**Report to the CEOS SIT Meeting**

**Status of the Report:**

**The GEO Water Strategy: From Observations to Decisions**

The Task

At an earlier CEOS meeting a report was submitted outlining the need for an updated GEO Water Strategy. Under the auspices of the GEO IGWCO Community of Practice a writing team was formed to prepare a Water Strategy report that it could bring to the GEO Plenary in January 2014 for approval. A draft of the report will be circulated to CEOS members before their next full meeting and to the summer GEO Executive meeting. This report provides an update on progress in preparing the GEO Water Strategy report.

Status of the Report

The GEO Water Strategy report has been developing with Chapters 1 to 10 now in a draft stage. They can begin to be peer reviewed and revised. Chapters 11 (Institutional and Funding Issues), 12 (Toward an Implementation Plan),and 13 still need more discussion and broader inputs before they can be recognized as representative draft sections.

Rather than providing the full draft, appendices have been provided here to enable CEOS SIT members to gain a better appreciation for the report. Included are:

* Appendix 1: A list of the Table of Contents
* Appendix 2: A summary of the content of each chapter
* Appendix 3: The very preliminary recommendations from the report
* Appendix 4: Experts who contributed to the GEO Water Strategy report.

Authorship

More than 30 experts (listed in Appendix 4) have contributed to this report. Others have been encouraged to provide review comments. Monthly teleconference calls are held and a revised version of the draft report is produced each month.

Regional Consultations

The following regional consultations have been held or are in the planning stage:

* Nov. 29 - Dec. 1, 2012: US GEO Water Strategy Workshop (San Francisco, CA)
* December 5, 2012: AGU Town Hall meeting on the GEO Water Strategy
* February 26, 2013: Asian Consultation session on the GEO Water Strategy at the Asian Pacific GEO Symposium (Ahmadabad, India)
* April 11, 2013: EGU Town Hall on the GEO Water Strategy
* April 17-18, 2013: European GEO Water Strategy Workshop (Barcelona, Spain)

Next Steps:

After the GEO Water Strategy report is adopted by the Group on Earth Observations as a basis for its post-2015 water activities, GEO will request CEOS (satellites) and WMO (in-situ) to develop action plans for how they will contribute to the new water programme. A structured report consolidating these and possibly other commitments will serve as the new GEO Water Implementation plan and the basis for the post-2015 GEO water task. The completion of CEOS action items will be used an important metric for tracking the progress of post-2015 GEO water activities.

Recommendations

It is recommended the CEOS SIT agree to:

1. Recognize the progress that has been made in developing the GEO Water Strategy
2. CEOS members provide feedback on the approach to the Report
3. CEOS members provide comments on the chapter content (see Appendix 2 in the written report) and guidance on the formulation of the recommendations (see Appendix 3 in the written report); and
4. Consider how CEOS might provide an ongoing review function for the   
   writing team through to completion.

Comments on the report should be sent to Richard Lawford (r[ichard.lawford@morgan.edu](mailto:ichard.lawford@morgan.edu)) and to Osamu Ochiai (ochiai.osamu@jaxa.jp).

Report prepared on behalf of the GEO Water Strategy writing team by:

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Appendix A: Table of Contents for the GEO Water Strategy Document

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2. Background
3. User Needs for Water Data and User Engagement
4. Overview of observational systems
   1. The role of satellites in providing water data (CEOS)

4.2 The role of in-situ data and the status of in-situ observational networks and data systems

1. Existing and Planned Observational Systems for Priority Water Cycle Variables

The status of water cycle measurements:

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5.2 Precipitation

5.3 Evapotranspiration

5.4 Soil moisture

5.5 Runoff and discharge

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5.7 Sub-surface water storage

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1. Existing and Planned Observational Systems for Priority Water Quality Variables
2. Data Issues
3. Water Cycle Interoperability and Integration
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8. Recommendations for preparing for Water Cycle activities in Phase II of GEO
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Appendix 2: Chapter Summaries

**1. Purpose of the report**

The availability of quality water continues to be a major issue for the development of the Earth’s resources. Water is essential for ensuring food and energy security, for facilitating poverty reduction and health security in underdeveloped parts of the world, and for the maintenance of ecosystems and biodiversity. There is a growing realization that the available water in many regions of the world will not be sufficient to meet emerging demands. As was recognized in the long text from Rio +20, the extent of the problem will only be known and the plans to address these limitations will only be developed if we have adequate observations in both time and space.

The report outlines a strategy for providing observations in a form suited to supporting decision-making. This strategy involves the development and delivery of information services that will enable the integrated management of water resources at the national, basin, and global scales. The report is intended for GEO members (nations and organizations) who need to understand how they can contribute to a stronger Water activity within GEO. It also addresses the needs of a water resources community that seeks information on modernized management systems and wants to take full advantage of the new science and technologies, to stakeholders of all types, including researchers who need to understand where priorities and new technologies will be emerging in the next decade, to investors who need to plan strategies to effectively invest in future water infrastructure and treatment facilities, and to the end users who need strategies to secure their access to clean water.

In order to deal with these needs and to facilitate the use of Earth Observations in water management, the GEOSS water strategy has adopted the following objectives:

1) Provide a framework for guiding decisions regarding priorities and strategies for the maintenance and enhancement of water cycle observations to support:

• Monitoring of climate variability and change

• Effective water management and sustainable development of water resources

• Societal applications for resource development and environmental management

• Specification of initial conditions for prediction systems

• Research directed at priority water cycle questions

2) Enable improved water management based on a better quantification of fluxes and stores in the global water cycle, eventually leading toward an ability to close the water budget, and assessments of the quality of water.

3) Promote strategies that will facilitate the acquisition, processing, and distribution of data products needed for effective management of the world’s water resources.

4) Provide expertise, information systems, and datasets to the global, regional, and national water communities through support to UN Water and its programmes, ICSU Future Earth Programmes, non-governmental water programmes such as the Global Water Partnership, and regional and national water and Earth Observation programmes.

5) Increase availability and use of data, information, and indicators of quality of inland and near-coastal waters to support an operational water quality decision-making system.

1. **Background - Role of GEO and freshwater issues**

GEO has provided a framework within which issues related to water could be integrated with other issues that provide societal benefits (see Table 1). GEO continues to promote open access and distribution of data at minimum cost. Within the limits of a volunteer system, GEO helps to bring the principles of good governance to water management.

This chapter provides descriptions of areas where water information and GEO principles are critical, including:

1. The security of domestic and potable water supplies in many areas of the world
2. The Water-Energy-Food security nexus, including the effects of energy development and intensive food production, which create new demands for water and lead to by-products that decrease the quality of water
3. Requirements of the environment and biodiversity for water
4. Strategies for adaptation of water resource systems to climate change
5. Support for the implementation of new water management structures such as polycentric governance and Integrated Water Resources Management
6. Extremes, including floods and droughts, and their effects on planning for protection and secure water supplies
7. Priorities for water arising from the Sustainable Development Goals.

