water use and to model water scarcity in the context of climate change, information on water availability and water use are needed. (Döll et al., 1999; Vörösmarty et al., 2000). As for climate impact assessment, water quality is critical information because it determines is the utility of water available for the requisite use. Thus, water quantity observations that consider availability, distribution, location, and scarcity need to be co-ordinated with water quality aspects of systems that address human health, ecosystem viability, water use requirements, and the transport of materials. The following observations and data are particularly important for water availability studies:

- Area (and volume) of lakes and wetlands (time series);
- For assessing the role and impact of artificial reservoirs: location, volume-area function and management record of reservoirs, river discharge directly upstream and downstream of (large) lakes and reservoirs, and naturalised flows;
- For assessing the impact of water quality: location and other data for wastewater treatment plants, water quality parameters (in particular nutrients) in rivers, and source emissions of relevant substances, particularly nutrients;
- For assessing water use and its impact: withdrawals and consumptive water use differentiated according to source (groundwater, surface water) and user sector (agriculture, households, manufacturing, cooling, etc.) and administrative units (e.g., counties, provinces,..).

4.5 Understanding the Global Water Cycle

Isotopic tracers provide a mechanism for assessing our ability to understand the dynamics of the water cycle by allowing us to account for the flux of water between natural reservoirs (clouds, humidity, surface storage in lakes, surface channels, soil, plants, ground water, etc.), and by assessing the processes through which the water molecules proceed in the water cycle. Stable isotopes of oxygen (Oxygen-18) and hydrogen (Deuterium) have long been known to vary in precipitation and atmospheric moisture in response to meteorological conditions and moisture sources (Rozanski et al, 1993; Araguas-Araguas, 2000; Gat, 2000). Isotopic methods using tracers such as Tritium can be used to study catchment-scale dynamics, both the partitioning of water between surface and groundwater components and the residence time of water within a watershed. (Michel, 1992.) While an isotope network exists (Global Network for Isotopes in Precipitation, GNIP), few global or continental scale data sets of isotopes in runoff have been obtained so far. (An exception is the work of Coplen and Kendall, 2000.)

Concurrent observations of variability in precipitation, surface water and groundwater, as well as information on their isotopic composition will more fully test our ability to determine water balance and the water and energy exchange processes, and hence better understand both climatic processes and the hydrologic cycle.

4.6 Summary

Table 1 provides a summary overview of the importance and usefulness of individual hydrological variables in relation to the five thematic areas. The type of use of each variable is also given. The table provides a link to the discussion of individual variables that follows in section 6.

Table 1. ***Summary Table of Applications vs. Hydrological Variables***

Variable	Climate and weather forecasting	Climate variability, trend	Diagnosis, mitigation, adaptation	Sustainable development	Improved understanding of water cycle
Surface water – discharge	e (v)	e	e	e	e
Surface water storage fluxes	e (v)	e	d	e	e
Ground water fluxes	d	e	d	e	e
Water use	-	-	d	e	e
BGC transport	-	-	e	d	e
Isotopic signatures	-	d	-	d	e
Precipitation	e (i,v)	e	-	e	e
Evapotranspiration	d	-	-	d	e
Vapour pressure/ relative humidity	e	-	-	-	d
Soil moisture	e (v)	-	-	d	e (v)
Snow water equivalent	e (i)	e	-	e	e

e= essential; d= desirable; v= validation; i= input

5. Existing International Sources of Hydrologic Data

5.1 Global Precipitation Climatology Centre

The Global Precipitation Climatology Centre (GPCC) is operated by the Deutscher Wetterdienst (DWD, National Meteorological Service), located in Offenbach, Germany, under the auspices of the World Meteorological Organisation (WMO). The Centre was established in 1989 and contributes to the World Climate Research Programme's (WCRP) Global Precipitation Climatology Project (GPCP) and the Global Climate Observing System (GCOS).

The general task of the GPCP is the compilation of global gridded precipitation data sets based on observational data. The products are designed for the global climate research community and are especially required for:

- Verification of global climate models
- Investigation of climate anomalies, variability and special phenomena such as the El Niño - Southern Oscillation
- Study of the global water balance.

The scientific and technical functions of the GPCC are defined by the ‘Implementation and Data Management Plan for the Global Precipitation Climatology Project’ (WMO/TD-No. 367) and comprise:

- Acquisition, reformatting and storage of in situ observed precipitation data
- Monitoring of the data availability
- Quality-control, flagging, and correction of the data
- Calculation of monthly area-mean precipitation on a grid for land-surface based on conventional measurements
- Error assessment, estimation of the accuracy of the product, with regard to systematic measuring errors, data coding and transmission errors, sampling errors (station density), and methodical errors (analysis)
- Participation in merging of satellite and raingauge data of GPCP and in the further development of the method
- Development of advanced quality control and analysis techniques
- Dissemination of the products and research results to the scientific community.

To date, GPCC has collected monthly precipitation data from about 40,000 stations world-wide. Data from 7,000 stations are routinely updated and analysed near real-time. The other data are delivered in delayed time from 150 countries on a voluntary basis. The data collection of GPCC is primarily based on direct sources (contacts to the operators or official data centres) and is logistically supported by the WMO. But the GPCC also co-operates with other groups (as of Climate Research Unit, Norwich/UK, and of NCDC, Asheville/NC) in order to complete the database. The delivery and data processing of the large data amounts causes serious delays in the analysis.

The global gridded products, i.e. the gridded satellite-raingauge combined monthly precipitation data set of the GPCP (resolution 2.5° by 2.5°, 1979 to present) and the raingauge-based monthly analyses of the GPCC (resolution 2.5° by 2.5°, 1971 to 1994, and 2.5° by 2.5°, 1986 to present) are accessible via Internet. Due to the interest of the data originators (owners), the point precipitation data obtained by the GPCC cannot be made available. More information on GPCC is available at <http://www.dwd.de/research/gpcc/>.

5.2 Global Runoff Data Centre

The Global Runoff Data Centre (GRDC) has been established at the Federal Institute of Hydrology in Koblenz, Germany in 1988. Operating under the auspices of WMO, the principal objective of the GRDC is to collect and disseminate hydrological data to support projects within the World Climate Programme (WCP) and the World Climate Research Programme (WCRP) of WMO as well as for other programmes. With regard to GRDC, the Twelfth Congress of WMO adopted Resolution 21 (Cg-XII) which encourages Members (countries) "to support the GRDC through the provision of the hydrological data and related information that it needs".

GRDC provides a mechanism for international exchange of data pertaining to river flows on a continuous, long-term basis. The scope of data collection is global, regional and river basin-scale. The Centre employs a state-of-the-art Database Management System that ensures rapid data entry and retrieval services, complex queries, and fast response to data requests. So far, 147 countries contributed to the development of the database, which now consists of data from over 3800 stations monitoring about 2900 rivers world-wide. The database is being continuously updated. More information on GRDC is available at <http//:www.bafg.de/grdc.htm>.

5.3 UNEP GEMS/Water Collaborating Centre

The GEMS/Water Programme, which operates as the global water quality monitoring arm of the United Nations Environment Programme (UNEP), can bring the needed water quality information to a global hydrological network. The GEMS/Water Collaborating Centre in Burlington, Canada has for many years collaborated with GRDC on areas of common interest. The strength of this existing partnership can be brought forward in the design and establishment of the hydrological network.

The UNEP GEMS/Water Collaborating Centre in Canada undertakes a programme to achieve four major objectives:
1. Maintenance and expansion of the GEMS/Water global database
2. Expansion and development of the GEMS/Water monitoring network for water quality
3. Capacity building of water quality monitoring capabilities in developing countries
4. Water quality assessments at the global and regional scales in co-operation with other UN agencies.

To meet these objectives the GEMS/Water Collaborating Centre operates the global water quality data bank located at the Canadian National Water Research Institute; undertakes analysis, assessment, and interpretation activities; implements capacity building activities through country missions; and initiates training activities in conjunction with the United Nations University (UNU).

UNEP GEMS/Water operates world-wide, maintaining collaboration with WHO, WMO, UNESCO and other organisations and agencies which bring their expertise together on international activities. GEMS/Water operates and maintains a global water quality database comprised of data received from the participating national monitoring programmes. Approximately 100 countries are currently listed as participants. Since 1998, the number of participating and active countries in GEMS/Water has increased by 20 percent; the growing interest and activity reflects the rising importance placed upon water quality issues around the world. Expanded details of the structure and activities of the UNEP GEMS/Water Programme are provided in Annex III of this report. More information on UNEP GEMS/Water is available at <http//www.cciw.ca/gems>.

5.4 IAEA/WMO – GNIP

The Global Network for Isotopes in Precipitation (GNIP) is operated by the Isotope Hydrology Section of the International Atomic Energy Agency in Vienna, Austria. This world-wide survey of the isotopic composition of monthly precipitation started as early as 1961 in co-operation with WMO to study the raising Tritium levels in the atmosphere caused by nuclear weapon tests. The programme also aimed to provide systematic data on the global stable isotope content of precipitation as a basis for the use of environmental isotopes in hydrological investigations. It was soon recognised that the collected GNIP data are also useful in other water-related fields like climatology, oceanography and hydrometeorology.

GNIP reached its maximum in the early 1960s with 220 operative stations. Currently more than 180 stations are in operation from a total of 530 stations in the GNIP database. More than 30 percent of all isotope analyses are performed at the IAEA Isotope Hydrology Laboratory, while the others are measured in more than 30 collaborating laboratories. Altogether >100000 isotope measurements were performed within the GNIP. All the operation is done on a voluntary basis both by the sample collecting meteorological stations and by the analysing laboratories. In the past the data were published regularly in IAEA data books. For several years the whole database has been available on line from the IAEA GNIP homepage (http://www.iaea.org/programs/ri/gnip/gnipmain.htm). Details on GNIP are provided in Annex III.

5.5 WHYCOS

The World Hydrological Cycle Observing System (WHYCOS) was launched by WMO in 1993 with the aim of promoting co-operation in the collection and exchange of hydrological data at the river basin, regional and international levels and in developing products of interest to the participating countries. WHYCOS is being developed through a series of regional (HYCOS) projects, each of which includes a network of 40-50 Data Collection Platforms (DCP) reporting in real-time. Currently, some twelve projects are at various stages of implementation or development. In the spirit of WMO Resolution 25 (Congress XIII, 1999), the exchange of data collected within the framework of each HYCOS project is a pre-condition agreed to by the participating countries. Data from the projects in the Mediterranean basin and in Southern Africa are now accessible on the Internet. Information on the status of the various HYCOS projects is provided in Annex III.

WHYCOS is global in concept, but implemented on a regional basis. Reporting frequency is daily or shorter (3-hourly), thus providing near real-time access to data. At present, MED-HYCOS and SADC-HYCOS are reporting, and within the next 3 years three or four other operating HYCOS projects will also be active. More information on WHYCOS is available at < http://www.wmo.ch/>.

5.6 FRIEND

The collection of hydrological and related data in FRIEND (Flow Regimes from International and Experimental Network Data) is conducted in the framework of regional projects. Data collection is tailored to meet science needs defined in FRIEND working groups. Regional data centres store the data that are available to scientists collaborating in FRIEND projects. The amount of data varies largely from region to region. For example, the data archive of FRIEND Northwestern Europe contains hydrological records from more than 5000 stations. The majority of data is collected from small river basins. Access to data is based on rules established by the FRIEND networks, but one of the conditions is to contribute new data or ‘added-value’ science to enhance the understanding of high and low flows.

A presentation on the FRIEND project was made by Dr Grabs on behalf of Dr Bonell from IHP/UNESCO. The meeting participants discussed the presentation and the strong scientific underpinning of the programme. Participants felt that regional FRIEND projects should review their data dissemination policy to make the data and information useful within the framework of a global hydrological network, which requires free and unrestricted access to hydrological data and information. The meeting noted that some FRIEND projects tend to have a more liberal approach to this issue than others do. The participants recommended that regional FRIEND co-ordinators should be briefed about results of this meeting and that requests be issued to share selected data from FRIEND networks**.** More information on FRIEND is available at http://www.pangea.org/orgs/unesco/friend/.

5.7 GEWEX

A major goal of GEWEX is better understanding of the global hydrological cycle so as to enable an improved prediction of weather and climate, climate variability, and the availability of water resources. At the core of GEWEX are the Continental Scale Experiments (CSE). Data is held in distributed data centres and archives. In a planned Co-ordinated Enhanced Observation Period (CEOP), GEWEX will achieve an array of simultaneous, consistent set of observation of a large variety of hydrological, meteorological and energy flux variables. CEOP will ultimately allow the integration of global observations in the CSEs in regional and global scale prediction models. More information on GEWEX is available at http://www.gewex.com/.

5.8 HELP

A presentation on the HELP project was made by Dr Grabs on behalf of Dr Bonell. HELP is a joint UNESCO/WMO programme that is designed to establish a global network of catchments to improve the links between hydrology and the needs of society. It is a crosscutting programme of the UNESCO International Hydrological Programme, and will contribute to the World Freshwater Assessment Programme as well as the Hydrology and Water Resources Programme of WMO.

The vital importance of water in sustaining human and environmental health is the key driving force behind HELP. However, no international hydrological programme has addressed key water resource issues in the field and integrated them with policy and management needs. HELP will change this by creating a new approach to integrated catchment management. The new approach is to use representative catchments with real water related problems as the setting within which hydrological scientists, water resources managers and water law and policy experts can work together. HELP is therefore a problem-driven and demand-responsive initiative that will focus on the following eight key issues:

- Water and food security
- Water quality and human health
- Water and the environment (environmental health)
- Water and potential conflicts
- Impact of climate variability on water resources
- Improved communications between hydrologists and society
- Water-related disaster prevention and mitigation (flood control, drought management)
- Water for socioeconomic development.

The outputs of HELP will be new data for better process understanding of water transfer into, through and out of drainage basins (10^4 km^2 or larger), linked with models that are more suitable for the revision of current water policy and water resources management practices in the above eight areas. More information on HELP is available at http://www.nwl.ac.uk/ih/help/index.html.
The group noted several areas of common interest, in particular with regard to climate change and variability, improved weather forecasts, and sustainable development. In this respect, HELP could become an important user of global hydrological network services in the future. The participants realised that the concept of HELP has not yet materialised into specific projects or activities to which direct links could be established, but this is expected to take place from 2001 onward.

In Asia, two major projects, the Pacific region FRIEND and the GAME are being carried out. These projects promote the mutual data exchange and will contribute to the initiation of a global hydrological network in the region. The data obtained in the co-operative intensive observation period (1997, 1998) of GAME are now being analysed by the researchers who joined the project and will later become open to other researchers.

5.9 TEMS

The Terrestrial Ecosystem Monitoring Sites (TEMS) database was created in the mid-1980s by the Global Environment Monitoring System Programme Activity Centre (GEMS/PAC) of UNEP in Nairobi, Kenya. It was built as a register of terrestrial observation sites which access, measure, monitor and catalogue ecological data.

During the planning phase of GTOS (1993-1995), TEMS served the internal needs of GTOS but a number of requests were received to make the database more generally available. In 1994 the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) offered to manage and develop the TEMS database for GTOS. Since then, WSL has improved the available metadata, refined many of the tables, expanded the original database from approximately 150 sites to the present registered 700 sites, developed a user interface, and made TEMS accessible via the Internet. The following criteria have been applied to include sites into the TEMS database:

- The participating sites focus on activities directly relevant to one of the five key GTOS priority areas
- The participating sites actively collect, archive, and/or distribute environmental data on terrestrial/coastal ecosystems
- The participating sites have a stated interest in international collaboration that is tangible and includes responsible individuals who are committed to this orientation
- The participating sites have a reasonable history of terrestrial observations and/or security of long-term tenure and funding
- The participating sites either individually or collectively contribute to one or more levels in the Global Hierarchical Observing Strategy (GHOST; GCOS/GTOS, 1997).

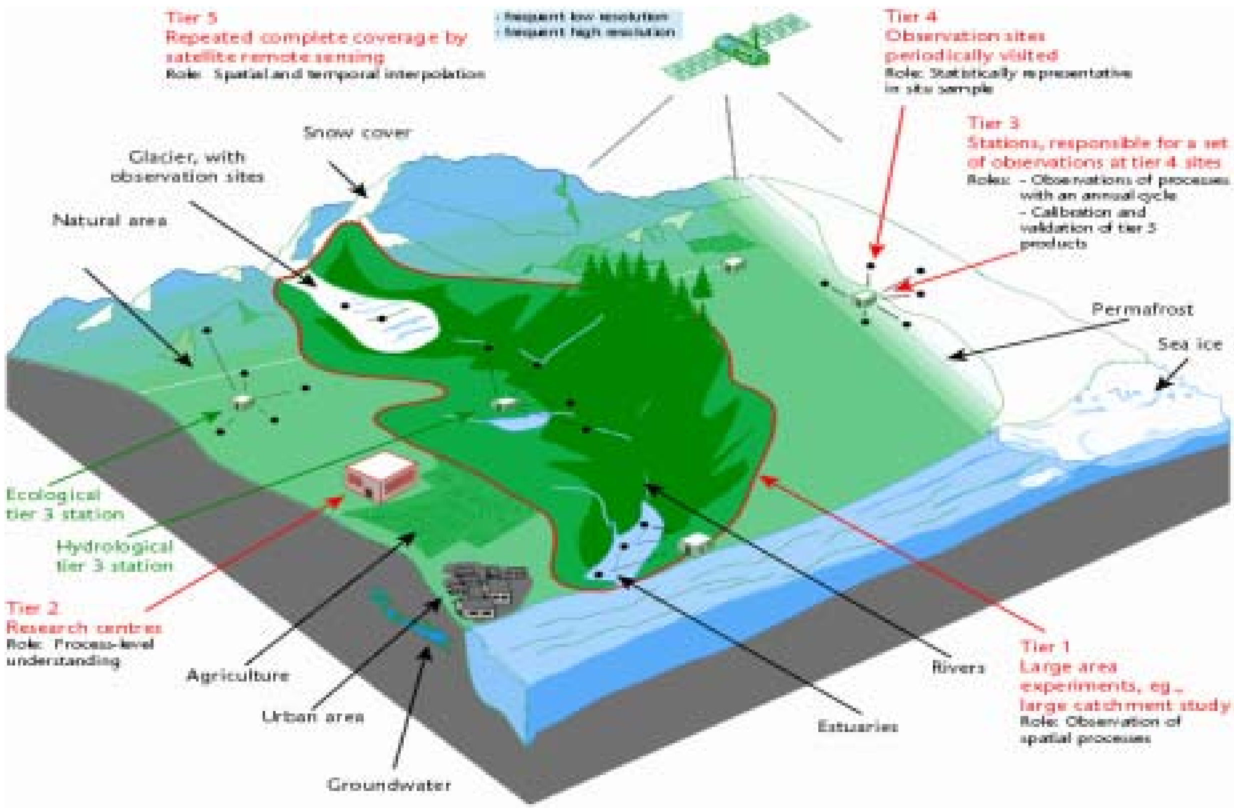


Figure 1. ***GHOST Tier Structure***

At its annual meetings in 1998 and 1999, TOPC reviewed the metadata base structure, and proposed several innovations for a new version of TEMS. Subsequently, a second version of TEMS was designed and prepared in MS-Access97 format at the GTOS Secretariat to include the following additional features and functions:

- Reduced set of environmental variables (from 530 to a core set of about 150) to cover the five GTOS issues listed above (except for toxics and pollution (planned)). Each variable has been classified as physical, chemical or biological
- Inclusion of socio-economic variables (common for all GTOS issues)
- Inclusion of definitions, rationale for measurements of these variables, methods and other ancillary information regarding the variables
- Links of variables and sites to GTOS issues, programmes (such as NPP and TCO), Conventions (climate change, biodiversity, desertification) and GTOS thematic networks
- Development of a set searchable maps (country boundaries, ecoregions, land cover etc.)
- Advanced query system (using Boolean operators i.e. AND, OR, NOT) with multiple criteria search

- Improving the resolution of the co-ordinate range for site location and search from degrees to seconds.
- The site manager address, telephone, email etc. are available for further information
- preparation of French and Spanish versions (planned)
- Links to the WMO/GCOS database on satellite sensors/missions of interest for space-borne measurement of certain variables (planned).

