

GEO Task US-09-01a: Critical Earth Observations Priorities

Water Societal Benefit Area



**GROUP ON
EARTH OBSERVATIONS**

User Interface Committee

US-09-01a Task Lead: Lawrence Friedl, USA/NASA
Water SBA Analyst: Sushel Unninayar, UMBC

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Group on Earth Observations

GEO Task US-09-01a:

Critical Earth Observation Priorities for Water SBA

Advisory Group Members & Analyst

The following people served as expert panelists for the ad hoc Advisory Group for the Water Societal Benefit Area (SBA) report under GEO Task US-09-01a. The Advisory Group supported the Analyst by identifying source materials, reviewing prioritization methodologies, assessing findings, and reviewing this report.

Abou AMANI, UNESCO Africa Regional Office
Douglas CRIPE, GEO Secretariat - Water
Maria DONOSO, UNESCO Paraguay Regional Office
Jay FAMIGLIETTI, University of California, Irvine
Wolfgang GRABS, WMO Hydrology and Water Resources
Steven GREB, State of Wisconsin Department of Water Resources
Rick LAWFORD, University of Winnipeg
Annuikka LIPPONEN, UNECE
Jinping LIU, UN-ESCAP and WMO Typhoon Committee
Massimo MEMENTI, ESA
Julius Wellens MENSAH, Ghana Hydrological Services and WMO
Osamu OCHIAI, JAXA and CEOS Water
Masami ONODA, GEO Secretariat
Bruce STEWART, Australia Bureau of Meteorology

The following person served as the Analyst for the Water Societal Benefit Area report under GEO Task US-09-01a, providing overall coordination of the analysis and preparation of this report.

Sushel UNNINAYAR, University of Maryland, Baltimore County, USA

GEO Task US-09-01a

Lawrence FRIEDL (USA/NASA) is the Task Lead for GEO Task US-09-01a; he is a member of the GEO User Interface Committee.

Amy Jo SWANSON (USA/Science Systems and Applications, Inc) is the US-09-01a Task Coordinator, providing logistics and coordination amongst the Analysts.

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Group on Earth Observations

GEO Task US-09-01a:

Critical Earth Observation Priorities for Water SBA

Summary

The goal of GEO Task US-09-01a is to identify the critical Earth observations for various societal benefit areas (SBAs). This report focuses on critical Earth observations for users associated with the Water SBA.

To assist with the analysis, the Analyst assembled an ad hoc Advisory Group of 14 members from around the world including representatives from 5 GEO Member Countries and 3 Participating Organizations. Responsibilities of the Advisory Group included selecting the types of water sub-areas for analysis, recommending relevant documents that highlight critical Earth observation priorities, and reviewing prioritization methods and the results.

To supplement document recommendations from the Advisory Group, the Analyst conducted literature and internet searches. The Analyst and Advisory Group reviewed 202 documents to obtain information that was relevant to the priority-setting analysis. The Water Team focused on observation needs identified by major international, regional, and national programs and projects. After evaluating these documents for their applicability to this task, the Analyst Team determined that all of the documents provided information on observation priorities that were relevant to the analysis.

The Analyst employed a semi-quantitative method to prioritize the observation parameters for the Water SBA. This method incorporated multiple factors, including rankings made by the Analyst in consultation with the Advisory Group. The rankings were based on a weighting scheme that considered the observational priorities that had already been established for various elements of the global water cycle. The method also integrated new findings from the priority-setting analysis, such as parameters currently unavailable because of technological limitations, parameters needed to derive information products for applied end users, and critical parameters needed to understand the water cycle.

Based on the results derived from analysis, the Water Team generated a list of Earth observations for the Water SBA for three different perspectives: global, regional, and local. The 48 observations listed below have the highest rankings for the global perspective and thus are considered to be observation priorities for the Water SBA. The observations are in no particular order and have approximately equal priority.

- Precipitation (Liquid, Solid and Mixed Phase)
- Soil Moisture (Surface/Sub-Surface)
- Soil Temperature (Surface/Sub-Surface)
- Evaporation (Lakes and Wetlands)
- Evapotranspiration (from Land Surface)

- Runoff/Stream Flow
- River Discharge (to Ocean Coastal Zones/Estuaries), Surface/Sub-terra, Major Rivers
- Glaciers & Ice Sheets (Extent/Depth)
- Ground Water & Aquifer Volumetric Change
- Land Cover, Vegetation Cover/Type
- Elevation/Topography
- Water Quality (Large Water Bodies, Major Rivers, Estuaries, Nutrients/Contaminants such as Nitrates, Sulfates, Phosphates; Dissolved Oxygen Content)
- Lakes/Reservoirs Levels (Including Other Surface Storages)
- Snow (Cover/Depth/Type, Snow Water Equivalent)
- Air Temperature (Surface Met/Hydromet)
- Air Moisture/Humidity (Surface Met/Hydromet)
- Winds (Surface Met/Hydromet)
- Evaporation (Oceans)
- Freeze/Thaw/Melt State & Margin
- Permafrost/Frozen Ground
- Soil Type (Classification)
- Soil Properties (Texture/Porosity, Hydraulic Conductivity, etc.)
- Surface Radiation Budget (Incoming/Outgoing Shortwave & Longwave)
- Top of Atmosphere Outgoing Longwave Radiation
- Surface Albedo and Emissivity (often a derived/estimated parameter)
- Clouds – Liquid Water Content
- Cloud Properties – Optical Depth/Extinction Coefficients
- Agricultural Water Use – from Surface Storages such as Reservoirs, Rivers, Channels, Canals
- Agricultural Water Use – Ground Water Draw
- Energy Non-Hydro Power Generation Water Demand/Use
- Urban Water Demand/Use – Large Mega-Cities
- Water Regulation – Trans-Boundary (Regional/International)
- Soil Composition (Chemical, Mineral, Nutrient, including soil pH, C, N, P, K)
- Ground Water Recharge/Discharge Rates
- Water Infiltration/Percolation & Rates (Land Surface)
- Cloud Properties (Cloud Condensation Nuclei, Particle-Size distribution and Phase/State, Cloud Liquid Water Content)
- Aerosols
- Sea Level Pressure (Surface Met/Hydromet)
- Land Use Classification (Agriculture, Urban, Industrial, etc.)
- Geologic Stratification and Geomorphological Classification
- Water Quality & Composition (organic/inorganic contaminants, isotopic, suspended particulates, turbidity, salinity, color)
- Water Quality (Drinking/Potable Water)
- Water Quality (Ground Water)
- Hydro-Energy Water Demand/Use
- Urban Water Demand/Use – Small Cities

- Sub-Urban Water Demand/Use – Distributed
- Water Regulation – National
- Water Regulation – Trans-Boundary (State/National)

These observation priorities represent a broad picture of global Earth observation priorities for water applications. The priorities of highest benefit to one geographic region may not provide any added value to another. However, regional, national, and local-level authorities and agencies will be able to use such priority lists in helping develop Earth observation strategies that are customized to their individual needs. This priority list was used in the Cross-SBA analysis to identify critical Earth observation priorities across all SBAs.

GEO Task US-09-01a: Critical Earth Observation Priorities for the Water SBA

1 Introduction

This report articulates Earth observation priorities for the Water Societal Benefit Area (SBA) based on an analysis of 202 publicly available documents, including documents produced by the Group on Earth Observations' Member Countries and Participating Organizations.

1.1 GEO and Societal Benefit Areas

The Group on Earth Observations (GEO)¹ is an intergovernmental organization working to improve the availability, access, and use of Earth observations to benefit society. GEO is coordinating efforts to build a Global Earth Observation System of Systems (GEOSS)². GEOSS builds on national, regional, and international observation systems to provide coordinated Earth observations from thousands of ground, airborne, *in situ*, and space-based instruments.

GEO is focused on enhancing the development and use of Earth observations in nine SBAs:

Agriculture	Biodiversity	Climate
Disasters	Ecosystems	Energy
Health	Water	Weather.

1.2 GEO Task US-09-01a

The objective of GEO Task US-09-01a is to establish and conduct a process to identify critical Earth observation priorities within each SBA and those common to the nine SBAs. Many countries and organizations have written reports, held workshops, sponsored projects, conducted surveys, and produced documents that specify Earth observation needs. In addition, researchers and practitioners have also identified and recommended key Earth observation needs in publications and peer-reviewed literature. Task US-09-01a focuses on compiling information on observation parameters from a representative sampling of these *existing* materials and analyzing across the materials to determine the priority observations.

This task considers all types of Earth observations, including ground, in situ, airborne, and space-based observations. This task includes direct measurements and derived parameters as well as model products. This task seeks to identify Earth observation needs across a full spectrum of user types and communities in each SBA, including observation needs from all geographic regions with significant representation from developing countries.

GEO will use the Earth observation priorities resulting from this task to determine, prioritize, and communicate gaps in current and future Earth observations. GEO Member Countries and

¹ GEO Website: <http://www.earthobservations.org>

² GEO 10-Year Implementation Plan: <http://www.earthobservations.org/documents.shtml>

Participating Organizations can use the results in determining priority investment opportunities for Earth observations.

1.3 Purpose of the Report

The primary purpose of this report is to articulate the critical Earth observation priorities for the Water SBA. The intent of this report is to describe the overall process and specific methodologies used to identify documents, analyze them, and determine a set of Earth observation parameters and characteristics. This report describes the prioritization methodologies used to determine the priority Earth observations for the Water SBA. This report also provides information on key challenges faced, feedback on the process, and recommendations for process improvements.

The primary audience for this report is the GEO User Interface Committee (UIC), which is managing Task US-09-01a for GEO. The GEO UIC will use the results of this report in combination with reports from the other eight SBAs. The GEO UIC will perform a meta-analysis across all nine SBA reports to identify critical Earth observation priorities common to many of the SBAs. Based on the nine SBA reports, the GEO UIC will produce an overall Task US-09-01a report, including the common observations and recommendations for GEO processes to determine Earth observation priorities in the future.

The report's authors anticipate that the GEO Secretariat, Committees, Member Countries, Participating Organizations, Observers, Communities of Practice, and the communities associated with the Water SBA are additional audiences for this report.

1.4 Scope of the Report

This report addresses the Earth observation priorities for the Water SBA. In particular, this report addresses four sub-areas associated with terrestrial hydrology and water resources: surface waters, ground waters, forcings on terrestrial hydrological elements, and water quality/use.

This report provides some background and contextual information about the Water SBA. However, this report is not intended as a handbook or primer on the Water SBA. A complete description of the Water SBA is beyond the scope of this report. Please consult the GEO website cited above for more information about the Water SBA.

This report focuses on the Earth observations relevant to the Water SBA, independent of any specific technology or collection method. Thus, the report addresses the “demand” side of observation needs and priorities. The report does not address the specific source of the observations or the sensor technology involved with producing the observations. Similarly, any discussions of visualization tools, decision support tools, or system processing characteristics (e.g., data format, data output) associated with the direct use of the observations are beyond the scope of this report.

In this report, the term “Earth observation” refers to parameters and variables (e.g., physical, geophysical, chemical, biological) sensed or measured, derived parameters and products, and related parameters from model outputs. The term “Earth observation priorities” refers to the parameters deemed to be of higher significance than others for the given SBA, as determined

through the methodologies described within. The report uses the terms “user needs” and “user requirements” interchangeably to refer to Earth observations that are articulated and desired by the groups and users in the cited documents. The term “requirements” is used generally in the report to reflect users’ wants and needs; the use of this term in this report does not imply technical, engineering specifications.

Following this introduction, the report discusses the overall approach and methodologies used in this analysis (Section 2). Section 3 presents a global overview of observations required for the monitoring and understanding of the global water/energy cycle processes of the Earth/climate system, and also defines the Water SBA and the specific sub-areas that were part of the analysis. Section 3 also includes a description of types of users, types of observational data and information needs, and a summary of the documentation used for the meta-data analysis. Section 4 discusses Earth observations for the water sub-areas with representative examples. Section 5.1 articulates the specific Earth observations for each water sub-area, and Section 5.2 presents observational specifications (e.g., space/time resolutions, accuracy and latency) for the selected priority observational requirements across the Water SBA. Sections 6 and 7 present additional findings from the analysis of the documents and the Analyst’s recommendations. The appendices include the documents utilized in the analysis as well as a list of acronyms used throughout the document. Appendix C summarizes the input to the Cross-SBA analysis.

2 Methodology

The Earth/climate system is dominated by the global water/energy cycle at all space and time scales. To understand processes within the system, monitor system functions, and construct models of the system, global observational requirements have been periodically reviewed in the past by several national and international programs and projects. Generally, these reviews have been carried out within the context of the scientific understanding of the Earth system at one point in time, and within constraints imposed by observational technology and/or feasibility. International data exchange/access systems and agreements between countries and regions to facilitate such data exchange have been extremely important and vital to the global or regional availability of critical water cycle parameters, an example of which are the global data exchange systems coordinated by the WMO, UNESCO, FAO, UNEP and other organizations. Regional examples include the exchange of data on transboundary basins: agreements between riparian countries with guidance provided by the UNECE Water Convention. However, it is noted that international and regional agreements typically allow for the date exchange of a sub-set of national observing systems, and thus can introduced constraints on the comprehensiveness of operational global observing systems. All of the above realities change with time and technology.

As a result, they have in the past introduced some biases in the specification of observing system requirements. This analysis scrutinizes observational requirements initially from first principles stemming from the basic science of global water cycle processes and first tier applications derived from or dependent on this understanding. The analysis relies on a multitude of previous major efforts to consolidate requirements that can often be scattered between different disciplines even for the same single observational parameter. A large number (over 200) of papers, reports,

programs, and project descriptions were reviewed to obtain information pertinent to the meta-data analysis for this exercise.

The basic methodological approach taken is to distill, scrutinize, and improve upon the observations requirements expressed by the aggregate of disparate though well established expert groups covering the multitude of disciplines researching the water cycle, and using or applying water cycle data and products (variables and parameters) to their respective day-to-day operations. Aside from operational/tactical (real-time and near-real-time) decision making, strategic and policy decisions introduce added dimensions for observations requirements. These user needs are also taken into account—they support the analysis and application of, for example, the long-term impacts of global climate change on the water cycle and specifically the availability of fresh water resources.

The analysis covers global, regional and local (and/or national scale) aspects of observational requirements, and also requirements for derived information products relevant to the management of terrestrial water resources and the terrestrial water cycle. Particular attention is paid to water resources management at the basin or watershed scale which can also cross state (within a large country) or national boundaries.

2.1 Task Process

The GEO UIC established a general process for each of the SBA Analysts to follow in order to ensure some consistency across the SBAs. This general process for each SBA involves nine (9) steps, as summarized in the following list:

- Step 1: Identify Analyst and Advisory Group for the SBA
- Step 2: Determine scope of topics within the SBA
- Step 3: Identify documents regarding observation priorities for the SBA
- Step 4: Develop analytic methods and priority-setting criteria
- Step 5: Review and analyze documents for priority Earth observations needs
- Step 6: Combine the information and develop a preliminary report
- Step 7: Gather feedback on the preliminary report
- Step 8: Perform any additional analysis
- Step 9: Complete the report on Earth observations for the SBA.

A detailed description of the general US-09-01a process is available at the Task website <http://sbageotask.larc.nasa.gov> or the GEO website. Some steps in the process occurred simultaneously or iteratively, such as identifying documents (Step 3) and reviewing documents (Step 5).

Several additional steps were also undertaken as briefly described below.

- Establish a relatively small Advisory Group (Advisory Group) of well recognized experts to guide the analysis and select the sub-set of parameters that this study should focus on from the large parameter space required to monitor the complexity of the Earth system as a whole.

- Promote and establish a broader expert group that reaches out to end users and applications, namely a “Community of Practice (CoP).”
- Identify and review a representative set of documents, papers, technical reports, and other expressions of observational requirements.
- Consolidate requirements with a focus on prioritization in order of importance to the extent possible while noting that any one observation type is of critical importance to one or more specialized sub-discipline.
- Prepare a final report to the GEO UIC following extensive review via the Advisory Group and the CoP, and through them the broader external community who may or may not have been involved directly in the iterative steps undertaken by the analysis.
- Incorporate feedback from the Advisory Group, CoP and GEO UIC, including specifications of requirements and/or parameters/variables that have not been included, if any.
- Identify aspects of requirements that were deemed (by Advisory Group, CoP) outside the focus or scope of this particular task but strongly recommended as future actions.
- Finalize report for the submission of the Preliminary Report to the GEO UIC.
- Revise the preliminary report following feedback and recommendations (for additional analysis) from the GEO UIC, and resubmit the report to GEO UIC after review by the Advisory Group, CoP, etc.
- Engage with the GEO UIC meta analysis process to help ensure that the Water SBA priorities are adequately integrated in the overall summarization.
- Review the final consolidated/integrated summary of priority observations requirements as prepared by GEO UIC to ensure that key items and recommendations relevant to the SBA-Water have been retained.

2.2 Analyst and Advisory Group

The Water SBA had an “Analyst” and an “Advisory Group” working together to identify documents, analyze them, and prioritize the Earth observations. The Analyst served as the main coordinator, and he managed the activities of the Task.

2.2.1 Analyst

The Analyst for the Water SBA was Sushel Unninayar, a Senior Research Scientist at the Goddard Earth Sciences and Technology Center at the University of Maryland, Baltimore County (UMBC).

2.2.2 Advisory Group

The general methodology for GEO Task US-09-01a includes the formation of an expert Advisory Group to help identify appropriate documents, provide feedback on the prioritization methods, and review the preliminary and final reports. The Water SBA Advisory Group was formed based on interactions with well established international, regional and national programs dealing with various aspects of water resources management, the global water cycle and relevant observing systems, the research community, water cycle applications community, as well as representatives who interact extensively with end users through various organizational entities and communities.

The Water SBA analysis was coordinated closely with the GEO-UIC member representing the water cycle, Rick Lawford. Masami Onoda, GEO Secretariat, Geneva, Switzerland, has provided considerable support for this activity. The Advisory Group provided guidance on all aspects of this analysis.

Table 1. Advisory Group for the Water SBA Analysis

Name	GEO Country or Organization	Affiliation	Geographic Region	Area of Expertise/ Specialty
Abou AMANI	UNESCO	UNESCO Africa Regional Office	Africa	Hydrology & Water Resources
Douglas CRIPE	GEO	GEO Secretariat - Water	International	Hydrology & Water Resources
Maria DONOSO	UNESCO	UNESCO Paraguay Regional Office	South/Central America	Hydrology & Water Resources
Jay FAMIGLIETTI	United States	University of California	North America	Hydrology & Climate
Wolfgang GRABS	WMO	WMO Hydrology and Water Resources	International	Hydrological Forecasting & Water Resources Development
Steven GREB	United States	State of Wisconsin Department of Water Resources	North America	Hydrology & Water Quality
Rick LAWFORD	Canada	University of Winnipeg	North America	Hydrology & Water Resources; Hydrometeorology
Annukka LIPPONEN	UNECE	UNECE	Asia/Middle East	Hydrology; Trans-boundary waters
Jinping LIU	UN-ESCAP	UN-ESCAP & WMO Typhoon Committee	East Asia	Hydrology, Meteorology, Typhoons
Massimo MENENTI	ESA	ESA	Europe	Remote Sensing, Hydrology, Water Resources Management
Julius Wellens MENSAH	Ghana	Ghana Hydrological Services & WMO	Africa	Hydrology & Water Resources
Osamu OCHIAI	Japan	JAXA & CEOS Water	International	Remote Sensing
Masami ONODA	GEO	GEO Secretariat	International	International Coordination

Name	GEO Country or Organization	Affiliation	Geographic Region	Area of Expertise/ Specialty
Bruce STEWART	Australia	Australia Bureau of Meteorology	Oceania/Australia	Agrometeorology, Weather, Hydrology & Water Resource

2.3 Methodology

Being a “water” planet, the global (or regional) water/energy cycles of the Earth/climate system are intertwined and entail the observation of a broad array of parameters and variables in order to understand and quantify water cycle processes. Such a comprehensive understanding is a prerequisite to quantifying the interactions and feedbacks within and between components of the Earth system.

Forcings on the water cycle also need to be measured. Observations of system state variables, as well as forcings and feedbacks form the substrate upon which models of various components of the water cycle are constructed – for diagnostic purposes, for applications to water resource management, and for prediction purposes. Models are also used to compute a range of derived parameters from system “state” parameters.

Derived parameters such as evapotranspiration either cannot be easily observed directly or the instrumentation networks or platforms are unavailable to make these measurements on a global or even regional basis. However these derived or computed parameters are needed by the end user for a variety of applications, and hence they need to be included in any comprehensive list of essential parameters for the water cycle.

The following step-wise methodology is applied in this analysis:

1. Review and identify a comprehensive set of “macro” parameters/variables required to observe the Earth/climate system. This step was deemed necessary to place in context the rationale for the eventual selection of critical water cycle parameters.
2. Identify key water cycle parameters as a subset of those needed for the whole Earth/climate system (in Step 1).
3. With guidance from the Water SBA Advisory Group, further reduce the number of key water cycle parameters to identify a more focused set (from Step 2) of parameters that directly relate to the terrestrial water cycle – the main theme of the GEO Water SBA as defined by the guidance provided by the GEO UIC. A broad range of user types and needs were taken into account.
4. Analyze documents from well established international and national/regional sources/literature that describe and/or specify priorities for water cycle observations as well as comment on accuracy and space/time resolution specifications.
5. Analyze previously established prioritizations and requirements (Step 4) for gaps and missing requirements based on this analysis taking into account more recent literature, feedback from water cycle communities, and advances in science and technology.
6. Prepare a cohesive, representative summary for the purposes of GEO UIC.

7. Obtain feedback from the Water SBA Advisory Group and Community of Practice. Prepare the draft preliminary report for further review and comment prior to finalization. [Steps 4, 5, 6, 7 are expected to go through several iterative cycles.]
8. Submit preliminary report to GEO UIC.
9. Review feedback from GEO UIC with the Water SBA Advisory Group and CoP.
10. Carry out additional analysis and/or recommend future actions to cover items that are deemed beyond the scope of this particular task but necessary for a more comprehensive treatment of requirements in a broader sense than originally envisaged by this task.
11. Revise and finalize report.

2.3.1 Documents

This report takes maximum advantage of analyses of user requirements and observational priorities which are regularly carried out by the broader hydrological community within the framework of well established institutional processes – international, regional, and national.

Substantive efforts have been made to develop mature mechanisms to identify on a regular basis user requirements for a large and growing number of applications by international and regional organizations such as those supported and/or coordinated by national hydrological services under the auspices of the World Meteorological Organization whose membership includes both National Meteorological Services (NMSs) and National Hydrological Services (NHSs).

