Global Terrestrial Observing System

Report of the Expert Meeting on Hydrological Data for Global Observing Systems

(Geneva, Switzerland, 29 April - 1 May, 1996)

September 1996

GCOS – 27
GTOS – 2

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Contents

Administrative Report

I. Opening of the Session

The Expert Meeting on Hydrological Data for Global Observing Systems was held in the Geneva International Conference Centre from 29 April to 1 May 1996. The list of participants is given in Annex 1 to this report.

The meeting was opened on Monday, 29 April at 10h00 by Mr Kraemer, Director of the Hydrology and Water Resources (HWR) Department of the WMO Secretariat, who spoke of the work of the Department on hydrological data.

The meeting unanimously elected Mr Rodda as chairman, and adopted the agenda given in Annex 2 to this report.

II. Introduction to GCOS and GTOS

Mr Spence, Director of the Joint Planning Office for the Global Climate Observing System (GCOS) and Mr Hielkema, interim Executive Secretary of the Global Terrestrial Observing System (GTOS) made opening statements. They provided an introduction to GCOS and GTOS and presented the expectations of their programmes as to the outcome of the meeting.

Mr Spence described the concept of the GCOS Initial Operational System (IOS) relying on existing facilities and measurements. In addition the IOS identified needed enhancements that were practical from a cost perspective. He also described the relationship between the various global observing systems. Mr Spence explained that the thing all the global observing systems had in common was climate.

Mr Hielkema explained that while GTOS had been in the planning for two years it was only in March that he had been appointed as the interim Executive Secretary. He informed the meeting of the plans for launching a pilot project on system definition studies.

III. Presentation of Relevant Programmes

A number of oral presentations of programmes relevant to GCOS and GTOS were delivered by participants in the meeting, as indicated in Annex 3.

Mr Cihlar described the work of the GCOS/GTOS Terrestrial Observation Panel for Climate (TOPC). He explained that the TOPC was in the process of revising the GCOS/GTOS Plan for Terrestrial Climate-related Observations and welcomed any comments that the panel members might have. He also presented the concept of a tier system. He explained that the system was developed primarily in relation to ecological variables, but the TOPC wanted to know if the concept was also applicable to hydrological variables. Details of the sampling procedure based on the tier concept are presented in Annex 4. The meeting discussed the tier concept and concluded that, with some modification it was applicable to hydrological variables.

Mr Kaczmarek presented his working paper on Hydrological Data in Global Climate and Terrestrial Observing Systems, which is attached as Annex 5.

Mr Stewart discussed the results of the Basic Hydrological Network Assessment Project (BNAP). This study was the first major attempt to analyse the current level of basic hydrological networks from a global perspective. For many years, hydrologists and water resources managers have relied on the network density criteria established arbitrarily by experts to determine the minimum size of the required networks. The inadequacy of hydrological networks was recognized at the 1977 United Nations Water Conference and in the resulting Mar del Plata Action Plan. It was noted that in most countries there were serious inadequacies in the availability of data on water resources, particularly in relation to ground water and water quality. Its recommendations included a call to improve networks and network densities.

In the BNAP study, the adequacy of hydrological networks has been evaluated on a global basis, using data supplied by 58 countries from around the world. "Basic" stations are those required for minimum water resources management, and are generally long-term stations monitoring unregulated flows. Results suggest that the highest station densities are found in small islands, hilly, mountainous, and coastal physiographic regions, in temperate climates, and in basins with 500,000 to 2,500,000 people. Ground water networks are the most dense based on physiography, climate, and population. Results vary considerably, however, even between basins with similar characteristics. Network adequacy was assessed in two ways. Firstly, application of current WMO density criteria indicates that water quality, evaporation, and sediment networks satisfy the minimum guidelines on average, while precipitation and discharge networks are lacking. Secondly, evaluation of "needed" densities, as reported by the participating countries, suggests that the ground water and water quality networks are adequate, with inadequacies apparent for the rest of the hydrological variables and all physiographic classes studied. Again, results vary considerably by country, hydrological variable, and physiography.

Overall, basic ground water networks appear to meet needs, while basic water quality, evaporation, and sediment networks are of questionable adequacy, and basic discharge, water temperature, and precipitation monitoring networks appear to be least adequate to meet minimum water management needs. The relative results obtained appear to be consistent with WMO's current density guidelines. Proposed revisions to the minimum hydrological network density criteria were also presented. For the specific results of the study, the reader is referred to the document The Adequacy of Hydrological Networks: A Global Assessment (WMO/TD - No. 740) by A. Perks, T. Winkler and B. Stewart.

Mr Rudolf described the Global Precipitation Climatology Centre (GPCC) which holds precipitation data sets from over 40,000 stations. He also reviewed a number of activities of the Centre and reported of their data products, such as gridded precipitation fields. The GPCC has developed a 2.5 degree by 2.5 degree gridded precipitation product for the world. They are working toward a 1 degree by 1 degree product. In response to a question regarding the feasibility of developing a .5 degree by .5 degree product, Mr Rudolf explained that it would be possible for some regions, but in other regions there were insufficient data.

Mr Grabs informed the meeting of the mandate and activities of the Global Runoff Data Centre (GRDC) whose holdings embrace at present daily and monthly data on river flow from over 3300 stations worldwide. The key objective of GRDC is to ease the access of WMO Members to data necessary for implementation of water resources projects of global or regional character. The GRDC interacts with national and regional hydrological data centres, and with other global-scale centres. Among the recent activities of GRDC is the study of a fluxes of freshwater into oceans, including a sensitivity analysis in order to determine the minimum number of rivers that need to be monitored.

Mr Gustard presented information on the UNESCO-IHP Project on Flow Regimes for Experimental and Network Data (FRIEND). Although many of the IHP activities are oriented towards research rather than operational hydrology, this particular UNESCO-IHP project requires the collection of large sets of hydrological data. The current FRIEND database contains daily discharge data from a number of small catchments which should be relatively free from anthropogenic influences. The project that started in 1986 in Western and Northern Europe, where it has now a data base of around 4,000 stations, now has a number of other regional implementations in other continents; the most recent development being the Hindu Kush - Himalayan FRIEND.

Ms Enderlein described the activities of the Global Environment Monitoring System - Water (GEMS-Water), implemented by WHO with the support of UNEP, where data from 80 rivers are collected and altogether 50 water quality variables are considered. In particular, she mentioned a recent project designed to provide a GEMS/WATER contribution to the global register of river inputs to the oceans (GLORI).

Mr Kundzewicz reviewed global-scale issues where hydrological data are necessary and compiled a list of global data centres, which is attached as Annex 6 to this report. He also elaborated on alternative versions of the statement of the problem of building an initial observing system for hydrological data. Two possible strategies were presented to develop sets of hydrological stations for purposes of global observing systems. They differ by the point of departure, being either the needs of observing systems (scientific approach) or the availability of existing networks (practical approach). The former strategy would estimate the network necessary to obtain hydrological data fulfilling the goal of the global observing systems without being preoccupied, initially, with the existing network. In the latter approach, the assumption is taken that only existing sites are available and the initial global network is defined from existing data bases, such as GRDC.