In addition, all the 700 sites registered so far have been re-contacted to update information on their sites; new questionnaires have been developed for this purpose. The re-registration is presently in progress. The present Access version of TEMS will be available on CD-ROM. An Oracle version of TEMS is in preparation and will be accessible via Internet. Site managers will then be able to update information on their sites through remote access.

6. Required Hydrological Observations and their Availability

The following 11 variables were identified as important by TOPC (section 2.4) and confirmed by the meeting participants. Each variable was then analysed to ascertain the present status of the observations and data products, their adequacy, and key actions required improving the status of these observations.

6.1 Surface Water-Discharge

1. Available data

1a. Point data
Discharge is typically calculated at a particular location in a river from measured water levels (the 'stage' or water level) by means of a transformation or rating curves developed for the particular channel cross-section at which the stage is measured. At many stations the water level is measured automatically in time-steps of several minutes to one hour. Because of the dynamics of the river bed, this rating curve has to be recalibrated with appropriate frequency. Other factors can also influence the transformation stage → discharge, including the presence of ice or vegetation or debris in the channel. Flow in a channel can be influenced by factors such as changes in land use, withdrawal for water use, or contributions from artificial water storage reservoirs, and thus discharge does not necessarily represent a response to climatic conditions.

The primary sources for hydrological data and information are the national Hydrological Services (NHS). These data are subsequently made available to other programs. For example, GRDC is the primary source for historical time series containing daily and monthly discharge data globally. WHYCOS and FRIEND potentially have global scope but are implemented through regional projects. GRDC has recently made substantial progress in compiling information on hydrological real-time data available on the Internet. Data collected from the Internet could be a component of a global hydrological network, and WMO therefore intends to request Member countries to provide information on stations that operate now and report in real-time. After obtaining this information a list of stations will be compiled in co-operation with

GRDC which WMO will explicitly request the Member countries to include in a global hydrological network. Examples of stage height and/or discharge measurements now available via the Internet include the US Geological Survey (http://water.usgs.gov/), Water Resources Research Centre in Hungary (http://www.vituki.hu), and hydrometeorological services of South America, Central America and the Caribbean whose data are available via a pilot web-based system R-Hydronet (http://www.r-hydronet.sr.unh.edu). This system was developed by the University of New Hampshire with the support of UNESCO Regional Office for Science and Technology ROSTLAC in Montevideo, Uruguay and provides access at three levels (anyone, participating services, and data owners).

1b. Gridded data

Observed river discharge represents the aggregated signal of the spatially variable runoff which is generated on the land surface as a surplus of precipitation. The excess water leaves land mass horizontally via various transport mechanism (surface sheet flow, groundwater flow, or river flow). Observed river discharge is the aggregated signal of this surplus water measured at some specific location along the river.

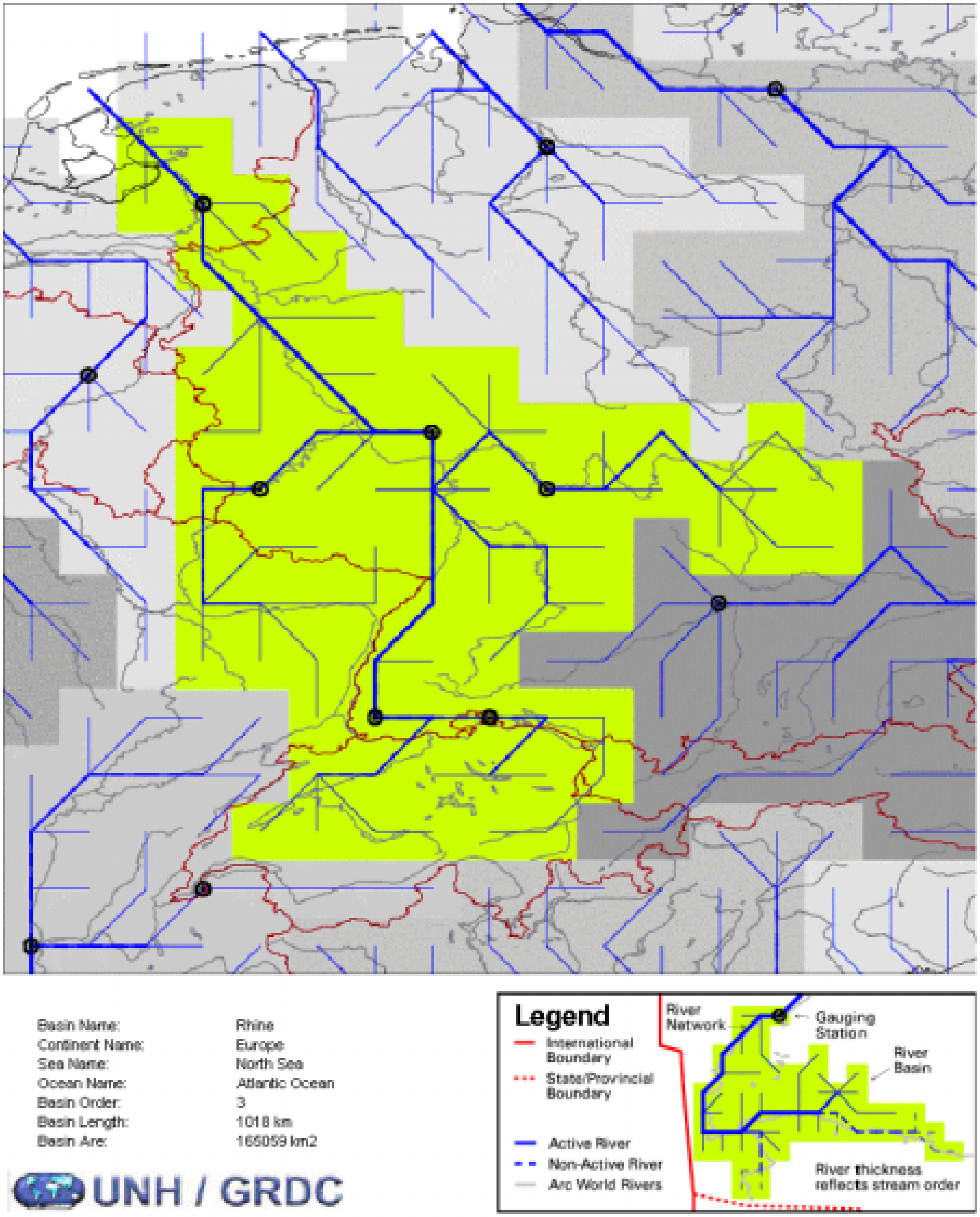
Since runoff cannot be measured directly over large areas, discharge at a river station is employed as the related measured variable. In contrast to most of the hydra-meteorological variables measured at a point, discharge has an area-integrating character. However, its regionalisation (i.e., determination of the spatial distribution of runoff) brings along some specific problems. The traditional approach employs water balance model calculation that considers precipitation and evapotranspiration computed from other measured climate variables (air temperature, vapour pressure, solar radiation). A better approach is to apportion the observed river discharge over the contributing landmass (Fekete et al., 1999). Since river discharge is typically measured at 10-20 percent accuracy (Dingman, 1994) as one of the most accurately measured component of the hydrological cycle (Grabs et al., 1996; Hagemann and Dumenil, 1998), runoff estimates derived in this manner should have higher accuracy.

The pre-condition to obtaining gridded runoff fields from discharge is an acceptable relation between the river stations, its discharge data, and the grid cells. This relation may be established from a digital elevation model (DEM), converted into an elevation grid and used to calculate the flow direction for each grid cell so that an artificial river net is produced. In addition, a net of basin boundaries can be created from the elevation grid. The main difficulty is that DEM will not capture all topographic features that should be considered in modelling the natural flow. Most problems will be found in very flat areas and in locations where the natural rivers cross mountains through narrow canyons. Since these cases can produce dramatic errors in the artificial river net the DEM must be manually edited by creating virtual walls or canyons to initiate flow directions resembling the natural flow. - Another problem is connected with the precise location of the river stations. Because of the differences between the artificial and the natural river nets one must manually establish the relation between the existing stations and the artificial river (Figure 2). Currently, different methods are under development for reducing the errors mentioned above and to make the procedures more automated.

After the artificial river net is linked with the discharge measurement stations, it is possible to estimate runoff for individual grid cells. Most of the available models use monthly means of discharge or long-term averages of monthly means. If the time step is reduced to daily or hourly, new types of models will be needed which better account for the storage capacity properties of the rivers and basins.

At present, only few gridded runoff products with a global coverage are available and all consider only long term means of variables. One of the most detailed global DEM is the USGS' 30 arc-second digital elevation model of the world. Under the name HYDRO1k it includes the gridded flow directions and river net. However, while this gridded network is the best available one at high resolution, it still suffers from errors since detailed manual corrections were limited by the enormous amount of data processed. At the present time GRDC is investigating these data sets for different potential applications.

A simple algorithm developed recently (Fekete et al., 2000) offers rescaling high resolution gridded networks (such as HYDRO1k) to any coarser resolution. Applying coarser resolution networks for large scale studies has two advantages. First, the gridded network is more manageable for correction and manipulations. Second, the coarser resolution requires less computation in horizontal water transport schemes. Thus, a 5-10 km resolution of gridded networks is probably appropriate for flow simulation at daily time steps, and 0.5^o x 0.5^o networks should satisfy the need of monthly flow simulations.



Example from: The UNH, GRDC Global Composite Runoff Data Set (v1.0) on CD, 2000

Figure 2. ***Topology for Gridded Discharge Products***

2. Does it meet requirements?

At the present time there is almost no international exchange of near real-time (NRT) or real-time (RT) discharge data. Only in few areas, regulated by international agreements and river commissions, NRT data exchange is taking place. In recent years, increasingly more national hydrological services present NRT data from their main river stations on the Internet (see above), so far mostly as stage level with a daily time step.

For climate and weather prediction purposes gridded runoff fields are necessary in NRT mode (section 4). This requires an access to suitable discharge data from selected hydrological stations world-wide. Furthermore, it requires an operational gridded runoff field-generating product.

Runoff is measured more reliably than precipitation and evaporation, and since the difference between precipitation and evaporation shows stronger temporal variation, trend analysis is easier to perform. However, trends are often not so much caused by climatological variations as by local impacts on the hydrological regime (such as local water extraction and consumptive use). Therefore, separation of local factors and regional or global change is difficult without the additional information on water use (section 4.3, 4.4).

3. Key actions

The extent of Internet - accessible discharge and water-level data should be determined. Priority attention should be given to the 200 stations used by GRDC in the calculation of the freshwater fluxes into the ocean (Grabs et al., 1996). This subset should be gradually extended, and the final list of stations should be identified after also considering results of network design studies (see Fekete and Vörösmarty, Appendix 3).

As a starting point for a global hydrological network, data should be obtained from the 200 gauging stations close to the mouth of rivers. These data should be available in a timely manner, where possible in near real-time mode wherever possible. In relation to the GEWEX CSEs and particularly efforts to compile global data sets in an Co-ordinated Enhanced Observation Period (CEOP) between 2002 and 2005, liaison should be established to take advantage of these data collection efforts and to promote the role of the global hydrological network in the GEWEX Hydrometeorological Panel (GHP).

WHYCOS and FRIEND regions might contribute to a global hydrological network as regional centres for collecting real-time data. This could be done via a Web interface with upload and download capabilities (section 7).

Concerning observation needs, it was concluded that stage heights with corresponding rating curves should be reported, in addition to discharge. Rating curves are important as metadata for the gauging stations, however their time-varying nature must be taken into consideration. It was recognised that the conversion of gauge heights into discharge outside the control of the institution responsible for the collection of data might result in serious quality assurance questions.

The usefulness of existing gridded runoff field products for quasi-operational use should be tested. These products could also be used easily as an additional input for climate forecast models (validation and calibration). They could be presented on the Internet using tools such as similar to the GPCC-visualizer (http://www.dwd.de/research/gpcc/visu_gpcc.html).

An ongoing review of new developments in hydrometry should be maintained (e.g., the proposed HYDRA-SAT; Vörösmarty et al., 1999;http://lshp.gsfc.nasa.gov/Post2002/hydrasat/hydrasat2.html).

4. Historical data

At the global scale GRDC collects and archives daily and monthly discharge data from approximately 3800 selected stations with a more-or-less regular updating by NHSs. Most NHSs store all of their discharge and water-level data at country level in different non-standard formats.

6.2 Surface Water Storage Fluxes

This variable is directly related to the retention of surface fluxes in lakes, reservoirs and wetlands. The participants also discussed the issue of water storage in river channels, flood plains and large estuaries but decided to exclude these types of storage for the initial period.

At present, most climate circulation models do not realistically model lateral water fluxes, in part because of inadequate information on flow times; flow retention in dams, reservoirs, lakes and wetlands; and the evaporative loss of water from storage surfaces. Improved data are therefore required to increase the realism of the model results.

1. Available data

At the present, coherent lake reservoir data bases with global coverage do not exist, however pieces are available at various locations. The International Lake Environment Committee (ILEC, a non-governmental organisation established in 1986 in Japan, http://www.ilec.or.ip/e_index.html) maintains a database of lakes and reservoirs, however this database does not contain time-series of relevant hydrological variables. Another lake database, the MSSL/WCMC/UN Global Lake and Catchment Conservation Database', was developed by Mullard Space Science Laboratory of the University College London as a prototype for remote sensing applications (Birkett and Mason, 1995). It includes over 1400 lakes and reservoirs, but a very limited set of attributes (lake names, location, country, surface area and elevation estimated from Operational Navigational Charts maps, etc.; http://wwwcpg.mssl.ucl.ac.uk/orgs/un/glaccd/html/mgld.html). Remote sensing (satellite altimetry, and monitoring of the area of lakes and reservoirs) has the potential to provide some of these attributes (Birkett and Mason, 1995).

The International Commission on Large Dams (ICOLD) maintains a registry of dams (ICOLD, 1988). This database was originally published in books (paper form only), but recently became available electronically on CD-ROM. The ICOLD registry contains information on several thousand reservoirs, assembled from an engineering perspective. One criterion for including reservoirs in this registry was to have 15 m or higher construction, thus potentially leaving out many reservoirs in plain regions where several metres high dam construction might result in large inundation. While detailed information on the dam construction (purpose, height, length and volume of the construction, construction type, spillway capacity,) are provided beside basic information on the reservoir itself (maximum capacity, reservoir surface area, etc.), but other essential information (including location, mean discharge through the reservoir) is missing. The only way to geographically identify these reservoirs is by the nearest city and river names that are provided as part of the database. Several attempts have been made to identify these dams on maps and correct the information (by UNH, GRDC, CESR). – In related efforts, USGS developed a dam inventory for the US, and Russia maintains a database of lakes and reservoirs of the national territory.

The merging of the above mentioned lake and reservoir data sets with the available digital maps could be a basis for a more detailed global lake/reservoir database, but this work is not trivial and needs extensive manual effort.

It was noted that at present no dynamic information is available on lakes and reservoirs (level changes, operation, etc.). Remote sensing (satellite altimetry, monitoring of the surface area) has the potential to solve this problem. The group was informed that NASA GSFC is working on using satellite altimetry (TOPEX/POSEIDON, ERS-1) to measure lake and reservoir levels (Birkett, 1998).

2. Does it meet requirements?
No. At the present time, global information on surface water storage in lakes, reservoirs and wetlands is inadequate in terms of coverage and time-series observation of changes in the storage volume at all scales. However, it was noted that higher resolution information available only in some regions is also important, given the regional nature of some hydrological issues.

3. Key actions
The State Hydrological Institute (SHI), St. Petersburg, Russia expressed an interest in hosting a global data centre for lakes and reservoirs. WMO intends to follow up on these activities. Furthermore, contacts should be made with ILEC to determine a possible inclusion of its database.

6.3 Groundwater Fluxes

Groundwater fluxes have a major influence on the dynamics of the global hydrological cycle (Zekster and Loaiciga, 1993). Because groundwater tends to respond more slowly to short term climatic variations than do surface water resources, this variable is often not considered to be of first-order importance from climate change perspective. A US National Research Council panel (Panel on Climate Observing Systems Status, 1999) considered groundwater data to be of low importance for the detection of groundwater change, but highly important to climate questions because of its high potential impact. Alley et al. (1999) also noted that climate can be a key consideration in the sustainability of ground water resources.

1. Available data

The group recognised that, similarly as for surface water storage fluxes, no global ground water flux data sets are readily available at the present. Some attempts have been made to organise national collections of time series data, notably by the Netherlands, the UK and the US, and some regional data sets are accessible via Internet.

2. Does it meet requirements?

No.

3. Key actions

An International Groundwater Resource Assessment Center (IGRAC) has been proposed by the Government of the Netherlands to the WMO Commission on Hydrology. If accepted at the November 2000 meetings in Nigeria, this center will close an important information gap. It is expected that variables to be documented by IGRAC would include: groundwater levels in boreholes, water volume changes, aquifer characteristics such as porosity and transmissivity, aquifer withdrawal rates, recharge rates, and well productivity.

6.4 Biogeochemical Transport from Land to Ocean

These measurements are intended to quantify the transport of carbon, phosphorus and other elements from the terrestrial environment to oceans.

1. Available data

At present no comprehensive global monitoring programme is in place. However, GEMS/Water obtains data from numerous water quality observing stations (refer to section 5.3 and Appendix 3), although the water quality information is not available near real-time. The Centre releases data products and assessment results, while the distribution of raw data is governed by agreements with data providers. All data in the GEMS/Water Global Database are available for use in global and regional assessments undertaken by the UNEP GEMS/Water Collaborating Centre (GWCC) and may be used in other assessment programs where the GWCC is participating.

GEMS/Water produces publications guiding the design and operations of freshwater monitoring programmes at the national and multi-national levels. The GEMS/Water Operations Guide is available in five languages and is provided at no charge to participating countries. The guide includes sections on site selection, sampling procedures, data handling, and database operations. This information is a valuable tool in establishing BGC transport data requirements, particularly in developing countries. Similarly, GEMS/Water produces information on quality control design and data integrity along with an analytical methods manual and methods dictionary.

Recent assessment reports include Persistent Organic Pollutants in the Asia/Pacific Rim, and Persistent Organic Pollutants in the Russian Federation. A detailed listing of GEMS/Water products is available on the GEMS/Water web site <http://www.cciw.ca/gems>.

Other programmes and activities relevant to BGC fluxes from land to oceans include the IGBP project Land Ocean Interaction in the Coastal Zone (LOICZ), the multi-agency programme Land Based Sources of Pollution, and the UNEP Global Programme of Action.

2. Does it meet requirements?

The requirements for comprehensive information on BGC transport from land to oceans cannot be fully met by the existing observation sites. However, the data are sufficient to provide the preliminary input to this component, and funding as well as other support will be required for expanded operations.

3. Key actions

- A list of water quality variables needs to be developed through consultation with scientific and other users; carbon, nitrogen and other nutrients should be considered (GCOS, 1997). The serious impact of micro-pollutants (such as chemicals in the POP family) on the environment was recognised. However, the scarcity of qualified analysing laboratories would pose a severe constraint on operational monitoring systems. The GEMS/Water Analytical Methods Dictionary will be made available to collaborating organisations to assist in improving BGC transport observations.

- Data collection activities should be intensified. Co-ordination of data acquisition is needed to ensure that an appropriate data mesh can be achieved, particularly for the computation of fluxes.

- Contacts should be made through GEMS/Water with other groups collecting or using biogeochemical data (LOICZ, UNEP, etc.) to investigate areas of possible co-operation.

6.5 Isotopic Signatures

1. Available data

About 180 precipitation stations presently collect samples for monthly isotopic analysis by GNIP. More frequent measurements are undertaken for a few research stations over shorter periods. The GNIP database is available for public use<http://www.iaea.org/programs/ri/gnip/gnipinfo.htm>and presently contains data until 1998. Each year an update is released, with the time delay of about two years being unavoidable due to the complicated laboratory analysis procedures and data reporting to IAEA. The GNIP database will soon be merged in the more comprehensive data system ISOHIS (Isotope Hydrology Information System), which will include data from IAEA technical co-operation projects on water resources assessment and management (local/regional field studies on surface and ground water of typically two years' duration).