Substantial additional material is derived from major programs, especially regional and national, of UNESCO, FAO and other international organizations such as ICSU. This analysis integrates the efforts of many organizations and agencies expended over many years and involving all countries and user communities in countries. Steps were taken to incorporate, as appropriate, requirements stemming from reviews of observational data needs as articulated by parallel efforts within major international, regional, and national programs and projects. The report strives to summarize the findings of the constituent bodies of these organizations as regards priority observations for the Water SBA. Due attention was paid to identifying gaps or missing requirements in previous efforts at consolidating requirements, especially gaps in prioritization for various legacy reasons, and including a treatment of such gaps in this analysis accompanied by a justification for the same.

The documentation references used in this analysis are extensive and have been detailed in Appendix B. One may refer, in general terms, to the documentation references as belonging to two categorical classes:

(1) Primary or major Tier I references to priority parameter selection and specifications stemming from the compilations produced through intensive and extensive international or regional or national efforts that involved inputs from constituent bodies of organizations and hundreds if not thousands of individuals – they represent all geographic regions of the world as well as all user communities within the scope of the agencies and organizations involved in the generation and delivery of products for the end user.

(2) Tier II references to information as found in regional projects, and numerous individual published papers which have a bearing on the water cycle and/or research/applications projects

which reflect on space/time resolution and accuracy requirements. They include those pertaining to various geospatial scales ranging from global to regional to local. Implicit in this analysis is a representative consolidation of several hundreds of direct or indirect references which could total in the thousands + range due to the large number of references embedded within the Tier I and Tier II reference lists.

An effort is made to provide GEO UIC with substantial documentary evidence that supports the integrated conclusions of this analysis.

It would not be an overstatement to mention that the most recent extensive high-level prioritization of observational requirements is represented by that undertaken under the rubric of “global climate change,” within which many (though not all) aspects of the water cycle have been included within the purview of requirements for the Global Climate Observing System (GCOS) and, in particular, the Global Terrestrial Observing System (GTOS) for climate change. Somewhat independent but parallel assessments have been made by the Integrated Global Water Cycle Observations (IGWCO) theme of the Integrated Global Observing Strategy-Partners (IGOS-P), and the WMO’s Hydrology and Water Resources Programme (HWRP).

Other major contributions to this report derive from the various international and regional/national programs and projects of UNESCO and FAO, UNDP, regional UN programs, among others such as the U.S. National Research Council’s (NRC’s) Decadal Survey.

The analysis also takes into account the extensive consolidations of requirements regularly compiled by major international and regional/national research/applications programs – i.e., requirements for and on operational or systematic observing systems/programs that are needed to provide the underlying data framework for global scale applications.

Here, a distinction is made between such broad, large-scale research/applications needs and those that define requirements for very specific field campaigns of limited time duration and spatial extent. The latter generally call for advanced specialized instrumentation platforms.

It is recognized, however, that research instrumentation often represents a test bed for the future development and deployment of operational global observing systems once they have been demonstrated and proven to be of value.

2.3.2 Analytic Methods

This analysis concentrated on extracting and consolidating requirements for critical observation priorities for the GEO Water SBA as expressed in the documentation published by various authoritative organizations and published works.

Additional efforts were made to incorporate deficiencies in previous analyses of requirements. It is underscored that requirements by the user vary substantially as regards space/time resolutions even for the very same water cycle parameter/variable. Requirements also vary with application between basic research (processes), applied research (development of applications), and operational practice. Correspondingly, data delivery times or the requirements for the same can also vary substantially.

A more complete exposé on this subject is possible but it might also unduly expand the scope of this report. Frequently, observational time resolution specifications are stated based on operational needs and/or feasibility as regards observing technology and/or data exchange systems. This is often referred as the “fit-for-purpose” aspects of data collection systems.

Space resolutions are typically contingent on the resolution of various “models,” or decision support systems or product delivery tools used by various sectors. Generally, space resolutions (specifications) tend to vary depending on whether the observation is to be a part of a “global” observation system or a regional/national system. The latter can call for substantially higher space/time resolution requirements than that required for global systems.

National and/or regional sub-grid scale (model derived) requirements increase with locality. Such requirements, while implemented at the local scale, define user needs at that scale and do not necessarily reflect on the requirements of the same user for global observations. This analysis attempts to capture the nuances mentioned above by summarizing requirements with a scale dependency and a range that depends on the said scale be it time or space and be it local or regional or global.

2.3.3 Prioritization Methods

Prioritization of critical observations for the Water SBA is achieved by the analysis of stated requirements from a variety of well established and credible sources. But, the analysis adds new developments in technology, methodology, models, data analysis and product delivery defined by current end-user needs.

A basic criterion used in this analysis is that the prioritized requirement is not constrained by existing observational technology be it in-situ or space-based. Nor should it be constrained by existing international data exchange systems. Consequently, the requirements as consolidated in this report may or may not be currently achievable or implemented or even implementable without further advances in technology and data processing and data exchange systems.

The prioritization treatment is intentionally constrained to those water cycle parameters and variables that are necessary to observe/monitor the terrestrial water cycle – a focus of this report. This choice/selection or focus was made to reduce the overlap and redundancy with the other themes of the GEO UIC, especially climate and weather. However, completely eliminating redundancy is not possible due to the nature of the physics and dynamics of the natural Earth system.

Namely, the water cycle will indubitably be a dominant part of the climate system as also a determining force behind weather systems as well as many other component systems carried by the GEO’s thematic SBAs. The water cycle also plays a critical role in the functioning of the carbon cycle and natural ecosystems. Moreover, as a determinant of the suitability (or not) of various habitat to support ecological and biological structures, aspects of the water cycle impinge on issues in the area of health and vector borne disease propagation, among others.

Attention is paid to the role of water as a critical component of the climate-energy-food nexus. Thus, while a major effort is made to reduce the number of parameters and variables that are to be the focus of this SBA report, included are details to cover the extent of the end user needs in various other sectors for data from water cycle observing systems. This analysis provides a prioritization that reflects the concerns and requirements of the end users of water cycle observations and observing systems.

Due to the diversity of end users, the variables and parameters selected as priority encompass both state variables as also forcing and feedback variables that control or modify local to regional to global terrestrial water cycle processes. A conscious effort was made to constrain the list of critical variables.

Omitted are a large spectrum of parameters and variables that are critical to the global water/energy cycle. But, they are expected to be covered by other GEO SBAs such as Climate, Weather, Ecosystems, Health, and Energy. Oceanic variables are a good example of what is not covered by this report though it would be a critical variable for the global water cycle, and even the terrestrial water cycle when considering observations needed to make predictions of precipitation for example – a parameter which involves the global atmospheric general circulation and the coupled atmosphere-ocean-land system. The basic approach taken for prioritization includes a strong weighting on observational priorities already established for various elements of the global water cycle.

To this initial weighting new findings discovered during the meta-data analysis carried out through this analysis are incorporated. In particular, a number of observational requirements for variables and corresponding space/time resolutions are notably omitted in previous traditional analysis of requirements due to their not being available on account of technology limitations, or unavailable due to limited (or no) international or regional data exchange agreements or systems.

Another class of variable-type is that of parameters that are customarily derived through model or algorithm computations. All such variables and parameters are, however, needed by various user sectors and communities to improve their modus operandi. Thus, they are explicitly included in this analysis.

Summary of Prioritization Criteria Used

Due attention is paid to:

- End user needs and user requirements for observations and derived information – a priority for the GEO UIC. A large number of user sectors and end user functions were taken into account and reviewed. But a direct engagement or discussion has not taken place and is outside the scope of this report with, for example, “water managers” in their day-to-day operational activities such as water allocations, demand management, crop water demand, etc. Such a degree of direct engagement is foreseen as a potential future activity through, perhaps, the Water Community of Practice.
- The observations used to derive information products that deliver applications of societal benefit.

- The critical observations needed to understand and characterize the physical/dynamical structure of the global/regional/local water cycle system and processes that determine terrestrial fresh water resources.
- Consideration of both “water” system state variables and forcing/feedback variables – the latter determine water “system” variability and longer-term “change,” both of which are needed by the end user.
- Specific requirements for derived variables/parameters: algorithmic, dynamical/empirical model output, information from data analysis schemes, and decision support systems/tools, among others. These derived information products often relate to parameters that are not measured directly or are not available (no data exchange system in place), or are not in a form that can be utilized by the end applications sectors.

Additionally, the analysis has been careful to not be constrained by existing observing systems or existing operational data exchange systems because they, typically, have restricted the definition of requirements for future observing systems and their design and implementation.

3 Water SBA

3.1 Water SBA Description

The GEO UIC defines the Water societal benefits area is as follows: *improving water resource management through better understanding of the water cycle*. Water-related issues addressed by GEOSS will include: precipitation, soil moisture, stream-flow, lake and reservoir levels, snow cover, glaciers and ice, evaporation and transpiration, groundwater, and water quality and water use.

GEOSS implementation will improve integrated water resource management by bringing together observations, prediction, and decision support systems and by creating better linkages to climate and other data. In situ networks and the automation of data collection will be consolidated, and the capacity to collect and use hydrological observations will be built where it is lacking.

3.2 The Scope of the Water Challenge (Ref. IGWCO)

Almost all aspects of the Earth system involve or rely on water. The Earth is unique among the planets because water is maintained in vapor, liquid and ice forms over its surface. Water and energy are intimately involved in driving the atmospheric and oceanic general circulation, and consequently climate and weather prediction systems must consider water as a primary component.

The Earth's ecosystems are dependent on water for their survival. Humans are no exception because they also have requirements for water. In addition, human activities (anthropogenic impact) affect the water cycle not only indirectly as global warming affects precipitation patterns, but also directly as the river control, irrigation, etc., and general water management practices reorganize the patterns of water movement and impact on its quality.

The complexity of these interactions and the range of their space and time scales add to the difficulty of defining observational requirements for the water cycle. Clearly, a very wide range of observations, research, and infrastructure are needed to understand the water cycle, to provide predictions of variations in the water cycle and their potential consequences, and to evaluate the human-water cycle interactions.

In addition, energy variables such as radiation and surface fluxes are critical. Energy is important because the cycling of water is determined by the distribution of energy, and the movements of energy within the Earth system are frequently associated with the movement or change of phase of water.

Within the Earth system water is stored in three principal reservoirs, namely the oceans, atmosphere, and land (including surface and subsurface water storage), and is continuously cycling between these reservoirs.

The water cycling through the Earth system satisfies human needs and uses, supports the Earth's ecosystems and provides basic functions in the atmosphere's circulation by exchanging heat between the equator and the polar-regions. This cycling, which is modulated by the march of the seasons and by shorter-term variations in the weather, ensures long-term continuity in the water supply.

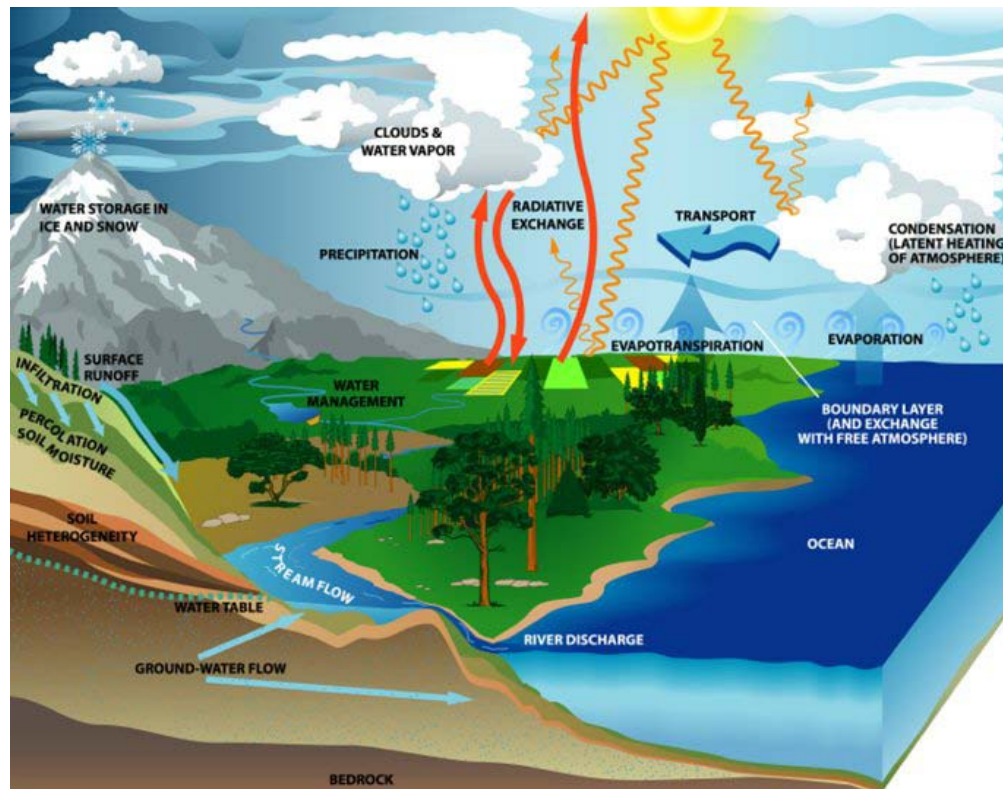
The dimensional scope of the “water cycle” is best illustrated by Figure 1. The water cycle involves atmospheric, oceanic and terrestrial Earth system components that continually interact with each other.

Furthermore, the water cycle is inseparable from the energy cycle of the Earth system and consequently the two need to be observed and investigated as an indivisible pair in the design construct and specification of global observing systems.

The almost 100% overlap with other GEO SBAs such as Climate and Weather should be rather clear, even if some of them do not necessarily take into account several surface and sub-surface terrestrial hydrological/water cycle processes in a sufficient detail as required for the optimum monitoring and management of fresh water resources – a vital distinction that is important to the Water SBA.

To reduce redundancy, an effort is made in this analysis to focus on those components of the water cycle that impact terrestrial water availability and use. The demand side of this equation is also considered important. Additional details and criterion used to define the focus of this study are provided in later sections of this report.

Figure 1. The Water Cycle Dominates the Earth-Climate System. [Schematic of the Water Cycle (From GCRP-2003)]



3.3 Global Overview of Needs and Requirements for Observations for the Monitoring, Understanding, and Modeling of Water/Energy Cycle Processes of the Earth/Climate System

Global/regional/local observations (and time series) are required for a broad range of parameters/variables to:

- Monitor the water/energy cycle for diagnostic analysis, prediction, and assessment activities (e.g., prediction of hydrological extremes, assessment of water resources availability for various uses)
- Provide the basis for diagnostic research
- Understand basic processes and the relationships between component sub-systems of the water/energy cycle
- Identify and detect trends
- Attribute cause (of changes in mean state and variability)
- Develop/improve models (and process parameterizations) to simulate and predict changes
- Address up-scaling and down-scaling issues
- Quantify and represent, in models, the coupling/interactions between atmospheric, ocean, land surface, vegetation, cryospheric and hydrological component sub-systems
- Distinguish between changes induced by natural and human induced forcings, and
- Quantify the impacts of global change on natural and managed ecosystems.

Observations provide a fundamental substrate upon which research is conducted. Theoretical research depends on observational verification to confirm or refute hypothesis. All model parameterizations depend on observations, as does the derivation of algorithms for remote sensing platforms (space-based and surface-based).

The global nature of the water/energy cycle dictates that data sets (and time series) be constructed from a combination of satellite and in-situ measurements. Increasingly, data assimilation models are used to integrate/combine data (observational and/or derived) from a multitude of disparate platforms.

Retrospective re-analysis to construct (or re-construct) integrated data time series in the form of “gridded fields” has become an accepted practice. These data sets are used extensively by the broader research and applications communities.

Observing the Earth system requires the definition of a key set of parameters or variables that collectively describe its dynamic character. It is sometimes mathematically convenient to consider “internal” state variables and “forcing or feedback” variables for each component of the Earth system, as detailed in Table 2.

A state variable, as the name implies, would provide monitoring information on the basic internal structure and state of a system or subsystem. A forcing or feedback variable would comprise a parameter which could change the state of a system or subsystem. Consonant with such an approach, the set of variables identified in Table 2 could be considered a minimum set to adequately describe the state and behavior of the physical Earth system when considering time scales ranging from days to years and decades.

For longer time scales, processes and interactions within the “solid” Earth need to be taken into account, as well as solar, orbital and planetary gravitational interactions. It is underscored that the distinction between state and forcing variables is to an extent an artifact of the partitioning of the Earth system into land, atmosphere and ocean. In doing so, a state variable for one component could be, and often is, a forcing or feedback variable for another component. However, a partitioning of the Earth system becomes useful, if not necessary, to enable observing systems and models to be constructed. Table 2 contains a summary of the parameters that need to be observed in order to monitor the total Earth system.

Table 2. Summary of State and Forcing/Feedback Variables to Observe/Monitor the Earth System (and the Water Cycle “W”). Summary of “State” and “Forcing/Feedback” variables required to observe the major components of Earth system. “[W]” denotes the key variables and parameters required for the observation and monitoring of the “Water/Energy Cycle” and Water/energy cycle processes. “I” (“S”) denotes measurements that can be made by in-situ (space-based) instruments and that operational or systematic (research) observing systems/networks and international programs exist. “i” (“s”) denotes that the in-situ (space-based) measurements made are restricted in space and/or time coverage, or that operational monitoring and data exchange systems do not exist, or that the measurements made are insufficient in accuracy or precision. In some cases, the parameters flagged by an “i” (“s”) may see significant improvements in the near future. (Ref. Adapted from SU-1, SU-2).

STATE VARIABLES (SV)	EXTERNAL FORCING OR FEEDBACK VARIABLES (FV)
(1) ATMOSPHERE	
• wind (I/s) [W]	• sea surface temperature (I/S) [W]
• upper air temperature (I/S) [W]	• land surface soil moisture/temperature (i/I/s) [W]
• surface air temperature (I/s) [W]	• land surface structure and topography (I/S) [W]
• sea level pressure (I)	• land surface vegetation (I/S) [W]
• upper air water vapor (I/S) [W]	• GHGs, ozone & chemistry, aerosols (i/S) [W]
• surface air humidity/Wv (I/s) [W]	• evaporation and evapotranspiration (i/s) [W]
• precipitation (I/S) [W]	• snow/ice cover (i/s) [W]
• clouds (i/S) [W]	• SW and LW radiation budget--surface (i/s) [W]
• liquid Water content (i/S) [W]	• Solar Irrad. & Atm. SW/LW radiation Budget (S)
(2) OCEAN	
• upper ocean currents (I/s)	• ocean surface wind & wind stress (i/S) [W]
• surface ocean temperature (I/S) [W]	• incoming surface shortwave radiation (i/s)
• sea level/surface topography (I/S)	• downwelling longwave radiation (i/s)
• upper ocean surface salinity (I/s) [W]	• surface air temperature/humidity (I/s) [W]
• sea ice (I/S) [W]	• precipitation (fresh water/salinity flux) (i/s) [W]
• mid and deep ocean currents (i)	• fresh water flux from rivers & ice melt (i/s) [W]
• sub-surface thermal structure (I)	• evaporation (i/s) [W]
• sub-surface salinity structure (I)	• geothermal heat flux--ocean bottom (i)
• ocean biomass/phytoplankton (i/S)	• organic & inorganic effluents (into ocean) (i/s)
(3) TERRESTRIAL: LAND/WATER	
• topography/elevation (I/S) [W]	• incoming shortwave radiation (I/s) [W]
• land cover (I/S) [W]	• net downwelling longwave radiation (i/s) [W]
• soil moisture/wetness (I/s) [W]	• surface winds (I) [W]
• soil structure/type (I/s) [W]	• surface air temperature & humidity (I/s) [W]
• vegetation/biomass vigor (I/S) [W]	• evaporation & evapotranspiration (i/s) [W]
• Water runoff (I/s) [W]	• precipitation (I/S) [W]
• surface ground temperature (I/S) [W]	• land use & land use practices (I/s) [W]
• snow/ice cover (I/S) [W]	• deforestation, (i/s) [W]
• sub-surface temp & moisture (I/s) [W]	• human impacts--land degradation (i/s) [W]
• soil C,N,P, nutrients (I)	• erosion, sediment transport (i/s) [W]
• necromass (plant litter) (i)	• fire occurrence (I/S) [W]
• sub-surface biome/vigor (i)	• volcanic effects (on surface) (I/s)
• land use (I/s) [W]	• biodiversity (i/s)
• ground water (& subterra flow) (i/s) [W]	• chemical (fertilizer/pesticide & gas exchange) (i) [W]
• lakes and reservoirs (I/S) [W]	• waste disposal & other contaminants (i) [W]
• rivers and river flow (I/s) [W]	• earthquakes, tectonic motions (I/S)
• glaciers and ice sheets (I/S) [W]	• nutrients and soil microbial activity (i)
• water-turbidity, N, P, D-Ox, Isotopic (I/s) [W]	• coastal zones/margins (I/S) [W]

Table 2 may be elaborated into one of substantially greater complexity if detailed processes are taken into account. Here, we apply a large-to-global scale filter to reduce the number of macro variables needed to define the Earth system from the perspective of a particular time window of research and application.

Table 2 may be considered fairly comprehensive, but by no means exhaustive. It is presented to provide a framework for Earth observations. Water/energy cycle parameters are “flagged” by a “**W**.” The **W**-list is rather extensive, indicating that the water/energy cycle is involved or invoked in almost all components of the Earth/climate system.

Global/international in situ and space-based satellite observing systems that are reasonably well established are denoted parenthetically by “I/S.” Those that are deficient for one or more reason are denoted by “i/s.” Variables and parameters that are required for research, diagnostics and applications related to the global water and energy cycle are flagged by “[**W**].”

Table 2 is partitioned into "State" variables and "Forcing and/or Feedback" variables for the three major components of the Earth system, namely: Atmosphere, Ocean and Terrestrial (Land and Water). By this definition, a state variable for one component can be a forcing/feedback variable for another. An example is sea surface temperature (SST), a state variable for the ocean, and a forcing variable for the atmosphere. Another example is soil moisture, a state variable for terrestrial hydrology while a forcing variable for atmospheric processes.

Similarly, evapotranspiration could be a state, forcing or feedback variable for atmospheric and terrestrial hydro processes. Often, the distinctions are made for observational and computational expediency.

3.4 GEOSS 10-Year Implementation Plan (2005) and Water Related Variables/Parameters

The GEOSS 10-Year Implementation Plan (Reference Document – February 2005) identifies various water cycle variables as important for the nine GEO SBAs (Chapter 4: Societal Benefits, Requirements, and Earth Observations). The requirements, without prioritization or further specification, as stated in the GEOSS 10-Year Plan have been noted and incorporated in this analysis of requirements.