IV. Discussion of Needs of GCOS and GTOS for Hydrological Observations

Needs of GCOS and GTOS for hydrological observations were discussed in a number of presentations, starting from the opening addresses of representatives of the two Global Observing Systems. However, during the meeting, several speakers recognized that GTOS had many data needs that had not yet been developed, hence the meeting concentrated on those variables that were required by the climate community.

The meeting decided to divide the hydrological variables of interest to global observing systems into two groups of variables which were each considered by a subgroup of participants. The first subgroup, chaired by Mr Cilhar, dealt with precipitation, both a real and point, evapotranspiration, snow cover area and snow water equivalent. The responsibility of the second subgroup, chaired by Mr Bonell, was to consider surface water - discharge and runoff, surface water storage flux, freshwater flux to oceans, biogeochemical material transport to oceans and groundwater storage fluxes. In addition, it was found necessary to consider the lake and river freeze-up and break-up. The chairman of the meeting presented the subgroup with a questionnaire covering a number of aspects germane to items 4 to 7 of the agenda. This is attached as Annex 7. In responding to the questionnaire, participants assessed each of the hydrological variables compiled in the report of the GCOS/GTOS Terrestrial Observation Panel and, where necessary, suggested additional variables. The meeting also analyzed the accuracy specification. The results of deliberations for each variable considered are compiled in Annex 8.

The meeting stressed the importance of precipitation as the output process from meteorological and climatological systems and the input process to hydrological system. Due to the cross-cutting nature of precipitation it was proposed that precipitation should be considered as both a meteorological and a hydrological variable. As snow and ice are also hydrological elements, it was decided to include also relevant considerations of these elements.

The meeting noted that the use of two variables - surface water discharge and runoff is confusing. Since the word runoff, as used in the literature, has a number of different meanings, it was recommended that discharge be the only variable listed.

V. Assembling Hydrological Data Sets at Regional and International Levels

Presentations by representatives of four large international data bases (GPCC, GRDC, FRIEND and GEMS-Water) helped the meeting understand different aspects of the performance of data bases and the problems related to them.

It was stressed that the hydrological services in many developing countries are in decline. The meeting agreed on the need to up-grade and/or rehabilitate existing stations in developing countries which are of primary importance for global observing systems. Some of these stations may be of little importance for national needs of a developing country but yet they play an important role in the global context.

VI. Development of a Set of Criteria for Network and Site Selection

The subgroups referred to above discussed criteria for network and site selection for all hydrological variables of concern to global observing systems. The results are compiled in Annex 8.

VII. Definition of a Preliminary Network of Stations (Initial Operational System)

On a variable to variable case, an Initial Operational System (IOS) was proposed. This was the case, for instance, for surface water discharge, where the existing network identified by GRDC can serve as the first step in the definition of the required network.

VIII. Future Action

Actions related to individual variables were discussed, following the questionnaire presented in Annex 7. These actions are compiled in Annex 8.

IV. Closure

The meeting closed on Wednesday, 1 May at 15:00 hours.

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Annex 2: Agenda

I. Opening

II. Introduction to GCOS and GTOS

III. Presentation of relevant programmes

IV. Discussion of needs of GCOS and GTOS for hydrological observations

V. Assembling hydrological data sets at regional and international levels

VI. Development of a set of criteria for network and site selection

VII. Definition of a preliminary network of stations

VIII. Future action

IX. Closure

Annex 3: Presentations under Agenda Items I to III

1.	Statement by WMO	Dieter Kraemer
2.	Statement on GCOS	Tom Spence
3.	Statement on GTOS	Jelle Hielkema
4.	Terrestrial Observation Panel and description of the tier system	Josef Cihlar
5.	Hydrological data in global climate and terrestrial observing systems	Zdzislaw Kaczmarek
6.	Basic Hydrology Network Assessment	Bruce Stewart
7.	Description of GPCC	Bruno Rudolf
8.	Description of GRDC	Wolfgang Grabs
9.	FRIEND	Alan Gustard
10.	Introduction to GEMS-Water	Ute Enderlein
11.	Hydrological data for global observing systems	Zbigniew Kundzewicz

Annex 4: Sampling Based on the Tier Concept

1. Successful execution of the GCOS and GTOS programmes requires that information about numerous variables be obtained for terrestrial environment around the world and converted into homogenous data sets. These data sets are necessary to achieve the GCOS objectives of climate change detection, assessment of seasonal and interannual variability, model validation, etc.; and the GTOS objective of detecting and assessing the impact of climate change on terrestrial ecosystems, among others. To obtain such data sets implies that each variable is measured at many locations around the world, with the necessary temporal frequency, accuracy and consistency so that the needed global data sets can be generated from these measurements. Since most variables of interest vary both in time and in space, often quite rapidly, this poses a formidable challenge.

2. The fundamental constraint of global observing systems is that it is not practically feasible to measure all of the variables all of the time everywhere. This dictates that a sampling design must be used to most effectively utilize available resources in obtaining the information at the global scale. For example, one of the efficient sampling designs is stratified random sampling in which the distribution of samples in the population is based on the distribution of the variability within the population of interest. The highly variable portions (or strata) of the population are then sampled more intensively than those with less variability.

3. Since each variable may have its own distribution of variability globally, a different stratification should in principle be envisioned for each GCOS/GTOS variable of interest. This would imply that many different sites would be required around the world, each providing measurements for one or few variables. Again, this would be practically very difficult to implement, besides being too costly. Fortunately, many variables of interest vary in similar manner, i.e. their stratifications more or less coincide. For example, variables related to biogeochemical cycling are closely related to the vegetation characteristics. In defining a sampling program, one can thus envision stratification based on biome, land cover, or vegetation type. Similarly, some variables describing hydrological processes co-vary at the scale of a watershed or a river basin. Such co-variations have been employed in the past in the establishment of research centres or sites at which numerous processes and variables are investigated. An example are Long-Term Ecological Reserves, agricultural research stations, experimental watersheds, etc.

4. A variable of interest may often be measured in many different ways. For example, soil organic matter content may be measured directly through chemical analysis, indirectly using spectrophotometry, or simply related to soil colour through the use of colour charts. Such procedures usually differ in accuracy, complexity, and costs. It is thus possible to make many (but less accurate) measurements with a simple approach but only few using a complex, expensive procedure.

5. Various measurement techniques also provide results over different spatial domains. For example, direct, detailed measurements can be applied to few locations

because of logistics and costs. On the other hand, indirect methods such as space observations provide the means of covering the whole globe, with a spatial resolution that can be selected through sensor design and mission management.

6. The three above aspects of determining the global distribution of a variable: co-variance with other variables of interest, different techniques for measuring the variable, and the different capabilities for spatial coverage can be used to define a comprehensive global monitoring system. In such a system, various measurement approaches for a variable should be combined so as to maximize the quality of the resulting global data products. Furthermore, the measurements of different variables should be coordinated so that the cost effectiveness of the entire system is maximized.

7. With the above considerations in mind, concept of tiers is defined for GCOS/GTOS terrestrial observation purposes. In principle, 'tier' characterizes the measurement approach to a variable and is defined in three ways:

- the number of GCOS/GTOS variables measured at the same location; this is a reflection of the degree of co-variance among the different variables of interest;

- the accuracy/precision of the method used to measure the variable; and

- the spatial frequency with which the variable is sampled.