The operational use of isotope measurement in riverine environment was extensively discussed at the meeting. While the monitoring programme has research flavour at the present time, the physical processes are well known and the isotope measurements could be used immediately for water balance studies using e.g. water stable isotopes (Kendall, 1997).

In addition to the GNIP data base, several modelling groups have published gridded global data sets on the stable isotopic composition of precipitation and air moisture.

2. Does it meet requirements?

No, in terms of a NRT network, which is not feasible for any parameter to be measured in laboratories. Yes, in terms of scientific communities requesting such isotopic information for studies of climate change, paleoclimate and hydrological investigations.

3. Key actions

It is suggested that as an initial step, up to 30 stations in representative river basins be identified, perhaps with special focus on the GEWEX and WHYCOS regions and possibly also FRIEND and HELP basins. The participants recommended that a mechanism should be developed to promote isotope measurements; WMO and UNESCO may also assist in this regard. The most useful isotopes have already been identified: $\delta^{18}O$, $\delta^{2}H$, and ^{3}H. The group further recommended placing emphasis on flux stations with very good data series and on stations with high observation frequency. GEMS/Water will inquire about the extent of isotope analysis through the GEMS/Water network and will consider the application of water sampling for further isotope analysis undertaken by IAEA programmes (GNIP). In 2001/2002, IAEA will launch an international co-ordinated research programme to investigate in detail the feasibility and pre-conditions necessary for a river basin isotope sampling network.

4. Historical data

Virtually all existing historical data are incorporated in GNIP.

6.6 Water Use

1. Available data

1a. Polygon data

Internationally, water use data are highly heterogeneous in quality and availability (administrative, spatial and temporal). The most recent historical and present-day estimates of withdrawal and consumptive water use are provided by Shiklomanov (1999) who provides information for 26 natural-economic regions covering the whole globe as well as for selected countries. The World Resources Institute (1998) provides a compilation of sectoral water withdrawals by country. The only consistent data set for water use, with a high spatial resolution (county level) is available for the United States in the 5-year reports of the USGS (USGS, 1998).

1b. Gridded data

At the University of Kassel, the WaterGAP 2 model is used to derive sectoral water uses for the year 1995 with a resolution of 0.5° x 0.5°. Model results are based on published data on irrigated areas, livestock numbers, and country values of domestic and industrial water use. Due to the high uncertainty of the input data, the gridded water use data are also uncertain.

2. Does it meet requirements?

No.

3. Key actions

Appropriate national bodies should be encouraged to develop a reporting model of spatially resolved sectoral water use. The USGS scheme (reporting by both political and hydrologic spatial units, for various economic/industrial sectors, on a five-year time step) could be used as an appropriate model format. Furthermore, countries should make the information on water use internationally available. The participants were also informed that water quality indicators would be proposed as part of the World Water Development Report, to be published in early 2002.

6.7 Precipitation

1. Available data

1a. Point data

Precipitation is observed at a large number of stations (about 200,000 world-wide) in national meteorological or hydrological networks. Most of the data are used mainly in a national framework.

Various meteorological variables including precipitation depth and type are routinely observed on an hourly to daily basis at synoptic weather stations. The data are transmitted in RT or NRT as SYNOP to the national meteorological services. A subset of the records (nominally from 8,000 stations) is exchanged globally among the national meteorological services using the World Weather Watch Global Telecommunication System (GTS). Within this system, precipitation data are presently available from about 4,000 stations. Additional synoptic data are exchanged regionally (RBSN = Regional Baseline Synoptic Network) or through bilateral agreements.

Daily climatic data of precipitation and air temperature are also observed by large networks. Monthly-summarised observations are also globally exchanged as CLIMAT via GTS from nominally 2,200 but actually ~1,200 stations. The CLIMAT and SYNOP collections are partly overlapping. Users can obtain the global, regional or national synoptic or climate data from the national meteorological services on request.

About 1,000 stations, globally distributed and providing historical time-series and still being operated, are defined in the GCOS Surface Network (GSN). Monitoring centres supervise the data availability. These stations are partly overlapping the CLIMAT collective.

Additional precipitation data are collected in delayed time by individual institutes based on special bilateral or international agreements. The use and distribution of these data is generally restricted to defined projects.

1b. Gridded data

The access to gridded data is generally less restricted than to point data. There are several sources of global or regional gridded precipitation data:

- Derived from raingauge data (GPCC, CRU)
- Based on satellite observations (NOAA, NASA)
- Combined from raingauge and satellite data (GPCP, NCEP)
- Produced from NWP model data assimilation or forecasts (ECMWF, national meteorological services)
- Radar-based (quantitative data only for few regions or countries available, e.g. Japan, USA)
- Special regional combined or single-source analyses (e.g. GEWEX CSEs).

Gridded data should provide accuracy measures or information on the error with the precipitation on the grid.

2. Does it meet requirements?

The observational database of global gridded precipitation data sets is not yet sufficient in terms of the number of stations and the timeliness of data availability. Even for a relatively coarse product (global monthly product with a spatial resolution of 1.0° x 1.0°) data from 40,000 raingauge stations world-wide should be available on a routine basis and in timely fashion.

3. Key actions

- Regulation of the global exchange of additional precipitation data. Renew emphasis should be placed on the recommendations of 10th WMO Congress 1987 to increase the dissemination of precipitation CLIMAT reports globally from 2,200 stations as nominal now to 25,000 stations (WMO Technical Regulations (B.1.) 3.1.1.2).

- Evaluation of other data transmission systems if GTS is unable to support larger data amounts.

- Supporting the initiative of an international Global Precipitation Mission (GPM) as a global follow-up to the Tropical Rainfall Mapping Mission (TRMM).

4. Historical data

The Global Historical Climatology Network project of NCDC in Asheville, US collects available historical precipitation and air temperature data. The data set is freely available at WDC-A for research purposes. The temporal and spatial coverage of this collection is very heterogeneous and contains numerous gaps. An additional quality control and supervision of the entire data set would be very valuable.

Gridded precipitation data derived from raingauges are available for the entire 20th century from CRU. However, the temporal and spatial coverage of the data used in the analysis is very heterogeneous and partly incomplete. CRU and GPCC are working to improve and homogenise the database.

6.8 Evapotranspiration

This section only considers 'direct' measurements of actual ET, not potential evapotranspiration (PET) estimates from formulae or from pan evaporimeters. Strictly speaking, even the direct measurements are estimates because of the observation methods used.

1. Available data

1a. Point data

Traditional assessments of ET have been made using lysimeters. Recent developments using flux towers enable estimates to be made using eddy correlation and Bowen Ratio techniques. There are relatively few of the towers and the longest time series are ~5 - 10 years. Estimates using both methods are not exchanged internationally and are rarely available in real time, even nationally. There are intentions, however, to make some estimates (e.g., from the ARM/CART sites in Oklahoma, USA) available in near-real time to evaluate the performance of reanalysis and operational analyses.

1b. Gridded data

There are as yet no gridded ET products, except possibly in climatological (long-term averages) atlases.

2. Does it meet requirements?

At present data availability preclude the use of ET estimates for model validation in operational analyses. ET is used in few climate variability and change studies, partly because of availability but principally because long time series do not exist. ET is a component of the water balance and is thus important for hydrological and ecosystem modelling. In many studies, use is generally made of PET calculated from formulae.

3. Key actions

A pilot project is needed to test whether estimates from the few FLUXNET sites can be made available in near-real time. The project should also consider methods for evaluating the performance of operational analyses and whether the raw measurements can be directly assimilated by operational analyses, potentially improving global scale prediction on time scales of 2 days and longer.

4. Historical data

(a) FLUXNET

FLUXNET data area available for one to <10 years for a variety of terrestrial sites. An Internet site has been set up to facilitate the acquisition and exchange of these observations (http://www-eosdis.ornl.gov/FLUXNET/).

(b) Lysimeter
These data are likely to be archived locally, principally by the agroclimatological centres that collected the data.

6.9 Vapour Pressure

It was decided at the meeting to substitute vapour pressure for the originally defined relative humidity. An important reason is that vapour pressure is reported on GTS, is directly useful for NWP modelling and, given air temperature, can be used to compute relative humidity (New et al., 1999, 2000).

1. Available data

1a. Point data

The components needed to calculate vapour pressure are measured at the vast majority of GTS stations on the SYNOP and CLIMAT networks. All the issues, therefore, that relate to precipitation apply for this variable. In addition, new data sources are emerging (e.g., sensors installed on aircraft platforms) that are likely to increase in importance in the future.

1b. Gridded data

Fields are available for the surface in the reanalyses (e.g., by NCEP) and in all operational analyses.

2. Does it meet requirements?

As with precipitation, more station data from the RBSN/RCIN could be exchanged, improving the density of point measurements in some WMO regions and the quality of reanalysis/NWP data sets.

Vapour pressure is rarely used in climate variability and change assessments, although it is an important component of many potential evapotranspiration formulas and consequently is a factor in many water cycle and sustainable development studies. On monthly time scales, however, it has correlation decay lengths comparable to temperature (New *et al.*, 1999, 2000), so a network as dense as for precipitation is not required.

3. Key Actions

- Improve the density of measurements, and facilitate international exchange by making RBSN/RBCN data available to all regions (as for precipitation measurements).

4. Historical data

Monthly values, part of CLIMAT messages, have been archived at a number of centres (e.g. WDC-A, NCDC/NCAR) since vapour pressure was added to the CLIMAT network in 1961.

Gridded fields of vapour pressure at a 0.5° x 0.5° resolution are available from the Climatic Research Unit (CRU, UEA) for the period starting in 1901 (New *et al.*, 1999, 2000). These fields use measurements from the CLIMAT network after 1961 and empirically derived relationships before this date (using cloudiness and diurnal temperature range). Fields before 1961 are less reliable because they are based on these empirical relationships and the data for the primary valuables are less spatially complete.

6.10 Soil Moisture

1. Available data

1a. Point data

A number of networks for soil moisture measurements exist in different parts of the globe. However, at this time there are no co-ordinated international networks for such measurements on a regular basis. The Illinois, US network includes soil moisture measurements at 19 stations from 1981 to the present and represents one example of data source suitable for some climatological studies.

Recent advances in the technology of soil moisture measurement have made it feasible to establish sites for automated soil moisture and soil temperature profile measurements. The US Department of Agriculture is implementing a Soil Climate Analysis Network (SCAN) for the USA and currently has more than 40 stations reporting in real time. A multi-scale network of heat dissipation sensors was also installed in 1996 within the Oklahoma-Kansas region. This network consists of 132 stations, recording observations as often as every 30 minutes. Several of the GEWEX CSEs (including GAME, GCIP and the LBA) have supported the installation of automated soil moisture sensors as part of their research activities.

1b. Gridded data

There are no gridded soil moisture data sets currently produced from point measurements. The global modelling and prediction centres that currently operate coupled land surface-hydrology/atmosphere models for analysis and predictions are capable of producing gridded soil moisture data as an output from these coupled models; however, these outputs are highly model-dependent.

A research project supported by GCIP is now producing experimental gridded soil moisture data using a Land Data Assimilation System (LDAS) which covers the conterminous US (Mitchell et al., 1999). LDAS could be implemented as part of the operations by NCEP if the current experiment achieves improving weather predictions from the regional NWP model. In another project, a soil moisture index for Europe and Africa is derived from meteorological satellite data; this work is done within the framework of the EUMETSAT Satellite Application Facility for Land Surface Analysis (Land-SAF) and is led in Germany by the Federal Institute of Hydrology.

2. Does it meet requirements?

The requirement for soil moisture data for weather and climate prediction is not being met except as derived within the prediction model. For sustainable development it may be necessary to use separate models tuned to hydrology and carbon with the goal of developing an integrated land/biosphere model.

3. Key Actions

- Encourage further development of the model-based regional soil moisture products and their extension to a global scope and ongoing operation
- Support the installation of point measurements at appropriate meteorological stations, especially those designated as part of the regional and global synoptic networks of WMO
- Support further assembly of historical soil moisture data sets for climate variability and change assessment. This should include the compilation of available point measurements and the preparation of retrospective LDAS model-based soil moisture products
- Support development of satellite missions capable of delivering soil moisture information such as the currently planned Soil Moisture Ocean Salinity (SMOS) mission by the European Space Agency.

4. Historical data

In situ measurements of soil moisture have been made by a number of countries around the globe during the past 70 years. Robock et al. (2000) describe a global soil moisture data bank dedicated to collection, dissemination and analysis of soil moisture data from around the globe. The data bank, as of late 1999, had soil moisture observations from over 600 stations from a large variety of global climates, including the former Soviet Union, China, Mongolia, India and the US. Most of the data are in situ gravimetric measurements of soil moisture; all extend for at least six years and most for >15 years. Most of the stations have grass vegetation, and some are agricultural sites.

The lack of routine observations of soil moisture has led to the use of surrogate measurements and modelled estimates as substitutes, thus limiting the possibility of verification and intercomparisons among 'non-standard" estimates of this variable. One of these is referred to as "soil wetness" which refers to the amount of soil water computed from a land-surface model. The Global Soil Wetness Project (GSWP) is an ongoing modelling activity of the International Satellite Land Surface Climatology Project (ISLSCP). One of the goals of the GSWP is to produce state-of-the-art global data sets of soil moisture, surface fluxes, and related hydrologic quantities. A Pilot Phase of the GSWP made use of the ISLSCP Initiative I data to produce a two-year global data set of soil moisture, temperature, runoff, and surface fluxes by integrating one-way uncoupled land-surface parameterisation (using externally specified surface forcing and standardised soil and vegetation distributions; Dirmeyer et al., 1999).

6.11 Snow Depth and Snow Water Equivalent

1. Available data

1a. Point data

Snow depth is reported in the WMO synoptic code. Snow water equivalent data are largely based on snow surveys conducted by countries at higher latitudes.

1b. Gridded data

Daily operational products of areal extent of snow cover in the Northern Hemisphere are generated by the

NOAA National Environmental Satellite Data and Information Service (NESDIS). Regionally, operational snow water equivalent products are prepared daily for the western portion of the USA by the NOAA/National Operational Hydrology Remote Sensing Center using ground based and airborne survey data as well as satellite data. Products for the eastern USA are made as needed based on snow cover analysis.

2. Does it meet requirements?
The areal extent of snow cover for the Northern Hemisphere is adequate for the current applications in regional and global prediction models. The currently available snow water equivalent data are too limited in geographic coverage for weather and climate forecasting purposes.

3. Key actions

- Evaluate the feasibility of producing modelled snow water equivalent products using energy balance principles and mesoscale atmospheric model output.

- Support the further development of deriving snow water equivalent and snow cover from satellite data
- Endorse the plans of the Climate in the Cryosphere (CLIC) subprogram in the WCRP to collect global cryospheric data including snow water equivalent.

4. Historical data
Gridded products of areal snow cover exist since the advent of the operational polar orbiting meteorological satellites in the late 1960's with evolutionary improvements in quality resulting from improvement in the sensors and the analysis techniques. Synoptic observations of snow depth exist as part of the global archive for this data set. The WDC-A maintains various holdings of data on climate, glaciers, ice cores, ice sheets, lake and river ice, snow, permafrost and frozen ground <http://nsidc.org/NSIDC/CATALOG/index.html>.

6.12 Integration of Hydrological Information in a Geographical Information System

The assembly of hydrological data sets is the first step in applying these in hydrological analysis, but due to the spatial nature of hydrological processes it is essential that they be organised in a coherent way. The incorporation of gridded data into a geographic information system (GIS) context must give special attention to the co-registration of point data (discharge gauging stations or the location of reservoirs, water uptake, pollution sources, etc.) to gridded river networks. One advantage of linking different data sets within GIS is the ability to identify inconsistencies in the different data layers, e.g. catchment area reported at discharge gauging stations vs. the catchment area estimated from a simulated gridded river network; identification of the adjacent downstream gauging station; calculation of inter-station areas and inter-station discharge; co-registration of reservoirs, gridded river network and runoff fields; residency time (reservoir capacity / discharge); and others.

7. Toward a Global Hydrological Network

In section 4., the major applications requiring hydrological observations were identified. To meet these observation requirements, a capability must exist to evaluate requirements and to acquire, assemble and make available global data sets of hydrological observations. This capability should be able to deliver observations with the appropriate spatial resolution, observational frequency, timeliness, and quality. It is proposed that these roles be met by a Global Terrestrial Network for Hydrology, GTN-H. This network would complement other existing global terrestrial networks grouped under GT-Net (http://www.fao.org/GTOS/PAGES/Gtnet.htm), namely GTN-G for glaciers, GTN-P for permafrost, and GTN-E for ecosystem observations (see also section 2.3, 2.4).

The primary users of GTN-H products will include international conventions (Framework Convention on Climate Change, Convention on Biological Diversity, Convention to Combat Desertification); global observing systems; major water-related programmes and initiatives of the United Nations; the research community with focus on national to global scales; and regional and national agencies concerned with climate change impacts and sustainable development. As discussed in more detail below, the network would initially be formed through an association of existing data acquisition networks, data assembly facilities, and product generation centres; new capabilities would be added as and where required and feasible.

7.1 Functions

GTN-H is envisioned to have the following functions:

- Promote and monitor making of the required observations, monitor their quality and ease of delivery and advise co-operating institutions so that the observations are responsive to and consistent with the evolving user needs
- Provide timely access to hydrological metadata and to the data needed to generate products
- Generate or facilitate the generation of relevant products and the related documentation, satisfying timeliness and quality requirements of users
- Promote standardisation of observations and the use of best practices
- Provide access to data and products within the existing framework, such as WMO Resolutions 40 and 25
- Obtain user feedback, and ensure responsiveness to it and to changing needs within the diverse user community.

In general, GTN-H activities will concentrate on hydrological data and products, including data acquisition and assembly; product generation, distribution and archiving; etc. However, GTN-H must also be linked with, and responsive to, a broader framework, both thematically and organisationally. For example, from a climate perspective the main objective is to observe regional and local changes in hydrological variables that respond to or force climate, directly or indirectly, and to understand the processes by which these variations occur, rather than documenting climate change detection per se.

Figure 3 illustrates some of the GTN-H functions and feedback loops. An important distinction needs to be made on the basis of timeliness of data delivery. Real-time hydrological data are needed continually for numerical weather prediction, for some aspects of seasonal climate forecasting, as well as for assessment of hydrologic conditions when anticipating hydrologic hazards such as flooding. These measurements can be assimilated directly into the models, thus requiring no further assembly or generation of products. The data can now be made available primarily through GTS, a system established and operated to support the World Weather Watch Programme of WMO, NWP and related applications. However, it may be feasible to also use the Internet for data transmission such as currently done nationally by the USGS; this aspect would require careful analysis of the implications for global distribution. As Figure 3 indicates, products requiring assembly, screening and processing of the original observations are produced in delayed time, with the length of delay varying depending on the nature of the product as well as the data handling capabilities.

In general, GTN-H is concerned with the terrestrial portion of the global water cycle, that is, the movement of water on, above and below the earth's surface. Therefore, it must interface with other aspects of the earth system: energy fluxes and biogeochemical cycles, notably the global carbon cycle and its terrestrial component; terrestrial sediment flux processes; the oceanic, atmospheric, and cryospheric parts of the global water cycle; and the earth’s climate. For the same reasons, GTN-H evolution needs to include consultation and collaboration with programs and agencies that are concerned with these aspects of the earth system.