They form an initial beginning basis for the analysis prior to amalgamation with other more elaborate statements of requirements and/or assessments of importance or priority. The variables contained in the GEO 10-Year Plan are summarized in Table 3. Only those variables or parameters directly involving water in some form were selected.

Thus, neither variables nor parameters that interact with, influence, or force elements of water cycle processes, nor those that feedback on or with water are included below, with the exception of those listed by the Water SBA. Some of the variables that do not appear in Table 3 were, however, considered important to this analysis of requirements for the water SBA and are consequently incorporated in later sections of this report.

It should be noted that unlike the GEO 10-Year Plan’s identification of variables, this analysis aggregates parameters and variables in order to condense the set of critical variables. Namely, clouds are characterized by a single variable with the implication that all cloud parameters need to be observed – such as cloud top height, cloud base, cloud optical properties, etc.

Table 3. Summary of “Water” Variables/Parameters Derived from the GEOSS 10-Year Implementation Plan

<p>Water parameters identified by SBA-Disasters (Table 4.1.5, GEOSS 10-Year Plan):</p> <ul style="list-style-type: none"> - Water chemistry, natural and contaminated - Sediment and other(e.g., oil etc.) discharges into water - Water levels (groundwater) and pore pressure - Streamflow: stage, discharge and volume - Inundation area (floods, storm surge, tsunami) - Soil moisture - Precipitation - Snow/ice cover: area, concentration, thickness, water content, rate of spring snow melt, ice break up, ice jams - Coastal erosion or deposition, new navigational hazards or obstructions, icebergs - Waves, height and patterns (ocean, large lakes), currents - Tidal/coastal water levels - Moisture content of atmosphere <p>Water parameters identified by SBA-Health (Table 4.2.5, GEOSS 10-Year Plan):</p> <ul style="list-style-type: none"> - Drinking water quality - Drinking water chemical quality (e.g., salinity, metals, nitrate, fluoride, POPs and PCBs) - Geology and geochemistry of soils and water (e.g., arsenic, fluoride and iodine) - Pathogens in domestic and recreational water - Drainage basin flows - Precipitation and soil moisture <p>Water parameters identified by SBA-Energy (Table 4.3.5, GEOSS 10-Year Plan)—Land, Atmosphere, Ocean:</p> <ul style="list-style-type: none"> - Soil maps and variables - Hydrological variables - Weather and short-term forecasts - Extreme weather - Climate statistics for atmosphere variables - Sea ice - Salinity - Tides - Extreme events—Hurricanes, Tsunami, Enso <p>Water parameters identified by SBA-Climate (Table 4.4.5, GEOSS 10-Year Plan):</p> <ul style="list-style-type: none"> - Precipitation - Water vapor - Cloud properties - Sea surface salinity - Sea ice - River discharge - Water use - Ground water - Lake levels - Snow cover - Glaciers and ice caps - Permafrost and seasonally frozen ground 	<p>Water parameters identified by SBA-Water (Table 4.5.5, GEOSS 10-Year Plan):</p> <p>(a) Water flux information:</p> <ul style="list-style-type: none"> - Surface liquid precipitation - Surface solid precipitation - Atmospheric precipitation - Evaporation - Transpiration - Streamflow <p>(b) Water storage information:</p> <ul style="list-style-type: none"> - Soil moisture (surface) - Soil moisture (vadose zone) - Ground water storage - Ground water level - Lake and river extent - Lake and river level - Reservoir extent - Reservoir level - Snow cover - Snow water equivalent - Ground ice - Permafrost/frozen soil - Glaciers, ice caps, ice sheets - Clouds - Wind speed - Wind direction - Air temperature - Water vapor - Atmospheric pressure <p>(c) Radiation and Energy Balance:</p> <ul style="list-style-type: none"> - Downward shortwave radiation - Downward longwave radiation - Albedo - Emissivity - Surface temperature - Fractional vegetation cover - Sensible heat flux - Latent heat flux - Soil heat flux <p>(d) Other Bio-geo-physical info.:</p> <ul style="list-style-type: none"> - Topography/geography - Vegetation type - Vegetation rooting depth - Vegetation height - Land use and its change - Soil type - Sea surface salinity - Sea level - Sea surface temperature - Water chemistry (quality, isotopic ratio) - Nutrient cycling - Irrigated area - Irrigation amount - Industrial water use - Drinking water - Population density - Water demand for nature conservation - Ecosystem water demand - Water pollution <p>Water parameters identified by SBA-Weather (Table 4.6.5, GEOSS 10-Year Plan):</p> <ul style="list-style-type: none"> - Air specific humidity (at surface) - Cloud base height - Cloud cover 	<ul style="list-style-type: none"> - Cloud ice profile - Cloud imagery - Cloud top height - Cloud top temperature - Cloud type - Cloud water profile - Precipitation index (daily cumulative) - Precipitation rate (liquid and solid) at the surface - Sea-ice cover - Sea-ice surface temperature - Sea-ice thickness - Snow cover - Snow water equivalent - Soil moisture - Specific humidity profile <p>Water parameters identified by SBA-Ecosystems (Table 4.7.5):</p> <ul style="list-style-type: none"> - Water fluxes (evaporation) - Humidity (near surface) - Precipitation - Water and soil salinity - Soil moisture - Optical properties of water - Soil, sediment and water column organic matter - River discharge pattern <p>Water parameters identified by SBA-Agriculture (Table 4.8.5):</p> <ul style="list-style-type: none"> - Within-season crop condition: Greenness and water stress - Drought risk - Area affected by salinization, water erosion, wind erosion - Water availability and quality for irrigation and pastoralism - Irrigated area and quantity of water for irrigation - Wetland area <p>Water parameters identified by SBA-Biodiversity (Table 4.9.5, GEOSS 10-Year Plan):</p> <ul style="list-style-type: none"> - Nil: No water variables/parameters mentioned <p>Examples of information provided by the SBA-Water to/for other SBA's (Table 4.10.3, GEOSS 10-Year Plan):</p> <ul style="list-style-type: none"> - Water→Disasters: Risk of floods and droughts - Water→Health: Water borne pathogens, pollutants; Availability of safe water for drinking - Water→Energy: Hydroelectric potential - Water→Climate: Water cycle and energy budgets - Water→Weather: Fluxes of energy and water; Surface boundary conditions - Water→Ecosystems: Water quantity and water quality - Water→Agriculture: Availability and suitability for irrigation - Water→Biodiversity: Water amount, water quality
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Such a degree of granularity is generally not included in this analysis even though some are referred to by example. Some parameters in Table 3 are not considered as observable variables, but rather derived or computed parameters based on what is observed. Thus, “rate of spring snow melt” is not carried by this analysis as variable since it would be computed by observing snow cover and depth with a specification on frequency of observation which would provide melt timing information by calculation.

There are also several variables identified by the Water SBA that are not considered by this analysis because they are covered by the Climate SBA, such as, for example, oceanic variables such as salinity/fresh water fluxes into and out of the ocean surface.

3.5 Essential Climate Variables (Ref. GCOS, UNFCCC, IPCC)

Over the past decade or more, strenuous efforts and reviews have been carried out by the international community, through the many international organizations, to define and identify essential climate variables (ECVs) as required to monitor the Earth system, and especially those that are involved in climate processes within the atmosphere, the oceans, and the land surface. They were codified and adopted by the IPCC and the UNFCCC as a guide to international observing and data exchange systems.

To quote the WMO and GCOS: essential climate variables are required to support the work of the UNFCCC and the IPCC:

[<http://www.wmo.int/pages/prog/gcos/index.php?name=EssentialClimateVariables>].

All ECVs are technically and economically feasible for systematic observation. It is these variables for which international exchange is required for both current and historical observations. Additional variables required for research purposes are not included in this table. It is emphasized that the ordering within the table is simply for convenience and is not an indicator of relative priority. Currently, there are 44 ECVs plus soil moisture recognized as an emerging ECV.

Table 4. IPCC and UNFCCC Essential Climate Variables (ECVs)

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	<p>Surface: Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour.</p> <p>Upper-air: Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction, Water vapour, Cloud properties.</p> <p>Composition: Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases^[1], Aerosol properties.</p>

Domain	Essential Climate Variables
Oceanic	<p>Surface: Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean colour (for biological activity), Carbon dioxide partial pressure.</p> <p>Sub-surface: Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton.</p>
Terrestrial ^[2]	River discharge, Water use, Ground water, Lake levels, Snow cover, Glaciers and ice caps, Permafrost and seasonally-frozen ground, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (fAPAR), Leaf area index (LAI), Biomass, Fire disturbance, Soil moisture ^[3] .

- [1] Includes nitrous oxide (N₂O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF₆), and perfluorocarbons (PFCs).
- [2] Includes runoff (m³ s⁻¹), ground water extraction rates (m³ yr⁻¹) and location, snow cover extent (km²) and duration, snow depth (cm), glacier/ice cap inventory and mass balance (kg m⁻² yr⁻¹), glacier length (m), ice sheet mass balance (kg m⁻² yr⁻¹) and extent (km²), permafrost extent (km²), temperature profiles and active layer thickness, above ground biomass (t/ha), burnt area (ha), date and location of active fire, burn efficiency (% vegetation burned/unit area).
- [3] Recognized as an emerging Essential Climate Variable (not part of the 44).

The GCOS monitoring principles adopted for the purposes of climate apply equally well to all GEOSS variables and parameters, and especially those that pertain to the Water SBA. They are repeated here for information purposes – excerpts from:

<http://www.wmo.int/pages/prog/gcos/index.php?name=ClimateMonitoringPrinciples>

“The ten basic principles (in paraphrased form) were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999. This complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17th Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP-9 in December 2003.

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.

5. Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6. Operation of historically-uninterrupted stations and observing systems should be maintained.
7. High priority for additional observations should be focused on data-poor regions, poorly observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted.
10. Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.
Furthermore, operators of satellite systems for monitoring climate need to:
 - (a) Take steps to make radiance calibration, calibration-monitoring and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system; and (b) Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term inter-annual) changes can be resolved. Thus satellite systems for climate monitoring should adhere to the following specific principles:
11. Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained.
12. A suitable period of overlap for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations.
13. Continuity of satellite measurements (i.e., elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.
14. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.
15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.
16. Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate.
17. Data systems needed to facilitate user access to climate products, metadata and raw data, including key data for delayed-mode analysis, should be established and maintained.
18. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on decommissioned satellites.
19. Complementary in situ baseline observations for satellite measurements should be maintained through appropriate activities and cooperation.
20. Random errors and time-dependent biases in satellite observations and derived products should be identified.

3.6 Changing Basis for Planning Water Works (Ref. IGWCO)

The scientific basis for planning water works is changing. Basic plans for water resources have been made conventionally by using a probability security level of extreme events, which is estimated from long time series of hydrological data in a targeted basin by assuming a stationary stochastic rainfall process.

In the main, only data from within the basin and/or surrounding area have traditionally been used for the water resources management. However, it has been suggested that events in different seasons and different areas interact together and generate temporal and spatial variability connecting with atmosphere-land-ocean interactions.

The water cycle shows very large intra-seasonal, seasonal, inter-annual and longer-term variability with spatial scale from regional to global. The potential effects of global warming on trends in the water cycle also challenge some of the premises of water resources planning that are based on the stationary stochastic rainfall process. Effective local water resources management for a limited period requires global water cycle observations to develop improved understanding and modeling capabilities on natural and anthropogenic water variations.

A major challenge relates to quantifying the amount of water in the surface stores that could provide freshwater to human societies and to the measurement and prediction the flux of water through the atmosphere, and in particular, the amount falling to the ground as rain and snow. At present the ability to monitor precipitation and changes in surface and subsurface stores around the globe is limited despite rather massive improvements in observing technology, especially remote sensing.

Given the breadth of issues that must be addressed within the water cycle theme, it is important to establish priorities and focus.

3.7 Water Sub-Areas

The primary rationale for the selection of sub-areas is “societal benefits” as chosen by GEO as a fundamental focus. Thus, sectors affected or impacted by the availability (or not) of water immediately introduces a definition of some well acknowledged areas of interest. Upon deciding that this analysis should focus on terrestrial water cycle observations as opposed to the whole range of variables and parameters that govern all Earth system water cycle processes, the Water SBA sub-areas chosen logically fall into certain categorical sets such as: surface waters, sub-surface waters; forcings (on the terrestrial waters); and water quality/use.

The broad sub-areas categories are mapped against priority observational variables and parameters that are needed by the chosen water sub areas. There are many more variables than reflected here if one were to delineate this selection into further sub-categories. However, doing so would make this report/analysis overly complex for the high policy level as represented by GEO and the GEOSS.

The same argument may be applied to the selection of parameters and variables. Namely, the parameters identified here can be construed in some cases to represent macro parameters/variables. Thus, they could be expanded into a broader range of detailed sub-

elements. That level of detail is omitted in this report, though implied by example. Information containing a higher level of granularity (or specificity) is contained in the references cited in this analysis.

Mentioned before, the global/regional water cycle encompasses the entire Earth/climate system. However, the word “water” from an applications and “societal benefits” dimension suggests a focus on the terrestrial water cycle as reflected in the GEO UIC terms of reference for the Water SBA.

This filter has been applied in this analysis while taking into account that terrestrial water cycle processes cannot be treated in isolation from other Earth/climate system processes that directly interact with the terrestrial water cycle. In fact, the water cycle is an integral part of an interactive multi-dimensional system of systems.

Monitoring the system “state” variables would confine the parameter list. But, doing so would also lead to neglecting user requirements for observations and derived products necessary for predictions and projections of change to, for example, reservoir management. This analysis has been careful to not ignore such needs.

The observational variables and parameters covered by the sub-areas were ascertained following the document research to be particularly relevant to the following end user sectors:

- (1) Water Resource(s) management
- (2) Climate and Global Change
- (3) Weather and Extremes
- (4) Climate Prediction (S-to-IA)
- (5) Industrial/Economic Aspects, Including Agriculture
- (6) Environmental Aspects/Dimensions
- (7) Emergency Management Aspects
- (8) Transportation Industry Needs
- (9) Health and Water Related Vectors
- (10) Tourism and Recreation

The above listing while representative and possibly comprehensive is not necessarily all inclusive. One could add several other end-user sectors. Moreover, this analysis considers a substantial breakdown of user sector by functional categories – approximately 75. Each one corresponds to yet another user sector, depending on definition of sectors vs. functions. Table 5 lists the complete list of user functional categories considered by this report.

Table 5. Users of Water SBA Observations

Application Area	User Type
Water Resource Management	Research Hydrology
	Land Surface/Hydro Modeling
	Stream/River Forecasting
	Flood Forecasting

Application Area	User Type
	Reservoir Management
	Water Resources Allocation
	Water Resources Planning
	Urban Water Supply
	Water Quality Management
	Drought Forecasting
	Drought Monitoring
	Drought Mitigation/Management
	Flood Control Management
	Flood Control Planning
	Catchment Management
Climate and Global Change	UN/IPCC
	UN/FCCC
	Climate Science
	Climate Adaptation/Mitigation
	Climate Change Modeling
	Downscaling Global/Regional
	Climate Simulation Modeling
Weather and Extremes	Weather Research
	Weather Forecasting
	Hurricanes
	Storm Surge
	Snow/Blizzards/Avalanche
	Tornadoes
Climate Prediction (S&A)	Med-Term Weather Prediction
	Monthly-Seasonal Climate Prediction
	Inter-annual Climate Prediction
	Climate Applications Analysis
	Climate Impacts Analysis
Industrial/Economic	Agronomy/Farming
	Irrigation Scheduling
	Hydro-Power Engineering
	Energy (other) Engineering
	Heating/Cooling Engineering
	Land Use Planning
	Insurance Industry
	Urban Planners
	City Development Zoning
	Inland Water Fisheries
	Coastal Fisheries

Application Area	User Type
Environmental	Forest Management
	Forest Conservation
	Ecosystems
	Environmental Engineering
	Environmental Impact Assessment
	Estuary Management
	Wetland Conservation
	Sea Level Rise (coastal)
	Salinity & Intrusion
Emergency Management	Fire Prevention Planning
	Fire Fighting
	Environmental Protection/ Management
	Natural Disaster Management
	Natural Hazards Risk Assessment
Transportation	Civilian Use/Demand
	Road/Traffic Management
	Aviation Control
	Shipping Control
	Airlines
	Coastal Navigation
	River/Canal Transport
Health	Epidemiology
	Disease Outbreak Prediction
	Water Quality Assessment
	Water Pollution Forecasting
Tourism/ Recreation	Hotel Management
	Beach Resort Management
	Ski Resort Management
	Travel Planning
	Lake Resort Management

3.8 User Types

Users of water cycle data and information include those involved in a broad range of applications sectors such as: agriculture, reservoir management, water resource management, irrigation scheduling, urban water supply, drinking water utilities, waste/storm water utilities, energy sector, transportation (e.g., river, canals), ecosystem management, forestry and ecosystem management, natural disaster prevention mitigation (fires, droughts, floods), health sector (prevention and mitigation of spread of vector borne/water borne disease vectors), water quality management (land, coastal zones), among others such as infrastructure planners/builders (dams,

levees, dykes, canals), ground water recharge projects, water allocation permitting authorities, land use management and zoning, among others.

Basic and applied research scientists in various water cycle and related disciplines are other categories of primary users, especially those associated with diagnostic analysis, dynamic and statistical/empirical modeling, data assimilation, data analysis, applications product development, data and information delivery systems, decision support systems, early warning systems, and resource planning and management systems

Table 5 elaborates with specific detail and identifies the types of end users considered in this analysis. They are cross-mapped to the chosen Water SBA sub-areas, as well as with observational variables/parameters.

3.9 Types of Observational Data and Derived Information Needs

The global water cycle and the intertwined energy cycle are intrinsic to climate system variability and climate change, the carbon cycle, ecosystems, fresh water resources, coastal zones and other critical Earth system components upon which societies world over are dependent on or are subject to. Depending on time scale, the water cycle acts as both a forcing or feedback element of changes in the Earth climate system, with significant impacts on natural resources, managed ecosystems and social and industrial infrastructures.

Global observations of water cycle variables are actually needed for at least four quite different purposes.

First, long term records of significant climate and hydrologic indicators are required to characterize variability and explore the predictability of the global energy and water cycle, based on observed characteristic time scales of disturbance phenomenon or events and the apparent responses by the Earth system to these water cycle events.

Second, comprehensive observations of all aspects of the complex processes involved in the global energy and water cycle are required to explore the interactions between these processes and conduct penetrating tests of their numerical representations (modeling).

Third, complete observation-based determinations of relevant state parameters are needed (ideally) to initialize prediction models.

Fourth, global water cycle observations and modeling/prediction outputs are needed for the development of decision support products for societal applications in effective water management, the sustainable development of the world's water resources, and, more generally, the development and management of environmental resources many of which are water dependent.

Observation requirements for process studies, energy and water cycle predictions, and applications introduce added dimensions beyond that of monitoring the global water cycle. While many important land surface hydrologic processes can be characterized from in situ measurements only, satellite observations are essential to embrace the global energy and water

cycle, which involves the global atmospheric dynamics and global fluxes over land and the oceans.

Satellite remote sensing provides meaningful information about the vast majority of the Earth system variables where in situ measurements are sparse (e.g. over oceans, remote polar regions, or mountainous terrain). On the other hand, remote sensing involves considerable ingenuity and heuristic manipulations in the process of extracting the desired information from indirect measurements.

Increasingly, satellite and in situ observing systems are viewed as indispensable parts of the integrated observing strategy, and both are used to derive the needed observational data fields and products for research, prediction models, and applications.

3.10 Documents

The documentation used in this analytical report is described in briefly in Section 2.3.1 and further elaborated in Appendix B. As called for by the GEO UIC, Tables 6 and 7 attempt to capture an overview of the documentation used to substantiate the identification of and the rationale/basis for the critical observations priorities for the Water SBA.

Table 6 shows the sub-categorization applied by this analysis. Each cell (denoted by “N(i,i)” is expanded in Table 7 and shows the precise documents that fall into each category – the basic numbering of the reference list is contained in the “Master” reference list in Appendix B. Figure 2 depicts the number of references per cell category. To be noted is that any one particular reference may appear in more than one category.

Thus, an international document reference to observational requirements could simultaneously contain information on global, regional, and local scales. Thus, such a reference would appear in “cells” N(1,1), N(1,2), and N(1,3), for example. Similarly, a multi-national/regional document reference could contain information on requirements that pertain to global, regional, etc., space scales as well as national/sub-national/local.

Thus, a document reference in the category could also justifiably appear under national/sub-national. That is, a reference under the primary category of N(2,2) could also appear or overlap with the reference under N(2,3) and/or N(3,3). There are also several cases of documents that were generated under the primary category of national or local but address global observational requirements. Such a document would fall under N(1,3).

And, if a document also contains information on other categories, then it would also appear under those categories. Thus, the same document reference (e.g., the N(1,1) mentioned before) would also appear under the cell category N(2,3), and possibly N(3,3). Partitioning the “master” document reference list under the cellular categorization in Table 6 allows to reader to obtain more detailed information on the particular domain of interest to that reader. Many references thus overlap in their categorical classification

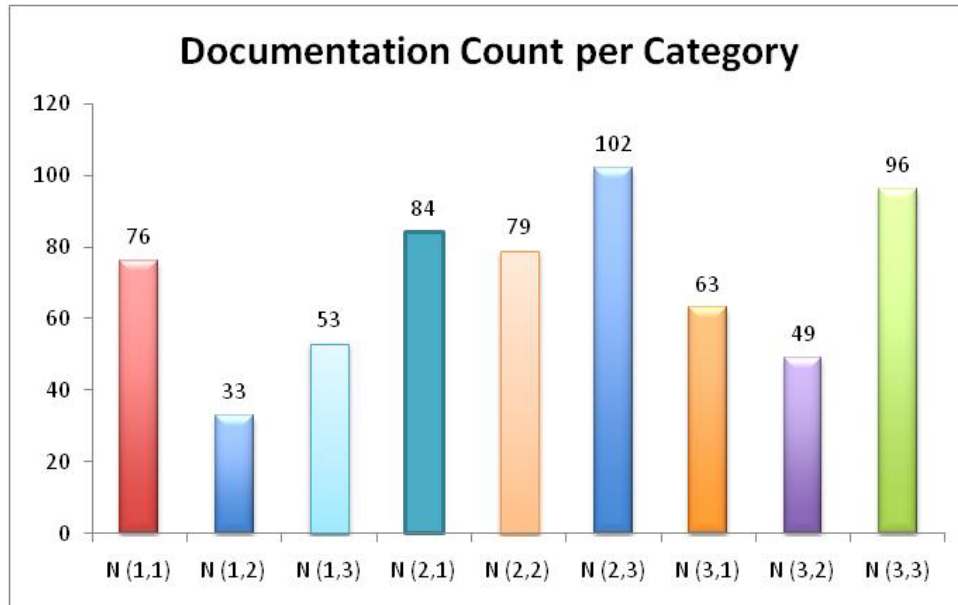
Table 6. Document References Identified by Subcategories Referring to Either Space Scale (Global, Regional, Local) or by Geopolitical Dimensions (International, Multi-National/Regional, National/Local).