**Table 1.** Linkages of water with other GEO Societal Benefit Areas (SBAs)

|  |  |
| --- | --- |
| Societal Benefit Area | Links with Water Information |
| Agriculture | Drought Monitoring, Irrigation Planning, Water-Energy-Food Nexus, Soil Moisture, Fertilizers and Water Quality |
| Biodiversity | Water Stress and impacts in biota, Water infrastructure and biodiversity |
| Climate | Evapotranspiration, Precipitation, Soil Moisture, Drought, Adaptation to Climate Change |
| Ecosystems | Water and Ecosystem services, Aquatic habitat in drought conditions |
| Energy | Hydropower, Cooling water, Geothermal |
| Geohazards | Floods, Droughts, Groundwater |
| Health | Water quality, Precipitation, Surface Water Store, Availability of potable water |
| Land Management | Runoff, Erosion, Sediment production, Infiltration |
| Oceans | Coastal runoff |
| Socio-Economic | Water use, Role of water in trade, urban water issues |
| Water Management | Water availability, Snowpack, Streamflow, Surface water store, Water withdrawals, Water Infrastructure planning |
| Weather | Precipitation, Soil moisture, Floods monitoring and prediction |

1. **User Engagement and Needs for Water Data**

The challenge of engaging users in testing new Earth Observation products and providing insights about their information needs for water cycle needs is a major challenge. Increasingly, governments fund programmes based on public commitment to the application or service; consequently, user loyalty is linked to sustainability. There is a need to develop a more structured approach between the providers of new Earth Observation data products and the users who will benefit from them. Public investment into the collection of new data types and the use of those data to create new products outstrips the investment in developing structured user engagement.

This chapter outlines some new ideas related to user engagement. It also documents the results of a recent GEO survey of user needs for water data as a starting point for defining user needs and then identifies a path for reviewing needs on a regular basis. (The full report is available at <http://sbageotask.larc.nasa.gov/Water_US0901a-FINAL.pdf>.) The chapter looks at the potential social and economic benefits of using Earth Observations in decision-making. While the importance of Earth Observations for improved decision-making is recognized, realizing its full benefits is complicated by the fact that decisions can span many time scales as they extend from long-term planning to short-term operational decisions. Although final conclusions have not been reached, this chapter identifies strategies for increasing user engagement and developing better assessments of the value of water information.

1. **Overview of observational systems**

The strengths and weaknesses of satellite and in-situ data and the adequacy of existing coordination mechanism are described in this chapter. Satellite data provide many opportunities to increase the information available for water management. Their global nature also helps to address the problems of data continuity in trans-boundary basins where complete, consolidated, and consistent information may be difficult to obtain. Administrative mechanisms for coordinating the different types of data are described in the chapter. The role of CEOS as the coordinator of initiatives by the major space agencies, including operational agencies (e.g., EMETSAT, NOAA) and research agencies (e.g., JAXA, NASA, ESA) is discussed.

The World Meteorological Organization (WMO) manages the requirements for the operational agency satellite observing programmes and maintains the Global Observing System (GOS), an inventory of the requirements for satellite data related to weather, water, and climate. The Rolling Requirements Review Process carried out by WMO is a key input to user needs considerations, as described in Chapter 3. The Coordination Group for Meteorological Satellites (CGMS) provides an international forum for the exchange of technical information on geostationary and polar orbiting meteorological satellite systems, which is also described in this chapter. CGMS manages the International Precipitation Working Group (IPWG), a key contributor to the Water Strategy. IPWG focuses the scientific community on operational and research satellite-based quantitative precipitation measurement issues and challenges.

CEOS coordinates these measurements and works to sustain the supply of the most critical water cycle parameters in order to facilitate the development of consensus regarding the transfer of variables from research mission observations to operations; to coordinate the development of new analytical methodologies for long-term series of satellite measurements; to explore new approaches for converting satellite measurements into useful parameters; development of assimilation methodologies to integrate satellite and in-situ observations; capacity building; sustained observational programmes; and sensor and system developments.

## The diffuse responsibility for in-situ observations makes it difficult to sustain commitments to integrated data products. Within nations, different departments take the lead for different variables, while between nations there are often either no protocols or protocols that are not always followed. WMO has taken the lead for weather, water, and climate variables and, through the Global Terrestrial Network for Hydrology (GTN-H), has set up a coordination mechanism. The role of in-situ data and the status of in-situ observational networks and data systems are monitored by the GTN-H, which operates to meet these recommendations by collecting hydrometeorological information from a variety of sources. GTN-H is a system of systems that engages a growing number of partners dedicated to collecting and archiving information about various components of the hydrological cycle.

1. **Existing and Planned Observational Systems for Priority Water Cycle Variables**

This chapter provides the views of subject experts and product developers on the data available for assessing different water cycle variables. Each variable is discussed in terms of its role, the status of its observational systems, its gaps and shortcomings in the system, and recommendation for action. The recommendations are included in Appendix 3.

**5.1 Clouds and Water Vapour**

Water vapour and clouds are important for accurate precipitation forecasts. Water vapour has a positive feedback effect that amplifies the effects of climate change. Clouds are a precursor to the formation of precipitation and multiple influences of the energy budget. In global climate models, a modest error in predicted cloud cover could impair model estimations of global climate change. The lack of adequate data on the horizontal and vertical distributions of clouds, their scaling properties, and cloud microphysical properties account for some of the difficulty in improving cloud parameterizations. The interactions between clouds and aerosols increase these complexities for both radiation budgets and precipitation formation.

Although space-based measurements of humidity are useful for the upper troposphere, the important fine structure of water vapour, especially in the lower troposphere, is poorly measured from space. Ground-based Raman LIDAR or Differential Absorption LIDAR can meet the requirements, but space-borne LIDAR is unable to measure water vapour under warm clouds due to the high attenuation of the signal in these clouds. Column water vapour values retrieved from Global Positioning Systems (GPS) have proven to be a reliable source of information.

In the last four decades, satellites have enabled the development of two-dimensional cloud cover distributions by space-borne visible and infrared radiometers. However, the vertical distributions of cloud are crucial. Cloud droplet distributions are becoming more important as cloud resolving models become more popular. Space borne Mie LIDAR, a cloud radar (W-band radar) on the CloudSat satellite, and similar instrumentation on the EarthCARE mission (2016) will address this need.

Cloud Top-Of-the-Atmosphere measurements have a common bias in cloud top radiances, which cannot be determined unambiguously due to different cloud layering. Vertical profiles of latent heating have been made possible by the emergence of active sounding sensors that can probe the vertical structure of the cloudy atmosphere. The “A-train” has facilitated comparisons of cloud and aerosol measurements, although the focus is on optical properties. Missing profile measurements for improved model development include cloud and precipitation microphysics, (including number concentrations and sizes; aerosol microphysics and in-cloud vertical motions.