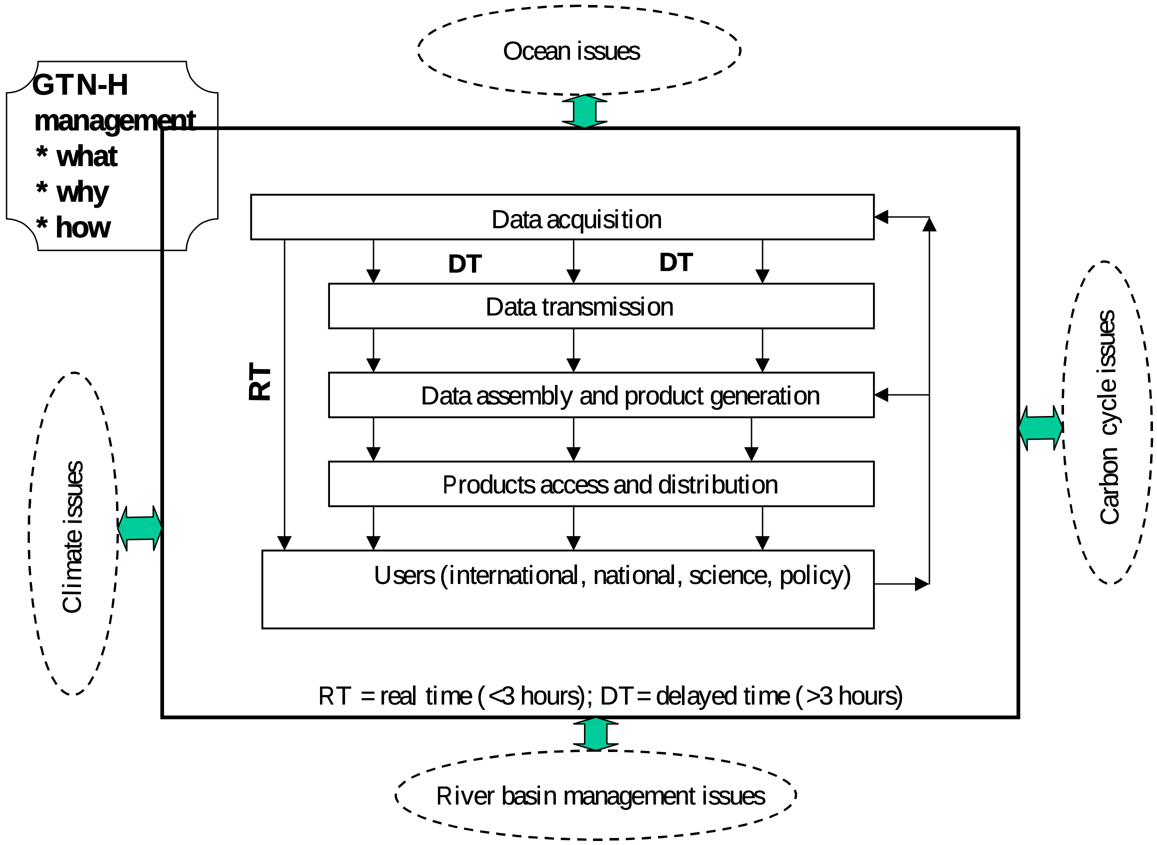


Figure 3. ***The General Context and Data Functions of GTN-H***

7.2 Attributes

GTN-H is envisioned to have the following major characteristics:

- It will be a cluster of networks, created through collaboration of existing networks where possible. Only in specific areas where requirements are not met or significant observational gaps exist would additional capabilities be established;
- Its domain is global, thus must ensure consistent global coverage. The global framework will be structured to accommodate regional to national enhancements as desired, e.g. in spatial or temporal resolution, variables observed, etc. Over time, it will strive to increase the coherence among the participating networks, particularly through collocation of observing sites and through consistent measurement protocols;
- It will take maximum advantage of existing sites, data and product centres, and hydrological services;
- It will consider the production of global products for hydrological variables as its major goal;
- It will stress accumulation of coherent multivariate data sets which are necessary for the understanding of hydrological and climatological processes, as well as the assessment of resource sustainability;
- Its products and compilations will be available without restriction.

It is suggested that the spatial context of individual sites in GTN-H be established using global site - specific data sets with designated hydrologic connectivity between sites as well as global gridded data sets, with the grid cell size chosen in relation to the requirement as well as to the data type(s) under consideration. Normally, the various grid sizes would be nested, giving flexibility in scaling and data handling. The catchment topology (stream networks, watershed boundaries, topography, land cover and land use distribution) can also be readily accommodated through co-registered overlays. These various GTN-H attributes can be readily linked once placed in a geographic context, and existing information processing tools (e.g., geographic information system software) can be used to achieve efficient data utilisation. Initial steps in this direction have been taken by GRDC and UNH (see also section 6.1 and 6.12). The various levels of observation intensity at individual sites can be accommodated through the tier concept of the Global Hierarchical Observation Strategy (GHOST; GCOS/GTOS, 1997).

7.3 GTN-H Components

It is envisioned that GTN-H will consist of several components, which are necessary to carry out the functions identified in section 7.1 and illustrated in Figure 3. Figure 4 considers these from the perspective of the existing networks and proposed participating agencies. A number of the hydrological variables of interest are presently being collected (section 6.), and a subset is being made available. Most of the data collection takes place at the national level, executed and funded by national hydrological or meteorological agencies. To various degrees, these data are presently assembled by international centres to generate global or regional products (section 6.). Figure 4 indicates that these centres are at various stages of evolution. For some variables (discharge, precipitation, snow water equivalent, isotopic composition of precipitation, BGC fluxes into oceans, vapour pressure) such centres and associated data access mechanisms exist; in these cases, some products are being generated and others are feasible during the initial phase of GTN-H establishment. For other variables (evapotranspiration), data collection is underway and centres for data use exist, however data access is not well developed. For the remaining variables (surface water storage fluxes, ground water fluxes, soil moisture, water use), the main problems are inadequate data collection, difficult access to relevant information, lack of data handling centres, or a combination of these. Figure 4 also shows the centres that are sufficiently developed and active to become effective GTN-H contributors from the outset. These issues are addressed further in the discussion on GTN-H implementation plan (section 7.5) and recommendations (section 8.).

To ensure success of the GTN-H, an end-to-end approach needs to be adopted for its planning and implementation. The term "end-to-end" management of data and information describes a process rather than a sequence of actions. In particular, it implies the establishment of a feedback loop between the providers of data and information and the user of the information (Figure 3).

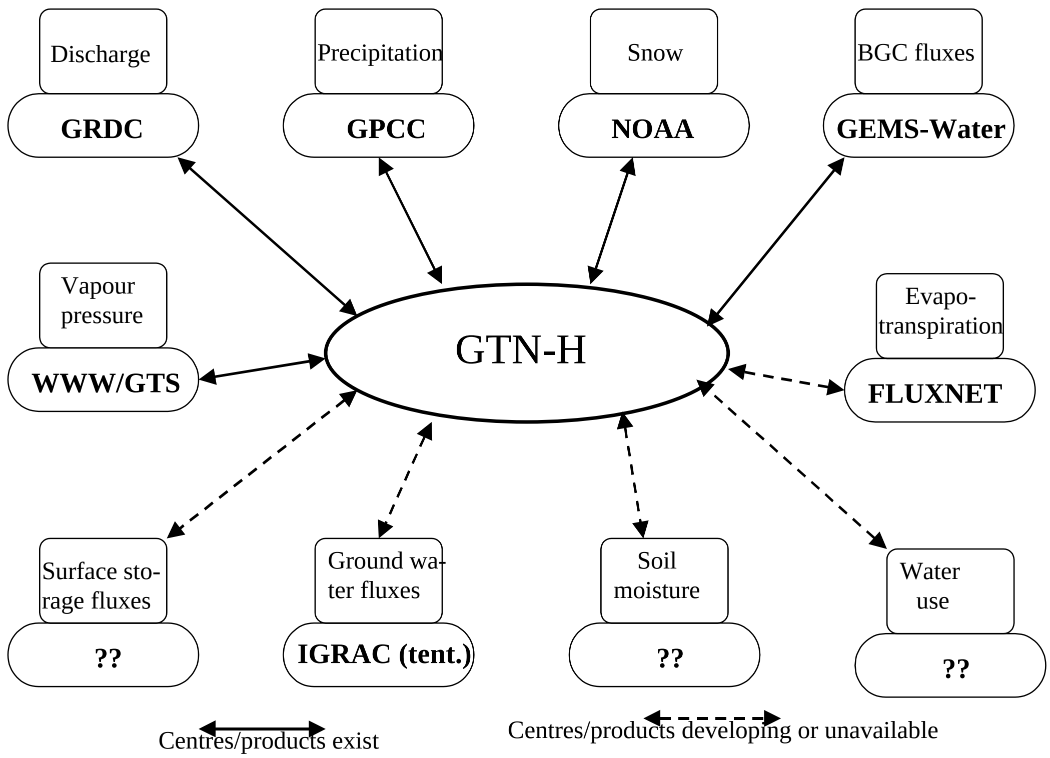


Figure 4. ***Proposed Initial Configuration of GTN-H***

The specific arrangements for data flow are likely to differ based on the type of data, the characteristics and capabilities of contributing sites and networks, and the timeliness requirements. As an example, Figure 5 shows the potential use of the Internet for handling the access to runoff data and the derived products.

State - of - the - art information systems and communication technology are at the heart of the proposed GTN-H. Information will also flow from/to GOSIC, INFOCLIMA, INFOHYDRO and INFOTERRA. In the development of the GTN-H it is essential to establish linkages with existing data centres. This is particularly important where additional data and variables are the subject of related programmes and projects such as water quality and isotopes in hydrology.

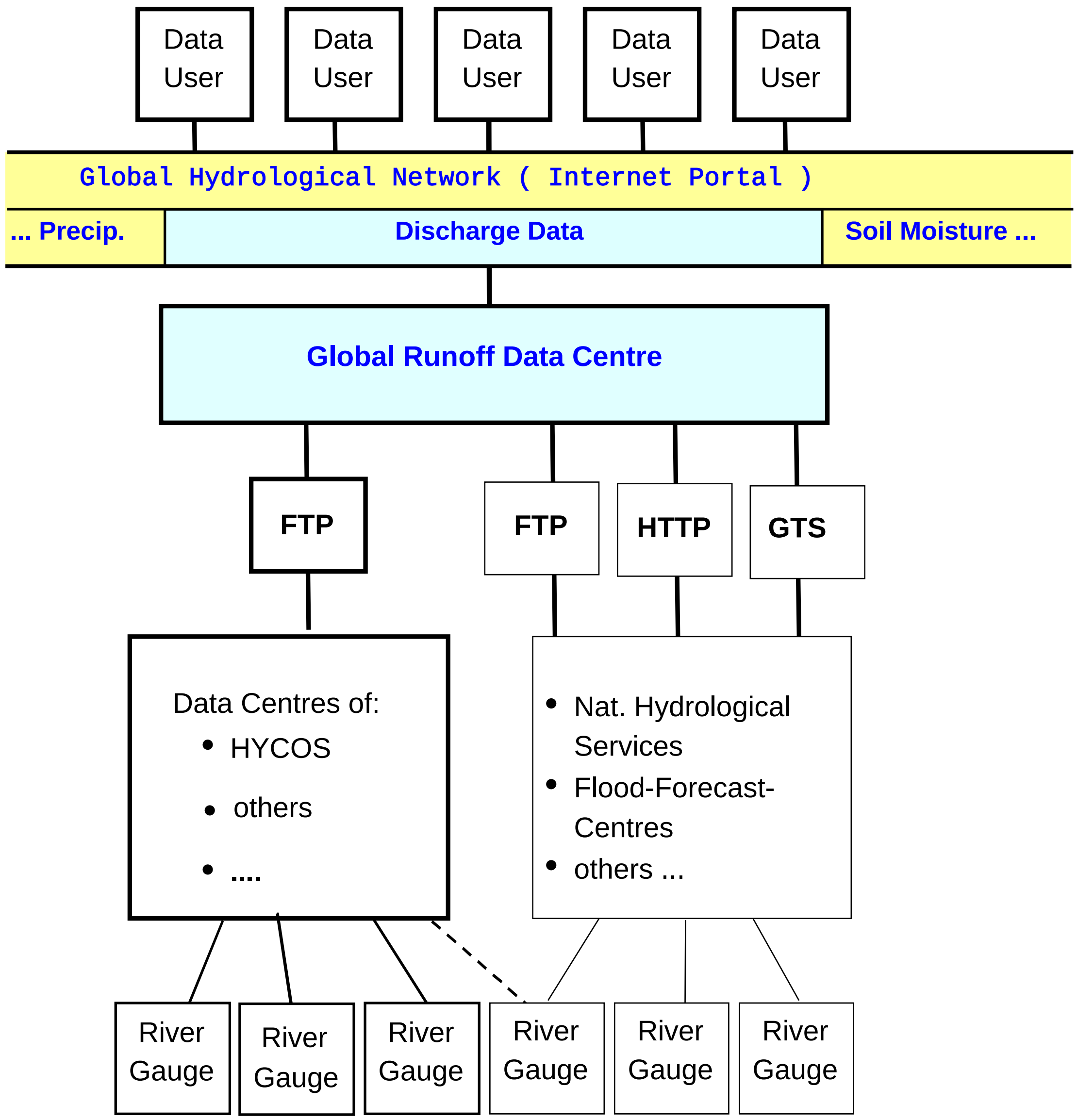


Figure 5. ***A Scenario for GTN-H Data and Product Delivery via Internet***

7.4 Hydrological Observation Panel for Climate

Three global observing systems have been established in the 1990s to enable systematic, long-term observation and assessment of the earth system in general, and the role of climate in particular: the Global Climate Observing System (GCOS, 1995; http://www.wmo.ch), the Global Ocean Observing System (GOOS; http://ioc.unesco.org/goos/goostoc.htm); and the Global Terrestrial Observing System (GTOS, 1998; http://www.fao.org/gtos). These are in addition to the World Weather Watch (http://www.wmo.ch) and other WMO programs which have been in existence for many years and which provide the relevant atmospheric observations. Each of these observing systems encompasses space and in situ observations, and each is organised to maximise the efficiency and effectiveness of making the observations for global as well as regional applications.

The overall direction for the development of each global observing system is provided by a steering committee. In turn the scientific input to the steering committee as well as some implementation activities are the mandate of scientific panels established as part of the programs. Since from the scientific as well as organisational perspectives many of the observation issues are very broad, the implementation of the global observing systems must be approached through close collaboration with other activities in the observation and scientific communities. This is dealt with by ensuring broad representation of observation and research agencies in the steering committees, and by co-sponsorship of the science panels. In general, these panels are sponsored jointly by two or more international programs. The terms of reference for the panels are defined by the panel’s co-sponsors, and the panels report to all the sponsoring organisations. The co-sponsorship helps ensure that the various programs are co-ordinated at the scientific and technical levels, and that the advice provided to the steering committees has been formulated in the broad context of related activities. In this way, the science panels are responsible to the major international programs that are relevant to the panels' work. In the terrestrial domain, two science panels have been established for the Global Terrestrial Observing System so far: the Terrestrial Observation Panel for Climate (TOPC) in 1995 and the Global Observation of Forest Cover (GOFC) Panel in 2000.

Since hydrology issues concern mainly the terrestrial environment, TOPC has been the panel responsible for these on behalf of GCOS and GTOS. Its activities included an initial analysis of the observation issues and identification of critical variables (GCOS, 1997), definition of satellite observation requirements (TOPC, 1998), and others (GTOS, 2000). However, there are other important hydrological issues beyond TOPC terms of reference that are relevant to GTOS' five themes, especially sustainable availability of water resources and pollution/toxicity (GTOS, 1998). These have been dealt with to some extent by TOPC (TOPC, 1999) but only at a general level. Application areas discussed at this workshop (section 3., 4.) have confirmed the importance of the non-climate issues in the terrestrial hydrological domain, and have highlighted the urgent need for more focused attention to this area.

An important task of the science panels is to contribute to the initial implementation of the observing systems. Thus, TOPC has led the establishment of global in situ observing networks, initially built by co-ordinating activities of existing networks and engaging these in systematic global observation. Three such networks have been established so far (TOPC, 1999) that focus on ecology <http://www.ilternet.edu/>, glaciers <http://www.geo.unizh.ch/wgms/>, and permafrost <http://sts.gsc.nrcan.gc.ca/permafrost/gtn-p.htm>. Similarly, GOFC has developed regional networks as part of its implementation (Figure 6). This expert meeting developed the framework for a similar network in hydrology but it also identified a number of critical issues that require scientific guidance and initiative. Previous experience from the global observing systems demonstrates that scientific advice is a critical element of success for the observation networks and of the products the networks generate.

Based on the above considerations, it is proposed that in addition to GTN-H, a Hydrological Observation Panel for Climate (HOPC) be established as a new science co-ordinating panel with an advisory function. Its terms of reference might be patterned TOPC (Annex IV.), with due considerations to hydrology-specific science and organisational aspects as well as the present situation, programs and concerns. In particular, they need to recognise that hydrological issues are complex scientifically, administratively, and politically. Figure 6 shows GTN-H as a network that receives organisational, administrative and scientific guidance primarily from HOPC, although its activities are also important to some aspects of the mandate of TOPC and other similar groups. To be successful, HOPC will need to receive guidance from the sponsoring agencies in developing recommendations and proposed actions that are practical, lead to progress, and meet the needs and expectations of the sponsors.

The composition of HOPC will be crucial for the successful implementation GTN-H. In addition to the representation of the sponsoring agencies, panel members should provide linkages to sponsoring agencies, the agencies participating in GTN-H, the scientific community, and to clients/product users. Establishing these cross-linkages will be a key mechanism for enabling GTN-H to work efficiently and effectively. GTOS, GCOS, WMO and its constituent programs, ICSU, and IHP/UNESCO are among the desirable sponsors. Major GTN-H participants should also be represented (Figure 4).

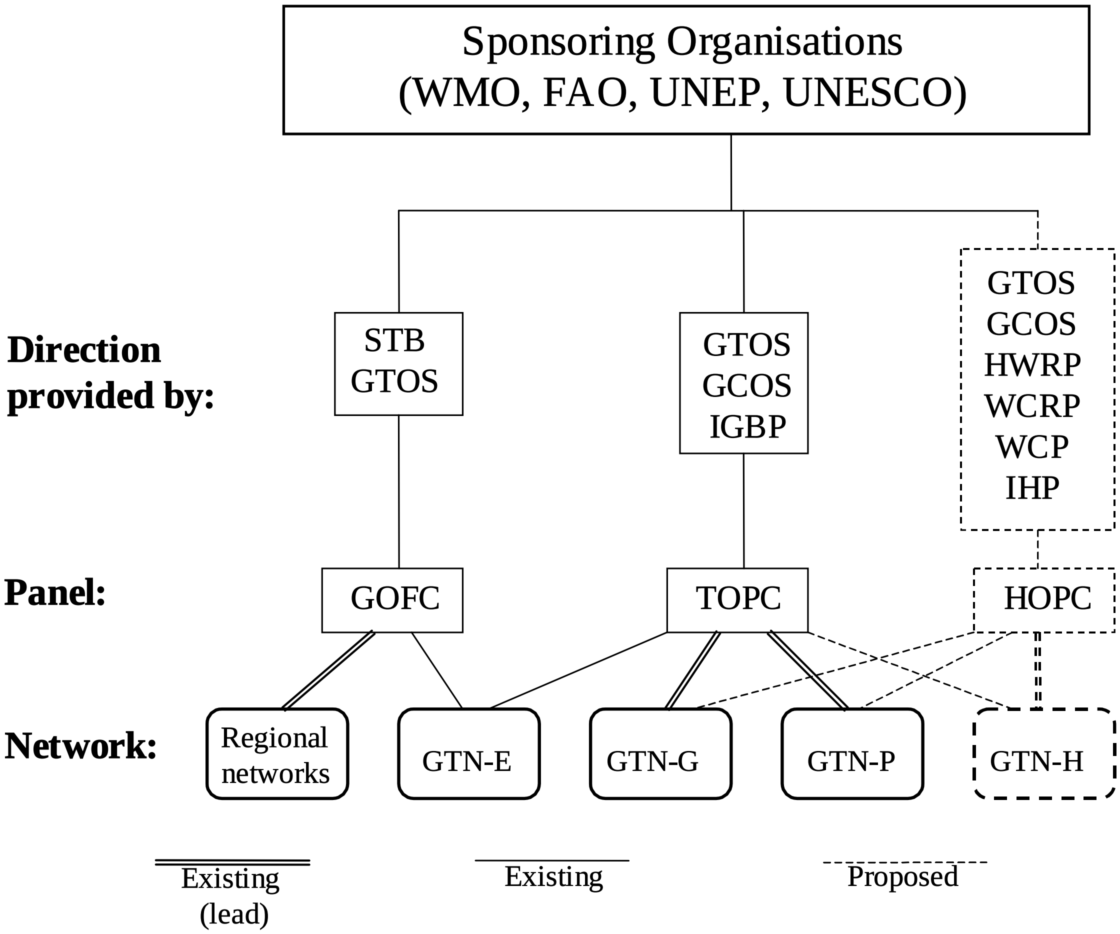


Figure 6. ***The Proposed Organisational Relationships Involving GTN-H***

7.5 Initial Implementation

To advance the implementation of systematic global hydrological observation, the following activities are proposed by the participants:

- Establish a Hydrological Observation Panel for Climate (HOPC, section 7.4), with the mandate to guide the development and implementation of systematic long-term global observations on behalf of, and in collaboration with the sponsoring programs/agencies. HOPC should also be the lead panel guiding the work of GTN-H, in consultation with other panels
- Obtain endorsements and co-sponsorship for HOPC
- Establish GTN-H as outlined in this report and based on further elaboration of more detailed plans by HOPC

- Obtain endorsement for GTN-H from the proposed sponsors and participants; obtain agreements to participate and contribute resources by the existing observing networks, data and product centres, and other important contributors
- Identify major present barriers to more effective use of existing data and products, and implement remedial measures
- In consultation with clients define data products, milestones, and work plan (see initial version in section 7.6). This should include a useful new product within 2-3 years that will demonstrate the effectiveness of GTN-H
- Implement the plan.