	International Documents –International Organizations, Agencies – Programs/Projects/ Studies/Reports/Papers	Multi-National &/or Regional &/or Multi- State – Agencies, Institutes, Programs, Projects, Studies...	National/Sub- National/Local – Agencies, Institutes, Programs, Projects, Studies....
Global-Scale: Generally referring to large-scale requirements for global observations and data exchange systems/platforms	N(1,1)	N(1,2)	N(1,3)
Regional-Scale: Includes multi-national, trans-boundary, and/or multi-state/province within large countries/regions	N(2,1)	N(2,2)	N(2,3)
Local-Scale: Generally referring to national or sub-national and local area space scales	N(3,1)	N(3,2)	N(3,3)

Table 7. Details Providing Document References per Cell in Table 6.

N (1,1)	N (1,2)	N (1,3)
1,2,3,4,5,6,7,9,13,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,31,33,34,39,40,41,54,55,56,57,60,63,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,100,101,104,105,106,107,108,110,127,128,129,148,157,196,202	2,3,4,5,6,7,8,9,32,33,34,39,53,62,67,119,120,121,122,125,128,131,133,135,148,157,167,173,174,192,196,199,200	2,4,6,7,30,35,52,53,62,65,66,67,96,102,103,109,111,112,114,115,116,119,120,121,122,125,131,132,133,135,137,144,146,149,150,154,167,168,171,173,174,176,180,181,183,184,187,188,189,192,197,198,199
N (2,1)	N (2,2)	N (2,3)
2,3,4,5,6,7,8,9,10,11,12,15,16,17,18,21,22,23,24,25,26,27,29,31,32,33,34,36,37,39,40,41,42,55,56,57,58,59,60,61,62,63,69,70,71,72,73,74,75,76,77,78,79,80,81,82,84,87,88,91,93,94,95,97,98,99,102,107,108,110,115,127,128,129,148,151,157,160,164,175,195,200,201,202	2,3,4,5,6,7,8,9,11,30,32,33,34,36,37,38,39,53,58,61,62,67,93,94,98,102,113,117,118,119,120,121,122,124,125,128,131,133,135,136,138,139,140,141,142,143,148,149,150,151,153,154,157,160,161,163,164,165,166,168,169,172,173,174,175,177,178,179,183,190,191,192,194,195,196,197,199,200,201	2,4,6,7,30,35,36,38,49,52,53,58,59,61,64,65,66,67,95,96,102,103,109,111,112,113,114,115,116,117,118,119,120,122,123,124,125,126,130,131,132,133,134,135,136,137,138,139,140,141,142,143,144,145,146,147,149,150,152,153,154,155,156,157,158,159,160,161,162,163,164,165,166,168,169,171,172,173,174,176,177,178,179,180,181,182,183,184,185,186,187,188,189,190,191,192,193,194,195,197,198,199
N (3,1)	N (3,2)	N (3,3)
2,7,10,11,12,14,15,16,17,18,21,22,23,24,26,31,32,36,37,39,40,42,43,44,45,46,47,48,49,50,51,57,59,60,69,70,71,72,73,74,76,77,78,79,80,81,82,84,87,88,91,97,98,99,107,127,129,151,160,195,196,201,202	2,7,11,30,36,37,38,53,117,118,119,120,121,123,124,125,133,136,138,139,140,141,142,143,149,150,153,154,156,160,161,163,164,165,168,169,170,172,177,178,179,182,183,190,191,192,194,196,201	2,7,30,35,38,43,44,45,46,47,48,49,50,51,52,53,59,61,62,64,65,66,67,96,102,109,111,112,113,114,116,117,118,119,120,121,122,123,124,125,126,130,132,133,134,136,137,138,139,140,141,142,143,145,146,147,149,150,152,153,154,155,156,158,159,161,162,163,164,165,166,168,169,170,172,173,175,176,177,178,179,181,182,184,185,186,187,188,189,190,191,192,193,194,195,198

Figure 2. The Number of References per Cell Category.



Tables 6 and 7 and Figure 2 are to be considered representative or illustrative. The documentation used by this analysis was comprehensive, extensive, and covered the regions and thematic subtopics as required by the GEO UIC.

The summary in Tables 6 and 7 is designed to provide a measure of the extent and depth of the analysis, and to demonstrate that it is unlikely that any critical water cycle variable or parameter has been unknowingly or unwittingly left out. The documentary substantiation also takes into account, by implication, the documentary underpinnings of the various/numerous reports compiled by expert consultative groups involved in the cited documentation.

The sum total is rather vast. In some cases, authoritative compilations arrived at by consensus by institutionally established groups do not necessarily refer to specific documents. Rather, they imply or refer to the extensive world-wide representation of the organization's constituent bodies – which can be large, and include specialist from the user end of the spectrum to the instrument manufacturers to the users of data by an amorphous and broad range of communities.

4 Earth Observations for Water SBA Sub-Areas

The following sub-sections provide brief descriptions of the types of observations required for the sub-areas of the Water SBA. It is underscored that only a selection of variable/parameter types per sub-area are described (below) as examples. The complete list of variables and parameters considered in this report are contained in Chapter 5.

4.1 Sub-Area 1: Surface Waters and Fluxes (Including Land Surface Water Cycle Processes)

Reliable supplies of fresh water are an essential requirement for human prosperity and health, as well as ecosystem functioning. Water is an important, geo-socio-economic issue at local, national and global scales and changes in water resources are a part of the history of civilization. Both socially and economically, the impacts of water deficits and surpluses are large.

According to the International Water Management Institute (IWMI, 2008), a fifth of the world's people, more than 1.2 billion, live in areas of physical water scarcity, lacking enough water for everyone's demands. About 1.6 billion live in water-scarce basins, where human capacity or financial resources are likely to be insufficient to develop adequate water resources:

[http://www.iwmi.cgiar.org/assessment/files_new/synthesis/Summary_SynthesisBook.pdf]

In developing countries, water shortages are a major contribution to poverty and human misery. Food security, well-being, and ultimately economic and political stability depend upon the ability to provide reliable supplies of clean water. Rapid population growth and development pressures impose additional stresses on scarce resources. Drought turns such vulnerable situations into a crisis. Enhanced and timely information pertaining to water resources has the potential for increasing the development capability of many of these countries. As a result, there are increasing human, institutional, and infrastructure needs for access to and use of water cycle data in water resource management. (Ref. *GEOSS 10 Yr Plan-2005*)

In addition to water scarcity concerns, floods are the number one disaster in terms of loss of human life and property. On average, floods affect 140 million people each year, according to the latest World Disasters Report (IFRC/RCS, 2003). Furthermore, more than 5 million people die each year from water-borne diseases such as malaria and cholera. The global water cycle – the transport and distribution of large amounts of water, associated with its constant phase changes between the solid, liquid and gaseous states – is therefore one of the most important features of the Earth system, but one which cannot be described without linkage to the energy cycle on a global scale.

Surface Water Discharge (Ref. *WMO SOG*): Discharge is typically calculated at a particular location in a river from measured water levels by means of a transformation or rating curve developed for the particular channel cross-section at which the water level is measured. Flow in a channel can be influenced by factors such as changes in land use, withdrawal for water use, or contributions from artificial water storage reservoirs, and thus discharge does not necessarily represent a response to climatic conditions.

On a global scale, terrestrial hydrological observations are marginal and generally inadequate in remote and mountain areas. Access to hydrological data is frequently impeded due to a number of factors including fragmentation of data holdings and access restrictions. A new approach is the planned implementation of the Hydrological Applications and Runoff Network (HARON) in cooperation with the WMO, GCOS, and GRDC and facilitated by GEOSS.

Likewise, the WMO's WHYCOS contributes to the improvement of surface hydrological networks. On a regional basis for operational purposes, satellite water-level observations based on altimetry methods are available for large rivers and can now be utilized for major basins (wide rivers) and lakes in a semi-operational mode. Several satellite-based methods are available on demand to map the extent of flooding in floodplains or large riverine systems as well as the duration of flooding, including visual, infra-red and radar sensors.

Surface water storage fluxes(Ref. WMO SOG): This variable is directly related to the retention of surface fluxes in lakes, reservoirs and wetlands. There is also the issue of water storage in river channels, flood plains and large estuaries. While terrestrial observations are being made for lakes and reservoirs (levels of lakes and reservoirs, volumetric observations), space-based observations such as those derived from altimetric observations are also becoming available. Generally, observations are not yet available for wetlands, large floodplains and estuaries.

The availability of surface water storage fluxes for the major lakes and reservoirs would contribute to a more accurate modeling of lateral fluxes in climate circulation models. Presently, the ability of the ICESat/GLAS instrument to provide accurate measurements of lake level is being tested. However, many observation uncertainties still exist with regard to flow retention in dams, reservoirs, lakes and wetlands; and the evaporative loss of water from storage surfaces.

Streamflow and Surface Water Store Measurements (Ref. IGWCO) : Long-term streamflow measurements are the essential information source for many water resource applications including engineering designs for dams, reservoirs, river navigation systems, flood protection, irrigation scheduling, international water allocation agreements, ecosystem management and water management plans. During flood periods river levels must be known in order to monitor whether emergency procedures are needed or not.

During low flow periods it is important to know what flow levels are to determine the need for water releases or other possible conservation and water enhancement activities. Streamflow is also a critical variable for water management because allocation agreements are quantified so water availability and supplies must also be known to a high degree of accuracy. The quantity of water stored in temporary (ephemeral wetlands) or permanent natural reservoirs (lakes) and manmade reservoirs is also important to know, particularly if that water is being used to meet some agreement or to meet some environmental need.

From a scientific perspective streamflow is also a critical water cycle variable because it integrates all of the processes (e.g. runoff, evapotranspiration) taking place over the area of the basin and provides one final variable that can be readily measured.

As a result it is a very important parameter for use in calibrating and evaluating hydrological and coupled land-atmosphere models. Streamflow is also an important variable because it is the only component of the water balance that readily integrates processes over the entire basin thus it is more easily used in model development because it is not affected by the high frequency variability.

Streamflow also serves as a medium for many biological and chemical processes hence, the content of the streamflow can be viewed as a measure of ecological processes within the basin.

Isotopic measurements (Ref. IGWCO): Stable isotope ratios ($^{18}\text{O}/^{16}\text{O}$ and $^2\text{H}/^1\text{H}$) in river flow contain valuable information on the integrated effects of surface and subsurface hydrology (Gibson et al., 2002). Isotope data allow monitoring of climate and land use change impacts on basin hydrology. Time series of stable isotopes in river flow also are an excellent tool for characterizing water budgets of river basins and for improving regional and continental scale hydrological models (Fekete et al., 2003). *WMO-SOG-H: Isotopic signatures:* To improve understanding of the hydrological cycle, investigations of environmental isotopes in precipitation are required.

Isotope signatures in precipitation also constitute an essential tool for calibration and validation of atmospheric circulation models. At present, only a small global network of terrestrial isotope stations exists where all data are accessible. Especially for water balance studies, isotope observations using water stable isotopes could be used on an operational scale in riverine environments.

Evaporation (Ref. WMO-SOG-H): Evaporation is a critical value in the water balance equation as well as in regional water budget estimations. However, direct observations are sparse and most evaporation values are in fact derived estimates. Evaporation in the context of the SOG's refers to "direct" measurements of actual evaporation. Because of the observing methods, even direct measurements are estimates.

Terrestrial measurements on a global scale are declining in terms of spatial coverage at a time when traditional in situ observations like evaporation pans and lysimeters are largely discontinued. Replacing traditional observation methods by using flux towers, evaporation estimates are made using eddy correlation and Bowen Ratio techniques. The number of these towers is very limited and data are not readily available on a global scale. Isotopic measurements can provide an effective method to derive evaporation as ratio of change of water stable isotopes between vapor and the residual liquid.

4.2 Sub-Area 2: Ground Waters (Including Recharge/Discharge & Regolith Processes)

Ref. IGWCO WC Theme Report: A major portion of the world's fresh water is located under the Earth's land surface. Natural processes recharge (e.g., precipitation and infiltration) and discharge (e.g., springs) this reserve. However, in the past century, humans have started to withdraw large quantities of water from these reserves at rates that greatly exceed the rate of groundwater recharge.

Reductions in groundwater regime have implications for the water cycle because ground water supplies the base flow in many rivers. It also has major implications for water quality because the salinity of the extracted water frequently increases as the volume of the reservoir decreases. Furthermore, changing vegetation types in some areas have been shown to influence the rate at which plants withdraw water from the vadose zone.

In semiarid regions, vegetation change can affect the rate of groundwater recharge. For example, in Australia, the expansion of agriculture led to the removal of eucalyptus tree forests and resulted in much higher groundwater levels. Unfortunately, the rising water table brought saline waters to the surface and led to extensive soil salinization.

Given that groundwater is now an important resource that is coming under increasing pressure, methods for inventorying this resource and measuring changes in its availability are needed. Such measurements are also needed for scientific reasons.

Groundwater can also resupply the soil layers closer to the surface with moisture and thus influence soil moisture memory effects on the predictability of precipitation. In some areas with naturally high water tables, the water can rise above some of the lower land depressions during wet periods creating marshes and wetlands and leading to major changes in vegetation and land cover.

Many nations maintain groundwater programs and networks of wells that periodically measure the level of groundwater. The Hydrology and Water Resources Programme of the WMO collects, processes, stores and provides access to hydrological data through retrieval and publication of data, including data on the quantity and quality of groundwater.

Some groundwater data (groundwater level and quality variables) can be obtained through the WMO's Hydrological Information Referral Service (HIRS), although the records are not complete for the globe. For many countries, however, these data are nonexistent; and in countries where the data exist, they are generally incomplete and unreliable. Other related data (e.g., aquifer storage capacities and recharge rates) are not collected in most of the world.

Within ISARM (Internationally Shared Aquifer Resources Management), a joint project of IAH, UNESCO, FAO, UNECE, and others, groundwater monitoring networks are developed for pilot aquifers extending across country boundaries in different regions of the world. Standardizing groundwater monitoring practices should be developed to make the results comparable across boundaries.

As part of UNESCO IHP-V (1996-2001) a groundwater contamination inventory was undertaken and data on the extent of contamination were gathered by IHP National Committees and UNESCO Regional Offices of Science and Technology. UNESCO has supported the establishment of a monitoring system to evaluate deterioration in the quality of groundwater resources within some of the larger cities of the Western African countries. The aim of the project is to set up a regional observatory of aquifers vulnerability and early warning contamination for urban and "peri-urban" water supply. The International Groundwater Resources Assessment Center (IGRAC), created under the auspices of UNESCO and WMO,

addresses the general lack of information about the status of groundwater resources and acts as a catalyst for stimulating national and regional efforts in monitoring and assessing aquifer systems.

To support information provision by the European Environment Agency (EEA), groundwater monitoring strategies, including monitoring network design, applicable to different types of groundwater bodies and covering EEA member countries (32 in 2009) have been prepared. This EUROWATERNET samples existing national monitoring networks and databases:

[http://dd.eionet.europa.eu/dataset.jsp?ds_id=2011&mode=view].

In view of the limited in situ observations, a promising measurement concept is the gravimetric determination of changes in ground-water mass, based on extremely precise observation of time-dependent variations in the Earth gravity field, using space-based gravity gradiometer systems. Such gravity field measurements will be sensitive enough to detect the minute gravitational signature of changes in soil moisture or snow water equivalent over continents and the discharge/recharge of large underground aquifers.

The Gravity Recovery and Climate Experiment (GRACE) mission will use high-precision satellite-to-satellite tracking to measure changes in gravity field between two identical spacecraft on the same orbit. The sensitivity of this first demonstration of GRACE is expected to allow detection of changes in mass distribution equivalent to ± 1 cm variation in water storage over a 500×500 km² area.

Because the method is essentially gravimetric, no discrimination is possible between changes in water stored in various reservoirs (e.g., snow pack, soil moisture and groundwater). In addition, the ESA GOCE mission will measure different wavelengths in the gravity field and will contribute to the detection of changes in groundwater. Use of permanent scatterers with SAR has demonstrated the ability to detect ground surface movements on the order of millimeters per year. This technique has been applied to the detection of land surface movements arising from the depletion of groundwater aquifers.

The IAEA has been collecting stable and radioactive isotope (¹⁸O and ²H, ¹³C, ³H and ¹⁴C) data on groundwater systems from around the world for the last about 40 years. The objective of these efforts has been to determine the renewal of aquifers and the source of present groundwater recharge, if any. Isotope data collected through the IAEA projects are being made available through an internet site.

(Ref. National Framework for Groundwater Monitoring in the U.S.): To successfully manage present ground-water resources and ensure effective planning for future ground-water needs, an understanding of the processes and properties of the ground-water systems containing the water is required. This includes detailed information on ground-water levels because ground-water level measurements are the sole direct measure available to evaluate aquifer conditions. Increases in ground-water levels demonstrate increased quantities of water stored within an aquifer. Decreases in water levels demonstrate decreased quantities of water in storage. Uses of ground-water level monitoring data are critical to evaluate:

- short-term and long-term changes in ground-water recharge and storage,
- short-term and long-term impacts from climate variability (especially droughts),

- regional interstate and regional intrastate effects of ground-water development,
- the water-level surface (potentiometric surface) of the water table or confined aquifers,
- changes in ground-water flow directions,
- interactions between ground water and surface water, and/or
- ground-water flow and contaminant transport through computer modeling.

4.3 Sub-Area 3: Forcings on Terrestrial Hydrological Elements

This element was added to this analysis because the characterization of the physical/natural terrestrial “water” system, and processes that govern water cycle interactions, do not occur in isolation of other immediate neighbor elements of the Earth/climate system.

Thus, land surface and subsurface hydrological processes are “forced” by various near surface atmospheric/meteorological processes that need to be observed and monitored in order that terrestrial hydrological processes can be understood and modeled (dynamic and empirical) prior to their effective use in, for example, water resources management.

Moreover, there are substantial feedbacks between the terrestrial hydrological system and the atmosphere and the surrounding estuaries and coastal oceans. These forcings and feedbacks are critical observational variables that are an integral constituent of the set of Water SBA variables that need to be sustained within GEOSS.

Depending on time scale, forcings and feedbacks are somewhat interchangeable. Surface air temperature, humidity, clouds, and radiation budgets (at the land surface) would force terrestrial hydrological processes such as precipitation and evapotranspiration. Conversely, soil moisture changes and consequent evapotranspiration by vegetation could be construed as a forcing on the atmosphere by the terrestrial hydrological system, especially due to the longer “memory” time scales involved in soil moisture processes.

This analysis focuses on the variables related to the atmospheric forcings on terrestrial hydrology. Besides physical dynamic and thermodynamic parameters, this interaction also includes biogeochemical exchange of gases and various other atmospheric composition constituents. The biogeochemical exchange is confined in this report to hydrological/water cycle related variables. This category could be expanded upon at a later phase of GEO.

4.4 Sub-Area 4: Water Quality and Water Use

Significant differences in the health and well-being of people in various regions of the world still exist. Every year, over 2 billion people suffer from water-borne illnesses and water-related diseases account for 5 million deaths. Furthermore, more than one-fifth of the world’s people do not have access to safe drinking water and one-half of the world’s population does not have adequate sanitation. Therefore, water quality monitoring is critical to the future health of the human population as well as the health of the ecosystem by determining the current status of water quality conditions and helps anticipate, and hopefully avoids, future water catastrophes. Given the large number of global issues directly or indirectly linked to water resources, or more specifically here water quality, this priority area has been identified by GEO as one of the key societal benefit areas and seeks advances in earth observation capabilities. (*GEO Inland and*

The rapidly-growing global population is creating numerous stresses with serious health impacts, such as increased release of chemical emissions into the environment, and special attention needs to be paid to an observing system which can track indicators for these chemicals, especially persistent organic pollutants (POPs), heavy metals, polychlorinated biphenyls (PCBs), and pesticides.

The demands of this ever-increasing global population call for the development, communication, and fulfillment of user requirements for data and data products to aid in satisfying our fundamental needs for clean air and water, food, and shelter and in enhancing our present quality of life and the sustainable development necessary for our future.

Key health and environment indicators include factors such as forecasts of famine/food security, quality and quantity of water and soil for human use, occurrence of vector-borne and waterborne diseases, harmful algal blooms and seafood contamination, wild land fires, and severe weather. Another set of indicators includes air quality, recreational water quality and ultraviolet radiation indices.

Health and well-being policy development require a broader set of change indicators, such as land use, urban environment, transportation infrastructure, transportation patterns, energy use, agricultural-chemical use, long-range trans-boundary pollution, and waste management. (*Ref. GEOSS 10 Year Plan*)

As precipitation falls on the Earth's continents, the resultant runoff entrains a variety of dissolved and particulate substances, of both natural and anthropogenic origin. These land-based materials, together with those produced or deposited directly within the aquatic environment (e.g., algal blooms, spills) collectively contribute to inland and near-shore coastal water quality. Inland and coastal areas are of a particular concern as the majority of the world's population lives in these riparian and coastal areas.

In addition, concurrent with an increase in freshwater demand, the supply of "clean" water continues to dwindle as a result of contamination from pollutants. This contamination, from municipal and industrial discharges and non-point source runoff affects coastal receiving waters, inland water bodies and groundwater. Additional issues include: increased sedimentation that can adversely affect fisheries, shellfish, plant life and coral reefs; large influxes of nutrients that can potentially lead to harmful algal blooms, decreased dissolved oxygen and hypoxia in coastal areas; and water-borne pathogens.

Water quality monitoring and assessment can be grouped into two approaches: 1) In situ collected by field staff and 2) Earth observations or remotely sensed based on satellite, airborne or ground-based sensors. These approaches, sometimes in concert, can address water quality at local, regional and global scales. However, many water quality monitoring programs are deficient.

For example many countries lack the technical, institutional, financial resources and infrastructure, and sometimes, the political stability to conduct proper water quality assessments on a long-term basis. One international example with respect to global-scale in situ monitoring is the United Nations Environment Programme (UNEP) archives freshwater quality data from national and international cooperators around the world in their Global Environmental Monitoring System (GEMS).

