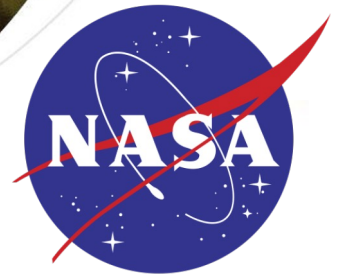


Community-Sourced NASA Terrestrial Water Cycle Science Opportunities

Overview and Outcomes
August 2026



Funding provided by
NASA's Terrestrial
Hydrology Program

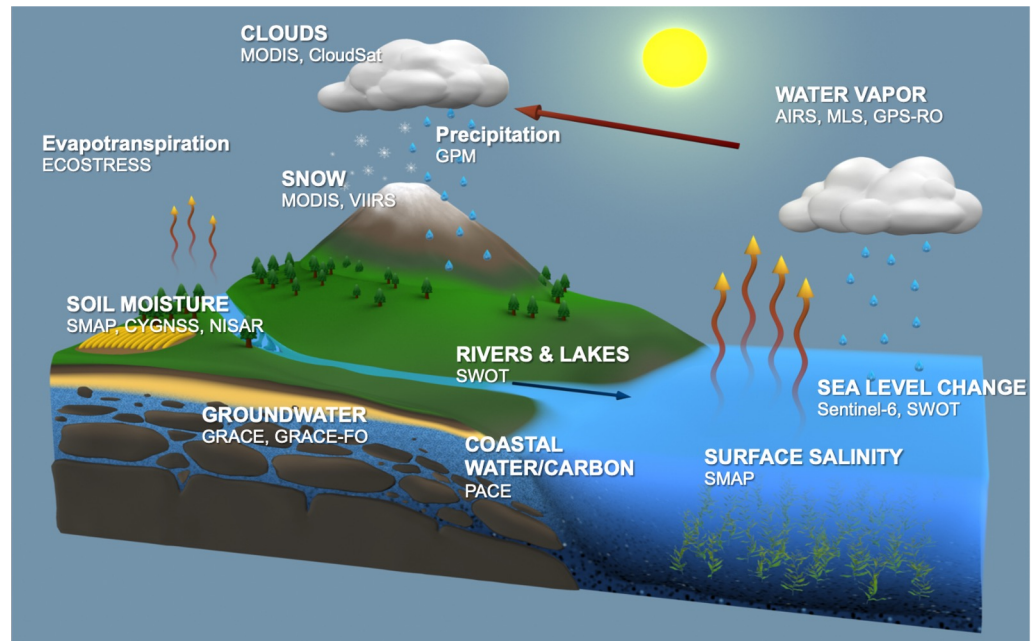
Grant 80NSSC25K7474

Overarching Aim

To continue and enhance the rigor and relevance of **Earth Observations and terrestrial water cycle science** to more effectively address challenges of relevance to **decision making and applications**.

This will be used to:

- inform the next Decadal Survey process for NASA
- elevate what advances are most needed now



Approach

To learn from interdisciplinary teams representing water-specific, societal-relevant convergent topical areas (**droughts, floods, water quality, water supply, water demand**) and expertise in **remote sensing, science, modeling and prediction, data science, and decision support** to:

- evaluate the value of existing data sources and capabilities
- assess new partnerships, technologies, and approaches
- identify science priorities that advance the ways space-based observations inform hydrological sciences *and* applications

To shape not just *what* we prioritize, but *how* we think about **advancing water cycle science to support decision-making and applications** in a resource-constrained environment.

Key components

Community questionnaire
(Dec 2025-Jan 2026)

Working groups meetings
(Jan-Mar 2026)

In-person synthesis workshop
(Apr 2026)

Post-synthesis working group
meetings (May 2026)

White papers for NASEM's RFI
(Aug 2026)

Synthesis report (Fall 2026)