8. For GCOS/GTOS purposes, a five-tier sampling concept is defined using these three criteria. For the lower tiers, the number of co-located measurements is higher, measurement techniques employed for the variable of interest are more complex, and the measurements are made at fewer locations than for higher tiers. Each measurement approach to a variable can be classified as belonging to one of the tiers. For example, precipitation measured continuously or at frequent intervals by (few) automatic recording stations and along with other meteorological variables is tier 1 measurement, while measurement once a day at (many) climatological stations (where no other variables or air temperature only are measured) may be tier 4.

9. Although the tier definition is developed in terms of measurements of individual variables, it can also be employed to 'sites', i.e. locations where sets of GCOS/GTOS variables are measured. At sites belonging to the lower tiers, more variables are measured with more complex methods but at fewer sites than at higher tiers. In the five-tier scheme, tier 1 includes sites not initially established for monitoring purposes but which otherwise meet the tier criteria. Tier 1 sites are established by comprehensive research programs aimed at understanding the environmental processes involved in climate and climate-ecosystems interactions and at the development and validation of models needed by GCOS and GTOS. In these studies, unique data sets are obtained which are of value to the global monitoring programs because of the models they underpin. It is to be expected that measurements at many of these sites will continue, thus becoming part of the global monitoring systems. Tiers 2 and 3 exist in many instances, as indicated below. Tier 5 (individual variable typically measured with high spatial frequency and lower accuracy/precision) contains principally satellite-based measurement techniques.

10. Tier 4 exists in some cases but not in most. It may serve two purposes: to provide spatially dense measurements for variables not measured (or not measurable) from satellites, or to provide a basis for statistical extrapolation of more intensive measurements from lower tiers. The design of tier 4 measurements can therefore be complicated.

11. When applied to existing sites on which global GCOS/GTOS observations may be based, the tiers have the following characteristics :

Tier	**characteristics**
1	Large-scale experiments. Very intensive measurement of a large number of variables over a ‘site’ of several hundred square kilometres or a transect of several thousand kilometre length, over a limited period of time. They obtain data to study processes, interactions among processes and ecosystem components, and to develop models describing these. GCOS/GTOS does not create or fund these, it simply ensures that the data and understanding from them are captured for future use. Examples are the IGBP Megatransects, GEWEX large catchment studies, ISLSCP projects, etc. May later continue observations of selected variables (similar to tier 2 or 3 sites).
2	Research centres with a large staff (>10 participating scientists), sophisticated and expensive infrastructure (the actual infrastructure varies with the research focus but may include laboratories, data loggers for continuous measurement, flux towers and gauging weirs, etc.). They tend to focus on one biome type for unmanaged ecosystems (e.g. the US-LTERs) or one crop type in the case of agricultural centres (e.g. CIAT, IRRI). GTOS/GTOS relies on these sites to develop process-level understanding and to make continuous measurements of fluxes and numerous other variables. There are thought to be about 100 such sites globally. In principle, there should be one per major crop type, biome type, aquatic system type and cryospheric type.
3	Research stations with permanent presence on site. Many hydrological observation sites fall into this category, as do ecological field stations and many agricultural research stations. Their principal function is to characterize the seasonal and interannual variations across the range of variability within each major ecosystem, crop system, aquatic system or cryospheric system. Globally, this is expected to require about 500 -1000 sites, the overwhelming majority of which already exist. The observations do not require very expensive, sophisticated or continuous measurements.
4	Sites which are revisited regularly but infrequently (once every 5-10 years). Their principal purpose is to provide information on variables that cannot be accurately obtained by remote sensing, or to provide statistically valid spatial information for extrapolating findings from the lower tiers.
5	Remote sensing, which is usually quasi-continuous in both time and space, but can provide data for only some of the variables of interest.

Annex 5: Hydrological Data in Global Climate and Terrestrial Observing Systems
(prepared by Mr Kaczmarek)

Background

1. This document presents a summary of discussion held during the second session of CHy Working Group on Operational Hydrology, Climate and the Environment (Silver Spring, 2 to 7 October 1995). In addition to WG members, a number of invited experts joined the meeting under the agenda item dealing with collection and processing of hydrological data for global climate and terrestrial observing systems.

2. The following discussion papers were distributed among the participants:

(a) Hydrological data in global climate and terrestrial observing systems (submitted by Mr. M. Beran, chairman of the Working Group);

(b) Hydrological data for global observing systems (submitted by the WMO Secretariat). Material contained in these papers was also employed in writing this summary.

3. Participants informed the meeting on developments regarding the following international activities relevant to global observing systems:

- Global Climate Observing System (GCOS),
- Global Terrestrial Observing System (GTOS),
- World Hydrological Cycle Observing System (WHYCOS),
- Flow Regimes for International Experimental and Network Data (FRIEND) project,
- Global Runoff Data Center in Koblenz,
- Intergovernmental Panel on Climate Change (IPCC).

4. The following strategy problems concerning the role of hydrologic data in global observing systems were investigated:

(a) detecting and documenting climate change and variability;

(b) detecting and documenting change in hydrological systems and its impacts to water resources;

(c) providing hydrological input to global climate model development and applications;

(d) enhancing the role of hydrology in studying land/soil degradation, natural ecosystems, biodiversity loss, etc. Main conclusions of the discussion on the above mentioned subjects are presented below. They should be considered as preliminary opinions and in most cases require further investigations.

Hydrological data for detecting climate change

5. The hydrological cycle affects and is affected by the earth's climate system in a fundamental sense. It contributes in a major way to the energy exchange between the earth surface and the atmosphere. The inherent difficulties, however, in using hydrologic observations in detecting and documenting climate variability and change are:

(a) low values of signal-to-noise ratio; the maybe climate change component is weak as compared to the strong natural variability of hydrologic variables;

(b) a possible compensatory effect: a rise of temperature (and consequently of potential evapotranspiration and increase in precipitation may lead to a small net effect on runoff;

(c) strong non-climatic anthropogenic impacts on water resources in many regions of the World, difficult to distinguish from the climate change signal.

6. To detect climate change and variability, the following standard hydrologic variables are to be considered:

6a. Discharge data: monthly data for seasonal and inter-annual changes, and instantaneous or event-based data for changes of extremes. Discharge measurements are routinely made by hydrological services (or other agencies), and easy to obtain. For the climate change assessment observations from catchments with minimal anthropogenic impacts (benchmark, pristine), or with accountable impacts should be used. A study is needed to ascribe a number of stations in various parts of the globe to document climate change and variability: density will not be uniform and depend on several factors, such as topography.

6b. Lake levels: data collected by national hydrological services and other institutions, for a set of large lakes with negligible/accountable anthropogenic impacts may be used. The required temporal resolution: monthly to annual.

6c. Ice phenomena in lakes and rivers: time series of dates of freeze-up and ice cover break-up may serve as an indicator of climate change. Such observations are usually made by national services or research institutions, but in some cases data may be available also from other sources (e.g. ice cover break-up reported in the press). It is required that for each typical GCM grid (e.g. 2.5^o by 2.5^o) a representative group of water bodies (one river, one shallow lake, and one deep lake) be selected for analysis.