**5.2 Precipitation**

Precipitation is required to provide the water needed for drinking, freshwater supply, and agricultural and forestry production, among many others. Precipitation measurements are crucial to understanding and predicting climate, weather, global water and energy cycle processes, and their consequences for life on Earth. Over land, the frequency and intensity of precipitation strongly influences surface hydrology, including runoff, soil moisture, and stream-flow. Extremes in precipitation produce floods and droughts, which have major impacts on human society, agriculture, and the natural environment. Methods of measuring precipitation include precipitation gauges, surface- and satellite-based precipitation radars, observations of passive microwave radiance from Low Earth Orbit (LEO) satellites, and infrared (IR) radiance observations of clouds from both LEO and Geostationary Earth Orbit satellites. Each of these are reviewed in this chapter. In the future, the Global Precipitation Mission will provide unprecedented observations.

While current precipitation observing systems provide extensive information, they have significant shortcomings. They include the lack of absolute values for use in calibration; the lack of coverage by surface observations; the errors in snowfall measurements; measurements in complex terrain; vertical distribution of precipitation and latent heating; product latency for derived or integrated products; and reprocessing.

**5.3 Evaporation and Evapotranspiration**

Evapotranspiration (ET) is the second largest component of the terrestrial water cycle at the global scale and must be determined with accuracy to close the global water budget. ET is the moisture flux from the atmosphere and determines the rate of plant growth and the rate of drying of the surface. Reductions in non-productive evaporative losses can be influential in increasing water availability. ET measurements can be used to estimate consumptive water loss, especially irrigation losses. ET is a difficult variable to measure. While heat and moisture fluxes over the oceans are important for balancing the global water and energy budgets, accurate flux values at a particular location can be derived from in-situ measurements and areal sea surface temperature estimates. Land-based ET measurements are generally provided by lysimetric and soil water balance methods as well as Bowen ratio, eddy covariance, scintillometer, and remote sensing methods. ET measurements continue to be labour-intensive because systematic biases (e.g., sensor calibration and model representation) and random errors (e.g., sensor noise) need to be removed from field measurements. Estimating ET and closing the water balance for continental to global scales has remains difficult. Measurement networks like FLUXNET need improved standards for processing and archiving their data. Sublimation, a special issue for cold regions, needs attention.

**5.4 Soil Moisture**

Soil moisture plays important roles in climate and water resource management. In particular, it regulates the partitioning of incoming radiative energy into sensible and latent heat fluxes and in partitioning precipitation between infiltration, runoff, and evaporation. The agricultural and forest communities are interested in soil moisture because it plays a critical role in supplying plants with water. At climate time scales, together with sea surface temperatures, it is a critical boundary condition controlling fluxes to the atmosphere.

Soil moisture monitoring has been slow to develop. Some national and regional in-situ soil moisture networks exist (e.g., Australia, China, France, Russia, United States) for agricultural and research purposes. A large number of those stations are now combined in the International Soil Moisture Network, in an effort to give access and to centralize the efforts undertaken by individual teams throughout the world. Over the past three decades, both active and passive microwave systems have been launched and tested with a significant increase, with the development of satellite missions over the past ten years. Active and passive microwave measurements in low microwave spectrum (1-10GHz) have been found to be sensitive to soil moisture and vegetation dynamics.

Passive microwave satellite observations are available from the European Space Agency’s Soil Moisture Ocean Salinity mission (SMOS), which provides operational soil moisture products at 15-km resolution and repeat coverage of one to three days. The validation of SMOS data is already close to the target accuracy. Other sources of passive soil moisture are the WindSat instrument on the U.S. Navy’s Coriolis satellite and JAXA’s AMSR-2 satellite.

Although passive microwave can provide reasonable data for terrain covered by thin or moderately dense vegetation, users require higher resolutions. NASA’s Soil Moisture Active Passive (SMAP) mission (to be launched in 2014) will produce a soil moisture product of 10-km spatial resolution by combining a radiometer and radar on the same space-borne platform. The fusion of an accurate low-resolution product with a high-resolution, yet noisier, radar product is expected to yield an accurate high-resolution dataset that brings observational requirements and technical possibilities closer together.

Some of the gaps in the Current Soil Moisture Programme relate to the maintenance of the in-situ data collection and its archival. Finances are an issue because many activities rely on research grants and hence may not be sustainable. The standardization of productsis also a challenge since there is no overseeing body for soil moisture measurements other than a volunteer network. The validation of satellite products is another challenge because the data available were not originally collected for validation purposes and must be up-scaled and transformed to the correct depth and soil type.

**5.5 Runoff and discharge**

River discharge, arguably the most accurately monitored water cycle element, is essential for water management, including designing and operating engineering works (dams, reservoirs, river regulation, etc.), providing various water-related services (navigation, flood protection, water supply for irrigation, municipal or industrial water use, and ecosystem management) and promoting healthy aquatic ecosystems. Extreme flow conditions (high or low flows) are of particular interest since these events stretch the resiliency of water management infrastructures. Stream flow also serves as a medium for many biological and chemical processes; hence, river discharge dynamics have a strong impact on aquatic habitats and the sustainability of ecosystem services in riverine environments. From a scientific perspective, stream flow integrates all of the processes (e.g., runoff and evapotranspiration) taking place over the area of the basin and provides one hydrologic output variable.

Critics of in-situ monitoring often note the lack of an adequate monitoring network. Recent work demonstrated that much of the monitoring infrastructure is either in place or operated in the past with gaps are limited to some parts of the developing world. In-situ methods are currently the most cost-effective, reliable options for stream flow measurement and remote sensing alternatives. They are likely to remain an elusive dream for the foreseeable future. Lack of data-sharing, which is more due to the lack of motivations to share rather than the often exaggerated incentives not to share, is a major obstacle in the better utilization of river discharge records. The steady decline of in-situ monitoring in general and discharge monitoring in particular are legitimate concerns.

River discharge is clearly better suited for in-situ monitoring, but remote sensing could provide invaluable contribution by complementing ground observation. Some centres utilize remote sensing solutions (e.g., the Dartmouth Flood Observatory) when they have other remote sensing assets in place.

Candidate remote sensing sensors for monitoring river discharge include various imaging sensors that monitor water extent and LIDAR or radar altimeters that can monitor river heights. Imaging sensors providing measurements of the water extent that can be related to discharge similar to stage heights are likely the most viable means to monitor river flows. The imaging radar altimeter envisioned for the Surface Water and Ocean Topography mission will be able to combine the measurement of surface water extent with water height, including measuring the surface slope along the river channel.

Research is needed to improve the interpretation of observable river flow properties (river height, width/surface area, or, possibly, velocity at a very coarse accuracy) in terms of river discharge. The accuracy of in-situ discharge measurements primarily comes from labour-intensive calibration of the stage height recording instrument. Remote sensing solutions that still require surveying on the ground are not viable alternatives.

New remote sensing sensors are likely to be more useful for the regular mapping of river channel properties (surface slope, surface width, height variations) and could guide a new generation of large-scale hydrological models.