In developing GTN-H the design of the metadata base as well as database implementation, operation and maintenance should be components of the strategic plan. A metadata base will also be required to handle information about the data that will be used to assist in interpretation and analysis.

7.6 Proposed Products

Table 2 describes potential GTN-H products that were identified by meeting participants as important to a variety of clients, with several being feasible within the initial GTN-H period.

Table 2. ***Proposed GTN-H Products for the Initial Period***

Product name	**Content**	**Use**	**Spatial resolution**	**Temporal resolution**	**Time-liness**	**Contact**
Discharge	gridded runoff fields	Water balance computations	1^o x 1^o	Monthly (ongoing)	DT (delayed time)	GRDC (W. Fröhlich)
Discharge	Point data	Weather forecasting (model validation)	N/A	Daily (ongoing)	NRT (near-real time)	GRDC (W. Fröhlich)
Soil moisture	Gridded (preferably)	Weather forecasting (assimilation in models)	TBD	Daily (ongoing)	NRT	CEOP (J. Leese)
Discharge	Regional totals	Global water cycle analysis	by region	Monthly	DT	GRDC (W. Fröhlich)
Discharge	Point data	Regional water cycle analysis	For CEOP regions	Daily and monthly > (CEOP period)	DT	GRDC (W. Fröhlich)
BGC flux into oceans	By major watershed	Global BGC cycles analysis	By watershed	Daily to monthly (ongoing)	DT	GEMS Water (A. Fraser)
Isotope composition	$\delta^{18}O$, $\delta^{2}H$, ^{3}H	Various	By station	Weekly to monthly (ongoing)	DT	IAEA (M. Gröning)

Product name	Content	Use	Spatial resolution	Temporal resolution	Time-liness	Contact
Hydrographic separation	Discharge as % of inputs	Regional water cycle analysis	By watershed	Weekly to monthly (ongoing)	DT	IAEA (M. Gröning)
Isotope composition	$\delta^{18}O$, $\delta^{2}H$	Global BGC cycles analysis	By station	Weekly to monthly (ongoing)	DT	IAEA (M. Gröning)
Hydrographic separation	Discharge as % of inputs	Global BGC cycles analysis	By watershed	Weekly to monthly (ongoing)	DT	IAEA (M. Gröning)
Precipitation	Solid and liquid	Regional water cycle analysis	For CEOP regions	Daily (CEOP period)	DT	GPCC (B. Rudolf)
Precipitation	Solid and liquid separately	Regional water cycle analysis	1dx1d globally; 0.5^{o} x 0.5^{o} regionally	Daily and monthly (global ongoing, regional for limited periods)	DT	GPCC (B. Rudolf)
Snow water equivalent	Gridded	Various	TBD	TBD	DT	NOAA
Ground water fluxes	Aquifer withdrawal rates	Various	By aquifer	TBD	DT	TBD
Water use	Differentiated consumptive use	Various	Point or polygon	Monthly, ongoing	DT	GRDC (W. Fröhlich) University of Kassel, P. Döll
Water use	Gridded consumptive use	Various	0.5^{o} x 0.5^{o}	Monthly	DT	University of Kassel, P. Döll
Surface storage Flux	Volume changes in lakes and reservoirs	Water cycle analysis	Polygon	Monthly or seasonal (ongoing)	DT	TBD
Precipitation, evapotrans-piration, Other	Point data	Real time data for assimilation in models	Point	Daily	RT	TBD

7.7 Resources Required and Available

As a basis of the day-to-day operation of GTN-H, the participants felt that the collaborating institutions and data centres should cover operating expenses from their existing budgets. However, additional resources will be required to fund co-ordination activities of GTH-N and to assist partners who may have not sufficient resources to participate fully in the GTN-H activities. This is especially important in developing countries whose collaboration must be sought.

The following incremental cost items were identified:

- Organisation and conduct of meetings including those HOPC and travel involved in these activities
- Development and maintenance of a Web-site for GTN-H

- Publications
- Network design and implementation
- Short-term consultants and science contracts in particular for product generation.

Sources of funding were discussed in detail and the group agreed on the following list of sources for potential funding extra-budgetary activities of GTN-H:

- Contributions in kind from core funding institutions (mainly those who fund day-to-day operations of network participants and data centres)
- Services (in the form of products) to funding organisations at national and international levels
- General and specialised product generation on a non-profit base i.e. for development banks or regional economic commissions
- Funding organisations such as the European Union through their R&D programmes
- Private foundations
- Funding UN-agencies such as UNDP, FAO and WHO in support of specialised projects/programmes of these agencies.

Taking into consideration operating guidelines of the existing centres, GTN-H is expected to operate within the framework of major resolutions of the constituent bodies of the sponsoring UN agencies, including Resolutions 25 and 40 of WMO which concern the exchange of hydrological information. To ensure sustainability of GTN-H, international funding for programme development and operations must be an integral part of the strategy. Without financial commitment for resources at a level necessary for sustained activity by partner agencies, the GTN-H will not be successful. The participants agreed to investigate funding opportunities and encouraged collaborating centres and agencies to pro-actively seek additional funding to support GTN-H activities.

7.8 Potential Contributions

Workshop participants identified potential contributions to GTN-H that may be feasible from within existing resources. The delivery of these contributions needs to be confirmed through discussions with management of the network operators and agencies participating in GTN-H:

- CEOP: ensure link to GEWEX; facilitate GTN-H participation in CEOP. The GEWEX Hydrometeorological Panel is planning a Co-ordinated Enhanced Observation Period (CEOP) with a data collection taken from July 2001 through September 2003. The plans for compiling hydrometeorological data from a number of reference sites distributed over the continental areas of the globe (in the framework of the GEWEX Continental Scale Experiments) could provide an opportunity for a GTN-H pilot project involving eight of the eleven variables by GTN-H users.

- CESR: provide water use data product.

- CRU: participate in the definition, evaluation and application of GTN-H products; serve as link to AOPC/GCOS and the Hadley Centre; generate and provide related climate data sets (temperature, cloudiness, vapour pressure,..) updated for recent periods, monthly, 0.5^o x 0.5^o.

- GCOS: work with WMO departments to reach the goals and objectives of GTN-H; assist GTN-H to establish effective links with WCP-Water; actively pursue the development and endorsement of GTN-H; through WMO Secretary General and COP, obtain countries' support for and contributions to GTN-H activities; contribute to developing, and submit to COP, guidelines for countries' reports on the state of national observing systems; promote GTN-H and countries' contributions through regional GCOS workshops; promote the acceptance of, and work with TOPC, GTOS, HOPC and WCRP on a IGOS water theme;

- GEMS/Water: prepare a plan for GEMS/Water contribution to GTN-H for consideration by UNEP; expansion of the network to world-wide, in consultation with other participating GTN-H networks; evaluation of existing inventory data for computing total fluxes with GRDC; obtain additional existing data from countries; participate in the definition of GTN-H products; establish WWW links with GTN-H partners;

- GKSS: participate in the definition, evaluation and application of GTN-H products; serve as link to BALTEX and other regional users;

- GPCC: provide gridded precipitation products (ongoing); respond to recommendations of users as far as possible (e.g., separate solid and liquid precipitation products); quality control, quality analysis and documentation for all products; participation in the definition and generation of new products within GTN-H;

- GRDC: obtain and maintain overview of existing on-line discharge data sources; select and propose a subset of these to meet GTN-H needs, and update as appropriate; establish a metadata base for the above sources; in co-operation with UNH develop monthly gridded runoff field products (Table 2); if feasible given available data, generate water use products (Table 2);

- GTOS/FAO: actively pursue the development and approval of GTN-H; co-ordinate GTN-H incorporation in GTOS; provide secretariat support to GTN-H; with GCOS support organisation of meetings; provide limited travel support to meetings; facilitate collaboration with appropriate FAO Divisions (including Food Security, Water); provide access to water use statistics, food security data bases, ; incorporate GTN-H in the TEMS database; contribute to GTN-H publicity via SD Dimensions (WWW publication), GTOS reports; facilitate co-ordination between TCO, GTN-H and other activities;

- IAEA: maintain GNIP; maintain and increase the number of GNIP sites; establish hydrological isotope data base (ISOHIS) on hydrological projects (ground or surface water); if possible, establish a network of ~30 stations and make river discharge isotope measurements;

- Kyoto University: participate in the definition, evaluation and application of GTN-H products; serve as a link to GAME and FRIEND-ASIA; facilitate access to hydrological data in Japan, including consultation with government agencies;

- TOPC: provide input to the establishment of HOPC and GTN-H structure; participate in the definition, evaluation and application of GTN-H products; provide ongoing input to GTN-H activities on behalf of GCOS/GTOS needs and applications;

- UNESCO: assistance through regional FRIEND-networks, subject to agreements between regional FRIEND groups and GTN-H; collaboration can be envisaged in the fields of research projects, users and eventually exchange of hydrological data; recognition of GTN-H within the IHP programme; potential use of GTN-H data and services in the evolving UN World Water Development Programme; liaison of HELP activities with activities of GTN-H, in particular with regard to climate and water related issues, socio-economic (water use, sustainable development) subjects and hydrological process research and studies;

- UNH: participate in the definition, evaluation and application of GTN-H products; produce products in collaboration with other GTN-H participants; serve as a product algorithm development and product generation centre within the GTN-H framework, subject to data access arrangements; provide developed and tested algorithms to GTN-H and other participants for ongoing product generation;

- USGS: participate in the definition, evaluation and application of GTN-H products; if requested, serve as a contact with relevant USGS observation and research programs, including the hydrological observations available through the WWW;

- WMO (other than GCOS): participate in the design and setting up of GTN-H and provide continuing assistance, including links with national agencies through CHy and WMO management; contacting member countries to provide co-ordination of existing stations for large basins; place into geographic data base context with GRDC; facilitate effective collaboration with WHYCOS, including GTN-H access to WHYCOS observations; continue WMO support to GRDC, GPCC, and other centres as they develop; assist in developing linkages with WCRP, GEWEX CSEs, WCP-Water, International Strategy for Disaster Reduction (ISDR); promote GTN-H in the climate-hydrological community through articles in newsletters (CLIVAR, GEWEX, CEOS, others; promote data delivery to GTN-H with respect to GRDC, GPCC, and other data centres;; link with WCRP in general and GEWEX in particular to promote the establishment and use of GTN-H; support of activities of GTN-H within the World Climate Programme – Water (WCP-Water);in contact Member countries of WMO to provide information about existing Data Collection Platforms in large river basins (need some more information);.

7.9 Follow-up Actions

Based on the above discussions and the issues raised, participants identified a number of follow-up activities that are needed to pursue the development of the GTN-H. These include:

- Establishing contacts with other groups and programs to build on existing capabilities and interests. This can be achieved through presentations at meetings, discussions with programs, endorsements by key steering committees, and the development of collaborative activities. A more detailed list is provided below.
- Communication with national agencies that collect and archive hydrological data. WMO has established mechanisms for this purpose. In addition, GCOS regularly reports to COP through SBSTA on the status of observing systems and needed improvements, and provides an avenue for raising observation issues at the national level. It is important for GTN-H to clarify the range of requirements relative to national agencies, to ensure that the contacts are co-ordinated and result in rapid progress at the global level.

- Co-operation with GEWEX/CEOP. CEOP will establish high-quality regional data sets for most of the hydrological variables by means of satellite and in situ data as well as model assimilation, in several well distributed areas around the globe. GTN-H should to explore ways of collaborating with CEOP to enhance to production of global data sets. Given the CEOP schedule (starting in 2002), this is an urgent task.

- Inclusion of GTN-H sites and networks in the GTOS' TEMS.

- Timely application of hydrological observations is a critical emerging requirement for weather and climate forecasting concerned with time periods of 2-3 days or longer (section 3.). This has strong implication both for the observations themselves (number of sites and type of measurements) and for data transmission to the user agencies. For meteorological observations, GTS has been set up many years ago, and its operation is carefully managed by WMO and by national meteorological agencies. Addition of hydrological data presents a new requirement, and its incorporation into GTS will demand focused effort. GTN-H should explore this issue as a matter of priority and should, by involving the weather and climate forecasting as well as other relevant communities, initiate a process that will lead to the incorporation of hydrological data on GTS.

- There is an opportunity to improve timely access to hydrological data through the World Wide Web. This is already being done by some hydrological agencies around the world, and vigorous action in this direction is needed. The web may also be a temporary solution for making real time or near real time data available for critical applications, e.g. numerical weather and climate assimilation and prediction models, pending more permanent solution through GTS.

- The web should be used in the establishment of GTN-H as a network of networks. An early action should be the construction of a GTN-H home page with linkages to a) participating networks, b) relevant data sets, c) related programs, d) information systems and data bases (GOSIC, INFOTERRA, INFOCLIMA, INFOHYDRO).

- The establishment of GTN-H and HOPC should be presented to various groups concerned with hydrology issues, and appropriate feedback should be obtained. There are a variety of forums for this step, including:

  Steering Committees of GCOS (meeting 2000/09), GTOS SC
  ICSU Environmental Advisory Committee
  WMO Regional Association II session (2000/09)
  WMO CHy (2000/11)
  WMO Executive Council (2001/06)
  WCP-Water (2000/fall)
  SBSTA (2001/06)
  UN Advisory Co-ordination Committee, Sub-Committee/Water (ACC/Water; 2000/11)
  GHP meeting (2000/09)
  AGU conference (2000/fall) semi-annual meetings (December 2000 and Spring 2001)
  AMS meeting (2001/spring)
  IAHS conference (2001)

- The following schedule was considered desirable: draft report in July, 2000; draft final early September; final report October, 2000; establishment of GTN-H by the end of 2000.

8. Recommendations

Based on the meeting presentations and discussions the following recommendations are made:

1. A Global Terrestrial Network for Hydrology (GTN-H) should be established to meet the need for characterising hydrologic processes and to meet other needs for global hydrological observations. GTN-H should be formed as the hydrological complement of existing global terrestrial networks. GTN-H terms of reference should be established and should include the objective of meeting the needs of several programs for global and regional hydrological observations.

2. Potential GTN-H sponsors and participants identified at this meeting should be approached to obtain their endorsement and contributions.

3. A Hydrological Observation Panel for Climate (HOPC) should be established, with its major responsibility being to guide the development and implementation of GTN-H and to ensure its effectiveness.

4. HOPC should act in close cooperation with its sponsoring agencies, global observing systems (GCOS, GTOS, GOOS, WWW), institutions participating on behalf of the global observing

systems, and global research programs (especially IGBP and WCRP); and the HOPC terms of reference should be developed accordingly.

5. HOPC and GTN-H should develop a plan for meeting the data and product requirements by the various application communities. This plan should take advantage of the initial product generation activities, capabilities and interests of the participants (section 7.6). Early tangible and beneficial results should be an important goal in preparing this plan.

6. Near-future opportunities for the development of GTN-H should be vigorously pursued, including collaboration within CEOP.

7. The implementation of the recommendations should be undertaken by the sponsors of this meeting, i.e. GCOS, HWR/WMO and GTOS, with the interim assistance of TOPC.

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Annex I   List of Participants

WMO Expert Meeting on the Establishment of a Global Hydrological Network for Climate ,
Geisenheim, Germany, 26 – 30 June 2000

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Annex II Meeting Agenda

Venue:
Forschungsanstalt Geisenheim
Geisenheim, Germany

Monday, 26 June 2000

Theme: Goals and deliverables of the expert meeting;
Requirements for data and information

10:00 Transfer of participants from hotel to meeting place
10:30 Opening of the meeting
Welcome by Prof. K. Schaller (Director Research Institute Geisenheim)
Welcome by Mr V. Vent-Schmidt (Deutscher Wetterdienst)
10:45 Organisation of the meeting

- Election of the Chairperson
- Explanation of the provisional agenda
- Adoption of the agenda

11:00 Coffee break
11:15 Session: Goals of the meeting
W. Grabs: Summary of contributions received for the meeting
J. Landwehr, J. Cihlar: View of TOPC
A. Thomas: View of GCOS
P. Reichert: View of GTOS
J. Bassier: View of WMO/HWR
Discussion
12:45 Lunch
13:30 Session: Requirements for data and information
H. Grassl: General and global modelling aspects
P. Jones: The view of diagnostic climatology
B. Rudolf: The view of global precipitation climatology and water cycle
H.T. Mengelkamp: Hydrological component of climate models
P. Döll: Grid-based modelling of the criticality of water availability
W. Fröhlich: Basin-wide modelling of water availability and anthropogenic influences on hydrological regimes
15:00 Coffee break
15:30 General discussion
16:00 Review of results and documentation of recommendations and conclusions
17:00 Meeting adjourns
17:15 Transfer from meeting place to hotel
Optional:

19:00 Special event at Fachhochschule, Hoersaal 30 (Mensagebaeude)
Prof. Dr Hartmut Grassl (in German language):
"Klimaaenderung im 21. Jahrhundert – Koennen die Folgen fuer den Weinbau schon abgeschaetzt werden?"
Fachhochschule Geisenheim, Hoersaal 30 (Mensagebaeude)

Tuesday, 27 June

Theme: Availability and access to hydrological data for climate

08:30 Transfer from hotel to meeting place

09:00 Session on data centres, projects and studies
GPCC (B. Rudolf)
GRDC (W. Fröhlich)
GEMS/Water Collaborating Centre (Andy Fraser)
IAEA Isotope Hydrology (M. Gröning)

10:30 Coffee break

10:45 Session continues
WHYCOS (J. Bassier)
FRIEND (M. Bonell)
HELP (M. Bonell)
GEWEX (H. Grassl)
Water budget closure (B. Fekete)

12:00 Discussion

12:30 Lunch

14:00 Hydrological variables for climate: Availability and access to data and information
To be discussed under this agenda item:
- Availability and global coverage of selected hydrological variables
- Availability and global coverage of existing data collection programmes/initiatives/centres
- Mechanisms for the collection, archiving and exchange of hydrological data:
  - Reporting frequency (i.e. near real-time data);
  - Archiving facilities
  - Quality control
  - Data exchange policies
  - Data accessibility
  - Data products

15:15 Coffee break

15:30 Identification of minimum requirements for the collection, archiving and dissemination of network data
To be discussed under this agenda item:
- Priorities for the selection of hydrological variables

- Priority regions and river basins

16:45 Review of results and documentation of recommendations and conclusions
17:30 Meeting adjourns
17:45 Transfer from meeting place to hotel by cars

Wednesday, 28 June

Theme: Vision and strategy for the establishment of an initial Global Hydrological Network

08:30 Transfer from hotel to meeting place by cars
09:00 Principal objective of a Global Hydrological Network
To be discussed under this agenda item:
- Identification of major goals using a maximum overlap approach of user's requirements
- Definition of principal functions and deliveries of a Global Hydrological Network
- Identification of an initial network which can be implemented within short-term

12:30 Lunch
13:30 Strategic approach for the set-up and operation of an initial network
To be discussed under this agenda item:
- Selected variables
- Selected sites
- Identification of data sources (services, Global Data Centres)
- Strategic approach for the establishment of a global hydrological network

15:15 Coffee break
15:30 Review of results and documentation of recommendations and conclusions
16:30 Meeting adjourns
17:00 Visit of the agrometeorological unit of DWD
19:00 Wine tasting session and snacks
22:00 Transfer from meeting place to hotel by cars

Thursday, 29 June

Theme: Putting a concept to work: Planning for the implementation of a global hydrological network

08:30 Transfer from hotel to meeting place
09:00 Components of a global hydrological network
To be discussed under this agenda item (working groups may be established):
- Definition of guiding principles for the implementation of the network
- Structure of the network
- Operating responsibilities
- Collaboration with other relevant organisations, programmes, centres
- Reporting cycles

12:30 Lunch
13:30 Data acquisition, exchange and dissemination in the context of a Global Hydrological Network
14:15 Coffee break
14:30 Resources, funding mechanisms and opportunities
15:00 Formulation of an initial implementation plan
16:30 Review of results and documentation of recommendations and conclusions
17:30 Meeting adjourns
17:45 Transfer from meeting place to hotel

<u>Friday, 30 June</u>

Theme: Adoption of a plan for an initial Global Hydrological Network
08:30 Transfer from hotel to meeting place
09:00 Detailed review of discussions, recommendations and conclusions (Working groups)
10:00 Coffee break
10:15 Final discussion and presentation of draft document of the expert meeting
11:15 Adoption of the draft document
11:30 Closure of the Meeting
12:00 Lunch
13:00 Transfer from meeting place to the hotel and/or to the railway station Geisenheim

Annex III Invited Contributions

TOPC Requirements for a Global Hydrological Network for Climate

J. Landwehr and J. Cihlar

Background

The Terrestrial Observation Panel for Climate (TOPC) is a scientific advisory panel jointly sponsored by GTOS and GCOS, which in turn are both sponsored by WMO, UNEP, and ICSU, and GTOS by FAO and UNESCO, and GTOS by IOC. TOPC has several assignments, but a primary task is "to plan, formulate and design a long-term systematic observing system for those terrestrial properties and attributes which control the physical, biological and chemical processes affecting climate, are affected by climate change or serve as indicators of climate change, and which are essential to provide information concerning the impact of climate and climate change. [1] TOPC has completed a GCOS/GTOS plan for climate-related terrestrial observations, which identifies variables of concern to the biosphere, hydrosphere and cryosphere, accompanied by a rational for including each variable in an observation network.[2] TOPC has also proposed an observing strategy comprised of five hierarchical levels of observation by which to integrate this information; this system is called the Global Hierarchical Observation Strategy for Terrestrial System (GHOST) [3.]