6d. Snow cover: time series of the extent, duration and water equivalent of snow cover may serve as climate change indicator. Temporal resolution and spatial densities of snow measurements are described in WMO guidelines.

7. There is a number of other hydrologic variables of importance for detecting climate change, but presently observed mostly in a research context, as e.g. evapotranspiration, groundwater table in pristine aquifers, and lake stratification patterns. If available, such data should also be collected and analysed.

Detecting change in hydrologic and water resource systems

8. Most of the above mentioned hydrological observations, used for detecting change in climate may also serve to identify non-stationarities in hydrologic processes, and consequently assess changes in regional water supply and demand, and to evaluate possible enhancement of water-borne hazards (e.g. floods).

9. In particular, such data should be systematically compiled and analyzed for:

- globally significant freshwater bodies,
- pristine and/or "stable" ecosystems,
- research basins used for studying universal-type problems.

The variables under investigation should be appropriate to element/problem concerned, and dependent on element exhibiting impact (droughts and floods, ice break data, ecology of aquatic systems).

10. The globally significant freshwater bodies should include:

- a set of largest rivers of the World, accounting for at least 50% of total runoff to oceans;
- selected large lakes;
- largest World's aquifers;
- water bodies representative of major anthropogenic influences, selected on a basis of population, economic development, possible water induced international conflicts, etc.

11. The pristine and/or "stable" ecosystems should be distributed throughout the World reflecting various climatic and physiographic conditions. The stability concept should be rigorously defined.

12. Research basins should be selected in order to address universal problems, e.g. effects of urbanization, deforestation, role of mining, etc. Irrigated agriculture may be particularly sensitive to changes in precipitation, potential evapotranspiration and soil moisture. The selected experimental catchments should allow to study most critical problems identified in Agenda 21, be representative geographically and of different scales.

Hydrological data for environmental changes

13. The various 'problem areas' dealt with under this heading can be broadly divided into those where there is direct anthropogenic change leading to a defined problem and others whose changes are indirectly influenced by man's activity. Table 1 shows that broad division and the associated role of hydrological sciences.

14. It would be difficult to consider hydrologic data needs at the level of individual variables, because of the great diversity that exists in the underlining processes. Moreover, the hydrologist would in most cases be in support role to the specialists most directly involved in a given problem area.

15. This is less so in the case of water quality in rivers and lakes, and in wetlands. For water quality issues, a tier system was found to be a useful concept (about the GCOS tier system see e.g.: "GCOS/GTOS Plan for Terrestrial Climate-related Observations, version 1.0": WMO/TD - No. 721).

16. There are processes of pollution and its interaction with the aquatic environment for which a tier 1 and tier 2 approach is required. GEWEX and IGBP activities need to consider this issue, especially focused on environments where processes are understood. Also tier 3 gives a reasonable fit, because it is likely that hydrometric stations in WHYCOS would also serve as the location for water quality measurements.

17. The meeting agreed that it was only possible to give generalized guidance as to the role of hydrologic data in other areas. Hydrologists would play an important though supportive role in the design and implementation of the networks required to serve the needs at the various tiers.

MAN'S INFLUENCE	DIRECT	INDIRECT
PROBLEM AREA (examples)	AIR: acid rains LAND: desertification urbanization wetlands drainage deforestation WATER: water quality	ECOSYSTEMS: structure (Biodiversity) ECOSYSTEMS: processes (Biogeochemistry)
PROBLEM CHARACTERISTICS	- Problem specific - Location specific - Intensive	- Problem generalized - Globally distributed - Extensive
HYDROLOGIC IMPACT	- Linear - Determined by process	- System feedbacks - Generalized
ROLE OF HYDROLOGIST	- Leading (water quality, wetlands) - Supporting (others)	- Supporting

Input to climate model development and applications

18. A new focus for hydrology is what has been termed "macro-modelling". In essence this comprises modelling procedures for the elements of the water balance for very large basins, that are not too demanding of data and are consistent across main subcatchments or down the main river stem. Macro-modelling is justified both for water resources assessment and management in major basins, and because it is capable of adding surface and subsurface transports to soil-vegetation-atmosphere transport schemes (SVAT) that provide the land-surface description of general circulation models (GCM's).

19. Physically based models of land surface processes used as parameterization of sub-grid land surface processes in atmospheric GCM's require hydrologic and land surface data shown in Table 2.

Table 2

Hydrological data	Land surface data
- river discharge - catchment runoff - potential evapotranspiration - soil moisture - soil frost - groundwater table - snow cover - snow water equivalent	- topography - basin boundaries - geology - soil characteristics - vegetation - surface albedo - land use

20. The following aspects of model development and application require hydrological data gathered according to different data collection strategies:

(a) Model development phase:

- model formulation,
- estimation of model parameters,
- testing before application.

(b) Application phase:

- data to produce model inputs,
- data assimilation to produce model initial conditions,
- model testing, evaluation and verification.

21. Most components of surface water and energy budgets cannot be measured sufficiently well for budget to close, except possibly for limited experimental situations. For example, soil moisture at model scales cannot be measured directly and has not been measured historically at the scales of its influence on the atmosphere. Data sets of water and energy budget variables organized for model development and application must be

derived or assimilated from a wide range of observations. Some of these data sets are needed historically as well as in the future for model development, testing/evaluation, and for simulation of atmospheric processes.

22. Variables in water and energy budgets (both fluxes and state variables) include components of variability over a wide range of space and time scales (i.e. they are heterogeneous in space and time). In addition, most of the processes that govern their dynamics also have heterogeneous elements (e.g. soil characteristics, vegetation and topography).

23. Typical modelling scales for General Circulation Models and Numerical Weather Prediction Models (NWP's) range from about 10 km to more than 100 km. These models resolve processes at scales above grid scale, but process dynamics below grid scales must be parameterized at grid scale. The data needed to develop, test and operate these models must be derived for these scales from observations at other scales, routinely performed by national hydrologic and meteorological services.

24. An example of hydrologic data requirements for a continental-scale hydrologic project (GEWEX/GCIP - Mississippi river) is shown in Table 3.

Table 3

Parameter	Spatial resolution	Vertical resolution	Time resolution
Streamflow	4 - 40 km	N/A	1 hr - 24 hr
Groundwater level	4 - 40 km	< 100 ft	24 hr - monthly
Irrigation water use	4 - 40 km	N/A	min 24 hr
Permafrost	4 - 40 km	N/A	as available
Evaporation	4 - 40 km	N/A	1 hr - daily
Snow water equivalent	4 - 40 km	N/A	1 hr - daily
Snow depth	4 - 40 km	N/A	1 hr - daily
Snow cover extent	4 - 40 km	N/A	1 hr - daily
Soil moisture	4 - 40 km	depth to 6 ft	24 hr - monthly
Soil temperature	4 - 40 km	depth to 6 ft	6 hr - 24 hr
Basin boundaries	1 - 10 km	N/A	once

General issues

25. Other matters that have been discussed include:

- data quality control,
- archiving, accessibility, availability and processing of the data,
- the requirement and means of compressing large volumes of data and products into a usable form,
- the relative merits and possibilities of using distributed versus centralized data bases,
- establishing links to other data sources,
- the need for a long-term commitment from data suppliers, and
- the possible effects of commercialization of national services.