**5.6 Surface Water Storage**

Continental surface water storage pools (lakes, reservoirs, floodplains, wetlands, and river channels) are home to aquatic ecosystems and the primary freshwater resources for humans. Changes in these storage pools are important indicators of the underlying hydrological processes and essential information for water management. Standing water bodies (lakes, reservoirs, floodplains, and wetlands) are particularly poorly monitored due to their complex spatial extents combined with their innumerable occurrences and high temporal variability. The millions of high latitude lakes are just as difficult monitor on the ground as the vast floodplains and wetlands surrounding and interacting with large tropical rivers (e.g., the Amazon or the Congo).

Reservoirs are typically built after intensive field surveys; therefore, their geometries are accurately mapped before construction and their storage dynamics are thoroughly controlled during their lifetime. They are accurate means to monitor water bodies and fluxes where the relationships between water levels and the corresponding storage change are well established. However, data exchange on reservoir operation is practically non-existent, even in countries with otherwise open data-access policies (such as the United States or Canada).

Surface water bodies have distinct spectral properties; hence, water surfaces or the presence of water leads to strong remote sensing signals. However different surface water body types represent distinct monitoring challenges. This section provides an assessment of the potential for satellites to measure their characteristics.

**5.7. Sub-surface water storage**

Groundwater is becoming a more important resource for regions lacking a sufficient quantity of quality surface water supply, especially during droughts. Societal pressures, land use practices, and climate change have resulted in an increased reliance on groundwater. Groundwater recharge is related to the spatial and temporal distribution of precipitation intensity, evaporative demand, and the subsurface stratigraphic characterization. Methods for inventorying this resource and assessing changes in its availability are needed. Groundwater monitoring for a sound assessment of the current state of groundwater resources and for a reliable prediction of its change in the future is needed for informed decision-making and effective groundwater management.

While groundwater data are quite extensive in some countries, due to several challenges, groundwater data availability is still low. Well and other in-situ observations along with local well data and GPS data are necessary for evaluation and simulation of groundwater, leading to improved understanding and prediction of groundwater variations. In the absence of a global groundwater data system, UNESCO developed a **Global Groundwater Monitoring Network** (GGMN) programme. The GGMN facilitates **periodic assessments of changes in groundwater quantity and quality** by aggregating data and information from existing groundwater monitoring networks and regional hydrogeological knowledge. Simplicity of the application and clear information ownership (data remains with the supplier) are guaranteed to ensure the essential support and commitment of the global groundwater community for the GGMN programme.

Ground-based gravity surveys based on GPS in combination with the Global Navigation Satellite System and InSAR observations provide absolute changes in land height and elastic deformation, which in many cases reflects changes in soil texture (e.g., drying clay layer), leading to the inverse calculation of soil water content and a constraint on groundwater movement within terrestrial water models.

Groundwater cannot be directly measured from satellite or other remote sensing systems. However, the Gravity Recovery and Climate Experiment (GRACE) twin satellites measure variations in the geoid, which in turn can be linked to the Total Water Storage (TWS). When combined with a land surface model, GRACE can indirectly estimate secular trends in groundwater variations by quantifying the TWS monthly variations.

Coordinated monitoring of groundwater has many obstacles, from data sharing of well observations to agreement of the averaging kernel for the GRACE-observed spherical geoid. GRACE’s uncertainties range from one to several decimeters in TWS change uncertainty. There are significant differences between GRACE and GPS observations and it is not clear at this time which methodologies are most accurate. Land use water diversions that reduce groundwater levels are not adequately monitored or data is proprietary. This is often due to the economics of water.

**5.8 Cryosphere**

This section reviews the measurement of the main components of the cryosphere, namely: snow, river and lake ice, [sea ice,](http://www.global-greenhouse-warming.com/sea-ice.html) [glaciers](http://www.global-greenhouse-warming.com/glacial-retreat.html) and [ice caps,](http://www.global-greenhouse-warming.com/polar-caps.html) [ice shelves,](http://www.global-greenhouse-warming.com/Larsen-Ice-Shelf.html) [ice sheets,](http://www.global-greenhouse-warming.com/west-antarctic-ice-sheet.html) and [frozen ground](http://www.global-greenhouse-warming.com/permafrost.html). The cryosphere is the second-largest water storage for the Earth (after the oceans) and plays a major role in climate through the energy budget. Over the past few decades, reductions have been reported in permafrost, seasonally frozen ground and river and lake ice, ice sheets and glaciers, and snow cover. At mid and high latitudes, snow pack and glaciers store fresh water during the winter and release it in the spring, increasing water availability and flood potential. The albedo characteristics of snow also cause snow cover to affect the energy balance and climate change. Monitoring the retreating glaciers is important for assessing the impacts of climate change and predicting its effects on fresh water.

Snow, both in the atmosphere and on the ground, presents a special measurement challenge due to its low density and local transport by horizontal winds and eddies. In-situ snow measurement techniques include snow pillows, snow boards, and ruler measurements. Local snow processes such as drifting, blowing, sublimation, and aging processes add to the heterogeneity of the data and the non-representativeness of point measurements. In many regions, satellite data on snow cover are the only available source of information. Options for assessing snow conditions from space include passive microwave for snow of moderate depth, visible measurements for snow cover, and estimates of the thickness of dry snow with MODIS and AMSR. Research-operations partnerships are needed to ensure the continuity of these systems. Improved seasonally- and regionally-specific algorithms should be developed for extracting snow water-equivalent (SWE) from microwave-brightness temperatures.

Permafrost distribution has been assessed by temperature measurements made in boreholes drilled in the permafrost soils and by some soil temperature networks that provide information on the occurrence of frost. Satellite measurements such as the planned SMAP mission can provide more accurate and useful freeze/thaw products because of their improved ability to penetrate vegetation. Limitations in cryospheric measurements include sensor sensitivity to vegetation and snow covers, limited techniques for measuring snow-pack characteristics, including SWE, and separation of cloud and snow cover. The measurement of glacier volume is still experimental and also needs more research.

1. **Existing and Planned Observational Systems for Priority Water Quality Variables**

Water quality refers to the suitability of water for various uses or processes where the characteristics of the water are defined in terms of that use. Water quality issues are critical in human development. As is demonstrated by the water-related deaths of 1.8 million children per year, the lack of access to clean water and sanitation remains the world’s largest health problem.

Water quality monitoring approaches include in-situ discrete water sampling with sample collection, field measurements and laboratory analysis, in-situ continuous measurements using deployed, automated physicochemical and bio-optical instruments and samplers, and remote sensing-based methods ranging from sensors placed just above water to space-based satellite observations.