In situ methods can be both time consuming and locally expensive, so Earth observations is an emerging capability that can greatly bolster traditional in situ methods. However, the field is relatively new, especially in its application to water quality in inland and coastal regions. (*GEO Inland and Nearshore Coastal Water Quality Remote Sensing Workshop – 27-29 March, 2007, Geneva, Switzerland*)

Not only must ground water be present in sufficient quantity, but the water also needs to be of suitable quality for the intended use. Suitability of the ground water may depend on factors, such as taste and odor; presence of naturally occurring constituents, such as radionuclides or arsenic; microbial content; or presence of nitrates, pesticides, and other anthropogenic constituents. Saltwater or brackish water may contaminate water supplies in coastal areas as a result of the excessive withdrawal of ground water. (*Ref. National Framework for Groundwater Monitoring in the U.S.*)

Extended road salting along major corridors and in urban areas can contaminate aquifers. Aquifer contamination sources may be site specific (point) or diffuse (non-point). Commonly, contaminants are detected by monitoring wells, and contaminant transport is modeled by computer using ground-water level data to determine flow direction. The monitoring of spatial and temporal changes in ground-water quality must go hand-in-hand with ground-water level monitoring if the nation is to evaluate the usability of its ground-water resources.

5 Priority Earth Observations for the Water SBA

(*Ref. WMO-SOG-Hydrology*): The collection of hydrological data is crucial to improve our understanding of the hydrological cycle. They contribute to weather and climate related scientific and application issues, as well as to improved water resources management through better assessment methods.

The availability of data about hydrological extremes also makes a contribution to the reduction of the impacts of disasters. For most of the presently available observations, the adequacy of observational networks varies largely from region to region and observations for some of the variables described below are inadequate in terms of spatial and temporal coverage.

As a methodological approach it has become evident, that observations of hydrological variables on global and regional scales in a continuous and consistent manner will require integrated observation systems making use of both terrestrial as well as satellite observations. The use of data assimilation techniques using data from these integrated networks and multi-platform observations will give rise to improved products and services.

Temporal requirements for data used in operational hydrology are classified in two ways: 1) non- or slowly-time dependent data such as topography and land use and 2) time dependent data needed to initialize and update forecast models such as rainfall rates or soil moisture. Satellite data are the only means for providing high spatial and temporal resolution data in key regions (e.g., forested areas).

In situ data provide acceptable coverage in limited regions and are also used for calibration and validation of hydrological models and satellite measurements. To meet hydrological forecasting needs, the data must be available within ½ to 6 hours, depending upon the size of the basin and forecasting requirements. Products useful to hydrology are listed below with a description of how well they meet the hydrological model needs and whether or not they are time-sensitive.

For example, hydrologic variables such as snow cover, snow water equivalent, and soil moisture are dynamic variables that must be updated fairly frequently. Variables for which data delivery is time sensitive (less than 6 hours) are indicated.

5.1 Priority/Critical Macro-Observational Variables and Parameters Mapped Against Sub-Area, Applications Sector, and End-User Functional Categories and Types

The sub-areas and selection of critical observations derived from the meta-analysis of documents stating or implying requirements for water cycle observations are depicted in Table 8 which maps the Water SBA sub-areas with critical or priority water cycle related variables and parameters.

The Water SBA sub-areas are used as a tool to cluster the essential or critical Water SBA variables, as indicated in Table 8. This analysis report takes this a step further and cross-maps this cluster of observational variable types (categories) against various water cycle “User Sectors.”

These “User Sectors” are further categorized by end user functional types. It was felt that this type of cross-mapping would render a better analysis of “sectoral” and “end user” requirements. It was opined that this approach would provide “value added” information to the process besides providing a quantitative, measure of prioritization defined by user practice.

The critical variables and parameters per sub-area are as follows:

(1) Surface Waters, Fluxes, and Processes:

- Precipitation (liquid/snow/ice)
- Soil Moisture/Temperature (Surface and Vadose Zone)
- Evaporation and Evapotranspiration
- Runoff & Stream Flow/River Discharge/Stage...
- Lake/Reservoir-Area/Level/Depth....
- Snow/Ice Cover & Depth/SWE & Freeze-Thaw Margins...
- Glaciers/Ice Sheets, Permafrost, Frozen Ground—Area/Depth/Mass balance...

(2) Ground Water (Including Recharge/Discharge & Regolith Processes)

- Ground Water Table and Charge/Recharge Rates
- Aquifer Levels, Geologic Stratification, Volumetric...

- Soil type/Texture, Composition, Porosity/Conductivity...
- (3) Forcing Elements (e.g., Surface Meteorology, Surface Radiation Budgets and Clouds)**
 - SW, LW Surface Radiation Budgets, Albedo, Emissivity, and Clouds
 - Surface Air Temperature, Relative Humidity/Specific Humidity, Winds, Pressure...
 - Vegetation Cover/Type, Land Cover & Land Use
 - Topography and/or Geology
- (4) Water Quality and Use**
 - Water Quality/Composition – Organic/Inorganic/Isotopic
 - Nutrient and Contaminant Effluents/Fluxes into Water Bodies
 - Water Sources, Water Demand/Use & Regulation

End-user applications sectors or categories chosen as a representative selection for the purposes of this analysis are:

- (1) Water Resource(s) management
- (2) Climate and Global Change
- (3) Weather and Extremes
- (4) Climate Prediction (S-to-IA)
- (5) Industrial/Economic Aspects including Agriculture
- (6) Environmental Aspects/Dimensions
- (7) Emergency Management Aspects
- (8) Transportation Industry Needs
- (9) Health and Water Related Vector
- (10) Tourism and Recreation

The above sectoral areas are further broken down into approximately 75 user categories by job function or function related units as described in Sections 3.7 and 3.8. Each sub-sector and corresponding functional unit is mapped against the critical water cycle parameters/variables that are considered necessary for that particular sub-sector and functional unit.

Table 8 contains an assessment of how important a particular observation (or set of observations) is to any one sub-sector and functional unit. This assessment is numerically quantified and color coded. Thus a “high” priority is coded as “10” and colored **Red**. Correspondingly, a “medium” priority is coded as “5” and colored **Green**. A “low” priority is coded as “1” and colored **Yellow**. Parameters or variables that are not applicable to any one sector/functional type are coded as “0” and colored **Orange**.

It is underscored that the above mentioned prioritization refers to observational data required by or used by the respective end user sector or the end user function. Data “use” is a complex matter. While a particular end user may apply only a selected subset of observations for a particular application or decision making function, they concurrently and simultaneously also indirectly use the whole gamut of critical observations when they use a forecast/prediction model derived product to their specific task.

That is, even the low priority variables identified can be, de facto, high priority because of their being needed by the prediction model to provide the services/products as needed by the end user.

The assessment contained in Table 8 is based on the meta data analysis as well as requirements for observations from a large number of international, regional, and national programs that have defined user needs through numerous interactions. Those interactions, in aggregate, are supported by various published literature even if some are not quantitative, and they form the basis for this summarized analysis/assessment.

The results shown here represent the collective assessment made by the Analyst and the Advisory Group, as well as others who participated in the exercise. There is a subjective element involved in the process. Nevertheless, it is suggested that the analysis represents a useful first order effort to identify critical observations according to priorities that reflect their need and use by various sectors and sub-sectoral functional types despite the caveats as noted above.

The average scores need to be interpreted carefully. The ranking may not necessarily indicate a priority ranking in order of importance. For, example, if the cells with a magnitude of “1” (i.e., Yellow) are removed from the calculation, the average scores will typically be higher, and may better represent a ranking in order of importance.

Table 8. Water SBA Data Use/Needs: Priority Observations.

GEO-UIC-Water SBA-Draft Prelim Report-V#30--Table-Excel(03)-8Jan10.xls

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	
1	Table 4: WATER-SBA DATA USE/NEEDS: PARAMETER(S), USER CLASSES BY CATEGORY (SUB-AREA) and USER TYPE/FUNCTION & PRIORITY RANKING	Critical Terrestrial-Water Cycle Parameter(s)	Precipitation (liquid/snow/ice)	Soil Moisture/Temperature (Surface & Vadose Zone)	Evaporation & Evapotranspiratn	Runoff & Stream Flow /River Discharge /Stage...	Lake/Reservoir-Areal/Level/Depth	Snow/ice Cover & Depth/SWE/Freeze/Thaw Margins	Glaciers/ice Shets, Permafrost/Frozen Gnd--areal/depth	Gnd Watr Table & Charge/Recharge/Infiltration Rates	Aquifer Levels, Geologic Stratification, Volumetric	Soil type/Texture, Composit'n, Porosity/Conductivity..	Surface Radiation Budget & Albedo--SW, LW & Clouds	Hydromet--Sfc Air Temp. Humidity/Moisture, Winds, Press..	Vegetation Cover/Type, Land Cover & Land Use	Topographic and/or Geological and Geomorphological	WaterQuality/Composition--Organic/inorganic/isotopic	Nutrient/Contaminant Effluents/Fluxes-->Water Bodies	W-Sources/Demnd/Use/Consumptn/Regultn+Socioecon/Demogr	Obs.Time Series+Statistics & Paleo/Proxy	Dynamic/Statistical Model Outup/Analysis	Decision Support Information/Output	Average Score	Avg. Score w/out LOW (1), N/A (0) Cells	
2			<-----Surface Waters-----><---Gnd---			<--GW&R--><---			<Forcings-->			<WQ/Use>			<Other....>										
3	COLR CDE/#VALUE	HIGH	10			MED			5			LOW		1			N/A		0						
4	WATR RES. MANGMNT																								
5	Resrch Hydrology		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	5	9.8	9.8
6	Lnd Sfc/Hydro Modeling		10	10	10	10	10	10	10	10	5	10	10	10	10	10	10	5	10	10	10	10	10	9.5	9.5
7	Stream/River Frcasting		10	5	5	10	10	10	10	10	5	5	10	5	10	10	10	0	5	1	10	10	10	7.6	8.3
8	Flood Forecasting		10	10	10	10	10	5	5	10	5	5	10	5	10	10	10	1	5	1	10	10	10	7.9	8.6
9	Reservoir Management		10	0	10	10	10	10	10	10	5	5	5	10	10	10	10	10	10	10	10	10	10	8.8	9.2
10	Water Res. Allocation		10	5	5	10	10	10	10	5	10	10	0	5	10	10	0	10	10	10	10	10	10	8.0	8.9
11	Water Res. Planning		10	5	5	10	10	10	10	10	10	10	10	5	10	10	10	10	10	10	10	10	10	9.3	9.3
12	Urban Water Supply		10	0	0	10	10	10	10	5	10	10	0	0	10	10	0	10	10	10	5	10	10	6.8	9.3
13	Water Quality Managmnt		10	0	0	10	5	1	1	5	10	5	0	0	10	5	10	10	10	5	5	10	5.6	7.9	
14	Drought Monitoring		10	10	5	10	5	5	1	5	1	1	5	10	5	0	0	0	0	10	10	10	5.2	7.7	
15	Drought Forecasting		10	10	10	10	5	10	1	5	1	1	0	10	5	0	0	0	0	10	10	10	5.4	8.8	
16	Drought Miti. Mangmnt		10	10	1	10	10	10	5	10	10	5	1	10	10	10	5	0	5	1	5	10	6.9	8.4	
17	Flood Control Managmnt		10	10	0	10	10	5	5	10	5	10	0	5	10	10	5	10	10	5	5	10	7.3	8.1	
18	Flood Control Planning		10	10	0	10	10	5	10	10	5	10	0	5	10	10	5	10	10	5	5	10	7.5	8.3	
19	Catchment Management		10	10	10	10	10	5	10	10	10	10	10	10	10	10	1	10	10	10	10	10	9.3	9.7	
20	CLIMATE & GLOBAL CHANGE																								
21	UN/IPCC		10	10	10	10	1	5	10	5	5	1	10	10	10	5	1	0	0	10	10	10	6.7	8.7	
22	UN/FCCC		10	10	10	5	1	5	10	5	1	1	10	10	10	5	1	0	0	10	10	10	6.2	8.6	
23	Climate Science		10	10	10	10	10	10	10	10	10	5	10	10	10	10	5	5	5	10	10	10	9.0	9.0	
24	Clim. Adapt/Mitigat'n		10	10	5	10	10	10	10	10	5	10	5	10	10	10	10	10	10	10	10	10	9.3	9.3	
25	Climate Chnge Modeling		10	10	10	5	1	10	10	5	5	5	10	10	10	10	0	5	0	10	10	10	7.3	8.5	
26	Downscaling Glob--Reg		10	10	10	10	5	10	1	10	10	5	10	10	10	10	0	5	0	10	10	10	7.8	9.1	
27	Clim. Simulatn Modeling		10	10	10	5	5	10	10	5	5	5	10	10	10	10	0	5	0	10	10	10	7.5	8.3	
28	WEATHER & EXTREMES																								
29	Weather Research		10	10	10	1	5	10	1	1	1	1	10	10	10	10	0	0	0	10	10	10	6.0	9.6	
30	Weather Forecasting		10	10	5	5	5	10	1	1	1	1	10	10	5	10	0	0	0	10	10	10	5.7	8.5	
31	Hurricanes		10	1	1	1	10	0	0	5	1	1	1	10	10	1	0	0	0	10	10	10	4.1	9.4	
32	Storm Surge		10	1	1	5	10	1	0	5	1	5	0	10	10	10	5	5	0	10	10	10	5.5	8.1	

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	
1	Table 4: WATER-SBA DATA USE/NEEDS: PARAMETER(S), USER CLASSES BY CATEGORY (SUB-AREA) and USER TYPE/FUNCTION & PRIORITY RANKING	Critical Terrestrial-Water Cycle Parameter(s)	Precipitation (liquid/snow/ice)	Soil Moisture/Temperature (Surface & Vadose Zone)	Evaporation & Evapotranspiration	Runoff & Stream Flow /River Discharge /Stage..	Lake/Reservoir-Area/Level/Depth	Snow/ice Cover & Depth/SWE/Freeze/Thaw Margins	Glaciers/Ice Shets, Permafrost/Frozen Gnd--area/depth	Gnd Water Table & Charge/Recharge/Infiltration Rates	Aquifer Levels, Geologic Stratification, Volumetric	Soil type/Texture, Composit'n, Porosity/Conductivity..	Surface Radiation Budget & Albedo--SW, LW & Clouds	Hydromet--Sfc Air Temp, Humidity/Moisture, Winds, Press..	Vegetation Cover/Type, Land Cover & Land Use	Topographic and/or Geological and Geomorphological	WaterQuality/Composition--Organic/inorganic/isotopic	Nutrient/Contaminant Effluents/Fluxes-->Water Bodies	W-Sources/Demnd/Use/Consumptn/Regulin+Socioecon/Demogr	Obs. Time Series+Statistics & Paleo/Proxy	Dynamic/Statistical Model Output/Analysis	Decision Support Information/Output	Average Score	Avg. Score w/out LOW (1), N/A (0) Cells	
33	Snow/Blizzrd/Avalanch		10	1	0	0	0	10	0	0	0	0	5	10	10	10	0	0	0	10	10	10	4.3	9.4	
34	Tornadoes		10	1	1	1	0	0	0	0	0	0	0	10	10	1	0	0	0	10	10	10	3.2	10.0	
35	CLIMATE PREDICTN (S&A)																								
36	Med-Term W-Predictn		10	10	5	1	1	10	0	0	0	1	5	10	5	5	0	0	0	10	10	10	4.7	8.2	
37	Mnthly-Season Predictn		10	10	10	1	1	10	1	1	1	1	5	10	5	5	0	0	0	10	10	10	5.1	8.6	
38	Interannual Clim Predictn		10	10	10	5	5	10	5	1	1	1	5	10	5	5	0	0	0	10	10	10	5.7	7.9	
39	Clim Applicatns Analysis		10	10	5	10	10	10	5	5	10	1	10	10	10	10	10	10	5	10	10	10	8.6	8.9	
40	Clim. Impacts Analysys		10	10	5	10	10	10	10	10	10	1	10	10	10	10	10	10	5	10	10	10	9.1	9.5	
41	INDUSTRY/ECONOMIC																								
42	Agronomy/Farming		10	10	10	10	5	10	5	10	10	10	10	10	10	10	10	10	10	10	10	10	9.5	9.5	
43	Irrigation Scheduling		10	10	10	10	10	10	1	10	10	10	10	10	10	1	5	10	10	10	10	10	8.9	9.7	
44	Hyd-Powr Enigneering		10	0	10	10	10	10	5	0	1	0	0	5	0	10	0	0	10	10	10	10	5.6	9.2	
45	Energy(other) Enginrng		10	0	5	5	5	5	0	0	0	0	0	5	0	0	0	0	5	10	10	10	3.5	7.0	
46	Hting/cooling Enginr		5	1	10	0	0	10	0	0	0	0	5	10	0	0	0	0	5	10	10	10	3.8	8.3	
47	Land Use Planning		10	10	1	5	1	10	1	10	10	10	10	10	10	10	10	10	10	5	10	10	8.2	9.4	
48	Insurance industry		5	1	1	10	5	1	1	1	1	1	1	5	10	5	1	1	5	10	5	10	4.0	7.0	
49	Urban Planners		5	10	1	5	5	10	1	5	5	10	5	10	10	10	10	10	10	5	10	10	7.4	8.1	
50	City Developmnt Zoning		5	10	1	5	5	10	1	5	5	10	1	10	10	10	10	10	10	1	10	10	7.0	8.4	
51	Inland Water Fisheries		5	0	0	10	10	0	0	0	1	0	1	10	10	5	10	10	10	1	10	10	5.2	9.1	
52	Coastal Fisheries		5	0	0	5	0	0	0	0	0	0	1	10	1	1	10	10	1	1	10	10	3.4	8.6	
53	ENVIRONMENTAL																								
54	Forest Management		10	10	5	10	5	10	5	10	5	10	10	10	10	10	10	10	5	10	5	10	8.5	8.5	
55	Forest Conservation		10	10	5	10	5	10	5	10	5	10	10	10	10	10	10	10	5	10	5	10	8.5	8.5	
56	Ecosystems		10	10	5	10	5	10	1	10	5	10	10	10	10	10	10	10	10	5	10	10	8.6	8.9	
57	Env. Engineering		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10.0	10.0
58	Env. Impact Assessmnt		10	10	1	5	10	10	10	10	10	10	5	10	10	10	10	10	10	10	10	10	9.1	9.5	
59	Estuary Management		5	10	1	10	5	1	1	1	1	5	5	10	10	10	10	10	10	5	10	10	6.5	8.3	
60	Wetland Conservation		10	10	5	10	10	5	1	10	10	10	10	10	10	10	10	10	10	5	10	10	8.8	9.2	
61	Sea Level Rise (coastal)		1	5	0	1	0	0	10	1	0	10	1	1	5	10	0	0	0	10	10	10	3.8	8.8	
62	Salinity & Intrusion		10	5	1	10	5	0	0	10	0	10	0	1	5	10	10	0	1	5	10	10	5.2	8.3	
63	EMRGNCY MANGMNT																								
64	Fire Prevention Planning		10	10	5	5	10	10	0	1	5	5	1	10	10	5	0	0	1	1	1	10	5.0	7.9	

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1	Table 4: WATER-SBA DATA USE/NEEDS: PARAMETER(S), USER CLASSES BY CATEGORY (SUB-AREA) and USER TYPE/FUNCTION & PRIORITY RANKING	Critical Terrestrial-Water Cycle Parameter(s)	Precipitation (liquid/snow/ice)	Soil Moisture/Temperature (Surface & Vadose Zone)	Evaporation & Evapotranspiration	Runoff & Stream Flow /River Discharge /Stage--	Lake/Reservoir-Areal/Level/Depth	Snow/ice Cover & Depth/SWE/Freeze/Thaw Margins	Glaciers/Ice Shets, Permafrost/Frozen Grnd--area/depth	Grnd Water Table & Charge/Recharge/Infiltration Rates	Aquifer Levels, Geologic Stratification, Volumetric	Soil type/Texture, Composit'n, Porosity/Conductivity..	Surface Radiation Budget & Albedo--SW, LW & Clouds	Hydromet--Srfc Air Temp, Humidity/Moisture, Winds, Press...	Vegetation Cover/Type, Land Cover & Land Use	Topographic and/or Geological and Geomorphological	WaterQuality/Composition--Organic/Inorganic/isotopic	Nutrient/Contaminant Effluents/Fluxes-->Water Bodies	W-Sources/Demnd/Use/Consumptn/Regulatin+Socioecon/Demogr	Obs.Time Series+Statistics & Paleo/Proxy	Dynamic/Statistical Model Output/Analysis	Decision Support Information/Output	Average Score	Avg. Score w/out LOW (1), N/A (0) Cells
65	Fire Fighting		10	5	1	1	0	1	0	1	1	5	5	10	10	5	0	0	1	1	1	10	3.4	7.5
66	Env. Potect. Managmnt		10	10	5	10	10	10	5	5	10	10	10	10	10	5	10	10	10	10	10	10	8.9	8.9
67	Nat. Disaster Managemnt		10	5	1	10	5	5	1	1	10	10	1	10	10	5	10	5	5	10	5	10	6.5	7.8
68	Nat. Haz. Risk Assessmnt		10	5	1	10	5	5	1	10	5	10	1	10	10	5	10	5	5	10	5	10	6.7	7.6
69	TRANSPORTATION																							
70	Civilian Use/demand		10	5	1	1	5	10	1	1	1	5	1	10	10	5	10	1	10	1	1	10	5.0	8.2
71	Road/Traffic Managemnt		5	1	1	1	1	10	1	0	0	0	1	10	10	5	0	0	0	10	5	10	3.6	8.1
72	Aviation Control		10	0	0	0	0	10	0	0	0	0	1	10	1	0	0	0	0	5	5	10	2.6	8.3
73	Shipping Control		5	0	0	1	0	10	0	0	0	0	0	5	1	1	0	0	0	5	5	10	2.2	6.7
74	Airlines		10	0	0	0	0	10	0	0	0	0	0	10	1	5	0	0	5	5	5	10	3.1	7.5
75	Coastal Navigation		5	0	0	1	0	10	0	0	0	0	0	5	1	1	0	0	0	5	5	10	2.2	6.7
76	River/Canal Transport		5	1	1	5	10	10	1	5	5	5	1	5	5	1	5	1	1	5	5	10	4.4	6.2
77	HEALTH																							
78	Epidemiology		10	10	1	1	1	5	1	0	1	1	1	10	5	1	5	5	1	10	10	10	4.5	8.0
79	Disease Outbrk Predictn		10	10	5	1	1	1	1	0	1	1	1	10	5	1	10	5	0	10	10	10	4.7	8.5
80	Water Qual. Assessmnt		10	5	0	10	10	0	0	10	10	10	0	0	10	1	10	10	10	10	5	10	6.6	9.3
81	Water Pollutn Forecstng		10	5	1	10	10	1	1	10	10	10	1	1	10	1	10	10	10	5	5	10	6.6	8.9
82	TOURISM/RECREATN																							
83	Hotel Management		5	1	0	1	5	10	1	0	0	1	5	10	10	5	10	1	1	1	1	5	3.7	7.2
84	Beach Resort Mngmnt		10	0	0	5	5	0	0	1	1	1	5	10	5	5	10	1	1	1	1	5	3.4	6.7
85	Skii Resort Managmnt		10	5	1	0	1	10	10	0	0	1	5	10	5	10	5	1	1	5	5	10	4.8	7.5
86	Travel Planning		5	0	0	0	0	10	0	0	0	0	5	10	1	10	10	0	0	1	1	5	2.9	7.9
87	Lake Resort Managmnt		10	1	5	10	10	5	1	5	5	1	5	10	10	10	10	5	10	10	5	5	6.7	7.6
88	Others--TBD																							
89	Average Score (All)		9	6	4	6	6	7	4	5	4	5	5	9	8	7	5	5	5	8	7	10		
90	Av. Scr. w/out "1's, 0's"		9	9	8	9	8	9	8	8	8	8	8	9	9	8	9	9	9	9	8	10		

5.2 Priority/Critical Water SBA Observations: Consolidated Requirements per Observational Variable/Parameter--Space/Time Resolutions, Accuracy, Data Latency, and Documentation Cross-References

In fundamental physical or “visceral” terms, there is, conceivably, little dispute that precipitation, evaporation/evapotranspiration, soil moisture, ground water, and others such as surface temperature, humidity, winds and radiation budgets constitute the first order “drivers” for the management of water and water related resources be it in the form of direct precipitation use, or in the form of stream/river systems, lakes, reservoirs and subterranean aquifers. It is assumed that agricultural/land use drivers are covered by soil moisture even if information on land use is also needed to assess their impact on water related variables.