There was a general agreement on the importance of collecting metadata on hydrologic stations: its location, instrumentation, collection procedures etc.

Annex 6: Global Hydrological Databases

1. Hydrological data exchange and the formation of global data bases is a difficult, time-consuming and sensitive process. Unlike meteorological data, hydrological data are usually only held and distributed at national level. Limited international exchange of hydrological data has taken place, but usually only when required for operational purposes, such as flood forecasting on international rivers. Some exchange for research purposes has existed, though. Hydrological data are the responsibility of a wide variety of organizations and ministries within individual countries, which makes the problem of data exchange difficult at the national and even more so at the international level.

2. In spite of the above, a number of global hydrological data bases do exist, such as:

(i) The Global Runoff Data Centre (GRDC) of WMO in the Federal Institute of Hydrology, Koblenz, Germany;

(ii) The Global Precipitation Climatology Centre (GPCC) of WMO in the German Weather Service, Offenbach, Germany;

(iii) The Global Environment Monitoring System (GEMS-WATER) of UNEP with assistance of WHO, water quality data being held in the Quality Monitoring Centre managed by the Canadian Centre for Inland Waters in Burlington, Canada;

(iv) The Flow Regimes from International Experimental and Network Data (FRIEND) data base (flow data, originally from research basins in Europe but broadening) co-ordinated from the Institute of Hydrology, Wallingford, UK within the context of UNESCO's IHP-V;

(v) The National Snow and Ice Data Centre (WDC-A Glaciology) held by CIRES, University of Colorado, Boulder, USA;

(vi) The World Glacier Monitoring Service acting under the umbrella of ICSI of IAHS with the support of IGSU/FAGS, UNESCO/IHP and UNEP/GEMS, with its Secretariat in ETH Zurich, Switzerland;

(vii) The Global Resources Inventory Database (GRID) of UNEP, which has a wide range of different types of data, some of it water-related, held in several locations;

(viii) The remote sensing programme at the Mullard Space Science Laboratory of the University College London aims to monitor and interpret short and medium term lake volume changes. The MSSL Global Lakes Database contains location and lake type information along with lake levels and areas for over 1400 inland water bodies including, as far as possible, all lakes and reservoirs but not lagoons, with surface areas in excess of 100 km^2.

(ix) A data base of the state of the world lakes has been created by the International Lake Environment Committee (ILEC) and the Lake Biwa Research Institute (Japan).

(x) The Global Network "Isotopes in Precipitation" (GNIP) of IAEA is operated with the assistance of WMO and collects data worldwide on the contents of stable environmental isotopes in precipitation. These data, kept in IAEA, Vienna, are useful as a benchmark for testing the relations between isotopic composition of precipitation and climate (temperature, volume of precipitation, source of moisture).

3. WMO, as the specialized agency of the United Nations in charge of meteorology and operational hydrology, is promoting, in association with the World Bank and other UN agencies concerned, the establishment of the World Hydrological Cycle Observing System (WHYCOS) which is intended to provide real-time information on a number of hydrological and meteorological variables. WHYCOS should act as a tool for the improvement of collection, dissemination and use of high quality, standardized and consistent hydrological and related information at a national, river basin, regional and international levels. The system is to be based on a world-wide network of key stations linked by satellite with an associated quality-controlled data base for variables characterizing the quantity and quality of water, plus basic hydrologically-relevant meteorological variables. WHYCOS is potentially of great importance to water resources assessment on the global, regional and national scales. Initially, WHYCOS will consist of about 1000 stations world-wide, sited on major rivers, including one site near to the river mouth, yet beyond the extent of saline intrusion. Each station will monitor up to 15 variables such as river water parameters (stage, temperature, pH, conductivity, turbidity, dissolved oxygen) and atmospheric parameters (precipitation, air temperature, relative humidity, wind speed and net radiation). The data collected will be transmitted via satellite to regional and global centres. WHYCOS stations will generally be selected as sub-sets of the existing station networks agreed with the national agencies, usually those with long time series of records. In the developed world, where many good quality stations already operate, WHYCOS will capitalize on them. The effort will essentially be a matter of choosing benchmark, or reference stations, up-grading and networking. However, in the developing world, substantial investment will have to be allocated for establishing the stations themselves and the capacity building programme for the National Hydrological Services participating in WHYCOS. The implementation of the first component of the WHYCOS has recently been initiated for countries of the Mediterranean and the Black Sea Basin (MED-HYCOS) under a World Bank grant. The concept is being developed also for other regions, such as SADC Africa (SADC-HYCOS), Latin America and the Caribbean (CARIB-HYCOS) and for the Aral Sea Basin (ARAL-HYCOS).

4. There are a wealth of other important hydrological data bases being formed in a number of international programmes. One of the main objectives of the Global Energy and Water Cycle Experiment (executed under the World Climate Research Programme jointly sponsored by WMO, ICSU, and the IOC of UNESCO) is to determine the hydrological cycle and energy fluxes by means of global measurements of observable atmospheric and surface properties. The scientific plan for GEWEX calls for a major

data collection effort to complement the existing river discharge data. Such GEWEX projects as GCIP (GEWEX Continental-scale International Programme), GEWEX Asian Monsoon Experiment (GAME), MAGS in the Mackenzie drainage basin, BALTEX in the Baltic Sea Basin, LBA, that is Large-scale Biosphere-atmosphere Experiment in Amazonia and others collect hydrological data, needed for research into energy and water transfer. These projects may substantially complement the available hydrological data by variables which are not observed routinely (e.g. remotely sensed monitoring of soil moisture). Because most of the GEWEX hydrological activities are organised on a regional level, it may be expected that a number of regional hydrological data bases will contribute to the overall goals of GCOS.

5. The Biospheric Aspects of the Hydrological Cycle (BAHC) Project was established within the International Geosphere - Biosphere Programme (IGBP) of ICSU. BAHC has developed a framework for interdisciplinary research activities to address the question - how does vegetation interact with physical processes of the hydrological cycle. BAHC will use different data sources, and one of the Project's task is to gather and summarize worldwide data on vegetation and soils. Observations from space are expected to support data obtained from land-surface experiments.

Annex 7: Questionnaire Covering Items 4 to 7 of the Agenda

1) Are the variables correct?
Are additional variables needed?
If this is the case, develop a new sheet using the format found in Appendix 1 of the GCOS/GTOS Plan for Terrestrial Climate-related Observations.

2) Are the spatial and temporal resolution requirements appropriate?
If not what should they be?

3) Is the accuracy specification correct?
If not what should it be?

4) What are the criteria for site selection?
Do we need a uniform density?

5) Can an Initial Operational System be defined?
What existing networks already exist that will meet the needs?
If possible, indicate what gaps exist?
What enhancements are necessary?

6) What actions are necessary to begin to implement the system?

Annex 8: Requirements on Hydrological Data for Global Observing System

The views and recommendations of the meeting regarding the various hydrological variables considered are recorded below. They relate principally to Annex 1 of the GCOS/GTOS Plan for Terrestrial Climate-related Observations, version 1.0, November 1995, GCOS-21, WMO/TD-No. 721, UNEP/EAP.TR/95.07 and a draft list of variables endorsed by the TOPC III at its meeting held in Cape Town, South Africa from 19 to 22 March 1996.