Satellite remote sensingisemerging as a potential alternative for assessing water quality in countries that do not have the resources to maintain in-situ monitoring programmes. Currently, remote sensing applications to determine water quality are limited to measuring selected substances or conditions with the large spatial and systematic temporal coverage that influence and change optical and/or thermal characteristics of the surface water properties. Remote sensing provides large ranges of measurement scales, geospatial consistency, and regular repeat visit times. However, these measurements are subject to weather (cloud cover) and atmospheric conditions (smoke, haze, and dust), which may be present at critical times for monitoring. The lack of adequate calibration data is also a limitation in the expanded use of remote sensing data. The United Nations Environment Programme Global Environment Monitoring System Water Programme is the most complete system worldwide on fresh water quality. Although further assessment is needed, this database may be able to serve as an archive of calibration and validation data.

River sediments transport the influences of the quality and biodiversity of surface waters, riparian environments, and the functioning of coastal zones. Given the pressures on rivers arising from human population increases and agricultural production, more sediment measurements are needed to support studies of scaling and the need for a holistic approach to sedimentation problems.

Water quality monitoring and early alert systems are tools of great benefit to decision-makers to regulate effluents and to provide drinking water to communities; the greatest need is for waste water treatment. Data collection programs (in-situ and remote sensing) are needed to facilitate the implementation of more extensive and efficient waste water treatment.

1. **Data Issues**

Chapter 7 deals with data issues ranging from data acquisition to the delivery of useable information to support improved decision-making. Measurement issues arise when satellite and in-situ sensors are not properly characterized and calibrated. In order to make useful data products, the raw radiance data from satellites must be transformed into data by calibrating and validating algorithms and models that will transform raw radiances data into meaningful observations. Identifying appropriate target datasets is a major issue for the calibration process.

Data processing and distribution issues arise because users in all parts of the world want real-time access to adequate observational data. Often this is not possible because of the uneven distribution of observing stations and delays in collecting, quality controlling, and processing the data. Other complexities include difficulties in the management of the large volumes of diverse data types; large data volumes, which create problems for existing data archival systems; lags in data dissemination due to delays in receiving the data from observational sites/ systems; the need for advisory services and detailed metadata for data products; the number of non-standardized data exchange formats and transmission protocols; and the general incompatibility of database standards and modes of access that ensure the continuity of remote sensing products, especially in the transition of products from the research mode to the operational mode. In-situ data are affected by the lack of access to historical data, poor efficiency of quality assurance for the data, and declining network densities and utilities. Data archival issues include those arising from inadequate coordination and standardization of the language of data exchange and, for some countries, database protection legislation may impede the flow of scientific information.

Other issues that need to be addressed include data integration, distribution, and access. An integrated data management system is central to any global water observing strategy. At present, observing systems lack integration, a situation that is further aggravated by incompatible data management plans between observing systems. Metadata databases that will serve as the central knowledge integrator can be developed for observational data with a focus on priority applications.

Observations for applications such as early warning and prediction systems to decision-making or decision support systems need to be integrated into seamless and mutually interdependent streams. Combined/integrated (in-situ and satellite) observations are required for regional to global data coverage for monitoring purposes. Early warning systems are particularly critical because they often support costly evacuation decisions and need to be very accurate, relying on comprehensive monitoring and forecast information. Prediction systems typically need to be initialized and updated by a much broader range and spatial domain of observational variables than those required for site- or region-specific hazard warnings. Data requirements are very system-specific and rely on data interoperability and open data exchange.

Preventative actions necessary in response to any particular warning/prediction will differ with user sector. “Managed” water systems usually have legally binding requirements that differ with region, state, and nation to supply their customer base. Transboundary issues can often make these matters more complex. Strategic (long-term) decision-making is rendered more complex, which in turn requires longer-term time horizons. The GEO Water Strategy’s role in such decision-making frameworks is to make sure that accurate, integrated observations are made available to support the decision-making process.

**8. Water Cycle Interoperability and Integration**

It is challenging to characterize and track the system in a manner that captures the complexity and harmony of nature and at the same time allows for the system to be managed in an integrated way for the benefit of all. Integration enables providers and users to maximize the benefits derived from Earth Observations; develop more robust decision support systems; reduce the uncertainties in resource management decisions made in data-sparse areas; and facilitate the sharing of data across systems/sectors.

Integration is needed across observational systems, data, data-model systems, models, science, solutions, and people networks. For GEO, integration across different Societal Benefit Areas is an important end goal. Within the GEO Water Strategy, integration is being promoted through the development of integrated data products that combine remote sensing and in-situ data. Integration across variables can lead to better modeling and prediction and integrated management of resources across governments and disciplines/agencies.

Interoperability provides a critical step toward Integration. Interoperability must be incorporated into the design of archives and analysis systems to allow data and products to be moved from one system to another in near-real time. GEOSS builds upon and adds value to functioning Earth observation systems by facilitating increased interoperability. This interoperability is achieved primarily by specifying how GEOSS components should exchange data and information at their interfaces. It could also include protocols for data transfer, analysis, and visualization systems for processing data and systems operating at local and national scales.

GEO supports interoperability through the GEOSS Common Infrastructure (GCI). Components central to the GCI and the Components and Services Registry and the Standards and Interoperability Registry and the Standards and Interoperability Forum have developed interoperability approaches for different functions. The GEOSS Architecture Implementation Pilot procedure develops and pilots new process and infrastructure components for the GCI and the broader GEOSS architecture. The Water Strategy will identify ways in which it can more effectively influence and interact with these groups to advance this cause. The Water Cycle Integrator is an important initiative that provides a conceptual framework for integrating across SBAs as well as a set of tools that promote an integrated approach to collecting and analyzing data and interpreting it for water management purposes.

Data assimilation systems combine observations with a dynamical model, using the model’s equations to provide time continuity and coupling between the estimated fields. Ensemble data integration and modeling approaches are well encapsulated by NASA’s Land Information System, which is described as a software framework for high performance land surface modeling and data assimilation (see <http://lis.gsfc.nasa.gov/>). Research programmes play an important role in integrating water cycle observations into meaningful products. The Global Energy and Water Cycle Experiment (GEWEX) has developed many new products, including precipitation, cloud, water vapour, and radiation products on an experimental basis. A number of these concepts related to data integration using data from satellites, in-situ flux towers, and models were tested within the Coordinated Enhanced Observing Period and many of the GEO Water activities have their roots in the GEWEX programme.

**9. Capacity Building**

Capacity Building activities related to water address critical needs of nations, most commonly from the developing world. They also contribute to the overall GEOSS Capacity Building Strategy and demonstrate the value of GEOSS infrastructure and principles. The GEO capacity building strategy addresses the need for human capacity building through the education and training of individuals regarding Earth observation data and products; institutional capacity building by creating an environment for fostering the use of Earth observations, and infrastructure and knowledge capacity building related to knowledge, hardware, software, and information technology.

The Water Cycle Strategy supports the efforts of GEO by mobilizing the capacity building efforts of GEO Members and Participating Organizations; engaging resource providers in the GEO capacity building process; and enhancing capacity building efforts to ensure the integration of mature Earth observation-based information systems into day-by-day end-user practices.