Neither GCOS [4] nor GTOS [5] directly make observations nor generate data products; rather they each provide an operational framework for integrating, and enhancing observational systems of participating countries and organisations. Similarly, TOPC is not a data producer, but rather identifies data needs and works to facilitate a solution. Three Global Terrestrial Networks (GTN) have been established to date -- one for glaciers (GTN-G), permafrost (GTN-P), and terrestrial carbon flux measurements (GTN-E). [6., 7] These networks have been incorporated into the United Nations Framework Convention on Climate Change (UNFCCC) Reporting Guidelines for Global Climate Observing Systems. [8] The next GTN that must be developed is a GTN-H, that is a global terrestrial network for hydrology with which to assess climate variability, change and impacts. The genesis for this meeting arose from this need.

Hydrospheric Variables

TOPC has already identified hydrospheric variables to be critical for climate assessment [9] but collections of appropriate and freely exchanged data are limited [10] The set of 10 variables that TOPC has identified as necessary for analysis of climate change detection as well as impact assessment, from both a societal and scientific focus, includes

1. Surface water flow – discharge.
2. Surface water storage fluxes
3. Ground water storage fluxes]
4. Precipitation - accumulated (solid and liquid).
5. Evapotranspiration

6. Relative humidity (atmospheric water content near the surface)
7. Biogeochemical transport from land to oceans]
8 Soil moisture
9. Snow water equivalent (SWE) from snow melt
10. Water Use

The first nine variables were identified in the TOPC 1997 report [2], which also provides a rational for selection, as well as the frequency, spatial resolution, accuracy and precision needed. The latter attributes are generally dependent upon the tier or relevant observational level. The tenth variable, water use, was added to the TOPC list during the most recent TOPC meeting. [11] (It is suggested that a good model for reporting this variable can be found in the 5-year reports by the USGS of water use in the United states. [12]) Soil moisture (#8) has also been considered to be a biosphere variable in the TOPC report, and snow water equivalent (#9) to be a cryopsheric variable. Note that the set of variable includes all 3 phases of terrestrial hydrology: above, on and below the surface.

Single variable versus multi-variable data collection

Networks can be constructed as collections of single or multiple variables; both are needed. That is, information about one of the hydrospheric variables identified above can be useful as single variable time series of comparable quality globally available for many locations. This type of information is necessary to distinguish regional versus global trends.

For example, using the GTN-P web-available map product as an organising idea, the GTN-H could provide a comparable global map and accompanying data records for rivers discharging into the ocean, when any one of several possible conditions are met. These include: i) the river is among the top 300 major inputs of freshwater into the ocean which should account for about 60 percent of the estimated continental runoff (= precipitation minus evaporation) which flows into the oceans; ii) the river is a major freshwater source for a climatically sensitive region of the oceans, e.g. the North Atlantic or the Arctic Ocean; or iii) the river basin contributing the outflow has a population of above 1,000,000 inhabitants.

Multivariate time series of comparable quality and measurement frequency over a region are critical to modelling and process analysis, water balance studies, GIS support, etc. This has been one of the underlying tenets of WHYCOS [14] as well as other efforts.

Conclusion

The ideal is availability of data with minimal constraints, well-documented metadata, and easy (web) accessibility which would make it most valuable both for scientific and management use. To date, this has proved a challenge to the hydrologic community.

References

1.http://www.wmo.ch/web/gcos/topc.htm

2. GCOS/GTOS Plan for Terrestrial Climate-related Observations, version 2.0, June 1997, GCOS-32 (WMO/TD-No. 796, UNEP/DEIA/TR.97-7)
http://www.wmo.ch/web/gcos/pub/topv2_1.html

3. GHOST - Global Hierarchical Observing Strategy, June 1997, GCOS-33 WMO-No. 862)
http://www.wmo.ch/web/gcos/pub/ghost.html

4. http://www.wmo.ch/web/gcos/whatisgcos.htm

5. http://www.fao.org/GTOS/PAGES/D&IPlan.htm

6. http://sts.gsc.nrcan.gc.ca/permafrost/gtn-p.htm

7. Thematic GT-Net Networks discussed on:
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8. http://cop5.unfccc.de/resource/docs/1999/sbsta/13a02.htm

9. Report of the GCOS/GTOS Terrestrial Observation Panel for Climate, third session, Cape Town, South Africa, March 19-22, 1996,GCOS-23, GTOS-1.
http://www.wmo.ch/web/gcos/Publications/gcos-23.pdf

10. Report of the GCOS/GTOS Terrestrial Observation Panel for Climate, fourth session, Corvallis, USA, May 26-29, 1998, GCOS-46, GTOS-15.
http://www.fao.org/gtos/PAGES/topc/TOPC400.htm

11. Report of the GCOS/GTOS Terrestrial Observation Panel for Climate, fifth session, Birmingham, England, July 27-30, 1999, in review.

12. USGS, Estimated Use of Water in the United States in 1995
http://water.usgs.gov/watuse/pdf1995/html/

13. http://www.geography.uc.edu/~kenhinke/CALM/map.html

14. http://www.wmo.ch/web/homs/whycos.html

15. http://www.gos.udel.edu/ios/specific.asp

Hydrological Data and Information Requirements

P. Döll

1. General interest for a global hydrological network for climate and water resources

At the Center for Environmental Systems Research, one of our main research topics is the large-scale (global and continental) modelling of water related problems. We are developing a global model of water availability and water use (WaterGAP, a raster model with a resolution of 0.5°), which is used to develop scenarios of the future water (quantity) situation, e.g. for the World Commission on Water for the 21st Century. Besides, WaterGAP is applied in environmental security research. In the future, we intend to extend WaterGAP to water quality aspects. WaterGAP requires a large number of input data sets and some data sets for model validation, related to hydrological modelling and the modelling of water use by the domestic, industrial and agricultural sectors. For questions of environmental security and water management, additional data sets are needed. As all the desirable data are related to water and climate, and are global data sets, it appears to be appropriate to collect and archive them in a global hydrological network for climate and water resources.

2. Problem dimension from my perspective

My perspective is the perspective of a data user who wants easy access to a large variety of data for the whole globe which are well documented. Besides, to a very small extent, we have also derived 0.5 degree gridded data sets (irrigated areas, lakes and wetlands, drainage direction map); for these data sets, I want to find a location / an archive where our data sets can be easily found and retrieved (with due acknowledgment of the authorship).

3. Perceived objective and deliverables of a hydrological network

The hydrological network should produce, archive and distribute data sets incl. meta data sets. It should serve as a contact point with the authors of the data sets in case of questions. Maybe the network could also foster common research projects.

4. Data and information requirements

Spatial scale: global, temporal scale: long time series, temporal resolution: variable

Gridded data (spatial resolution 0.5° or higher):

- Meteorological data, in particular daily precipitation and extent/depth of snow cover
- Land cover

Point data:

- River discharge directly upstream and downstream of (large) lakes and reservoirs
- Naturalised flows
- Location, volume-area function and management of reservoirs
- Area (and volume) of lakes and wetlands (time series)
- Water quality parameters (nitrogen, phosphorus etc, from GEMS/Water)
- Evapotranspiration
- Soil moisture

Polygon data (for administrative units):

- Withdrawals and consumptive use differentiated according to source (groundwater, surface water) and user sector (agriculture, households, manufacturing, cooling etc.), similar to county-wise water use data for the USA (determined by United States Geological Survey)
- Water quality: source emissions of relevant substances.

Data should include information on how data set was derived, and on uncertainty of data.

5. Principal scientific and technological issues and problems
Water use data: In the main water use sector, the irrigation sector, water use is mostly not measured. In all sectors, the measurements are done by local users and results are not collected and archived centrally such that it is impossible to obtain measurement data when working at a larger scale. Following the USGS approach for the USA, the other countries should collect highly differentiated information on water use for spatial subunits by sending out, in a regular fashion (e.g. every five years) questionnaires to the administration in charge of the spatial subunit. Such a data collection requires a well-organized administration and the existence of measurement data at the local scale.

6. Possible users of the network
Researchers, water management planner (at the country-scale)

7. Product generation for users
Standard data sets should be made available, selection of spatial and temporal domain should be possible. To provide tailor-made products might be too ambitious, costly.

8. Approach and steps to implement a hydrological network
Water use data: 1. Identify, for each country, an institution that could collect water use data centrally (like USGS in USA). 2. Discuss USGS approach and modify approach 3. Find money

Additional Information:
For the generation of scenarios of future water availability and water use, information on the driving forces is required. These include meteorological information from GCMs; it would be desirable not only to be able to obtain selected results like from the IPCC Data Distribution Centre web site, but also meta data that include information on the uncertainty of the distributed GCM results. For water use scenarios, an existing gridded population distributing data set could be included; it would be desirable to develop population scenarios (also gridded). Other data relevant to water management issues include water prices.

Hydrological Observation Requirements

P. Jones

GCOS has set up two 'baseline' networks for long-term climate monitoring and related issues such as climate change detection. GUAN (GCOS Upper Air Network) consists of about 150 sites around the world where countries with stations will take radiosonde soundings with know equipment and to the highest levels possible. The network is only part of a more complete array of about 800 sites. The 150 sites, therefore, form a standard for assessing changes in instrumentation for the rest of the network.

GSN (GCOS Surface Network) is a near-1000 station network of roughly one station per 5 degree by 5 degree grid box. Countries with stations in this network will attempt to maintain the site, instruments and the environment in the immediate vicinity. Standard WMO statements regarding instrument changes etc apply to both GSN and GUAN (overlapping measurements etc when sites/instruments/times change). GSN is capable of monitoring hemispheric and global scale temperature variations (when combined with marine data) but needs to be augmented by more data to consider spatial variations in detail. For precipitation the network is inadequate for most applications, but it forms a baseline for more highly resolved data sets at the regional scale.

The Global Precipitation Climatology Centre (GPCC) produces gridded data at fine resolution from the basic GSN network augmented by SYNOP data and much more finely resolved national data sets. Drawback is that these data only extend back to 1986.

Both GSN and GUAN have online monitoring centres that have been set up to check both the receipt and the quality of data received. Reports go back to countries, generally through focal points. Archive centres have also been set up and historical data (daily records for the main climate variables for the whole record of the station) has been requested from all the countries that operate stations. Once received, the archive centre will make the data available via CD's and the WWW.

Neither network is ideal from a climate point of view, nor will they alone answer any of the questions in the climate change detection debate. Both networks were set up by WMO/GCOS through expert groups defining a network, which was then modified/agreed with each member country.

For a Global Hydrological Network a similar strategy would seem appropriate:

- the network be defined by an expert group
- monitoring and archive centres be set up
- involve gauging sites on rivers, which are large enough to be regionally
- representative, but not seriously affected by human influences
- catchments likely to remain unaffected by development
- long records of flow exist on daily and monthly timescales
- areal rainfall records available

- gauging conforms to a standard level and the degree of error is known
- catchment and geological maps available.

Issues in the Establishment of a Global Hydrological Network for Climate

B. M. Fekete and C. J. Vörösmarty[1]

Water Systems Analysis Group's interest in a global hydrological network

Water Systems Analysis Group of University of New Hampshire has over a decade experience in continental and global water balance and water transport models [21], [20], [16],[17]. Our group has developed various tools (water balance and water transport models and specialized GIS tools for gridded river network analysis) and global databases (RivDIS V1.0 [19] discharge station data, STN-30p gridded networks [18], [5] and gridded runoff fields [5], [6]). Our group is working on numerous projects that integrate hydrological models in atmospheric models, assess water resources and study the fresh water fluxes to the coastal regions, etc.

We see river discharge as a key information in studying the hydrological cycle. However, discharge is the most accurately measured element of the water cycle [11], [10], [14], its availability for large scale studies is limited [8]. Water is recognised as one of the most important limiting natural resources [13], [3], [4] and scientists recognize the value of river discharge information in global circulation models [12], [9], [15], [1], [2].

Our group is convinced that the availability of discharge data is essential in geo-sciences. We think, that access to discharge data would benefit both the data donor countries and the research community.

The problems of collecting hydrological data

The problems of collecting hydrological data is not any different than collecting other kind of data.

- The maintenance of the observing network is costly, therefore more and more country is scaling back its monitoring programs.
- Countries often consider hydrological data as strategic information, that they would not share or at least they would charge for the release of such data.
- The data collected by different countries often lack the standardization of monitoring methods and it could result inconsistencies across country boarders.
- Many countries lack the infrastructure for real time monitoring and the data transfer.

[1] Water Systems Analysis Group, Complex Systems Research Center, Institute for the Study of Earth Oceans and Space, University of New Hampshire

Still the availability and quality of hydrological data are still far better than other elements of the water resource questions (such as information irrigational, industrial or municipal water use, reservoir operation, etc.).

In order to improve the accessibility of hydrological information, we need to convince the hydrologic community about the benefits of collecting and sharing hydrological data. We think, that the best way to demonstrate the potentials by developing data products derived from the already available data. USGS already uploads discharge and stage height data for over 4000 gauging stations across the US. We are working on a prototype systems, which accesses this data via USGS's WEB interface and combines it with our river routing and modelling tools to derive gridded runoff and discharge fields.
Many countries need help or assistance to establish and maintain hydrological monitoring network. This requires search for potential funding.

WSAG Potential Contribution to a global hydrological monitoring network

Our group developed data processing capabilities in the last 10 years, which enables us to deliver value added product from hydrological monitoring data. Our tools allow:

- the integration of river discharge data into simulated gridded networks,
- improve quality control by exploring inconsistencies in consecutive gauging stations,
- develop value added data products such as gridded runoff fields [5], [7].

WSAG group is currently working on a prototype system to present river discharge data and value added gridded products such as gridded runoff and discharge fields for the Gulf of Maine basins (at 2-minute resolution). We are about to implement this system for the North American continent at 0.1 degree resolution (by the fall of this year) and the Danube basin at 5 or 3-minute resolution (by the end of this year). Our system already downloads real-time stage height and discharge data from over 4000 USGS gauging stations . In similar fashion, we are about to download real-time data from Hydroinfo (http://www.datanet.hu/hydroinfo/index.htm) website maintained by Water Resource Research Center, (Budapest, Hungary), which contains daily stage height and discharge information for gauging stations along the Danube and its major tributaries.

Our group is interested in extending the afore mentioned regional systems to global coverage.

Data requirements

A global hydrological network probably should concentrate on river flow information such as discharge and stage height. Since discharge is typically estimated by using stage height/discharge rating curves. We would prefer to have stage height data available with the corresponding rating curves.

Another question could be the network density. It is tempting to request as many station data as many is possible, but even if the data were available, processing large amount of data (particularly to perform thorough quality control) could be overwhelming. Fortunately, river discharges are integrated signals, therefore focusing on key gauging stations can give a good representation on the large scale hydrological processes. Our group did a little analysis on how many station would be necessary to monitor the actively flowing portion of the global land mass. Assuming 25,000 : km^2 station network density, 2300 discharge gauging stations would be sufficient to cover the actively flowing portion of the continental land mass. However, the 25,000 : km^2 area is an arbitrary threshold and someone could argue there are regions where denser network is necessary, the opposite is also true, that there are relatively large regions with quite uniform hydrology, where coarser station density might be satisfactory.

Comments on scientific or technological problems

The collection of hydrological data is well established in many countries. Automated real-time monitoring is in operation large part of the globe. The scientific challenge is to use the available hydrological data and develop data products which would convince the water management community about the benefits of monitoring and sharing hydrological data.

The timing of the establishment of such a network is probably the best from technological point. The recent advances in telecommunication technologies (the rapid growth of the Internet in particular) offer cost efficient solutions for the data exchange. Internet communication can be established over a wide range of hardware from amateur radio to fiber optic cables. A global hydrological monitoring system can rely on a well-established technology and computer network, which is already in place for large part of the globe. We would recommend WMO to join UNDP's Sustainable Development Networking Programme (http://www3.undp.org) and support the need for building the Internet in developing countries.

Outline of users of information from a network

Product generation

WSAG can envision short term and long term products. On the short term, real-time processing of hydrological data and generation of global gridded runoff and discharge fields is very feasible. Such information can be made available to the public via WEB interface as we discussed in section 3. On the long term, discharge forecast using climate data inputs from atmospheric models is also feasible.

Basic approach to implement a hydrological network

As we discussed in section 3, there are regions, where real-time hydrological monitoring networks are already in operation. Observations from some of the existing networks are already available on-line via the Internet. These existing data sources can be the starting point of a hydrological monitoring network. Our group already started to develop a system, which accesses these data sources and processes the observation in a simulated river network context. Once, our system is completed, we can demonstrate the benefits of sharing hydrological data to other nations.

The important next step is to convince those countries which do not share their data to change their policy. Some countries might need financial or technical assistance to equip and maintain their real-time monitoring network. WSAG group already started to include budget for data collection in its reseach projects. This could provide short term solution, but it is certainly can not be considered as a long term solution. Research grants are typically awarded for 3-4 year periods after which the continuation of the monitoring can not be guaranteed.