The number following the decimal point refers to the number of the question in Annex 7 For example, section 1.2 discusses whether the spatial and temporal resolution of precipitation data are appropriate.

1. Point Precipitation

1.1 The variables are correct, but it should be made clear that we are measuring total and solid precipitation and that liquid precipitation is obtained as the difference between the two.

1.2 The spatial density should be “as measured” for point precipitation. The frequency of derived values of cumulative precipitation should vary as follows:

Macro-scale studies: daily - but there is a real difficulty here because of the different times at which daily readings are taken around the globe (local time).

Meso-scale studies: hourly - with considerable precision being requested for some work, but probably unobtainable on a wide scale. One complicating factor is the micro-scale dynamics of certain rainfall events.

1.3 The raw data should be available, but they should be corrected for systematic errors before they are used. For both macro and micro scale studies: 0.1 mm should be the definition of precipitation as opposed to no-precipitation, with a desired accuracy of:

± 0.1 mm for 5 mm
± 2% for > 5 mm

Achievable operational accuracy: ± 5%.

1.4 We should make a concerted effort to use the data from existing sites. There are a very large number of these and efforts are probably better directed to obtaining existing data than to establishing new stations. Sites for inclusion in a data set should be chosen taking into account the location of discharge stations so that the two data sets can be used for river basin studies (in the tier framework, as applicable).

On a more general basis:

Macro-scale studies: the first need is for 40 000 stations based on an objective analysis.

We can use existing knowledge of actual versus desired stations based on information available to GPCC, that will be published soon, together with WMO criteria. These should give GPCC a basis for establishing guidelines for locating desired sites.
Meso/micro-scale studies: the network will depend on the purpose for which the data are to be used and the local climatic/topographic conditions. In most cases the request will be for all possible stations in the area concerned, even if this gives non-uniformity in the density of stations.

1.5 It is important to note that:

GPCC currently receives only monthly data and no daily data. They make available metadata about the point data that they hold but they are presently not authorized to release the data themselves.

An IOS could well be based on the GPCC holdings and its plans for a 40 000 station coverage if the above daily data access restrictions were relaxed. There is still a need for additional data from some regions to get a good global coverage, and GPCC can easily identify these, in particular by country.

1.6 Actions

- Pursue technological advances in the direct measurement of precipitation over oceans. [Directed at: WMO/GOOS]

- Continue using informal personal contacts to achieve the most comprehensive coverage possible until data delivery (continuation of delivery of data from countries supplying at the present, encouragement of countries not supplying data to do so), until routine data delivery to GPCC becomes more established. [Directed at: GPCC]

- Send a letter to all countries requesting that update of the precipitation measurements forwarded to GPCC, including the most recent data and all synoptic station data. [Directed at: GPCC, WMO]

- Design a future data flow structure for precipitation data and products (end to end). [Directed at: DIMP, GPCC]

2. Gridded Precipitation
(Variable also referred to as “areal precipitation”)

2.1 These data will be derived from point (rain gauge) measurements, satellite (thermal infrared, passive microwave) imaging data on 2.5o x 2.5o grids, and digital radar measurements. The proposed variables (TOP1) are adequate.

2.2 As regards spatial resolution and frequency, we should distinguish between:

Macro-scale studies: 1o x 1o grid, with daily and monthly data at continental-scale

Meso/micro-scale studies: 0.01o x 0.01o grid, with hourly data from digital radar and raingauges.

2.3 For all scales, the aim should be ±-5% accuracy.

2.4 Here the same comments apply as for “point precipitation”.

2.5 An IOS can be based on GPCC data with the aim of obtaining a monthly 1o x 1o data product with global coverage, based on an internal (GPCC) compilation at 0.5o x 0.5o. These data will be from point measurements merged with satellite estimates.

Data products for continental-scale purposes should be made available at 0.5o x 0.5o grid cell size.

Data on 0.01o grids are or will be available from regional projects.

The gaps identified under “point precipitation” are also applicable here, but the coverage is better, albeit with reduced accuracy, because of satellite coverage.

The primary enhancements should be a decrease of GPCC cell size to 0.5o x 0.5o for the global products (strongly dependent on improvements in the spatial resolution of satellite products). From the viewpoint of data processing at GPCC there are no technical problems in decreasing the cell size, but in practice the unavoidable need for manual control and checking would impose a high burden on current GPCC staff. A 0.5o product should include accuracy/error index for each grid cell.

2.6 Actions

- Include snow (water equivalent) observations from surface (possibly satellite) in gridded precipitation products.
[Directed at: WCRP/GPCC]

- Prepare a description of a potential 0.5o x 0.5o global monthly gridded precipitation product (making optimum use of the present data and providing confidence information) and obtain user evaluation of the product’s usefulness. [Directed at: GPCC, TOPC]

- Subject to a positive assessment, implement routine production of 0.5o x 0.5o monthly precipitation products. [Directed at: GPCC]

- Support the establishment of digital radar networks and associated surface networks. Archive derived products at meso- and micro-scale. [Directed at: WMO, regional agencies]

- Continue improvements in precipitation estimation using satellites, especially improvements in spatial resolution of he final products.

3. Variable: Evapotranspiration

3.1 It was clarified that what is needed is actual and not potential evapotranspiration. Otherwise, the variables as specified were adequate, although the units might read "kg/m2/day" to bring them in line with those for precipitation.

As with precipitation, a distinction was made under most headings between point and gridded values.

3.2
Point: 10 - 100 m2 on a daily basis.

Gridded:100 - 1000 km2 on a daily basis.

3.3 There exist no practical means of measuring evapotranspiration extensively (eddy correlation offers a means of measurements at few locations); most evapotranspiration (ET) data are therefore derived estimates. Unfortunately, there is no consistent approach and there are no broad-based data sets available at the present.

If the desire is only to monitor change over time, then absolute accuracy may not be important and consistency is the main requirement. However, if the data are to be used with precipitation and runoff in flux studies, then accuracy becomes important.

±20% or better should be the desired accuracy.

3.4

Point: the aim should be to locate and use the data collected and/or available from various activities (Tiers 1 to 3).

Gridded: the value of current point data for producing gridded sets is highly variable, depending on the location of the individual sites.

3.5

Point: An IOS may be developed, provided Tiers 1 to 3 sites archive relevant data.

Tier 3 studies, some long-term, could provide measurements/estimates of various types, and these should also be archived.

Examples of the above are data from GEWEX, ISLSCP and IGBP studies.

It will be important to ensure that the evapotranspiration estimates produced by these projects are seen as having a wider (GCOS/GTOS) use and are developed and archived with this in mind.

Gridded: There may be considerable potential value in the estimates of evapotranspiration derived by SVAT models, in particular those models contained within GCMs run to reanalyze past global data sets. It is understood that, at present, such estimates are not available and are possibly not even archived. However, together with remote sensed data, they could provide gridded estimates of value to GCOS and GTOS.