In practical terms, the GEO Water Strategy will enable GEO to demonstrate progress by networking activities that specifically build individual, institutional, and infrastructure capacity; leveraging resources for Earth observation capacity building efforts; increasing the use of Earth observation in policy and decision-making; enhancing the participation of developing countries in GEO and GEOSS; and applying e-science infrastructure for Earth observations education and training.

The GEO Water Strategy will provide an extensive state-of-the art assessment of GEO Water Cycle activities, especially in three developing regions, namely: Africa, Asia, and Latin and Central America. Relevant work is also being carried out in other parts of the world. The issues that arise in capacity development discussions in different geographical areas are shown in Table 2.

**Table 2.** Issues for Capacity Building in different regions of the world.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Africa** | **Asia** | **Latin Am** | **Europe** | **North Am** | **N Eurasia** | **AU** |
| **Floods** | Yes | Yes | Yes | Yes | Yes |  | Yes |
| **Droughts** | Yes | Yes |  |  | Yes | Yes | Yes |
| **Water Storage** | Yes |  | Yes |  |  | Yes |  |
| **Water quality** | Yes | Yes |  |  | Yes |  |  |
| **Adaptation to Climate change** | Yes | Yes | Yes | Yes | Yes | Yes |  |
| **Water for the Environment** | Yes | Yes | Yes |  | Yes |  | Yes |
| **Water for health** | Yes | Yes |  |  | Yes |  |  |

Water-related capacity building efforts will continue to address a number of the central GEO capacity building issues, including enabling capacity building through GEO Web Portals; enabling sustainable infrastructure capacity building efforts, technology transfer, and training; providing access to data sets that fulfill specific user requirements; strengthening Earth observation capacity building networks; facilitating the development of national and regional capabilities; and engaging donors through a coordinated approach to capacity building priorities.

The GEO Water Strategy will extend work in the geographical areas initiated in the first phase of GEO, but also expand to other areas of the globe. Currently the GEOSS Asian Water Cycle Initiative has a number of activities at the national level in approximately 20 countries that address four themes—flood, drought, water quality, and climate change—in sharing data, models, experiences, and knowledge, and implementing national capacity development projects.

Africa has many opportunities to take advantage of capacity building efforts, thanks to European, Japanese, and U.S. efforts. The GEOSS Africa Water Cycle Coordination Initiative demonstrates how GEOSS can provide fundamental services to support water management in Africa, including convergence and harmonization of observational activities, adoption of new techniques, implementation of interoperability arrangements, data-sharing, and effective data management to strengthen ongoing and planned water-related projects in Africa. A number of workshops and symposia have been held in Africa. They aimed to develop a programme of GEO Water activities in transboundary basins that will further the implementation of Integrated Water Resources Management. At the same time, the TIGER Initiative launched by ESA, the Canadian Space Agency, the Council of Scientific and Industrial Research, and UNESCO supports studies by African partners by providing access to space-based ESA data and products. TIGER also provides training on Earth Observations applications for water management. Through its collaboration with USAID, NASA has implemented a SERVIR system in Kenya and supported the implementation of Water Information System Platforms in North African (MENA) countries.

Capacity Building in Latin America is carried out by the Centre of Hydrologic and Spatial Information for Latin America and the Caribbean, which coordinates capacity building activities and workshops. After holding several workshops, the group has facilitated work in Belize with GEONETCAST, facilitated the transfer of Brazilian soil moisture data to the Soil Moisture Database, and collaborated with the Water Center for Arid and Semi-Arid Zones in Latin America and the Caribbean for drought monitoring. The space programmes of Brazil, Argentina, Peru, and Chile as well as agencies in Columbia are expected to feature in these Capacity Building activities in the post-2015 time frame.

Capacity Building in North America occurs as technology and know-how are transferred from producing organizations to users who can apply the information in research, government management, private sector management, education programmes, planning, and many other applications. A number of NASA-funded capacity building initiatives are supporting the transfer of technologies to the state level.

In Europe, capacity building has been led by EC and ESA. ESA supports capacity building by developing new data applications and by providing data freely to application projects. Areas in which these projects have had a benefit for GEO Water activities include extremes and information systems that allow people in different parts of the world to understand the consequences of extremes for their areas. The Northern Eurasia Earth System Partnership Initiative, a multidisciplinary programme of internationally-supported Earth systems and science research, has carried out a number for research projects and training programmes for young scientists in northern Eurasia.

**10. Linkages**

Given that the implementation of the GEO Water Strategy will have a significant coordination and educational component, networking will be foundational to its success. For this reason, a networking strategy is needed to ensure the development of targeted and effective interactions with collaborators and organizations that could be helpful for the implementation of the GEO Water Strategy. These interactions occur within international organizations, GEO members (nations), representatives of academia, and, possibly, the private sector. Links are needed to provide access to experts, regional networks, funding support, data, programmes, and all of the other assets needed to run an effective programme. At the international level, the GEO Water Task will continue to seek out contributions from and interactions with UN Water, WMO, UNESCO, UNEP, World Bank/GEF, WCRP/GEWEX, ICSU Future Earth, GWSP, IAHS, CEOS, GOS (GCOS and GTOS), and GTN-H, among others. Other key organizations and agencies at the national level include NASA, JAXA, NOAA, ESA, EUMETSAT, USGS, the European Commission, CMA, and the U.S. Water Partnership. During the past decade, Japanese and U.S. support for workshops and coordination has facilitated the success of GEO water activities.

**11. Institutional and Funding Issues**

Water resources are critical for economic development and societal well-being. It is appropriate for the water cycle community as a whole to reflect on the adequacy of the resultant observational systems and to see how this investment could be made more effective in terms of meeting the world’s needs. The policy and institutional environment in which these observational systems are managed is the result of a mosaic of decisions that have been made nationally and internationally over more than a century. In recent decades, in-situ observations have suffered from national budget cuts in the absence of a clear champion to speak on their behalf. The time has come for a stronger oversight of in-situ networks and data needs.

Space programmes face different challenges. In larger countries, the responsibilities for operational satellite have been left with mission agencies, while research agencies have led the development of research satellites. This approach has worked well in developing a rich suite of research satellites, but the transition from research to operations has been less efficient. Furthermore, users of research satellite products continue to seek assurances that there will be continuity of satellite and data products.

1. **Toward an Implementation Plan**

To implement the foregoing plan, the current implementation structure (a GEO Task and Community of Practice) will be reviewed to ensure that it is still the optimum way forward. In order to strengthen user interactions and the measurement of societal benefits, more emphasis will be placed on coordination in this area. The definition of the Water Task and the water activities in the post-2015 time frame will also need to be updated to reflect this emphasis. Given that support for meetings and coordination are limited, two of the more advanced possibilities for strengthening the GEO Water programme in the post-2015 time frame are the Water Cycle Integrator and the AfWCCI, which both have strong backing in Japan. It is hoped that other countries will also step forward to take leadership in other parts of the programme.