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Global Runoff Data Centre

W. Fröhlich

1. GRDC - main present activities

- Maintaining and continuous extending of the data base (at present more then 3700 stations)
- Develop and use of tools for plausibility data quality checking
- To finish the meta-DB of the GRDC-stations, for GIS-links use of Hydro1k *(knowing the problems of automatic basin border calculation)*
- Review the status of the selected data sets (freshwater fluxes, 200 station)
- To make data charts of the main stations web-accessible
- Screening the www to find all sites (data provider)/ tables with
    - actual data
    - historical data
- Think about splitting the GRDC-DB into 3 groups of data-access (for the convenience of data use)
    - free : data from all station that are already free accessible from other sources (mostly from the web)
    - to confirm: data access according the present regulation of GRDC-data dissemination
    - restricted: only meta-data and points of contact for data access further
- investigate the amount of that hydrological data which are already accessible via Internet
- check the feasibility of that data for an eventually use for CEOP-I, EFFS and/or others <u>(e.g. Global hydrological Network for Climate)</u>

2. An European Flood Forecasting System (EFFS)

2.1 Main Objectives:

- To take advantages of currently available medium-range weather forecasts (4-10 days)
- To produce reliable flood warnings beyond the current flood warning period of app. 3 days
- To design a medium-range flood forecasting system for Europe that will produce flood warnings on the basis of the medium-range weather forecasts
- To produce flood forecasts in regions where at present no flood forecasts are made on the basis of the newly developed system
- Timeframe: 2000 - 2003
- Financed by the EU

2.2 Scientific objectives:

- Development and application of downscaling techniques for weather forecasts that can be used in real-time operational flood warning systems over large areas
- Design a framework that allows for the use of different rainfall-runoff flood models linked to the medium-range weather forecasts in order to provide medium-range flood forecasts

- Investigate the concept of an overall water balance hydrological model as a basis for regional rainfall-runoff flood modelling
- Investigate the accuracy of the flood forecasts in space and time starting off from uncertainties in medium-range weather forecasts and assess the error propagation through the system
- Find methods to incorporate uncertainties both from the weather forecasts as well as from the hydrologic models to be used in operational forecasts and use them as a decision factor as part of the actual flood forecast
- Investigation and recommendations concerning methods to disseminate the forecasts to whom they might concern, and to retrieve feedback from the users

2.3 Participants

- WL / Delft Hydraulics (Delft, The Netherlands)
- RIZA (Arnhem, The Netherlands)
- European Centre for Medium-Range Weather Forecasts- ECMWF (Berkshire, UK)
- University of Bristol (Bristol, UK)
- Lancaster University (Lancaster, UK)
- Joint Research Centre (Ispra, Italy)
- University of Bologna (Bologna, Italy)
- Danish Meteorological Institute - DMI (Copenhagen, Denmark)
- Swedish Meteorological and Hydrological Institute - SMHI (Norrkoepping, Sweden)
- Deutsche Wetterdienst - DWD (Offenbach, Germany)
- Global Runoff Data Centre - GRDC (Koblenz, Germany)

2.4 Part of GRDC

- Deliver hydrological discharge data sets for calibration and validation of the hydrological models
- work out recommendations for exchange of information within the EFFS (coop. with SMHI)

therefore:

- To get an representative overview over the
  - existing operating Flood forecast- and warning systems in Europe
  - online accessible hydrological data in Europe
- consider the results of the questionnaire initiated by WMO - XII-RA VI Co-ordination Sub-group on Flood Forecasting and Warning (last year)

3. GEWEX - CEOP-I (2001-2002)

<u>GRDC contributions</u> will include:

- To compile and process daily discharge data (QA/QC)
- Comparative analysis of hydrological regimes in CSE regions
- Interannual variations of streamflow in selected regions

- Regional and global gridded composite runoff fields (0.5° grid)
- Contributions to analyses of teleconnections based on relevant GRDC data sets

4. GRDC input to the Expert meeting:

- Focus on the most problematic variables:
  - discharge, water level, water use
- Make clear:
  - What means "near real-time" in sense of climate products (latest data from today, yesterday, last week, last month...) ?
  - Which time step/resolution (hourly, 15 minutes, daily mean...) ?
  - How do consider the climate models/weather-forecast models large-scale water-diversions and irrigation?
  - How suitable is a strongly influenced measured river-discharge for climate validation?
  - Which discharge error is acceptable for climate purposes
- Define the essential stations, considering:
  - the length of historical data set
  - the importance of the river (e.g. selected 200 GRDC-station)
  - the quality of observations
  - other global DBs/programs (GEMS/Water, GNIP, HYCOS, ..)
- Find out the stations that have:
  - already data available on the web
  - create and maintain a meta-data-base of web-stations
- Start with:
  - an overlapping net of stations (essential stations + web-stations)
  - create and maintain the hydrological data-base accessible via the Internet
- Continuous quality check of that data
- Add step by step further stations
- Involve the data provider - keep close contact (keep them informed about use of data, results of quality check...)
- Give the selected stations an official status (accepted by CHy,..)
- Parallel to that, design a global information network for water use
  - together with FAO, WHO,UN-ECs...)
  - therefore make clear:
    - spatial and timely resolution
    - updating rhythm (every year?)
  - find out ways to use remote sensing information
- Make clear and transparent for all data-provider the benefit of a high dense hydrological near-real-time data network by developing useful products (e.g. gridded run-off fields..)
- Finally, do not reduce the efforts to request the free access to all hydrological data acc. Resolution 25
- Think about possibilities of remote sensing of water-level and discharge

WHYCOS: Status of Implementation and Development as of July 2000

J. Bassier

This document provides a brief description of the status of the various WHYCOS components (HYCOSs).

A. Regional HYCOSs under implementation

MED-HYCOS (the Mediterranean Rim)

The implementation of the MED-HYCOS project has continued and the agreement between WMO and the French Institute of Research for Development (IRD) for the hosting of the Pilot Regional Centre (PRC) at the IRD premises in Montpellier (France) has been extended until 31 December 2000. The network of DCP stations is being expanded; 35 stations have been sent to the eligible participating countries, 22 are already operational and the others are expected to be commissioned soon. The real time data transmitted by the DCPs are readily accessible on the project web site. The year 1999 was devoted principally to the enhancement of the MED-HYCOS Information System. New on-line tools for the analysis of the data available at the Regional Data Bank have been developed including in particular, cartographic interface for accessing hydrological data and information. Five experts from NHSs of the participating countries have been seconded to the PRC for varying periods up to one year to assist with the development of the MED-HYCOS Information System.

Data and information are available on the following Internet server: http://medhycos.mpl.ird.fr/

A proposal for MED-HYCOS phase II for the next four years (2001-2004) has been submitted by to the screening process. The project has been classified as a priority by the regional Mediterranean Technical Advisory Committee (MEDTAC) and by the Financial Advisory Committee of GWP. PRC and WMO Secretariat are finalizing the proposal for the extension of the project.

SADC-HYCOS (Southern Africa)

This project involving the countries of the South African Development Community – SADC (Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe) is in its full implementation phase. The progress of the project has been significant over the past year. Twenty-seven out of the planned 50 data collection platforms were installed and were fully operational at the end of November 1999. Most of the remaining stations are expected to be installed in 2000. A data base administrator has been assigned to the project by the PRC at the end of 1999.

The current phase of SADC HYCOS was initially planned to terminate in June 2000. However due to initial delays at the start of the project, security problems in some of the participating countries and devastating floods in the Eastern part of the project area in the beginning of year 2000, the SADC Water Sector Coordination Unit, in coordination with the PRC and WMO proposed to the European Commission that the project be extended until August 2001. This proposal was accepted by the European Commission.

Data and information on SADC-HYCOS are available at the following Internet site: http://www-dwaf.pwv.gov.za/sadchycos/ (use of Internet Explorer 5.0 software is required)

A Phase II Concept Note endorsed by SADC Water Sector has been submitted to GWP screening process in early 2000 and has been considered among the priorities for the sector. The proposal is made for a one-year consolidation and project preparation phase followed by a four-year period of implementation.

AOC-HYCOS Pilot Phase (Western and Central Africa)

This project was launched thanks to a grant of 2 million French Francs (US$ 300 000) from the Ministry of Foreign Affairs of France. Representatives of the NHSs of eleven countries from the sub-region (Burkina Faso, Cape Verde, Chad, Gambia, Ghana, Guinea, Mali, Mauritania, Niger, Nigeria and Senegal) that had expressed their interest in the project participated in a meeting (Ouagadougou, Burkina Faso, December 1999) to discuss the implementation of this pilot phase. One of the key objectives of the pilot phase is the transfer to a regional body and the consolidation of the activities of the Regional Hydrological Observatory for Western and Central Africa (OHRAOC). The OHRAOC was developed and operated by the French Institute of Research for Development (IRD, formerly ORSTOM). The Ouagadougou meeting supported a proposal that the Niger Basin Authority (NBA) and the CILSS Regional Centre AGRHYMET would have joint responsibility for the coordination of the pilot phase of AOC-HYCOS and for the operation of the regional database and associated Internet server. During the transition period, data and information are available at the Internet site http://ohraoc.ird.bf. The pilot phase is being considered by donors as a test run for a comprehensive regional HYCOS project, which could involve up to 23 countries of the sub-region. A technical review of the pilot phase and a donor meeting to discuss the funding of the comprehensive AOC HYCOS project are planned for 2001.

B. Regional HYCOSs under development

IGAD-HYCOS (Eastern Africa)

A project encompassing the Member countries of the Intergovernmental Authority for Development – IGAD (Djibouti, Eritrea, Ethiopia, Kenya, Sudan and Uganda) has been developed in 1999. The project document has been prepared by the WMO Secretariat with inputs from local experts and from the IGAD Secretariat. Funding for this preparatory phase was provided by the European Commission. The document was presented to the seventh meeting of the Heads of Meteorological and Hydrological Services of IGAD sub-region, which was held in Nairobi, Kenya in January 2000. The meeting recognised the importance of the project implementation for water resources development and management in the region and mandated the WMO and IGAD Secretariats to finalize the project document with a view to obtaining funds for project implementation. The project document has been endorsed by IGAD Member countries and been submitted to the European Commission.

Congo-HYCOS (the CONGO River Basin)

The project document for the Regional Hydrological, Meteorological and Climatological Information System (RHMCIS), including a hydrological component, which would be implemented as CONGO-HYCOS, was submitted to the European Commission in early 1999 and is being considered for possible funding. The concerned countries are Cameroon, Central African Republic, Congo, Democratic Republic of the Congo, Equatorial Guinea and Gabon. Contacts have been established with the World Bank funded Regional Environmental Information Management project and with the Association for Environmental Information Dissemination with the aim of promoting the projects among donors. The project is not actively promoted at present in view of the present security situation in the region.

Baltic-HYCOS (the Baltic Sea riparian countries)

A project document, which concerns the countries of the Baltic Sea drainage basin (Belarus, Czech Republic, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia, Slovakia, Sweden and Ukraine) has been prepared during 1999 by national experts from the region in co-operation with the WMO Secretariat. It was reviewed and adopted at a meeting of country representatives in Poland in December 1999. Support from external donors, in particular the European Commission is being sought for the project implementation. The meeting also agreed that some initial work on the Regional Data Bank could be undertaken without external resources and this is currently being investigated. Several of the participating countries offered to consider providing hydrological data so as to get this activity initiated.

CARIB-HYCOS (Central America and the Caribbean Islands)

A project document has been prepared which takes into account the needs of some of the island countries of the Caribbean Sea as well as the main land countries of Central America. However, the impact of Hurricane Mitch, which resulted in extensive damage to the hydrological infrastructure in Honduras, Nicaragua, El Salvador and Guatemala, as well as some new proposals from the region, called for a complete revision of this document. The new draft has been finalised by WMO Secretariat in June 2000. CARIB-HYCOS aims at providing a support to natural disaster prevention and water resources management. It has been subdivided into a Continental Component (COC/CARIB-HYCOS) covering Belize, Colombia, Costa Rica, El Salvador, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama and Venezuela, and a Caribbean Islands Component (CIC/CARIB-HYCOS) comprising some of the islands of the Greater and of the Lesser Antilles.

Black Sea-HYCOS (the Black Sea riparian countries)

A Black Sea-HYCOS project profile was prepared in June 1999 by experts from three countries of the Black Sea basin assisted by WMO. The project is a cooperative process between the NHSs of the riparian countries of the Black Sea (Bulgaria, Georgia, Moldova, Romania, Russia, Turkey and Ukraine), the Permanent Secretariat of the Black Sea Economic Co-operation (BSEC-PERMIS) and WMO. The project profile was discussed and adopted during the Black-Sea HYCOS start-up meeting, held in November 1999 in BSEC-PERMIS, Istanbul, Turkey. The year 2000 should see the preparation of national reports and the completion of a Regional Synthesis Report. This latter report would present substantial information required for a comprehensive project document to be finalized and submitted to donors by the beginning of 2001.

Aral-HYCOS

A draft project document has been prepared in co-operation with the five Central Asian States of the Aral Sea basin. This document will be discussed at a meeting with the country representatives in Tashkent in September 2000. The project will consolidate a number of on-going activities

C. Other HYCOS initiatives

The development of a project for the **Southwest Pacific region** was considered during the meeting of experts on "Hydrological Needs of Small Islands" held in Nadi, Fiji (October 1999). Beyond the data collection exercise, the major interest for a Pacific-HYCOS project was identified as enhancing regional co-operation and technical capacities of the NHSs. The meeting requested the WMO Secretariat, in collaboration with the countries and in consultation with the South Pacific Forum Secretariat, to develop a full project proposal. A draft project proposal was available in June 2000.

Work has been initiated for the development of others projects, namely**: Danube-HYCOS** (start-up meeting held in Budapest, Hungary in November 1999), **Caspian-HYCOS** (preliminary meeting held in Almaty, Kazakhstan in December 1999).

Proposals have also been made to initiate the development of HYCOS projects in the Amazon and in La Plata river basins in South America, as well as in the **Himalayan region** and the **Arctic** region.

GEMS/Water Programme

A.S. Fraser

1. The UNEP GEMS/Water Programme is the primary organization within the United Nations system charged with gathering information and data on water quality resources directly from collaborating national monitoring programmes throughout the world. GEMS/Water provides data, information and assessments through collaborative work with United Nations programmes on global and regional water quality resources issues. The GEMS/Water Collaborating Centre operates and maintains the global database that holds water quality data provided to the programme by participating national governments. The Collaborating Centre works with participating countries and agencies to bring together water quality data for major rivers and lakes throughout the world and contributes to international programmes such as: WWDR, GIWA, GPA, GEF, GESAMP, GWP. In the development of a global hydrological network for climate it is a natural step to consider the interactive dependencies between hydrology and water quality. The GEMS/Water Programme is supportive of the development of this initiative and will collaborate in areas where possible for the betterment of our understanding of world water resources.

2. Difficulties in establishing a global network are manifold but not insurmountable. The network must operate internationally under the good graces of agreements with national governments and agencies. When the political arrangements are made and the strategic orientation of the programme is set, the tactical arrangements to establish a working network need addressing. A companion database needs to be developed that contains meta data on the sampling database. A brief view follows.
    - Station Distribution
    - Parameters
    - Frequency of Sampling
    - Transportation Requirements
    - Sample Analysis (if required)
    - QA/QC
    - Data Transmission / Reception
    - Database Structure
    - Data Storage and Retrieval
    - Database Management

3. Environmental issues are usually cross-discipline and interaction and collaboration are necessary to produce comprehensive global assessments. The primary objective of the network is to obtain meaningful data to enable understanding of the components that are

identified with all aspects of the hydrologic cycle. Work should contribute to international assessments of the availability and distribution of water resources throughout the world. Climate change is high on the international agenda. The network must be able to contribute to the identification, assessment and recommendation development requirements of regional and global studies.

4. The network should provide data, information and ancillary meta data necessary for determining resolutions to issues of regional and global hydrologic cycles. The data must be representative of a region and compatible with other data obtained from the network. The network must be designed to be able to develop and produce information on trends and changes determined by scientific and statistical procedures. Flexibility in design and operation is necessary to enable new issues to be addressed. Interactions with other databases including water quality are a high priority.

5. A major problem to be addressed will be the desire to handle real-time or near real-time data. To achieve this, telemetry systems operating from remote sites some of which will be in developing countries will be necessary. The mechanisms to be successful are very complex. Quality of data is of primary concern. Suitable mechanisms for screening and editing data must be developed as an integral part of the network. International funding that provides stability of staff and operations of the network must be identified and assured.

6. Users of the data and information provided through the network can be identified.

    - United Nations agencies
    - United Nations Programmes
    - International research organisations
    - National governments and agencies
    - University research personnel
    - Public and private educational institutions
    - Private industry
    - Public

7. There are several levels of product generating activity that should be built into the network system.

    - Database synopsis, time period, stations, parameters, parameter classifications…
    - Basic statistical analysis and graphical depiction.
    - Regional data availability
    - Data summaries
    - Interpretive reports
    - User requested specific reports
    - Regional and global programme contributions

8. Planning and implementation strategy must be considered carefully and by consultation between all stakeholders. The basics:

    - Development of mission statement
    - Identification of lead agency and key personnel
    - Identification of partner agencies and key personnel
    - Structure and composition of executive steering committee
    - Development of strategic direction
    - Identification of primary financing organization
    - Preliminary budget development
    - Implementation schedule
    - Identification and evaluation of existing networks and network components
    - Compose network through agreements and establishment of new sites
    - Design and establish database systems
    - Design and implement data transfer protocol
    - Design and implement QA/QC programme

Soil Moisture Observations

J. Leese

Several workshops have been held during the past decade which focused on soil moisture. A 1994 workshop in Tiburion, California identifies scientific requirements of the atmospheric, hydrologic and ecological disciplines for soil moisture observations. It concluded that with recent advances in both knowledge and practice, an opportunity is clearly at hand to establish a comprehensive scientific framework for the global monitoring of soil moisture. One of the major conclusions was that a complicating factor in soil moisture, in addition to heterogeneity of soil properties and land surface attributes, is the complex control of the land surface energy and water balance by the atmosphere and the soil. This control is further modulated by plant activities in the root zone. Observing and understanding the switch between the control by the atmosphere and the control by the soil is central to the design and implementation of any monitoring system of soil moisture.

The GEWEX/BAHC International Workshop on Soil Moisture Monitoring, Analysis and Prediction for Hydrometeorological and Hydroclimatological Applications was held from 16 to 18 May 2000 at the University of Oklahoma, Norman, Oklahoma, USA. In considering the progress in land surfaces processes and modelling which entails the complex aspects of soil moisture it was decided to focus on the development of a strategic plan for the next five years in soil moisture monitoring, analysis and prediction for hydrometeorological and hydroclimatological applications. The plan should:

-- identify and recommend priorities for research;

-- demonstrate the scientific and technical feasibility of implementing a global system through one or more pilot projects or an evolutionary series of pilot projects; and.

-- contribute to the design of a global system which could be operational by the end of this decade

The Workshop participants concluded that the demonstration of the value of soil moisture in weather and climate prediction during the past decade has created a need to develop a system to provide this type of information on a global basis for operational use and further research. The progress in soil moisture monitoring makes it technically feasible to seriously work toward implementing such a global monitoring system during the coming decade. Among the Workshop recommendations are the following:

* The design for a global monitoring system should be based primarily on model derived estimates with in situ measurements and remotely sensed estimates serving as input data for assimilation and for evaluation of model output.

* Locations which can provide high quality and representative in situ measurements which are distributed over the global land masses should be identified as Reference Measurement Sites for the global monitoring system. The GEWEX and BAHC Programs dealing with land-surface processes and modelling can provide expert guidance on the selection of such Reference Measurement Sites.

* The development and implementation of a global model to produce model-derived estimates of soil moisture should be started immediately to demonstrate the capabilities of such a global monitoring system and to identify areas where further research and/or improvements to the input data are needed to achieve operational capability on a global scale.

* Develop a long-term strategy for remote sensing of properties required for soil moisture retrievals that considers improvements of spatial resolution, L-band and other sensors (precipitation, radiation, snow water equivalent, skin temperature), and recognizes physical hydrologic properties.

* Make satellite and in situ data available in real time.

* Add soil moisture measurements at synoptic stations as part of the Global Observing System of the World Weather Watch.

Hydrology for the Environment, Life and Policy (HELP): Real People, Real Catchments, Real Answers

M. Bonell

HELP is a joint UNESCO/WMO programme which is designed to establish a global network of catchments to improve the links between hydrology and the needs of society. It is a cross-cutting programme of the UNESCO International Hydrological Programme and will contribute to the World Freshwater Assessment Programme, and the Hydrology and Water Resources Programme of WMO.