Even within this subset, there are several time-scales of variability and predictability involved. To monitor and model water cycle processes there is a parallel need to include a host of other water cycle and associated variables and parameters. Building numerical models and prediction systems involve local to regional to global-scale coupling and interactions. Furthermore, active water management that buffers natural and managed (agriculture/forestry) ecosystems and infrastructures involve a variety of “human dimensions” that include regulatory, legal, economic and policy factors that govern water allocations among competing water user sectors.

Critical or priority observational requirements of the user sectors underscored by this analysis and report have already been detailed in Chapter 4 and Section 5.1, especially Table 8, arrived at by the meta analysis and feedback from the Advisory Group and CoP, supported by documentary evidence/substantiation.

Arguably, the basic priority observations as described by parameter or variable type are not in dispute. What makes this exercise somewhat complex is the specification of space-time resolutions and accuracy/precision, and latency or time delay in availability. There are varying requirements for these attributes. Some are due to historical legacy.

Some are due to the fact that observational requirements specifications are often dictated by what is technologically possible at any one given the time. Some (latency) are often decided based on existing operational data exchange systems. As regards accuracy and precision, there could be some measure of general confusion as to what these terms mean exactly within some communities – they are frequently used interchangeably. Most of the document references used by this report refer only to accuracy.

Precision requirements are generally not to be found. Both can be obtained from instrument manufacturers and other analyses which compare measurements made by operational networks with primary or secondary standards during calibration (and cross calibration) and validation exercises. On occasion, there are some issues regarding how well the instrument accuracy and precision (manufacturer supplied) applies to the derived geophysical data stream. This is especially true of satellite derived data representing an average over several pixels for example, when compared to in situ point data.

To be noted is that any measurement at a single point, be it in situ or satellite, is expected (by users, and also models) to represent a certain space domain and time domain. A discussion of

this subject is beyond the scope of this report. Notwithstanding, it should suffice to say that accuracy and precision are both important considerations in the design and deployment of observing systems and networks. Associated with this, information on observing practices and instrument maintenance and calibration are equally important.

Table 9 captures details on the space/time resolutions, accuracies and data latency for the key water cycle related variables and parameters. They are further partitioned by the sub-areas of analysis. This set of critical variables is deemed essential to adequately represent the terrestrial water cycle processes discussed in earlier sections. A partial list of major document cross-references is also provided for information.

In keeping with the GEO guidance, information is not retained on existing or near future observing system instrument networks or platforms that address the variables cited. There is, of course, a corresponding need for observations to be maintained on a long-term basis in order to provide the necessary time-series and statistics required by end users. The variables/parameters listed in Table 9 are a subset of the variables and parameters identified earlier in Table 2 for research and applications of the broader aspects of the global water cycle.

That is, we have applied a filter to narrow the scope (somewhat) to the atmospheric (boundary layer) and terrestrial hydrology of primarily land areas with a focus on societal benefits through the provision of needed data and information products for the management of fresh water resources, among other user sectors. Note: Requirements are not necessarily met by current observing systems with the exception of limited domains, but they represent user needs under the caveat of “best-practice” of/for future systems.

Table 10 is a summarized version of Table 9.

Table 9. Requirements for Priority/Critical Water Cycle Variables/Parameters for Terrestrial Hydrology and Water Resources, including Space/Time Resolutions, Accuracy/Units, and Latency. All specifications are application(s) dependent, particularly “latency.” The upper limits to accuracy specifications typically refer to “desired” as opposed operational availability. RT = Real Time, NRT = Near Real Time, DM = Delayed Mode.

Primary/Critical Terrestrial Water Cycle Variables and Parameters	Horizontal Resolution	Time Resolution	Vertical Resolution or Height Depth	Accuracy and/or Precision	Latency	Document Reference (Example Sub-Set)
SUB AREA-1: SURFACE WATERS (SW)						
<u>Precipitation (liq./solid)</u> [Sub-Area: SW]	L: 1km R: 10km G: 50 to 100 km to 500km Also stated variably as 5km to 50km etc.	L: 1 hr R: 3 hr G: 1 d. Also stated variably as: 0.08hr to 0.5hr; 1h to 12h, or 1d to 3d	N/A [Standard Height]	0.1mm/5% Also stated variably as: 0.1mm/h to 1mm/h or 0.5mm/hr to 3mm/hr; 0.5 mm/d to 5 mm/d; 2 mm/d to 10mm/d	0.1h to 6h or 3 hr-24hr; 1 d-2d; 7d to 30d; or RT and DT (App. Dependent)	GEO-10 A-45 E-65 C-24 C-78 G-37 W-WM SOG-H IGWCO WMO GCOS GTOS FAO WCRP IGBP NRC
<u>Soil Moisture</u> [Sub-Area: SW]	L: 0.1km to 1km R: 10km G: 50 to 100 km to 500 km. [Also stated variably as 0.01km to 250km for some applications]	L/R: 1 to 6 hrs (1-10d for vadose zone) R: 1d to 3d to 1wk; G: 1d to 30d to 3 months for some appl	10 cm Res. to 1m depth; 30cm-100 cm for vadose zone or to depth of water table	0.02 m ³ /m ³ . Or stated variably as 5g/kg to 10g/kg, or 10g/kg to 50g/kg. Other units also used: Pascals, or cm/mm per 100cms, or g/kg	Stated variably as NRT or 0.5d to 1d; 1-5 days to 10d to 30d to 144d to 720d (App. Dependent)	GEO-10 A-45 E-79 B-99 W-WM SOG-H IGWCO WCRP GTOS GCOS FAO WMO IGBP NRC
<u>Soil Temperature</u> [Sub-Area: SW]	L: 0.1km to 1km R: 10km G: 50 to 100 km to 500 km. Also stated variably as 0.01km to 250km	L/R: 1 to 6 hrs (1-10d for vadose zone) R: 1d to 3d to 1wk; G: 1d to 1m to 3 months	10 cm res. To 1m depth; 30cm-100 cm for vadose zone or to depth of water table	0.5°K to 1.0°K. Also stated variably as 0.3K to 2K or 1°K to 2°K, or 2K to 5K	3 hr to 6 hr for Land surface T. Other requireme nt follow SM: 1d-5d to 7d to 10d to 30d (App-	A-45 A-13 G-46 W-WM SOG-H IGWCO IGBP

Primary/Critical Terrestrial Water Cycle Variables and Parameters	Horizontal Resolution	Time Resolution	Vertical Resolution or Height Depth	Accuracy and/or Precision	Latency	Document Reference (Example Sub-Set)
					Dependent)	
<u>Evaporation/Evapotranspiration</u> [Sub-Area: SW]	L: 1km R: 10km G: 50 to 100 km to 200 km	L: 1 to 6 hrs R: 1 d G: 1 d to 1 m	Surface (E), and LS veg cover or canopy ht for ET	0.1 mm or 5% . Also stated in units of gms of H ₂ O/m ² /d	Generally Not specified. Or, RT (w/Precip) for point data assimilation/water budget models	E-46; SOG-H U1 U2 IPCC GCRP-SP IGWCO NRC
<u>Stream/River Flows/Stage/Runoff/Infiltration/Percolation...</u> [Sub-Area: SW]	L/R: 1km – 10km or point data [River Basins] G: 50km - 200 km for gridded or Global	L/R: 1 to 6 hrs R/G: 1d – 10d, Or 1d to 1 m [App. Dependent]	N/A [Flow/Stage / Level/height /flow]	5%-10% ; Units: m ³ /sec. Also quoted in cusecs (cubic feet per second)	Hourly to daily (NRT) for Point Data; DT for Gridded. Or: Hrs to days to months [App. Depend]	E-45 SOG-H IGWCO GCOS WCRP GTOS U-1,2
<u>River Discharge (Inland, Coastal)—Surface/Sub-terrestrial</u> [Sub-Area: SW]	L/R: 1km – 10km or point data [River Basins] G: 50km-200 km for Gridded or Global [Also stated as 10km – 100km for R/G]	L/R: 1 to 6 hrs R/G: 1d – 7d to 10d to 1m [Appl. Dependent]	N/A	5%-10% ; Units: m ³ /sec. Also quoted in cusecs (ft ³ /s)	Hourly to Daily (NRT) for Point Data and L/R Appl; Daily to Monthly to 3m for Delayed Mode and/or Global Appl	E-45 SOG-H IGWCO GCOS WCRP GTOS U-1,2
<u>Lakes/Reservoirs and Other Surface Storages</u> (e.g., Wetlands, Floodplains...)—Areal Extent/Depths/Levels & Out-Flows [Surface Storage & Flux]	L/R: 1km-40km G: 50 km to 100 km Also stated as Polygons	1wk to 1m Or 30d to 90d or Monthly to Annual [App Dep]	N/A	10cm-20cm (level); Or 5%. Units for other quantities (area, depth, volumetric) include Km ² ;	1wk-1m For L/R 30d to 90d for R/G	E-87 IGWCO SOG-H U-1,2 GCOS GTOS

Primary/Critical Terrestrial Water Cycle Variables and Parameters	Horizontal Resolution	Time Resolution	Vertical Resolution or Height Depth	Accuracy and/or Precision	Latency	Document Reference (Example Sub-Set)
[Sub-Area: SW]				meters; m ³ /s		
Snow/ice (Cover/Depth/Type) Snow Water Equivalent (SWE), Freeze/Thaw/Melt State, Margin [Sub-Area: SW]	L/R: 0.1km to 10km R/G: 50 km to 100 km [Also stated as 1km – 25km or 15km – 250km for some applications —e.g., snow cover for global climate; 10km – 25km for SWE]	L/R: 1d – 5d - 1wk R/G: 1d to 1m; Also stated as: 0.5hrs to 288hrs for snow melt conditions— App Dependent	N/A [Actual Depth]	5% - 10% or 25 km ² for Area (Regional/Gl obal); 5mm - 20mm for SWE. Units: mm/cm/inc hes for depth; km ² for area/extent; mm for SWE. 5% for Ground Ice; Also stated in terms of 2 to 5 classes	24 hrs, or 1d to 6d to 1m. 5-10 days for Ground Ice. Other specs include 1 hr to 144 hrs or 24hr to 144hr or 30hr to 360hrs etc. [App. Dependent]	A-45 C-246, 249,260; E-93, 77 B-111 F-68 H-48 IGWCO SOG-H GCOS GTOS WCRP WMO U-1,2
Glaciers/Ice Sheets/ Permafrost/Frozen Ground... (Extent, Depth/Thickness, Rate of Change....) [Sub-Area: SW]	L/R: 1km – 10km G: 50 km to 100 km; [Also stated as 0.01 km to 0.05 km for topography; 30m to 100m for glacial cover/topogr aphy; 0.25km to 10km for permafrost]	L/R: 1m - 1 yr R/G: 1m to 1yr to 10 yrs [E.g., 1yr to 5yr for glacial cover/topog raphy; 1d to 5d for permafrost]	N/A	5 x 10 ³ Kg/yr (mass balance)— also stated as 10 Kg/m ² /yr for ice sheet surf balance; 10m – 100m (area/extent); 5cm – 10cm – 20cm for elevation; Also stated as 5% - 10% for various parameters/ applications	1d to 5d for some parameters , and for others: 1m to 1yr to 2 yrs [App Dep]	A-14 E-50,51,52,94 ; C-252,254,25 5; H-48,49 IGWCO GCOS GTOS U-1 U-2
SUB-AREA-2: GROUND WATERS (GW)						
Ground Water Table & Charge, Recharge,	L/R: 1km – 10km R/G: 50km	1 m to 3m to 1 year depending	0.1 km; Variable-- depth	5% - 7% (Depth to W-Table);	1m to 3m Also stated as TBD –	IGWCO WMO Unesco

Primary/Critical Terrestrial Water Cycle Variables and Parameters	Horizontal Resolution	Time Resolution	Vertical Resolution or Height Depth	Accuracy and/or Precision	Latency	Document Reference (Example Sub-Set)
Infiltration Rates and Grnd Water Flows and Recycling) [Sub-Area: GW]	to 100 km; Also stated as >7000 wells for global or density of well sufficient to characterize water storage fluxes to within 20%	on variability		20% for fluxes; (cm/s or m ³ /s etc.)	App Dep	FAO E-49 SOG-H GCOS GTOS
Aquifer Levels, Geologic Stratification, Volumetric, and Flows and Recycling [Sub-Area: GW]	L/R: 1km – 10km R/G: 50km to 100 km; Also stated as All Major Aquifers or >7000 wells for global or density of well sufficient to characterize water storage fluxes to within 20%	1 m to 3m to 1 year depending on variability	0.1 km; Variable--depth	5% - 7% (Depth to W-Table); 20% for fluxes; (cm/s or m ³ /s etc.)	1m to 3m Also stated as TBD – App Dep	IGWCO WMO Unesco FAO E-49 SOG-H GCOS GTOS
Soil Type, Texture, Porosity, Conductivity and Composition (chemical, mineral, nutrient (Incl C,N,P..), isotopic...). —Parameters controlling or influencing Ground Water Fluxes & Biogeochemical transports [Sub-Area: GW]	L: 1 m to 1km R: 10km G: 50 km to 100 km Also stated as: 1hecatere to 10,000 hectares for station spacing. Also stated as 0.1km to 10km for e.g., agromet	1y to 2yrs to 10yrs	30 cm to 1 m from single pit or auger hole; Bulk Density from small volumes of about 100 cm ³	5% and/or Various. E.g., 5% in units of gm/m ² for composition parameters; Or also stated as 9 to 18 classes or 5 – 15 classes for soil type	10d to 30d to 90d	U-1 U-2 E9,78,81,82 ,83; B-102 FAO IGBP WMO
SUB-AREA-3: FORCING(S) ON TERRESTRIAL						

Primary/Critical Terrestrial Water Cycle Variables and Parameters	Horizontal Resolution	Time Resolution	Vertical Resolution or Height Depth	Accuracy and/or Precision	Latency	Document Reference (Example Sub-Set)
HYDRO ELEMENTS						
Surface Radiation Budget SW (Incl. fPAR) & LW (Incl TOA-OLR) + Related parameters such as Surf. Albedo, Emissivity... [Incoming, Reflected, Outgoing...] [Sub-Area: FRCNG]	L/R: 1km – 10km R/G: 10km – 50km - 100 km – 250km [For surface: Point measurements representative of several km ²] [Also stated as 24km – 100km for global and 1-8 km for global (satellite derived; 0.25km – 2km for fPAR)]	L/R: 1 hr – 3hr – 6hr- 12hr R/G: 3hr – 12hr - 1d- 3d- 1m [10 min means at centers for L/R]; [Also stated as 1d- 30d for some—e.g., fPAR] [App. Dependent]	N/A [Surface or at Standard Height Above Gnd or satellite]	2% to 5% to 10% of absol for Total LW,SW, fPAR etc; 1% (5W/m ²) absol for center networks; Units W/m ² ; Also stated as 10%-20% or variably as 1W/m ² to 5W/m ² to 10W/m ² to 20W /m ² for SW/LW radiation parameters; or 1% to 5% for e.g., emissivity. [App/Instrument or measurement type Dependent]	3hr to 1d to 5d to 1wk to 1m [App Dependent]	U-1 U-2 E-66, 35, 70; 69,67 G-39 A-14 C-268 IGWCO WMO WCRP WMO GCOS GTOS
Clouds (Type, cover/distribution, optical depth, CCN, aerosols, drop-size spectrum and phase,) [Sub-specs include: Cloud top height, cloud base height, total liquid water content, cloud particle/drop size and phase....etc.] [Sub-Area: FRCNG]	L/R: 1km – 10km R/G: 50km – 100km [Also stated as 50km – 250km or 100km – 500km for some global applications]	3 hr to 6hr to 24hr [App. Dependent]	0.15Km to 0.6Km for some cloud parameters] [Also stated as 0.5km to 2km for some parameters —e.g., cloud base height?— something wrong with this spec for climate research?]	Various: 5% to 10% to 20% (areal coverage); 10% - 20% or 10g/m ² - 20g/m ² for water/ice profiles) etc.; 0.5km for heights; 20% for LWC; [Various, for other parameters such as cloud &	1hr to 2hr for NRT data; and up to 7d to 1m for delayed [Also stated as 24hr – 48 hr, and 30d to 60d for some applications—e.g., climate]	A-45 B-57,61 C-27,13 G-34,36 H-19 E-44 WMO GCOS WCRP U-1 U-2

Primary/Critical Terrestrial Water Cycle Variables and Parameters	Horizontal Resolution	Time Resolution	Vertical Resolution or Height Depth	Accuracy and/or Precision	Latency	Document Reference (Example Sub-Set)
				aerosol (10%-20%) optical depth, transmissivity, particle size etc.] Also stated as 10% - 25% [Also stated as 0.2km to 1.0km for e.g., cloud top/ base height] [Also stated as 5 to 10 classes for cloud type]		
Hydromet/Met— Surface Air Temp., Moisture/Humidity , Winds, Pressure... [Sub-Area: FRCNG]	L: 1km R: 10km G: 50 to 100 km to 500km	L: 1 hr R: 3 hr G: 1 d ??	N/A [Standard Height Above Gnd]	1 %– 5% (Generic for group)		
Surface Temperature—Air [Sub-Area: FRCNG]	L/R: 1km – 10km R/G: 10km – 100km [Also stated as 50km – 250km or 100km to 500km for some global applications]	1hr to 3hr to 1d to 10d [App Dependent]	N/A [Std height above ground: 1.5m]	0.5K to 1.0K [for local to global] [Also stated as 0.2K to 0.5K, or 0.1K to 0.3K for some applications]	1hr – 3hr – 6hr for RT; Also stated as 1d to 2d and Up to 30d – 60d for some delayed applications—e.g., climate	A-45 B-96 C-70 G-46 C-415 U-1 U-2 WCRP GCOS WMO
Surface Moisture/Humidity—Air [Sub-Area: FRCNG]	L/R: 1km – 10km R/G: 10km – 50km-100km [Current systems vary between 100km to 500km for global]	1hr to 3hr to 1d to 10d [App Dependent]	N/A [Std height above ground: 1.5m] [0.3Km to 3Km for U/A]	1% to 5% [Units: % (RH) or gms H ₂ O/m ³ (water content)] Also stated as 1% - 2% or 2% - 10% or 5% - 10% Specific Humidity	1hr to 3 hr for NRT; 1d to 2d to 1m for Delayed mode applications	A-45 B-39 E-71 U-1 U-2 WMO WCRP GCOS

Primary/Critical Terrestrial Water Cycle Variables and Parameters	Horizontal Resolution	Time Resolution	Vertical Resolution or Height Depth	Accuracy and/or Precision	Latency	Document Reference (Example Sub-Set)
Surface Winds (Vector) [Sub-Area: FRCNG]	L: 1km – 10km & R: 10km – 50km R/G: 50km – 100km [Also stated as 200km to 500km for global]	1hr to 12hrs; Also stated as 0.0833hr to 0.167 hr for certain application such as Aeromet, or 6hr to 72 hrs for climate	N/A [Measured at 10m height for land & 1-40m height for ocean] [0.15Km – 0.167Km for U/A]	2 m/s – 5m/s; Also stated as 0.5m/s to 3m/s	0.1hr to 1hr to 3 hr to 6hr for NRT; 1d – 1m for Delayed [Also stated as 24hr to 168hrs for some applications]	A-45,12 B-122 E-92 G-51 U-1 U-2 WMO WCRP
Surface (Sea Level) Pressure [Mountainous areas report surface pressure & “reduced” sea level pressure by std. atmospheric computations]	L/R: 1km – 10km R/G: 50km – 100km – 250km [Also stated as 15km – 500km or 15km – 500km for global applications]	1hr – 12hr	N/A	0.5 hPa to 1hPa	RT: 0.1hr to 3hr to 6hr to 12hr for NRT	A-45 B-43 C-299, 300; U-1 U-2 WMO GCOS
Vegetation Cover/Type [Including LAI, NDVI, Roughness, Categorization by classes, and above & below ground biomass] [Sub-Area: FRCNG]	L/R: 1km – 10km R/G: 10km – 100km [Also stated as 50m to 500m or 0.25km – 10km, for some applications such as agromet and GCOS, or 16km to 100km for NDVI global/regional; or 1m to 10m for vegetation type-regional/loca	1d to 5d to 10d to 1wk to 1m to 3m to 1yr to 10yrs [Depending on measurement/instrument/observation type] [Also stated as 365d to 1500d for vegetation type—e.g., UNEP]	N/A	5% -10% (area by type) Or 10% in g/m ² Or Kg/Hectare for biomass Or 5%-10% (15%-25% of true value) for NDVI and leaf area indices in units of m ² /m ² . Units of Kg/m ² for NPP (Net Primary Production) [Also stated as 5 to 15 classes]	1d to 5d to 7d to 30d to 90d to 3m to 1yr [App. Dependent]	A-14,48 B-89,91 E-91,11, 86, 57; C-273, 278, 268; E-41, 42, 61; H-40 F-50 U-1 U-2 WCRP IGBP GTOS GCOS IGWCO WMO UNEP