1. **Recommendations for preparing for Water Cycle activities in post-2015 Phase of GEO**

(This chapter may be merged with Chapter 12)

**Appendix 3: Recommendations**

Chapter 3

1. Based on the need to more actively engage end users more directly in these needs assessments, it is recommended that:
2. A study (or studies) of the methods for assessing the requirements and needs be undertaken by identifying precisely which observational data types and derived information products are currently used in decision-making in end-user applications.
3. Following this step, an analysis should be carried out to identify the best available integrated observing technology and data analysis that could be delivered in a form and format that satisfies the input requirements to the end-user decision-making process. This should be done through sector-specific workshops, with a representative sampling of the end-user community.
4. Based on the need to engage users more directly in product development and evaluation, it is recommended that a process be developed to identify, articulate, and further refine user needs in the various water communities. The process should, at a minimum,
5. Identify types of users in the water community, incorporating existing information such as the GEO User Interface Committee lessons and documents regarding user engagement;
6. Identify other relevant GEO Societal Benefit Area connections to which water activities can make a key contribution;
7. Identify a variety of methods for working with users one-on-one to extrapolate water-related scientific parameters from their applications;
8. Take into account the various levels of water applications, from local to global;
9. Leverage existing GEO networks, projects, and Work Plan activities; and
10. Publish findings regularly.

Chapter 5

Some recommendations are appropriate to most water cycle variations, while there are others that apply to specific variables.

General:

1. In-situ observational networks should be strengthened to ensure that the required data are collected and made freely available to the international community. As an operational research activity, approaches should be studied to take advantage of the supplemental observational networks (for selected variables) that are maintained by volunteers, educational systems, and local governments.
2. Research on individual-sensor and multi-sensor algorithms should be supported. Operationally useful estimates from individual sensors over complex terrain, icy/snowy surfaces, coast, and land (in general) require substantial development work. For example, improved algorithms for the objective, optimal combination of precipitation and soil moisture observations from widely disparate sources must see continued research and development, potentially including assimilation approaches. Conversely, as an additional initiative, combinations incorporating both observations and numerical model/reanalysis estimates should be supported. This action should particularly benefit polar and cool-season mid-latitude regions, since the numerical results tend to validate better than observations in those conditions.
3. Institutions maintaining archives of water-cycle variables should apply modern standards of open data stewardship. High-quality products require consistently-processed, long-term datasets that are readily available; preferably including one version in the original coordinates (for example swath-footprint for satellite data). As new quality-control and algorithm versions are developed, these archives should be reprocessed to ensure that the community has ready access to consistently processed estimates for the entire period of record.

6. Based on this review of the current status of clouds and water vapour observations, it is recommended that:

a) A network of high-caliber radiosonde stations should be established in the equatorial areas to provide measurements where vertical distributions of water vapour are most critical for understanding the variability of the radiation budget.

b) Operational agencies should be encouraged to sustain research networks such as GPS and lidars and promote them into operations. Additionally, these observations should be consolidated into a system that is freely accessible by the scientific community.

d) Both IR and microwave hyperspectral technology should be expanded to develop space-borne sensors that can provide higher vertical resolution for water vapour profiles.

e) Satellite missions should be coordinated with field experiments to measure cloud properties, with the goal of providing data for the study of precipitation processes and energy budgets.

f) Techniques should be developed and applied to probe the vertical distribution and optical properties of cloud particles in the atmospheric column in order to provide measurement-based estimates of radiation-flux divergence.

g) An integrated approach to analysis of the data collected from the sensors of the “A-Train” and any similar follow-on missions like EarthCARE should be developed and sustained.

h) In the longer term, new methods for observing vertical profiles of microphysics and vertical motion information should be promoted. This requires developing a strategy for achieving these observations, including a pathway for technology development.

7. Based on this review of precipitation, it is recommended that:

a) The coverage and quality of satellite observations be improved to a constellation providing three-hourly (or more frequent) revisit times over the entire globe by a combination of GMI/AMSR2-class multi-channel conically scanning microwave imagers (the tool of choice for supplying data to the improved precipitation products that users have come to expect) and ATMS-class multi-channel cross-track microwave sounders (also helpful). Both kinds of instruments provide input data for a wide range of other geophysical retrievals, including clouds, water vapour, snow cover, oceanic wind speed, and surface fluxes.

b) Space-borne precipitation radar be made operational. The success of the TRMM PR has demonstrated that space-borne radar observations are among the most valuable multi-purpose observations of precipitation. The GPM DPR is expected to extend this result, but beyond GPM there must be a specific long-term plan for such an operational capability.]

1. National precipitation gauge networks be strengthened to ensure that the required data are collected and made available to the international community. As an operational research activity, approaches should be studied to take advantage of the supplemental gauge networks that are maintained by volunteers, education systems, and local governments.

8. Based on the survey of GEO ET activities It is recommended that:

a) Those providing ET measurements should make available sufficient descriptions of procedures, calibration, instrumentation, quality control, and site review, along with objective evaluation of results.

b) ET modeling and remote sensing estimates at the continental and global scales need significant improvements for better water resource managements and drought mitigation and adaptations. As a first step, ET output needs to be validated at the tower flux footprint scale (typically at approximately 100 meters).

c) A commitment by the space sciences community to continue to provide thermal band imaging sensors on satellites. Routine LST observations at high spatial/low temporal (e.g., Landsat), moderate spatial/temporal (e.g., MODIS), and low spatial/high temporal (e.g., GOES, Meteosat, and other geostationary platforms) are essential in order to improve ET estimation from field to continental and ultimately global scale.

d) Additional support to expand in situ collection of ET flux measurements and work toward providing adequately archived and operational flux data that is networked and accessible through the Internet.

e) Through workshops and pilot projects expand the use of ET products so they can be used with international end-user decision-support tools.

f) Further improve prognostic ET forecasts through use of observational diagnostic observations and data assimilation.

1. Based on the discussion of soil moisture it is recommended that:
2. Financial support should be increased for analysis. The main risk to soil moisture measurements on the ground is a termination of financial support, as many of the currently operational networks are financed through soft money. The definition of soil moisture as an ECV has already increased the awareness of governments to soil moisture and has ensured that governments are now obligated to report on this variable. However, to date, only little effort has been made to improve, extend, or support maintenance through government funding (this is different for the networks in the U.S. and China). To ensure a continuous operation of those networks, governments need to be lobbied to increase or establish funding for their support of such networks, as they are important for key applications in meteorology, environmental hazard predictions, and agriculture. Preferably, networks, including supersites, measuring the full spectrum of environmental variables should be established (akin to the Fluxnet sites).
3. Efforts in the validation of satellite missions through those soil moisture data networks be increased. Extensive work is already under way in Australia, France, and the US..A, but higher-density networks are required to better understand the spatial variability within a satellite footprint. Both upscaling and downscaling studies have to be intensified and validated against the in-situ networks. The creation of the ESA CCI Soil Moisture consortium is already addressing some of those issues, but it cannot function without a concerted global effort, bringing together in-situ networks (including detailed knowledge of the local surface conditions, such as vegetation and surface roughness), data from airborne campaigns, and satellite observations.

c) Work on radiative transfer models needs to continue. Soil samples should be analyzed for their spectral properties and reported back to a central body (e.g., the ESA CCI SM). Moreover, vegetation information used in the retrieval algorithm needs to be verified regularly on site. For this, vegetation observations are required at selected stations within the networks, allowing a continuous observation of the vegetation dynamics, which directly influences the soil moisture retrieval.