The vital importance of water in sustaining human and environmental health is the key driving force behind HELP. However, no international hydrological programme has addressed key water resource issues in the field and integrated them with policy and management needs. HELP will change this by creating a new approach to integrated catchment management. The new approach is to use real catchments, with real water related problems as the environment within which hydrological scientists, water resources managers and water law and policy experts can be brought together.

HELP is therefore a problem-driven and demand-responsive initiative that will focus on the following eight key issues:

- Water and food security
- Water quality and human health
- Water and the environment (environmental health)
- Water and potential conflicts
- Impact of climate variability on water resources
- Improved communications between hydrologists and society
- Water-related disaster prevention and mitigation (flood control, drought management)
- Water for socio-economic development

The outputs of HELP will be new data and models which are more suitable for the revision of current water policy and water resources management practices in all of the above eight areas.

Global Network for Isotopes in Precipitation (GNIP)

M. Gröning

1. The Global Network for Isotopes in Precipitation is operated by the Isotope Hydrology Section of the International Atomic Energy Agency, Vienna, Austria. This world-wide survey of the isotopic composition of monthly precipitation started as early as 1961 in co-operation with the WMO in order to study the raising Tritium levels in the atmosphere caused by nuclear weapon tests. The programme also aimed to provide systematic data on the global stable isotope content of precipitation as a basis for the use of environmental isotopes for hydrological investigations. Soon it was recognised that the collected GNIP data were also useful in other water-related fields like climatology, oceanography and hydra-meteorology. The data provided the backbone for the discipline now known as Isotope Hydrology.
   The network reached its maximum in the early 1960s with 220 operative stations. Currently, 180 stations are in operation from a total of more than 500 stations in the GNIP database. Altogether more than 100000 isotope measurements were performed within the GNIP. More than 30 percent of all isotope analyses are performed at the IAEA Isotope Hydrology Laboratory, the others are measured in more than 30 collaborating laboratories. All GNIP operation is done on a voluntary basis both by the sample collecting meteorological stations and by the analysing laboratories. Each dataset in the database consists out of monthly means for meteorological data (precipitation amount, mean temperature, relative air humidity) and the isotopic composition (oxygen and hydrogen stable isotope ratios as -values and Tritium concentration). In the past the data were published regularly in IAEA data books. Since several years the whole database is available online (http://www.iaea.org/programs/ri/gnip/gnipmain.htm) at the IAEA GNIP homepage. During the last years those data are more and more used for research in climate studies (e.g. El Nino, GCM model verification). Recently the IAEA and WMO have signed a Memorandum of Understanding to put this network on an official basis and to improve the co-operation and to increase the network A Scientific Steering Committee consists out of representatives from IAEA, WMO, PAGES, National Networks and invited experts and meets yearly to review the current status and to recommend improvements. Recent topics are filling the most important gaps in the geographical coverage (Africa, Russia and USA) and to ensure coverage of climatically sensitive regions (El Nino).

2. The climate change has received large attention by the scientific community as well as by the public. The relevance of GNIP and its data collection is not questioned. However, there is a big gap between understanding and active support.
   A major problem for GNIP is the absolutely voluntary basis of co-operation which is driven by a great enthusiasm of individual researchers and scientists for keeping the sampling and providing cost free isotope analyses in more than 30 network laboratories. No funding mechanism is established to foster the creation of stations (funding for this purpose is not possible within IAEA mandate).

3. The GNIP database is available on a cost free basis for researchers world-wide to foster and to facilitate isotopic investigations in the hydrological cycle (stable isotopes of hydrogen and oxygen as well as Tritium). More and more the available extended data set is used for modelling of atmospheric processes (GCMs) and for coupling of in-situ measurements with long term physical / meteorological processes traceable by isotope fractionation effects.

4. Formerly the data were published in books, since a few years the database is available for download on the IAEA GNIP homepage http://www.iaea.org/programs/ri/gnip/gnipmain.htm.
   The strengthening of this network depends on the accessibility and availability of the data (a new online search engine is in preparation). The next envisaged step is the coupling of the information on isotopic composition of precipitation (GNIP) with a hydrological database on isotope data in groundwater and surface water studies (ISOHIS – Isotope Hydrology Information System).

5. Major issues are budgetary constraints (all sampling and analyses outside the IAEA are done on a voluntary basis); time delays between sampling, measurement and publication (related to the problem of ownership and proper acknowledgement when using the data); uneven distribution of stations and lack of spatial coverage in some regions. Some positive developments were encountered recently (National GNIP Network for USA in preparation).

6. The users of GNIP data are scientists working in hydrology, modelling, atmospheric sciences and other disciplines using data of environmental stable isotopes or Tritium for water-related research (including biogeochemical studies and ecosystem studies).

7. The GNIP data are compiled and quality checked by the IAEA prior to release. In few cases the data submission to the IAEA is delayed for several years. However, near real-time production of data is not a major issue for a program operating since nearly 40 years and using statistical trends to derive small annual changes from large data sets.

8. The planned Hydrological Network could serve as a catalyst and support mechanism to facilitate the enhancement of GNIP in the future.

The Global Precipitation Climatology Centre (GPCC): Operational Analysis of Precipitation Based on Observations

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1 Introduction

The GPCC has been established in 1989 on invitation of the World Meteorological Organisation (WMO) as a German contribution to the World Climate Research Programme (WCRP). Later on, a long-term continuous operation of the centre has been accepted with regard to the Global Climate Observing System (GCOS). Data monitoring and quality control of the GCOS Surface Network Precipitation Data Set is performed at GPCC. The GPCC also operates a special arctic precipitation data archive for the Arctic Climate System Study (ACSYS, WCRP 1994) and it is active in the GEWEX Hydrometeorolgy Panel and contributes to regional projects, e.g. the Baltic Sea Experiment (BALTEX) and the Mesoscale Alpine Programme (MAP).

The GPCC is one of the major components of the Global Precipitation Climatology Project (GPCP). The common task of the GPCP is the compilation of global gridded precipitation data sets based all globally available observation systems, i.e. conventional surface networks and various satellite-observed radiances. Besides GPCC, contributors to the GPCP are the satellite operators (EUMETSAT, JMA, NOAA, and NASA) and several research institutes. The products are designed for the global climate research community and are especially required for the verification of global climate models, the investigation of climate variability and special phenomena such as the El Niño - Southern Oscillation, and the determination of the Earth's water balance and budgets (WCRP 1990).

The scientific and technical functions of the GPCC comprise:

- Collection of conventionally measured precipitation data from surface-based networks.
- Quality control of the data and correction of errors.
- Calculation of monthly gridded area-mean precipitation for the Earth's land surface.
- Error assessment for each individual grid box and month.
- Combination of the gridded results from surface-based observations and satellite data in co-operation with other GPCP-participants at the GPCP Merging Development Center (NASA Goddard Space Flight Center).
- Climatological studies based on results of the above analysis.
- Development of advanced analysis techniques.

Special functions within the Arctic Climate System Study (ACSYS) are:

- Establishment and operation of the Arctic Precipitation Data Archive (APDA).
- Collection of daily precipitation and snow depth data for the Arctic hydrological basin.
- Analysis and evaluation of precipitation, snow depth and its liquid water equivalent.

- Intercomparison of gridded total precipitation, snow depth, and river discharge for the large Arctic rivers (in co-operation with the Global Runoff Data Centre (GRDC).

2 The Observational Database

Conventionally measured data from raingauge networks are still the most reliable information to obtain area-averaged precipitation for the land surface. Satellite-based estimates are subject to larger biases and stochastic errors and need to be adjusted to in-situ observations (Barrett et al. 1994, Rudolf et al. 1996).

A first meteorological database for precipitation can be obtained from synoptically observed weather reports (at least with a daily resolution) and monthly climatic data, which are distributed world-wide as “SYNOP“ and „CLIMAT" reports via the World Weather Watch Global Telecommunication System (GTS). GPCC regularly collects monthly precipitation totals from these sources for nearly 7,000 stations world-wide. These data being available near real-time are the basis for monthly monitoring of the global precipitation, resp. the “Monitoring Product“ of the GPCC.

The data collection period as defined by the GPCP Implementation and Data Management Plan (WCRP 1990) starts with the year 1986. So far, national institutes from about 150 countries have supplied additional data on a voluntary basis, following the WMO requests and bilateral negotiation with GPCC. The entire GPCC database includes now monthly precipitation totals of about 48,000 stations (GPCC's full data set). The time series are largely complemented by climatological means for the normal period 1961-1990. The year with the best data coverage is 1987 with monthly precipitation data for about 38,000 stations.

A gradual decrease of the number of stations after 1987 down to 7,000 stations for 1999 (i.e. GPCC’s GTS data) is caused by the delay of the delivery of additional data and by the time required by the national agencies and subsequently by GPCC for data processing and quality-control (Rudolf et al. 1998). Also the spatial distribution of the data shows large data poor areas. The GPCC’s full data set still needs spatial and temporal complementation, as well as retrospective temporal extension (a precipitation re-analysis from 1961 onwards is required with regard to CLIVAR) and continuation of update deliveries to GPCC by the countries in future.

3 Problems of analyses of daily precipitation based on GTS data on a global scale

There is a strong demand from the international research community for analyses of daily precipitation. Just recently a satellite-based product of daily global precipitation on a 1° by 1° grid has become operational (http://rsd.gsfc.nasa.gov/912/gpcp/gpcp_daily_comb.html). Validation studies regarding this data set show, that it needs to be adjusted to raingauge data on a daily time scale. But until now it has not been possible to provide a global analysis of daily precipitation based on raingauge data, because of two major problems, the availability of raingauge data on a daily time resolution, and the definition of globally unique analysis days.

4 GPCC raingauge-based analyses of global land surface precipitation

The GPCC products, gridded data sets based on raingauge observations, are available in two resolutions, 2.5° by 2.5° and 1.0° by 1.0° geographical latitude and longitude, and with two different databases, i.e. near real-time with GTS data only ("GPCC Monitoring Product" based about 7,000 stations) and non real-time including complemented GTS data and additionally the data, which are delivered later from national institutions to the GPCC ("GPCC Full Data Product" based on 30,000 to 40,000 stations).
Variables which are supplied with both products on the grid are:

- Monthly precipitation amount (mm/month);
- Mean monthly precipitation for the normal period 1961-90 (mm/month);
- Monthly precipitation deviation from normal 1961-90 (mm/month);
- Monthly precipitation anomaly (percentage of normal 1961-90);
- Number of raingauges per grid cell for estimation of the sampling error;
- Mean correction factors for the systematic gauge-measuring error.

The raingauge-based global land surface precipitation analyses of the GPCC are the in-situ data basis of the satellite-raingauge combined data sets of the GPCP (Huffman et al. 1997) as well as of CMAP (Xie and Arkin, 1997).

5 Error Assessment

Area-means of precipitation derived from point data are contaminated by errors of different origin. These errors types first have to be treated and quantified separately, and the results then need be merged to a total error of the area-mean precipitation. The GPCC approach is described in the following:

1. Stochastic quality-related errors resulting from erroneous input data are minimized by a full high-level quality-control of all data used in the raingauge analysis.
2. Systematic measuring errors are compensated using long-term mean correction factors, which were derived by Legates (1987).
3. The sampling error has been investigated by GPCC using data from dense networks of Australia, Canada, Finland, Germany and USA (Rudolf et al. 1994).
4. The methodical error is much smaller than the sampling errors, and is neglected for large-scale GPCC analyses.

The total stochastic error on the grid is calculated from the individual error components, after systematic errors have been eliminated.

6 Research Activities

GPCC is going to prepare products of higher resolution and to develop advanced methods for quality-control, error assessment and spatial analysis. Items are:

- Development of a statistical basis for quality-control of monthly precipitation data;
- Development of an on-event-correction of precipitation data for systematic measuring errors (Fuchs et al. 2000);
- Validation of GPCP products, especially of those of one degree daily resolution (Rudolf and Rubel 2000);
- Evaluation of daily raingauge data for EuroTRMM (Verification of TRMM results);
- Development of a merged global historical precipitation data base;
- Precipitation and run-off data comparison studies;
- Further development of the Arctic precipitation climatology.

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An extended version of this report including figures can be downloaded from the Meeting Website on Internet:

http://www.dwd.de/research/gpcc/ghyclim2000/

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Annex IV Terrestrial Observation Panel for Climate Terms of Reference

Recognizing the need for specific and technical input concerning terrestrial observations for climate purposes, the sponsoring organisations of GTOS and the GCOS have jointly established TOPC with the following terms of reference.

In accordance with the overall plans of GCOS and GTOS:

1. To plan, formulate and design a long-term systematic observing system for those terrestrial properties1 and attributes which control the physical, biological and chemical processes affecting climate, are affected by climate change or serve as indicators of climate change, and which are essential to provide information concerning the impact of climate and climate change;
2. To review the needs of the user communities for climate related data and select a set of core variables, both in situ and space-based, at appropriate space and time scales, paying particular attention to the needs of developing countries;
3. To develop a strategy based on the concept of the Initial Operational System (IOS) which includes the assessment of existing in situ systems, the determination of deficiencies and the recommendation of necessary enhancements. (The Space-based Observation Panel will evaluate satellite programmes, determine deficiencies and recommend the necessary enhancements for those variables identified by this Panel that can be observed from space);
4. To seek, review and support for, implementation of the strategy from other relevant research and operational programmes (e.g., WCRP, IGBP, WWW, GAW, WHYCOS, GEMS, etc.);
5. To support the Joint Data and Information Management Panel (JDIMP) and other organisations as appropriate in the development of data management systems;
6. To co-ordinate activities with other global observing system panels and task groups to ensure consistency of requirements with the overall programmes;
7. To recommend a schedule of actions to address the gaps in present and planned systems;
8. To make other recommendations as appropriate;
9. To publish and update appropriate GCOS/GTOS studies and planning documents; and
10. To carry out agreed assignments from, and to report regularly to, the Steering Committees for GCOS and for GTOS.

1: Terrestrial properties include the climate relevant observations for the biosphere, cryosphere, and hydrosphere.

Annex V List of Acronyms

AOPC	Atmospheric Observation Panel for Climate
BALTEX	The Baltic Sea Experiment
BSEC	Black Sea Economic Cooperation
CALM	Circumpolar Active Layer Monitoring
CBS	Commission on Basic Systems
CEOP	Co-ordinated Enhanced Observation Period
CEOS	Committee on Earth Observation Satellites
CESR	Centre for Environmental Systems Research
CGIAR	Consultative Group for International Agricultural Research
CHy	Commission for Hydrology
CLIC	Climate and Cryosphere
CLIVAR	Climate Variability and Prediction Research Programme
COP	Conference of the Parties
CRU	Climate Research Unit
CSE	Continental Scale Experiment
DCP	Data Collection Platform
DEM	Digital Elevation Model
DMI	Danish Meteorological Institute (Copenhagen, Denmark)
DT	Delayed Time
DWD	Deutscher Wetterdienst
ECMWF	European Centre for Medium-Range Weather Forecasts
EFFS	European Flood Forecasting System
ENSO	El Nino/Southern Oscillation
ET	Evapotranspiration
FAO	Food ad Agriculture Organisation
FLUXNET	Flux network
FRIEND	Flow Regimes from International and Experimental Network Data
GAME	GEWEX Asian Monsoon Experiment
GAW	Global Atmospheric Watch
GCIP	GEWEX Continental- Scale International Project
GCM	General Circulation Model
GCOS	Global Climate Observing System
GEF	Global Environment Facility
GEMS	Global Environmental Monitoring System
GESAMP	Group of Experts on the Scientific Aspects of Marine Pollution
GEWEX	Global Energy and Water Cycle Experiment
GHOST	Global Hierarchical Observing Strategy
GHP	GEWEX Hydrometeorological Panel
GIS	Geographic Information System
GIWA	Global International Waters Assessment
GNIP	Global Network for Isotopes in Precipitation

GOFC	Global Observation of Forest Cover
GOOS	Global Ocean Observing System
GOSIC	Global Observing Systems Information Center
GPA	Global Programme of Action
GPCC	Global Precipitation Climatology Centre
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Mission
GRDC	Global Runoff Data Centre
GSN	GCOS Surface Network
GSWP	Global Soil Wetness Project
GT-Net	Global Terrestrial Observing Network
GTN-E	Global Terrestrial Observing Network for Ecology
GTN-G	Global Terrestrial Observing Network for Glaciers
GTN-H	Global Terrestrial Network for Hydrology
GTN-P	Global Terrestrial Observing Network for Permafrost
GTOS	Global Terrestrial Observing System
GTS	Global Telecommunications Service
GUAN	GCOS Upper Air Network
GWCC	GEMS/Water Collaborating Centre
GWP	Global Water Partnership
HELP	Hydrology for the Environment, Life and Policy
HOPC	Hydrology Observation Panel for Climate
HWR	Hydrology and Water Resources
HWRP	Hydrology and Water Resources Programme
HYCOS	Hydrological Cycle Observing System
HYDRA-SAT	Hydrological Altimetry Satellite
IAEA	International Atomic Energy Agency
IAHS	International Association of Hydrological Sciences
ICOLD	International Commission on Large Dams
ICSU	International Council of Scientific Unions
IGAD	Intergovernmental Authority of Development
IGBP	International Geosphere-Biosphere Program
IGOS	Integrated Global Observing Strategy
IGRAC	International Groundwater Resource Assessment Center
IHP	International Hydrology Programme (of UNESCO)
ILEC	International Lake Environment Committee
ILTER	International Long Term Ecological Research
INFOCLIMA	World Climate Data Information Referral Service
INFHYDRO	Hydrological Referral Information System
INFOTERRA	International Environment Information System
IOC	Intergovernmental Oceanographic Commission
IOS	Initial Operational System
IPA	International Permafrost Association
IPCC	Intergovernmental Panel on Climate Change

IRD	Institute of Research for Development
ISDR	International Strategy for Disaster Reduction
ISLSCP	International Satellite Land Surface Climatology Project
ISOHIS	Isotope Hydrology Information System
IWMI	International Water Management Institute
JDIMP	Joint Data and Information Management Panel
LBA	Large Scale Biosphere-Atmosphere Experiment in Amazonia
LDAS	Land Data Assimilation System
LOICZ	Land - Ocean Interaction in the Coastal Zone
MAGS	Mackenzie Basin GEWEX Study
MEDTAC	Mediterranean Technical Advisory Committee
MSSL	Mullard Space Science Laboratory
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration (US)
NBA	Niger Basin Authority
NCAR	National Center for Atmospheric Research (US)
NCDC	National Climatic Data Center (US)
NCEP	National Center for Environmental Prediction (US)
NHS	National Hydrological Service
NOAA	National Oceanic and Atmospheric Administration (US)
NPP	Net Primary Productivity
NRT	Near Real-Time
NWP	Numerical Weather Prediction
OHRAOC	Regional Hydrological Observatory for Western and Central Africa
OPAG	Open Programme Area Group
PAGES	Past Global Changes
PET	Potential evapotranspiration
POPs	Persistent Organochlorine Pollutants
PRC	Pilot Regional Centre
QA	Quality Assurance
QC	Quality Control
RBCN	Regional Basic Climate Network
RBSN	Regional Baseline Synoptic Network
RHMCIS	Regional Hydrological, Meteorological and Climatological Information System
RT	Real-Time
SADC	South African Development Community
SAF	Satellite Application Facility
SBSTA	Subsidiary Body for Scientific and Technical Advice
SHI	State Hydrological Institute
SMHI	Swedish Meteorological and Hydrological Institute
SMOS	Soil Moisture Ocean Salinity
SSMI	Special Sensor Microwave Imaging
TCO	Terrestrial Carbon Observation
TEMS	Terrestrial Ecosystem Monitoring Sites

TOPC	Terrestrial Observation Panel for Climate
TRMM	Tropical Rainfall Mapping Mission
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
UNH	University of New Hampshire
UNU	United Nations University
USGS	United States Geological Survey
WCP	World Climate Programme
WCP-Water	World Climate Programme – Water
WCRP	World Climate Research Programme
WDC	World Data Centre
WHO	World Health Organisation
WHYCOS	World Hydrological Cycle Observing System
WMO	World Meteorological Organisation
WSAG	Water Systems Analysis Group
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research
WWDP	World Water Development Programme
WWRD	World Water Development Report
WWWP	World Weather Watch Programme

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