3.6 Action

3.6.1

Point: Evapotranspiration

- Ensure that Tier 2 and 3 sites have quality ET data (through site selection, upgrade of measurements,..). [Directed at: GTOS, GOOS]

- Ensure that ET data are archived and readily accessible. [Directed at: DIMP]

3.6.2

Gridded: Evapotranspiration

- Prepare the description of a potential gridded ET product(s) prepared through data assimilation/reanalysis under some present or near future programs. [Directed at: WCRP/GPCC]

- Assess the usefulness of such a gridded global ET product(s). [Directed at: TOPC, GTOS]

4. Snow Cover Area (SCA) and Snow Water Equivalent (SWE)

4.1 The variables currently proposed are adequate. Snow cover area is itself of interest in radiation studies, but as a hydrological variable it can only be used in conjunction with estimates of SWE. Hence the two variables are taken together.

4.2 The focus for SCA and SWE should be on gridded products. A variety of point data will be used as a basis for deriving the gridded values.

Macro-scale studies: the spatial and temporal resolutions should be equal to those given for precipitation, or better if the accuracy is acceptable at 1o x 1o or 0.5o x 0.5o grid scale.

Meso/micro-scale studies: as for macro-scale, but better if the accuracy is acceptable.

4.3 SWE accuracy could be less stringent than for precipitation.

4.4 For SWE, emphasis should be put on using existing sites, even though they are not of uniform density.

4.5 A useful IOS can be developed for SCA based on global data sets using:

- synoptic reports from surface weather stations
- SCA (as vectors/polygons): NOAA-AVHRR
- SWE (gridded): SMMR, SSM/I (validation by in-situ data required)
- re-analysis (GCM) studies: here the quality and adequacy of the product has yet to be established.

The gridded values for meso/micro-scale should be archived with information on the estimated accuracy.

Various enhancements are possible, especially in combining point and spatial measurements. ACSYS studies could act as a test bed.

4.6 Actions

- Request snow data from synoptic meteorological stations to be supplied by nations to GPCC (see also 1. Point Precipitation, directed at: GPCC, WMO)

- Compare gridded snow products derived from satellite data with those from reanalyzed meteorological data. [Directed at: CRP/WG on Numerical Experiments, Committee on Atmospheric Sciences, GPCC]

5. Freshwater Flux to Oceans

5.1 Volume per time unit.

5.2 Spatial - based on statement of requirements of GCM modellers, LOICZ and ocean community (GOOS); sensitivity analysis may be helpful.

Temporal - mean daily / monthly.

5.3 5% desirable, 20% tolerated. Application of advanced existing technology (e. g. moving boat, Doppler current meter) needed for measurement of large rivers.

5.4 To cover as much as possible of the land masses to integrate better the flux into the ocean. This is dependent on the total number of stations. No - a uniform density is not needed.

5.5 Yes - based on the GRDC project for assessment of freshwater inflow to oceans. Initial number of stations may follow the GRDC study on representation of river runoff from continents into the oceans. There are gaps in the temporal coverage of the data and there is a need to cover some regions of the world more completely. There is a need to search for existing stations closer to river mouths than stations available in GRDC database at present, yet still free of pronounced tidal effects.

5.6 Actions

- Encourage countries to transmit to WMO homogeneous time series in a continuous mode. [Directed at: GRDC, WMO]

- Upgrade and rehabilitate existing stations. [Directed at: GRDC, WMO]

6. Bio-Geo-Chemical (BGC) Material Transport to Oceans
(Variable also referred to as "material transport from land to oceans via rivers")

Units of measure: concentration in mg (or micrograms, nanograms) per litre; fluxes in metric tonnes per year.

A longer-term objective should also be - monitoring pesticides and micropollutants.

6.1 Need for monitoring of other parameters: pH, conductivity, DO, BOD, water temperature, concentrations of silica and micropollutants. Assessment of loads and concentrations necessary.

6.2 Spatial: using the same tier 3 system as in the case of flux into the ocean. Attempt to co-locate discharge stations and water quality stations close to each other. Temporal resolution should be more variable: basically twice a month. Denser temporal sampling downstream of urban and/or industrial complexes. Event-based measurements with fine-time resolution data also necessary (e. g. inflow of agricultural pollutants). Refer to LOICZ.

6.3 Uniform accuracy for all variables concerned is impractical. Liaise with LOICZ.

6.4 Refer to LOICZ for criteria for site selection.

6.5 Yes based on the GEMS-Water project for assessment of BGC influx to oceans. There are a number of existing networks, the most appropriate of which is that of GEMS-Water. GEMS-Water does not have the capacity to cover all the major rivers. GEMS-Water lacks comprehensive country participation. Identify geographic areas where water quality sampling is deficient. Identify a national sampling systems that are not parts of GEMS-Water.

6.6 Actions

- Support GEMS-Water, strengthen co-operation with LOICZ. [Directed at: GCOS/GTOS, WMO]

- Upgrade and/or rehabilitate existing stations. Note: Many different methods exist for combining flow of water with chemistry and there are different ways of determining load. [Directed at: WMO]

7. Discharge

7.1 It is suggested that only one variable discharge be used, and that the term "runoff" be dropped. Discharge means volume of water flowing through a river for channel cross-section in unit time (after International Glossary of Hydrology, UNESCO and WMO, 1992). It can also be expressed as the equivalent depth of water per unit area. Runoff may be confused with the terminology associated with hill slope hydrology.

7.2 The spatial resolution of the data very much depends on the specific question that is being answered. It is felt that discharge measurements can be collected at three tiers. Tier 1 are detailed experimental catchments. These are process-based studies and are generally conducted in catchments of up to 100 km2. For tier 2 small pristine catchments up to 1000 km2 are appropriate for climate change detection. These catchments should have minimum interference from anthropogenic influence. Tier 3 catchments should be greater than 100 km2 and are used for national and regional runoff studies along the lines managed by the GRDC. Such catchments provide an overlap with tiers 1 and 2. The recommendation is that there should be flexibility in the area specified for each tier depending on the specific question that is being answered and the environmental conditions, e.g. mountains vis-à-vis plains.

For temporal resolution again it depends on the specific question being asked. With regard to data archiving, for tier 1 experiments it is generally expected that 15 minute to 1 hour data will need to be collected. For tier 2, hourly to mean daily and for tier 3, mean daily to monthly. Data should be collected as specified by WMO.

7.3 A specification of within 5% of the true value is extremely optimistic. In reality this level of accuracy may be achieved in tier 1 studies, and should be the goal of all data collection. In reality, due to tidal influence, ice dams etc. an accuracy of 15 to 20% could be considered acceptable.

7.4 No - a uniform density is not appropriate, and the specific sites to be selected depend very much on the question to be answered. In mountainous areas the density would need to be much greater than on a plain. There are two levels of site criteria. Technical criteria as specified by WMO, and criteria for a network design. The criteria specified in the report of the TOPC meeting in Cape Town seem appropriate. Specifically:

- Each participating country should have at least one site per biome type;
- They should be capable of providing the appropriate data;
- Sites in under-represented systems have priority over already-represented systems;
- Reasonable security of tenure is required.

All else being equal:

- Sites where research is also carried out are preferred;
- Long-established sites are preferred;
- Existing sites are preferred over sites which need to be established;

- National support for the site is preferred to sites dependent on external funding;
- Accessible, practical sites are preferred.