Primary/Critical Terrestrial Water Cycle Variables and Parameters	Horizontal Resolution	Time Resolution	Vertical Resolution or Height Depth	Accuracy and/or Precision	Latency	Document Reference (Example Sub-Set)
				[Also stated as 5t/ha to 10t/ha for e.g., biomass]		
Land Cover and Land Use [Incl Surf. Roughness] [Sub-Area: FRCNG]	L/R: 1km – 10km R/G: 10km – 100km [5m to 30m to 1km for some applications —especially for land use classifications] [Some measured at 1-10 m for vegetation to represent 1km-10km areas] [Also stated as 10m to 250,000m for e.g., hydrology, and 250m to 1000m for other applications]	10d to 1m to 3m to 1yr to 5yr to 10yrs [Depending on measureme nt/instrume nt/observati on type] [Also stated as 0.02yr to 1yr for e.g., hydrology]	N/A	5% in Units of Km ² or 20 – 40 Land Cover classes in units of Km ² per class/type. 10% in Units of m for roughness length (Z ₀). [Global accuracy of 20% is stated to be sufficient for some applications] Also stated as 4-10 classes for e.g., agromet, and 5-50 classes for hydro.]	1d to 7d to 10d to 1m to 1 yr [App. Dependent]	A-14 E-54, 10, 73; B-89 H-43 U-1 U-2 WMO FAO GCOS GTOS
Topographic and/or Geological and Geomorphological [Sub-Area: FRCNG]	30 arc sec grid; 120 postings per degree lat/long. Also stated as 1km – 100km and/or 100m to 1000m, and 250m to 10000m. [Appl. Dependent]	5yr to 10yr to 50yr. Also stated as 240m to 360m for e.g., Geoid] [Periodic updating w/new technology and better resolution]	N/A o sometimes stated as 1cm to 1 m	1m to 5m to 10m vertical [Also stated variably as: +/- 50m to 200m; 500m in vertical in steep areas; 1000m in horiz or better. Also stated as 1cm to	30d to 600d to 720d [Also stated as 12yr to 24 yr for e.g., Geoid] [App. Dependent]	U-1 U-2 IGWCO WCRP WMO GCOS GTOS ICSU

Primary/Critical Terrestrial Water Cycle Variables and Parameters	Horizontal Resolution	Time Resolution	Vertical Resolution or Height Depth	Accuracy and/or Precision	Latency	Document Reference (Example Sub-Set)
				5cm for Geoid]		
SUB-AREA-4: WATER QUALITY & WATER DEMAND/USE						
Water Quality & Composition-- organic/inorganic contaminants, isotopic, suspended particulates, turbidity, salinity, color...etc [Sub-Area: WQ/Use]	L/R: 1 m to 1km to 10km to 50km [Point Data] R/G: 50 km to 100 km to 500km [Typical WQ/WU data sampling networks and techniques do not correspond to the grid-based space-time resolutions as specified for other geophysical observational variables. [App. Dependent]	1m to 3m to 1yr (?)	N/A	Various—e.g., 10% in units of Moles/Liter for raw data. Also stated in terms of Moles per unit time per unit upstream basin area; Ions in ionic units; Also stated in mg/m ³ for some parameters	Various—e.g., 1m to 6m to 1yr after measurement? [App. Dependent, and/or Problem Dependent]]	E-74 U-1 U-2 IGWCO SOG-H
Nutrient/Contaminant Effluents/Fluxes→ Water Bodies/Flows [Sub-Area: WQ/Use]	Same as WQ? L/R: 1 m to 1km to 10km [Point Data] R/G: 50 km to 100 km	1m to 3m to 1yr to 10yrs?	N/A	Various [As in WQ?]	Various—e.g., 1m to 3m to 6m to 1yr after measurement?	? E-74 U-1 U-2 IGWCO? SOG-H
Water Sources, Water Demand/Draw/Use & Regulation [Differentiated Consumptive/Non-Consumptive Use] [Sub-Area: WQ/Use]	L/R: 1 m to 1km to 10km [Point Data] R/G: 50 km to 100 km. Also stated as Polygons. Some are inventories	Periodic (Variable): Monthly – Seasonal-Annual	N/A	Variable/Variou. Acc/Units: 10% (?) Engineering & Water Use Data Inventories. [Units for some/sever	1m to 6m to 1r or more [Location & Application Dependent]]	IGWCO SOG-H GTOS

Primary/Critical Terrestrial Water Cycle Variables and Parameters	Horizontal Resolution	Time Resolution	Vertical Resolution or Height Depth	Accuracy and/or Precision	Latency	Document Reference (Example Sub-Set)
				al water use indices are ill defined with nomenclatu re problems— e.g., those associated w/biogeoph ysical/socio eco aspects such as type, intensity, and water use for irrigation or ecosystem support		

Table 10. Summarized Requirements for Priority/Critical Water Cycle Variables/Parameters for Terrestrial Hydrology and Water Resources, including Space/Time Resolutions, Accuracy/Units, and Latency. All specifications are application(s) dependent, particularly “latency.” The upper limits to accuracy specifications typically refer to “desired” as opposed operational availability. RT = Real Time, NRT = Near Real Time, DM = Delayed Mode.

Primary/Critical Terrestrial Water Cycle Variables and Parameters	Horizontal Resolution	Time Resolution	Vertical Resolution or Height Depth	Accuracy and/or Precision	Latency
SUB AREA-1: SURFACE WATERS (SW)					
<u>Precipitation (liq./solid)</u> [Sub-Area: SW]	L: 1km R: 10km G: 50 to 100 km	L: </~ 1 hr R: 3 hr G: 3hr -1d.	N/A [Standard Height]	0.1mm/hr – 1 mm/hr and/or /5%	0.1h to 24hr to 7d to 30d; App Dependent
<u>Soil Moisture</u> [Sub-Area: SW]	L: 0.1km to 1km R: 10km G: 50 to 100 km to 500 km.	L: 1-6 hrs R: 1d-1wk; G: 1d- 30d-3m. Appl. Dependent	10 cm Res. to 1m depth;30cm-100 cm to water table	0.02 m ³ /m ³ . Or 5g/kg to 10g/kg - 50g/kg. Other units:Pascals,	Variable: NRT or 0.5d to 1d; 1d-10d-30d-144d-720d –App Depend.
<u>Soil Temperature</u> [Sub-Area: SW]	L: 0.1km to 1km R: 10km G: 50 to 100 km to 250km	L/R: 1-6 hr R: 1d to 3d to 1wk; G: 1d-1m- 3 months	10 cm Res. to 1m depth;30cm-100 cm to water table	0.5 ^o K -1.0 ^o K. Also stated as 0.3K to 2K or 1 ^o K to 2 ^o K , or 2K to 5K	3 hr to 6 hr for Land surface T. And/or same as Soil moisture
<u>Evaporation/Evapotranspiration</u> [Sub-Area: SW]	L: 1km R: 10km G: 50 to 100 km to 200 km	L: 1 to 6 hrs R: 1 d G: 1 d to 1 m	Surface (E), and LS veg cover or canopy ht for ET	0.1 mm or 5% . Also stated in units of gms of H ₂ O/m ² /d	Same as Precip. Or SM for point data assimil/water budget models
<u>Stream/River Flows/Stage/Runoff/Infiltration/Percolation...</u> [Sub-Area: SW]	L/R: 1km – 10km or point data [River Basins] G: 50km - 200 km for gridded/global	L/R: 1-6 hr R/G: 1d – 10d-1 m [App. Dependent]	N/A [Flow/Stage / Level/height /flow]	5%-10% ; Units:m**3.Or quoted in cusecs (cubic feet/s)	Hourly to daily for Point Data; DT (hrs-day-month)Grid ded: App-Dependent
<u>River Discharge (Inland, Coastal)—Surface/Sub-terra</u> [Sub-Area: SW]	L/R: 1km – 10km or point data [River Basins] R/G:10-100km G:50km-200	L/R:1-6 hr R/G: 1d-7d - 10d -1m [Appl. Dependent]	N/A	5%-10%; Units:m**3/s. Also quoted in cusecs (ft ³ /s)	Hrs – 1d(NRT) for Point Data and L/R Appl; 1d-1m-3m for

	km-Grid				DM/Glob App
Lakes/Reservoirs and Other Surface Storages (~Wetlands,Floodplains...) —Areal Extent, Depths, Levels & Out-Flows [Surface Storage & Flux] [Sub-Area: SW]	L/R: 1km-40km G: 50 km to 100 km Also stated as Polygons	1wk to 1m Or 30d to 90d or Monthly to Annual [App Dep]	N/A	10cm-20cm (level); Or 5%. Units for other quantities (area, depth, volumetric) incl. Km**2; meters; m ³ /s	1wk-1m For L/R 30d to 90d for R/G
Snow/ice (Cover/Depth/Type) Snow Water Equivalent (SWE), Freeze/Thaw/Melt State, Margin [Sub-Area: SW]	L/R: 0.1- 10km R/G: 50-100 km [Also stated as 1km – 25km or 15km – 250km for some appl.e.g., snow cover/SWE for global climate	L/R: 1d –5d - 1wk R/G: 1d to 1m; [0.5hrs for snow melt conditions— App Dep	N/A [Actual Depth]	5% - 10% or 2-5 classes or 25 km ² for Area (R/G); 5mm - 20mm for SWE. Units: mm/cm/inches for depth; km ² for area;5% for ice;	24 hrs, or 1d- 6d- 1m. 5-10 days for Ground Ice. Other specs include 1 hr to 144 hrs or 24hr to 144hr or 30hr to 360hrs etc. [App. Dependent]
Glaciers/Ice Sheets/ Permafrost/Frozen Ground... (Extent, Depth/Thickness, Rate of Change....) [Sub-Area: SW]	L/R: 1km – 10km G: 50-100 km; [Also stated as 0.01-0.05 km for topography; 30m to 100m for glacial cover, ; 0.25km to 10km for permafrost]	L/R: 1m -1 yr R/G: 1m to 1yr to 10 yrs [E.g., 1yr to 5yr for glacial cover/topography; 1d to 5d for permafrost]	N/A	5 x 10 ³ Kg/yr (mass balance)—also stated as 10 Kg/m ² /yr for ice sheet surf balance; 10m – 100m (area/extent); 5cm – 10cm – 20cm for elevation; Or 5% - 10% for other parameters	1d to 5d for some parameters , and for others: 1m to 1yr to 2 yrs [App Dependent]
SUB-AREA-2: GROUND WATERS (GW)					
Ground Water Table & Charge, Recharge, Infiltration Rates and Grnd Water Flows and Recycling) [Sub-Area: GW]	L/R: 1km – 10km R/G: 50-100 km; [>7000 wells for global # of wells sufficient to characterize water storage fluxes to	1 m to 3m to 1 year depending on variability	0.1 km; Variable-- depth	5% - 7% (Depth to W-Table); 20% for fluxes; (cm/s or m ³ /s etc.)	1m to 3m Also stated as TBD – [App Dependent]

	within 20%				
Aquifer Levels , Geologic Stratification, Volumetric, and Flows and Recycling [Sub-Area: GW]	L/R: 1km – 10km R/G: 50-100 km; [All Major Aquifers or >7000 wells for global density of well to characterize water storage fluxes to within 20%]	1 m to 3m to 1 year depending on variability	0.1 km; Variable-- depth	5% - 7% (Depth to W-Table); 20% for fluxes; (cm/s or m ³ /s etc.)	1m to 3m Also stated as TBD – App Dep
Soil Type, Texture, Porosity , Conductivity and Composition (chemical, mineral, nutrient (Incl C,N,P..), isotopic...). — Parameters controlling or influencing Ground Water Fluxes & Biogeochemical transports [Sub-Area: GW]	L: 1 m to 1km R: 10km G: 50 km-100 km Also stated as: 1 hectare to 10,000 hectares for station spacing. Or, 0.1km to 10km for e.g., agromet	1y to 2yrs to 10yrs	30 cm to 1 m from single pit or auger hole; Bulk Density from small volumes of about 100 cm ³	5% and/or Various. E.g., 5% in units of gm/m ² for composition parameters; Or also stated as 9 to 18 classes or 5 – 15 classes for soil type	10d to 30d to 90d [Applications Dependent]
SUB-AREA-3: FORCING(S) ON TERRESTRIAL HYDRO ELEMENTS					
Surface Radiation Budget SW (Incl. fPAR) & LW (Incl TOA-OLR) + Related parameters such as Surf. Albedo, Emissivity... [Incoming, Reflected, Outgoing...] [Sub-Area: FRCNG]	L/R: 1km – 10km R/G: 10km – 50km - 100 km – 250km [For surface: Point measurements representative of several km ²] [Also stated as 24km – 100km for global and 1-8 km for global (satellite derived; 0.25km – 2km for fPAR)]	L/R: 1 hr – 3hr –6hr-12hr R/G:3hr – 12hr - 1d-3d-1m [10 min means at centers for L/R]; [Also stated as 1d- 30d for some—e.g., fPAR] [App. Dependent]	N/A [Surface or at Standard Height Above Gnd or satellite]	2% to 5% to 10% of absol for Total LW,SW, fPAR etc; 1% (5W/m ²) absol for center networks; Units W/m ² ; Also stated as 10%-20% or variably as 1W/m ² to 5W/m ² to 10W/m ² to 20W /m ² for SW/LW radiation parameters; or 1% to 5% for e.g., emissivity. [App/Instrume	3hr to 1d to 5d to 1wk to1m [App Dependent]

				nt or measurement type Dependent]	
Clouds (Type, cover/distribution, optical depth, CCN, aerosols, drop-size spectrum and phase,) [Sub-specs include: Cloud top height, cloud base height, total liquid water content, cloud particle/drop size and phase....etc.] [Sub-Area: FRCNG]	L/R: 1km – 10km R/G: 50km – 100km [Also stated as 50km – 250km or 100km – 500km for some global applications]	3 hr to 6hr to 24hr [App. Dependent]	0.15Km to 0.6Km for some cloud parameters] [Also stated as 0.5km to 2km for some parameters —e.g., cloud base height?— something wrong with this spec for climate research?]	Various: 5% to 10% to 20% (areal coverage); 10% - 20% or 10g/m ² - 20g/m ² for water/ice profiles) etc.; 0.5km for heights; 20% for LWC; [Various, for other parameters such as cloud & aerosol (10%-20%) optical depth, transmissivity, particle size etc.] Also stated as 10% - 25% or 0.2km to 1.0km for e.g., cloud top/ base height] [Also stated as 5 to 10 classes for cloud type]	1hr to 2hr for NRT data; and up to 7d to 1m for delayed [Also stated as 24hr – 48 hr, and 30d to 60d for some applications—e.g., climate]
Hydromet/Met—Surface Air Temp., Moisture, Humidity, Winds, Pressure... [Sub-Area: FRCNG]	L: 1km R: 10km G: 50 to 100 km to 500km	L: 1 hr R: 3 hr G: 1 d ??	N/A [Standard Height Above Gnd]	1 – 5% or other [See below for details per parameter]	See below for details per parameter]
Surface Temperature—Air [Sub-Area: FRCNG]	L/R: 1km – 10km R/G: 10km – 100km [Also stated as 50km – 250km or 100km to 500km for some global applications]	1hr to 3hr to 1d to 10d [App Dependent]	N/A [Stnd height above ground: 1.5m]	0.5K to 1.0K [for local to global] [Also satted as 0.2K to 0.5K, or 0.1K to 0.3K for some applications	1hr – 3hr – 6hr for RT; Also stated as 1d to 2d and Up to 30d – 60d for some delayed application s—e.g., climate
Surface	L/R: 1km –	1hr to 3hr to	N/A	1% to 5%	1hr to 3 hr

Moisture/Humidity—Air [Sub-Area: FRCNG]	10km R/G: 10km – 50km- 100km [Current systems vary between 100km to 500km for global]	1d to 10d [App Dependent]	[Std height above ground: 1.5m] [0.3Km to 3Km for U/A]	[Units: % (RH) or gms H ₂ O/m ³ (water content)] Also stated as 1% - 2% or 2% - 10% or 5% - 10% Specific Humidity	for NRT; 1d to 2d to 1m for Delayed mode applications
Surface Winds (Vector) [Sub-Area: FRCNG]	L: 1km – 10km & R: 10km – 50km R/G: 50km – 100km [Also stated as 200km to 500km for global]	1hr to 12hrs; Also stated as 0.0833hr to 0.167 hr for certain application such as Aeromet, or 6hr to 72 hrs for climate	N/A [Measured at 10m height for land & 1-40m height for ocean] [0.15Km – 0.167Km for U/A]	2 m/s – 5m/s; Also stated as 0.5m/s to 3m/s	0.1hr to 1hr to 3 hr to 6hr for NRT; 1d – 1m for Delayed [Also stated as 24hr to 168hrs for some applications]
Surface (Sea Level) Pressure [Sub-Area: FRCNG] [Mountainous areas report surface pressure & “reduced” sea level pressure by std. atmospheric computations]	L/R: 1km – 10km R/G: 50km – 100km – 250km [Also stated as 15km – 500km or 15km – 500km for global applications]	1hr – 12hr	N/A	0.5 hPa to 1hPa	RT: 0.1hr to 3hr to 6hr to 12hr for NRT
Vegetation Cover/Type [Including LAI, NDVI, Roughness, Categorization by classes, and above & below ground biomass] [Sub-Area: FRCNG]	L/R: 1km – 10km R/G: 10km – 100km [Also stated as 50m to 500m or 0.25km – 10km, for some applications such as agromet ; or 1m to 10m for vegetation type-regional/local]	1d to 5d to 10d to 1wk to 1m to 3m to 1yr to 10yrs [Depending on Obs/Instr. type]	N/A	5% -10% (area by type) Or 10% in g/m ² Or Kg/Hectare or 5t/ha-10t/ha for biomass Or 5%-10% (15%-25% of true value) for NDVI and leaf area indices in units of m ² /m ² . Units of Kg/m ² for NPP [Also stated as 5 to 15 classes	1d to 5d to 7d to 30d to 90d to 3m to 1yr [App. Dependent]
Land Cover and Land Use	L/R: 1km –	10d to 1m to	N/A	5% in Units of	1d to 7d

[Incl Surf. Roughness] [Sub-Area: FRCNG]	10km R/G: 10km – 100km [5m -30m-1km for some appl., e.g., for land use classifications; Some measured at 1-10 m for vegetation to represent 1km-10km areas] applications]	3m to 1yr to 5yr to 10yrs [Depending on measurement/instrument/observation type] [Also stated as 0.02yr to 1yr for e.g., hydrology]		Km ² or 5 - 20 – 40- 50 Land Cover classes in units of Km ² per class/type; 10% in Units of m for roughness length (Z ₀). [Global accuracy of 20% stated as sufficient for some appl.]	to10d to 1m to 1 yr [App. Dependent]
Topographic and/or Geological and Geomorphological [Sub-Area: FRCNG]	30 arc sec grid; 120 postings per degree lat/long. Also stated as 1km – 100km and/or 100m to 1000m, and 250m to 10000m. [Appl. Dependent]	5yr-10yr-50yr. [Also stated as 240-360 months for e.g., Geoid] [updating w/new technology & better resolution]	N/A o sometimes stated as 1cm to 1 m	1m to 5m to 10m vertical [Also stated variably as: +/- 50m to 200m; 500m in vertical in steep areas; 1000m in horiz or better; 1cm to 5cm for Geoid]	30d to 600d to 720d [Also stated as 12yr to 24 yr for e.g., Geoid] [App. Dependent]
SUB-AREA-4: WATER QUALITY & WATER DEMAND/USE					
Water Quality & Composition-- organic/inorganic contaminants, isotopic, suspended particulates, turbidity, salinity, color...etc [Sub-Area: WQ/Use]	L/R: 1m-1km-10km-50km [Point Data] R/G: 50 km to 100 km to 500km [Typical WQ/WU data sampling networks and techniques do not correspond to the grid-based space-time resolutions as specified for other geophysical observational	1m to 3m to 1yr (?)	N/A	Various—e.g., 10% in units of Moles/Liter for raw data. Also stated in terms of Moles per unit time per unit upstream basin area; Ions in ionic units; Also stated in mg/m ³ for some parameters	Various—e.g., 1m to 6m to 1yr after measurement? [App. Dependent , and/or Problem Dependent]

	variables. [App. Dependent]				
Nutrient/Contaminant Effluents/Fluxes→Water Bodies/Flows [Sub-Area: WQ/Use]	Same as WQ? L/R: 1 m to 1km to 10km [Point Data] R/G: 50 km to 100 km	1m to 3m to 1yr to 10yrs?	N/A	Various [As in WQ?]	Various— e.g., 1m to 3m to 6m to 1yr after measurement?
Water Sources, Water Demand/Draw/Use & Regulation [Differentiated Consumptive/Non-Consumptive Use] [Sub-Area: WQ/Use]	L/R: 1 m to 1km to 10km [Point Data] R/G: 50 km to 100 km. Also stated as Polygons. Some are inventories	Periodic (Variable): Monthly – Seasonal- Annual	N/A	Variable/Various. Acc/Units: 10% (generic to group) Engineering & Water Use Data—Inventories. [Units for some/several water use indices are ill defined with nomenclature problems—e.g., those associated w/biogeophysical/socioeconomic concepts such as type, intensity, and water use for irrigation or ecosystem support	1m to 6m to 1year or more [Location & Application Dependent]

5.3 Priority Observations for the Water SBA

As described in Section 5.2, the Analyst generated a list of Earth observations for the Water SBA for three different perspectives: global, regional, and local. The 48 observations listed below have the highest rankings for the global perspective and thus are considered to be observation priorities for the Water SBA. The observations are in no particular order and have approximately equal value.