10. Based on the status of runoff and river discharge activities it is recommended that:

a) The first and foremost recommendation regarding river discharge monitoring is to reconsider the current emphasis on in-situ versus remote sensing monitoring so that one is not excluded over the other and that we instead find the best way to deploy in-situ and remote sensing sensors in a complementary manner. Instead of seeking solutions to replace in-situ observations with remote sensing or vice versa, scientists should devise new means to take advantage of both for more comprehensive monitoring.

b) Design a spatially more balanced global discharge monitoring network assuming different level in monitoring infrastructure investments (e.g., commitments to operate 5,000 versus 10,000 gauges) and demonstrate the price in terms of degraded monitoring capabilities as a function of station density.

1. Contrast the envisioned monitoring infrastructures with known operating gauges and identify observational gaps.
2. Develop remote sensing strategies complemented with ground surveying to map river channels.
3. Develop new hydrological data assimilation systems that could utilize both in-situ and remote sensing observation.
4. Given the need for surface water storage data for calibration and validation of satellites sensing surface water, priority should be given to upgrading the WMO Lakes and Reservoir data centre (HYDROLARE).

11. Given the needs identified in the groundwater section, it is recommended that:

1. GEO promote free and unlimited data exchange both for in-situ and remote sensing observations.
2. Continuation of the GRACE and follow-on missions at lower orbit yielding high spatial resolution.
3. Support IGRAC’s efforts establishing a global groundwater monitoring network, based on the principles of participatory monitoring in order to assess the state of groundwater and its change over time globally, which will also aid improving results from remote sensing
4. The need to develop a global hydrogeodetic repository that links directly to the GGMN be recognized.

12. Based on considerations of the needs for, and limitations of, snow measurements, it is recommended that:

a) Priority be given to research on the development of algorithms and new sensors to measure the water equivalent of snow on the ground under a wide range of vegetation conditions. Furthermore, it may be possible to design improved algorithms to more effectively utilize existing data sources.

b) Plans be developed, drawing on experience with cold-season satellite measurements and cold season field projects, for a mission optimized to measure cold-season processes and variables from space.

c) A field project be planned to deal directly with the measurement of snow, ice, and snowmelt processes in a mountainous region.

d) Attention be given to the further development of multispectral sensors that will be able to provide freeze/thaw patterns under different vegetation conditions.

e) Efforts be made to supplement the current network of snow-depth observations from selected manual climate-observing stations and global, daily snow-depth analyses with weekly measurements of SWE. An initiative should be launched to develop a research-quality data set of the climatology of snow properties, initially regionally, and eventually globally, integrating in-situ, microwave, and visible snow measurements.

Chapter 6

13. Based on this overview of water quality, it is recommended that:

1. A global-scale coordinated effort is needed to advance the future use of satellite remote sensing for water quality applications. In order to be successful this initiative will require the following:

* Continuity of existing satellites
* Development of new and improved sensor/platform technology, algorithm development, and calibration/validation activities
* Improvements in open and free data accessibility
* Establishment of a unified data repository
* Establishment of standard measurements for any in situ campaign supporting remote sensing
* An update of NASA protocols to include consideration of the high dynamic range of properties encountered in these systems that extends to include biogeochemical properties
* Establishment of a professional identity to cross freshwater with coastal, small scales with larger, science and societal considerations. Promote these ideas to IOCCG and other national space agencies for better cross-project and cross-national harmony.
* Promote education programmes and capacity building through new demonstration project initiatives that are coincident with technological advances. It is important to emphasize the need for strong linkages between the entities that produce the data and the end users. This relationship will ultimately determine the success of these tools for future water resource management.

1. Based on the discussions related to the chapter 7 on data management it is recommended that:

a) An inventory of current data services supporting IGWCO be developed.

b) A review of the effectiveness of WMO regulations on data exchange be undertaken.

c) A workshop be held with a broad cross-section of users of water cycle theme products. The results of this workshop should be used to better define the objectives and services for water cycle data archiving and distribution centers.

d) Plans be developed to ensure that vitally needed telecommunications infrastructure will be in place for the transmission of high-volume satellite datasets during the coming decades.

e) Plans be developed to rescue historical and local records and to make them available for historical water cycle studies and the assessment of local water issues.

f) IGWCO, through the influence of its international programmes and its role in GEO, take steps to promote the free and open exchange of streamflow, precipitation, and other water cycle data.

1. In view of the needs for integration and interoperability it is recommended that:
2. Current agency-funded efforts promoting interoperability be strengthened, since they are both doing the practical applied research on best practices and providing early examples. It is clear that continued research, development, and deployment are necessary.

b) Users and dataset developers need flexible, low-burden standards at all levels to enable easy adoption of the interoperability concepts being developed.

c) It is also the case that user support at the science/parameter level by individual dataset producers continues to be a crucial element, even as a more distributed and standards-based system is developed that frees the producers from having to support format and server issues.

d) A study be undertaken of how end-users deal with (or not) errors in the production of data/information products as accessible or delivered to them by various organizations and entities involved in global, regional, local observing systems, data interpretation and analysis systems, modeling and prediction systems, and decision making/support models.

1. In view of the wide variety of training materials that are emerging from various capacity building initiatives (Chapter 9) it is recommended that:
2. A web-based clearinghouse be established for water cycle training materials, primarily intended for professionals and pre-professional students. A wide variety of water cycle training materials appropriate to different audiences have been independently developed across many organizations. It will facilitate improved training and capacity building to have a central site through which presenters can find such materials for use under creative commons rules. The source organizations will continue to curate their own materials, while the clearinghouse seeks the widest possible range of sources and users, organizes the listings to facilitate discovery of audience- and topic-appropriate material, ensures the currency of its listings, and promotes best practices, such as providing back-end notes to give context to the material. Additionally, it is expected that the initial survey of materials will reveal gaps in training materials that organizations might choose to fill by developing and listing new materials or revising current materials. It is anticipated that the clearinghouse will need one or more full-time-equivalent positions.
3. GEO Water Capacity Building efforts have been marked by considerable diversity. As part of the GEO Water Strategy, workshops without specific geographical focus should be devoted to this topic and a broad strategy should be developed. The focus of this strategy should involve:
   * Developing synergies between the work done in different geographical areas and a means for more effectively transferring the results from one region to another.
   * Development of common training materials that can be used in different geographical areas.

Appendix 4

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