7.5 Yes for some purposes an IOS can be defined. For example we can immediately specify 150 to 200 stations at tier 3 that are required by GRDC to obtain regional and continental runoff to the oceans. These stations can become operational in the next two years. However, to define a very specific IOS, particularly for tiers 1 and 2, the climatologists and GTOS community need to define clearly the specific questions to be answered. The following discussion provides general principles that are to be followed in selecting the IOS.

For climate change detection, in addition to the 150 to 200 stations mentioned in the paragraph above, there is a need for additional stations at tier 3, being located in homogenous climates and with a minimum of anthropogenic influences, such as hydrologic structures. In the longer term, it is recommended to have at least one station for every 2o by 2o grid.

The network design needs to be carried out in conjunction with national agency needs. It is unrealistic to expect that individual nations will establish and operate stations exclusively for GTOS and GCOS. Therefore it is critical that sites be selected that serve multiple purposes. The selection processes for stations is different between the developing countries and the developed countries. In developed countries the most appropriate catchments from the existing set should be selected. In contrast, in most developing countries, it will be necessary to provide for upgrading and/or rehabilitation of stations to obtain a sufficient density.

There are a number of networks already in existence that will meet many of the climate needs of GTOS and GCOS. Many of the existing national networks are sufficient for climate purposes. Governments need to be encouraged to make their data readily available. It is suggested that GCOS and GTOS work through the FRIEND programme to encourage governments to make at least a subset of their data available to the GCOS/GTOS community.

First, it has to be assumed that the data provided are of sufficient quality, as there is so much variability in hydrological data that checking data quality after the fact is almost an impossibility. There are really three categories of enhancements that need to be considered:

1) Filling gaps in spatial and temporal resolution;

2) Upgrading of existing stations to improve collection, data quality and transmission of data; and

3) Rehabilitating stations where the infrastructure has to be replaced.

The order of priority should first be given to filling temporal gaps in existing records; then upgrading of stations; rehabilitation of existing stations; and lastly installation of new stations to fill spatial gaps.

7.6 Actions

- Establish the macro-scale network proposed by GRDC and enhance it to obtain a homogeneous time series. These stations should be asked to update data to fill time gaps. [Directed at: GCOS/GTOS]

- Improve transmission of data utilizing WHYCOS where possible. [Directed at: GCOS/GTOS]

- GCOS/GTOS working through UNESCO should request FRIEND for support in at least three areas:

1. Request at least a subset of the existing data sets be made available to GCOS/GTOS;
2. Advice on establishing the IOS and the selection of sites for tier 1 and tier 2;
3. Request the meta data catalogue.

[Directed at: GCOS/GTOS]

- GCOS and GTOS secretariats working with HWR, and FRIEND should identify existing data rich, experimental catchments at tier 1, and do all possible to assure that these data collection programmes continue. For tiers 1 through 3 there is an urgency that GTOS/GCOS secretariats and HWR give the highest priority to working with national governments to maintain a minimum number of stations and to work with developing countries to obtain donor support for upgrading and rehabilitation of stations. [Directed at: GCOS/GTOS, WMO/HWR]

8. Surface Water Flux

(Variable also referred to as surface water storage fluxes.)

8.1 The variables are correct and no additional ones are needed.

8.2 The spatial and temporal resolution are appropriate.

8.3 The accuracy for water level should be + 1 cm to + 50 cm depending on the scale.

The areal extent should be + 5%.

Volume should be + 1% to + 10% depending on depth of water.

8.4 Spatial resolution of 500 lakes and wetlands is appropriate.

8.5

The selection can be achieved, but the operational system needs to be assessed. The IUCN inventory needs consulting. The European Environment Agency data base also needs consultation for the European sector. There should be a cross reference with ILEC.

8.6 Actions

- Inventory of lakes and hydrometric networks. [Directed at: WMO/HWR]

- The following changes are suggested to page 87.

Units of Measure

add - open water evaporation
change - “flux measured in m3/observation period” to “net change in estimated volume fluxes measured in m3/observation period”

Rationale
Replace sentence: “If climate change is occurring to a hotter and drier mode, then ...” To “If climatic change is occurring, then lakes ...”

Accuracy/Precision
See 8.3 above.

R&D Needed
Assess wetland volume fluxes. The use of remote sensing for areal extent and improve lake level measurements using satellite altimetry.

9. Groundwater

Rather than answering the questions for this variable the meeting expressed considerable discomfort with the contents and context of the groundwater description as written. For example, there was recognition that groundwater withdrawals have led to subsidence and relative sea level rise in some local instances. The meeting saw the write-up as conveying a more pervasive global sea level influence that it felt was unfounded.

On the other hand, the meeting had a clear sense that shallow groundwater systems are important and are poorly documented components of the transport of radiatively active trace gases through the terrestrial environment, as well as indicators of the linkages between the hydrologic system and such climate conditions and events as the El Niño - Southern Oscillation (ENSO), at least for selected tropical and temperate regions.

The meeting strongly recommended completely rewriting the groundwater text to reflect the more direct climate-related uses as a basis for continued inclusion of groundwater as a variable in Annex 1 of the GCOS/GTOS Plan for Terrestrial Climate-related Observations.

Groundwater (Shallow Aquifer) Levels and Chemistry

Units of measure:
Depth to water in metres.
Concentrations in meq l-1.

Users:
Hydrologic and ecosystem modellers and researchers, climate system researchers.

Rationale:
Recent research indicates that aggrading temperate forests and forest soils sequester significantly larger amounts of carbon than previously thought, and may be an important repository of the "missing carbon." The mobilization of such carbon through the hydrologic system, especially shallow aquifers, is poorly understood and may be a key mechanism controlling carbon exchange between terrestrial hydrological and ecological systems and the atmosphere. The documentation of groundwater levels and chemistry, in conjunction with surface water conditions, is necessary to quantify the role played by terrestrial hydrologic systems in carbon sequestration and mobilization.

Frequency of measurement:
Monthly, and in conjunction with periodic storm events.

Spatial resolution:
10-100 observation wells at each process research watershed (Tier 1 sites --discharge).

Accuracy/precision required:
<1% of true depth.
Within 20% of true concentration.

R and D needed:
Improved understanding and modelling of ground water-surface water interactions, including water quality genesis, fate and transport of chemical weathering products, and solute transport of radiatively active trace gases.

Present status:
A relatively small number (<100), long-term process research watersheds currently exist world-wide.

Associated measurements:
Precipitation, discharge.

Action required:
Ensure continued viability and integrity of long-term, process research watersheds by continually demonstrating the value and utility of data and information produced at such sites to both research and resource management issues. [Direct at: WMO/HWR]

10. Lake and River Freeze-up/Break-up

10.1 Yes the variables correct, and no additional variables are needed.

10.2 Above 45o north and above 2,000 metres in elevation one river and one shallow lake with negligible anthropogenic impact should be selected for each 2.5o x 2.5o grid.

Daily observations are required to identify time series of dates of freeze-up and ice cover break-up.

10.3 The accuracy is correct.

10.4 See section 10.2.

10.5 Yes and initial operational system is possible. (See page 53 of GCOS-21)

10.6 Action

- A central archive and/or several regional archives (e.g. North America, Russia, Himalayas) are needed. [Directed at: WMO/HWR, GCOS/GTOS]