- Precipitation (Liquid, Solid and Mixed Phase)
- Soil Moisture (Surface/Sub-Surface)
- Soil Temperature (Surface/Sub-Surface)

- Evaporation (Lakes and Wetlands)
- Evapotranspiration (from Land Surface)
- Runoff/Stream Flow
- River Discharge (to Ocean Coastal Zones/Estuaries), Surface/Sub-terra, Major Rivers
- Glaciers & Ice Sheets (Extent/Depth)
- Ground Water & Aquifer Volumetric Change
- Land Cover, Vegetation Cover/Type
- Elevation/Topography
- Water Quality (Large Water Bodies, Major Rivers, Estuaries, Nutrients/Contaminants such as Nitrates, Sulfates, Phosphates; Dissolved Oxygen Content, etc.)
- Lakes/Reservoirs Levels (Including Other Surface Storages)
- Snow (Cover/Depth/Type, Snow Water Equivalent)
- Air Temperature (Surface Met/Hydromet)
- Air Moisture/Humidity (Surface Met/Hydromet)
- Winds (Surface Met/Hydromet)
- Evaporation (Oceans)
- Freeze/Thaw/Melt State & Margin
- Permafrost/Frozen Ground
- Soil Type (Classification)
- Soil Properties (Texture/Porosity, Hydraulic Conductivity, etc.)
- Surface Radiation Budget (Incoming/Outgoing Shortwave & Longwave)
- Top of Atmosphere (TOA) Outgoing Longwave Radiation
- Surface Albedo and Emissivity (often a derived/estimated parameter)
- Clouds – Liquid Water Content
- Cloud Properties – Optical Depth/Extinction Coefficients
- Agricultural Water Use – from Surface Storages such as Reservoirs, Rivers, Channels, Canals
- Agricultural Water Use – Ground Water Draw
- Energy Non-Hydro Power Generation Water Demand/Use
- Urban Water Demand/Use – Large Mega-Cities
- Water Regulation – Trans-Boundary (Regional/International)
- Soil Composition (Chemical, Mineral, Nutrient, including soil pH, C, N, P, K, and others)
- Ground Water Recharge/Discharge Rates
- Water Infiltration/Percolation & Rates (Land Surface)
- Cloud Properties (CCN, Particle-Size distribution and Phase/State, Cloud Liquid Water Content)
- Aerosols
- Sea Level Pressure (Surface Met/Hydromet)
- Land Use Classification (Agriculture, Urban, Industrial, etc.)
- Geologic Stratification & Geomorphological Classification
- Water Quality & Composition (organic/inorganic contaminants, isotopic, suspended particulates, turbidity, salinity, color...etc)
- Water Quality (Drinking/Potable Water)

- Water Quality (Ground Water)
- Hydro-Energy Water Demand/Use
- Urban Water Demand/Use – Small Cities
- Sub-Urban Water Demand/Use – Distributed (including Small Towns)
- Water Regulation – National
- Water Regulation – Trans-Boundary (State/National)

These observation priorities represent a broad picture of global Earth observation priorities for water applications. The priorities of highest benefit to one geographic region may not provide any added value to another. However, regional, national, and local-level authorities and agencies will be able to use such priority lists in helping develop Earth observation strategies that are customized to their individual needs. This priority list was used in the Cross-SBA analysis to identify critical Earth observation priorities across all SBAs, as described in Appendix C.

6 Additional Findings

6.1 Challenges and Grand Examples

The water budget at the terrestrial surface at any one point is determined by the difference between precipitation and evapotranspiration (ET) following basic water balance mathematics. Precipitation is measured, albeit to varying degrees of accuracy, by a combination of in situ rain gauges and various remote sensing techniques such as surface based (radar) and space-based satellite systems. But, evaporation/evapotranspiration remains elusive.

It is underscored that some very fundamental and critical water cycle variables still remain as significant challenges to the global observing systems and the international data exchange systems as agreed upon via international and regional agreements and protocols. Namely:

- Accurate precipitation measurements on a global basis remain a fundamental problem. To address this issue, planning continues on a “Global Precipitation Mission” that involves advanced space-based technologies, as well as enhanced in situ networks.
- Soil Moisture measurements remain a complex problem on a global and even regional basis. To this end, plans include the space-based components such as the Soil Moisture Active Passive (SMAP) mission. However, it would be concurrently most useful for GEO to consider the implementation of a corresponding global network of in situ soil moisture/temperature profiling stations, and corresponding international data exchange systems and protocols. Because, such a complimentary global system of space-based and in-situ observational networks would represent a “back-bone” observational system for driving more accurate hydrological and water resource management models.
- Other critical measurements, for which observational capacity exists, albeit in varying degrees of adequacy in different regions and countries, include ground water table measurements, river stage/height, reservoir levels, and water quality, among others.

While the above are well recognized, there are critical measurements which require even more complex technology developments. They include the following – the list is not all inclusive.

Evaporation/Evapotranspiration – A “next” generation challenge (Ref. NRC Decadal Survey)

Evaporation from land and ocean surfaces is poorly observed from in situ instruments and its climatology is not well known at present. Evaporation is not readily observable using remote sensing. Despite the observation issues, evaporation is central to Earth system science and its constitutive cycles (water, energy, and biogeochemical). Many aspects of climate and weather prediction depend upon accurate determination of these fluxes. Current meteorological products are not advanced enough to provide accurate information. Development of the capability to monitor evaporation directly constitutes a grand challenge for Earth system science.

Despite the inability to measure evaporation directly via remote sensing, it nevertheless is possible to measure states and processes that are needed to estimate evaporation. More accurate estimation of evaporation will require a new perspective on how multi-source measurements and models can be combined.

The goal should be to facilitate estimation of the diurnal cycle of evaporation over land and ocean surfaces with errors (at temporal resolutions sufficient to resolve the diurnal cycle) of less than 30 W/m^2 at 10 km resolution, and over the open ocean with an accuracy of 5 W/m^2 for a spatial resolution of 1° (about 100 km). These errors, while still substantial, would be small enough to be comparable to the errors in other terms in the global (and regional) water and energy budgets, and so would facilitate direct estimation of evaporation errors, rather than estimation as a residual term as is often done at present – for example the water and energy budget estimation for the Mississippi River basin.

Under turbulent conditions, evaporation is directly proportional to the latent heat flux (a component of the surface energy balance) and the carbon flux in the surface carbon balance. Evaporation also co-determines with precipitation – the rate of the global water cycle. The difference of evaporation and precipitation should be zero when globally aggregated, which gives a long-range performance goal for this grand challenge. The difficulty in measuring evaporation from space is that bulk parameterizations, which are the primary means for estimating evaporation, require knowledge of the near surface specific humidity, a measurement that continues to elude the scientific community.

Even space-borne profilers with very high vertical resolution are unable to resolve the boundary layer with the needed precision. Other quantities necessary for estimation of the latent heat flux include the surface wind speed and surface and near surface temperatures. Over the oceans, surface wind estimates are possible from both active and passive microwave instruments with reasonable accuracy, although under high wind conditions, only scatterometers have proven utility. Over land, direct measurement of surface wind from space is not currently possible. Although not a direct input to the latent heat flux parameterization, the surface temperature is needed to determine saturation vapor pressure at the surface in the case of ocean evaporation, and the actual surface humidity in the case of evaporation over land. Furthermore, the surface

and air temperatures together determine the stability of the surface layer, which affects the transfer coefficients used in the calculation of the latent heat flux.

Sea surface and land temperature measurements from a variety of current and planned sensors in both the visible/infrared and microwave wavelengths can provide diurnally-varying values with a relatively high level of accuracy, and a continued mix of space-borne microwave radiometers will continue this record. It should be noted that in addition to the satellite data limitations there are still unresolved issues with the bulk flux parameterizations themselves.

Remote sensing of land radiometric surface temperature (LST) is critical to all current schemes to estimate evapotranspiration remotely. LST is directly related to the sensible heat component of the energy balance, and is thus inversely proportional to latent energy and evaporation rates. The Bowen ratio (H/LE) is a relatively simple parameter summarizing the relationship between sensible and latent heat flux from a surface. Thermal remote sensing, therefore, can provide an integrated look at land surface evaporation, although overpass timing is critical (mid-afternoon radiant heating of the land surface provides the most useful signal). For some purposes, data from the Geostationary Operational Environmental Satellites (GOES) also can be used to derive LST and surface ET every hour under cloud-free conditions.

Other methods for inferring evaporation can, with a combination of measured and modeled techniques, give some understanding of this flux over large areas. For instance, atmospheric budget analysis using moisture convergence in combination with observed precipitation can be used to estimate evaporation by difference – a technique that is applicable over both land and ocean. Over the oceans, changes in upper ocean salinity combined with oceanic advection can be used to produce an estimate of evaporation (global time-varying salinity measurements from Aquarius are expected to greatly improve the basis for estimating space-time fields of evaporation over the oceans).

In both cases, knowledge of precipitation is a necessary constraint that is especially limiting over the oceans, and portions of the land where precipitation is poorly observed. Other promising techniques involve the fusion of satellite data with global or regional climate model products. However, the use of these model products eliminates the possibility of comparing the resulting evaporation fields as independent data sources.

Given the inability to measure evaporation directly over large areas (either using in situ or remote sensing methods) it is likely that the most significant progress in this area will be in combination with improvements in assimilation into models with improved boundary layer physics. We believe that progress in this area should be a primary focus of the community over the next decade. While it is not possible at present to define a satellite mission that would address the key science questions in this area, several planned satellite missions will have a central role, and should be supported.

These include VIIRS aboard NPOESS, which will provide functionality in terms of estimating land and sea surface temperature under clear sky conditions, as well as vegetation information over land, similar to that which currently can be derived from the Terra and Aqua MODIS

sensors. A high resolution thermal infrared sensor equivalent to those previously flown on board Landsat satellites would also be useful.

Nonetheless, a more focused effort to address the complex problem of how best to combine observations and modeling to produce consistent estimates of ocean and land evaporation is a pressing need, progress on which is essential before observation requirements can be fully specified.

Surface-based/in-situ (evapotranspiration) observations (Ref. Compendium—U-2)

Currently, potential evapotranspiration is derived from pan evaporation or estimated from measurements of dry bulb and wet bulb temperatures. Some methods use a combination of evaporation, net radiation, humidity, wind velocity and temperature. It is also measured from estimated evaporation rates from lake surfaces. Measurements are made at several thousand irregularly distributed sites worldwide.

The network is inadequate being too irregular in space and time. ET is an important parameter for terrestrial hydrologic systems but difficult to measure in an aerially representative manner on account of ET being highly variable both spatially and temporally. Many methods exist to estimate ET but each is subject to fairly large biases and errors. It is highly debatable as to how ET could be aggregated spatially.

In principle, ET may be measured/estimated using remote sensing measurements from difference between leaf temperature and air temperature. However, satellite optical imagery is unable to measure either leaf temperature or air temperature accurately, and radar imaging techniques are underdeveloped. Both require considerable more research before satellite observations can be used to estimate evapotranspiration. There is no international data collection or exchange system for ET or evaporation.

6.2 Community of Practices – User Needs for Priority Water Cycle Data and Derived Products

User needs in water sectors generally depend on or require the following:

- Long data time series (30 to 100+ yrs) and statistics on recurrence frequencies, extreme events, and probability density functions of key parameters that are measured directly with in situ or surface-based instrument networks and sectioned remote sensing (satellite) observing systems. Time resolution requirements range from approximately 1 hr to daily/weekly/monthly and longer time scales, depending on the variable in question and observational feasibility. Space resolution requirements range from 1 m to 1 km for local applications, between 10 to 50 km for regional applications, and from 50 to 100+ km for global applications. The observing systems for most water cycle parameters do not meet all of these requirements.
- Computations and models to derive a host of parameters that are not directly observed and/or not observed at the resolutions required. Models include data assimilation and analysis models.
- Forecast/predictions of parameters that force the water cycle and hydrological components of the Earth system. The required prediction time scales range from 10-15

minutes for flash floods, to 1 hr (for certain classes of hazard warnings) to 3 to 6 hrs (typically atmospheric parameters) to daily/weekly/monthly and seasonal/inter-annual and longer for other hydrological parameters. All forecast models require initial conditions from observations or from data assimilation models. Often the prediction skill decreases substantially with increasing prediction lead times. Ensemble and multi-model forecasts/predictions are commonly used to obtain probabilistic estimates of uncertainty or spreads for the predicted water cycle variables. A distinction is made here between forecasting/prediction and climate change “projections.” Climate change “projection” models are not reliant on initial conditions. However, the climate modeling community is beginning to explore the requirements for decadal climate prediction – which will be reliant on accurate initial state conditions for coupled models of the atmosphere-ocean-land surface.

- Inputs to decision support systems and models from a combination of observations, data analysis/assimilation models, and forecast/prediction models (as above) and from rule-based operational or planning boundaries. The latter include non-physical (system) parameters that can determine water allocations – examples include regulatory, legal, and political and policy factors. They can pose complex challenges and trans-boundary issues at the intersection of towns, counties, states/provinces, and countries.
- Inputs derived from the potential impact of future global climate change on the water cycle, especially on regional to local scales. Here, by “inputs” we refer to the outputs from global (coupled) climate change projection models. They are typically not sufficiently accurate for a host of water cycle/hydrological parameters (e.g., soil moisture) at the regional and sub-regional scale. Thus, down-scaling techniques/models that can be verified become necessary. Moreover, it becomes critical to assess the impact of global climate change on the statistics and probability density functions (PDFs) used in operational hydrological prediction systems and water resource management decision support systems.
- Inputs to the strategic planning of engineered structures that regulate the flow and use of fresh water.
- Information on biogeochemical changes that are associated with or induced by water cycle changes.

7 Analyst’s Recommendations

This analysis focused on determining requirements for priority observational variables and parameters for the Water SBA as guided by the collective experience and expertise of the Analyst and the Advisory Group. The analytical outcomes (results) are considered to be unprecedented. During the course of this interaction the Advisory Group felt that several additional types of requirements analyses were important if not essential to provide continuity beyond the scope of GEO Task US-09-01a and to provide further guidance to GEO in developing the implementation strategies for GEOSS.

Recommendation #1

Below are examples of the additional types of analysis or guidance products recommended by the Advisory Group for the consideration and action of/by of the GEO UIC in collaboration or

coordination with other GEO entities such as the GEO STC (Science and Technology Committee) and the GEO ADC (Data Committee), subject to the decisions of the GEO Plenary (governing body for GEOSS). They include:

- Requirements for the interoperability and integration of observing networks,
- Requirements for national, regional, and international data exchange systems and protocols,
- Requirements for calibration, inter-calibration, and validation of observational data from disparate platforms,
- Requirements for the standardization of observing practices,
- Requirements for the validation of derived analysis products such as gridded fields,
- Requirements for the calibration and validation of observations based model output products that are delivered to the end users,
- Inventories of available observing networks and data sets,
- Observational data quality control requirements,
- Metadata standards,
- Data management and data sets—requirements and inventories of data providers
- Requirements for a consistent, agreed upon process for uncertainty propagation from observations through model output products, and
- Transition from research to operational data and procedures and protocols for such transitions.

Recommendation #2

Consider the development of a practical “guide” to the design and deployment of local, national, and trans-boundary or regional/international observations networks for the management of terrestrial water resources. That is, a manual or handbook to provide the end user with specifications for the installation of an integrated fit-for-purpose surface (in situ) and/or remote sensing observing system that would address the needs of integrated water resources management. A complimentary guide on available space-based technologies was thought to be useful for local/national systems in developing nations to benefit from data products from such space-based systems. The Advisory Group noted that developing specific “guides” or “handbooks” was a complex matter and one that requires very site (or region) specific information that is typically not easily available on an international or global basis. Thus, the Advisory Group recommends that the GEO UIC explores, jointly with other GEO Committees, the process or mechanisms through which such a guide could be developed.

Associated with the above would be the need carry out a “gap” analysis. That is, an analysis that compares existing observing systems, networks, technologies, data exchange systems etc., with what is required at the local, regional, and global scale in order to address terrestrial water cycle requirements as defined by this report. The Advisory Group acknowledges that this is also a complex task. The Advisory Group also notes that there are several ongoing activities within various organizations and agencies that look at various aspects of the said issue. Notwithstanding, the Advisory Group recommends that GEO in collaboration with its membership takes action on this possibly through the GEO STC and in coordination with the various efforts of individual organizations and agencies that participate in the GEOSS concept.

Recommendation #3

The Water SBA Advisory Group recommends that Earth observation priorities for the different SBAs should not be developed in a stove-pipe manner despite the necessity to make the priorities SBA specific. Rather, at the level of the GEO UIC and the GEO STC it needs to be ensured that there is a framework for the cross-integration of SBAs and in particular their observation priorities. Important elements of this cross-integration relate to the objectives of Earth observations and increasingly to the issue of the generation of integrated products and assessments that are based on multi-sectoral observing systems and platforms and, on the technical level, on different platform implementations (i.e., satellite observations, in situ observations, qualitative observations).

Once this is addressed in the GEO UIC reports, this then needs to be taken up by the STC in the discussion of the technical implementation of integrated observing systems to ensure interoperability based on common standards and protocols on the levels of metadata, data management and communication systems. The term interoperability implies that there is no need for identical standards but rather that standards and protocols are made transparent in such a way that interfaces can be generated to ensure communication between different observation networks and platforms in both push and pull modes.

Appendix A: Abbreviations

CEOS	Committee on Earth Observation Satellites
CoP	Community of Practice
ECV	Essential Climate Variable
EEA	European Environment Agency
FAO	Food and Agriculture Organization
GCOS	Global Climate Observing System
GEMS	Global Environmental Monitoring System
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GLAS	Geoscience Laser Altimeter System
GOCE	Gravity Field and Steady-State Ocean Circulation Explorer
GOES	Geostationary Operational Environmental Satellites
GRACE	Gravity Recovery and Climate Experiment
GRDC	Global Runoff Data Centre
HARON	Hydrological Applications and Runoff Network
HIRS	Hydrological Information Referral Service
HWRP	Hydrology and Water Resources Programme
IAEA	International Atomic Energy Agency
IAH	International Association of Hydrologists
ICESat	Ice, Cloud and Land Elevation Satellite
ICSU	International Council for Science
IGOS	Integrated Global Observing Strategy
IGWCO	Integrated Global Water Cycle Observations
IPCC	Intergovernmental Panel on Climate Change
ISARM	Internationally Shared Aquifer Resources Management
IWMI	International Water Management Institute
LST	Land Surface Temperature
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NHS	National Hydrological Services
NMS	National Meteorological Services
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRC	National Research Council
PDF	Probability Density Function
SAR	Synthetic Aperture Radar
SBA	Societal Benefit Area
SMAP	Soil Moisture Active Passive
SOG	Statement of Guidance
STC	Science and Technology Committee
UIC	User Interface Committee
UNECE	United Nations Economic Commission for Europe
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

VIIRS	Visible/Infrared Imager Radiometer Suite
WHYCOS	World Hydrological Cycle Observing System
WMO	World Meteorological Organization

Appendix B: References

B.1 Master List of Document References

See Appendix B.2 for partitioning per “cell” as per Table 6, and as detailed in Table 7. Note that the color highlights are maintained to bring the salient information per reference to the reader. This list does not follow normal convention for the benefit of the external reader.

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B.2 Breakdown of Master Document References

Breakdown of the “Master” Document References according to Table 6 categories as organized in Table 7.

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Appendix C: Input to the Cross-SBA Analysis

At the conclusion of the individual SBA priority-setting analysis, the Water Analyst provided input on the overall critical Earth observation parameters for the Water SBA for inclusion in the Cross-SBA meta-analysis. Upon receiving input from the SBA Analysts, the Cross-SBA Analyst reviewed the priorities and combined observation parameters that are the same or very similar but have different names (e.g., precipitation intensity and precipitation duration). In some cases, the Cross-SBA Analyst extracted observation parameters from aggregated observation categories that were identified as priorities by individual SBAs and included these observation parameters as input to the Cross-SBA analysis. As a result, the number of observation priorities identified by individual SBAs may vary from the number of observations that were included in the Cross-SBA analysis. To the extent possible, the Cross-SBA Analyst focused on retaining the observation parameter terminology employed by the majority of the SBAs, in order to minimize regrouping and splitting of observations.

The Water SBA Analyst determined the overall critical Earth observation priorities for the Water SBA by using a semi-quantitative method to rank the observation categories, as described in Sections 2.3.3 and Chapter 5. Based on the results of the prioritization analysis, the 48 observations listed below have the highest rankings and thus are considered to be the observation priorities for the Water SBA. The Cross-SBA Analyst included these 48 observations in Methods 1-3 of the Cross-SBA analysis. Accounting for differences in observation terminology across the SBAs, the Water Team effectively contributed 50 observation parameters to Methods 1-3 of the Cross-SBA analysis. For the three different perspectives (global, regional, and local), the Water SBA Analyst divided the 48 observations into the three tiers representing “High,” “Medium,” and “Low” priority observations. The Cross-SBA Analyst used the global designation of priority for input to Cross-SBA Methods 2 and 3.

For Method 4, the Cross-SBA Analyst included the “High” priority observations as the “15 Most Critical” observations. Accounting for differences in observation terminology across the SBAs, the Water Team effectively contributed 28 observation parameters to Method 4 of the Cross-SBA analysis.

High

Precipitation (Liquid, Solid and Mixed Phase)

Soil Moisture (Surface/Sub-Surface)

Soil Temperature (Surface/Sub-Surface)

Evaporation (Lakes and Wetlands)

Evapotranspiration (from Land Surface)

Runoff/Stream Flow

River Discharge (to Ocean Coastal Zones/Estuaries), Surface/Sub-terra, Major Rivers

Glaciers & Ice Sheets (Extent/Depth)

Ground Water & Aquifer Volumetric Change

Land Cover, Vegetation Cover/Type

Elevation/Topography

Water Quality (Large Water Bodies, Major Rivers, Estuaries, Nutrients/Contaminants such as Nitrates, Sulfates, Phosphates; Dissolved Oxygen Content, etc.)

Lakes/Reservoirs Levels (Including Other Surface Storages)
Snow (Cover/Depth/Type, Snow Water Equivalent)
Air Temperature (Surface Met/Hydromet)
Air Moisture/Humidity (Surface Met/Hydromet)
Winds (Surface Met/Hydromet)

Medium

Evaporation (Oceans)
Freeze/Thaw/Melt State & Margin
Permafrost/Frozen Ground
Soil Type (Classification)
Soil Properties (Texture/Porosity, Hydraulic Conductivity, etc.)
Surface Radiation Budget (Incoming/Outgoing Shortwave & Longwave)
Top of Atmosphere (TOA) Outgoing Longwave Radiation
Surface Albedo and Emissivity (often a derived/estimated parameter)
Clouds – Liquid Water Content
Cloud Properties – Optical Depth/Extinction Coefficients
Agricultural Water Use – from Surface Storages such as Reservoirs, Rivers, Channels, Canals
Agricultural Water Use – Ground Water Draw
Energy Non-Hydro Power Generation Water Demand/Use
Urban Water Demand/Use – Large Mega-Cities
Water Regulation – Trans-Boundary (Regional/International)

Low

Soil Composition (Chemical, Mineral, Nutrient, including soil pH, C, N, P, K, and others)
Ground Water Recharge/Discharge Rates
Water Infiltration/Percolation & Rates (Land Surface)
Cloud Properties (CCN, Particle-Size distribution and Phase/State, Cloud Liquid Water Content)
Aerosols
Sea Level Pressure (Surface Met/Hydromet)
Land Use Classification (Agriculture, Urban, Industrial, etc.)
Geologic Stratification & Geomorphological Classification
Water Quality & Composition (organic/inorganic contaminants, isotopic, suspended particulates, turbidity, salinity, color...etc)
Water Quality (Drinking/Potable Water)
Water Quality (Ground Water)
Hydro-Energy Water Demand/Use
Urban Water Demand/Use – Small Cities
Sub-Urban Water Demand/Use – Distributed (including Small Towns)
Water Regulation – National
Water Regulation – Trans-Boundary (State/National)