A “Golden Age” of Terrestrial Water Cycle Observations

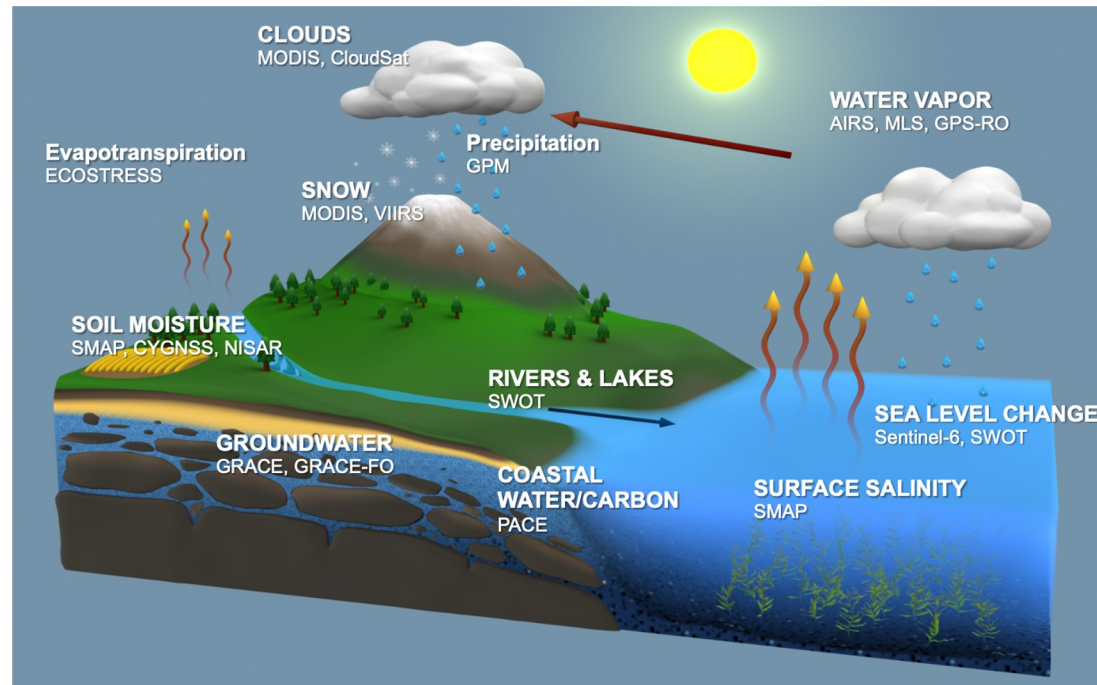
NASA has now provided at least one measurement of every major component of the water cycle

Decadal surveys

2007: mission driven, prove critical hydrologic variables could be reliably measured from space.

2017: "Targeted Observables." proving concepts emphasizing continuity, integration, and operationalization through a science- and observable-driven framework

2028: major challenges remain persistently in the "Partial / In Progress" category: snow, evapotranspiration, water quality, and integration of subsurface hydrology into predictive systems.



No longer sufficient to name a variable and expect a mission

We need to develop an ability to differentiate competing concepts and their potential contributions

Roles

Organizers (co-PIs)



Emily Jack-Scott
Aspen Global Change
Institute (AGCI)
Program Director



Sujay Kumar
NASA Goddard Space Flight
Center
Research Scientist



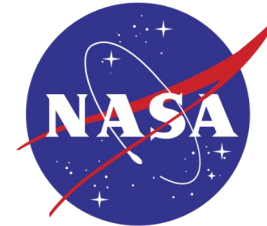
John T. Reager
Jet Propulsion Laboratory
Scientist



Timothy Schneider
National Center for
Atmospheric Research
(NCAR)
Project Manager III



Julie Vano
Aspen Global Change
Institute (AGCI)
Research Director



NASA PMs

- Craig Ferguson
- Erin Urquhart

Advisors

- John Bolten (GSFC)
- Stephanie Granger (JPL, ret)
- Jack Eggleston (USGS)
- Christa Peters-Lidard (WtrSense, LC; GSFC, ret)
- Peter van Oevelen (GMU; GEWEX)

Topical leads



Water Supply
Ethan Gutmann (NSF-NCAR)
Carrie Vuyovich (NASA)



Water Demand
Wade Crow (USDA-ARS)
Josh Fisher (Chapman Univ)



Water Quality
Bridget Seegers (NASA)
Steven Greb (UW)



Floods
Cédric David (NASA), Augusto Getirana (NASA), Paola Passalacqua (ETH Zürich)



Droughts
Amir AghaKouchak (UC Irvine), Justin Mankin (Dartmouth), Mark Svoboda (NDMC)



Reviewed concept

- Jay Famiglietti (ASU)
- Dennis Lettenmaier (UCLA, ret)
- Grey Nearing (Google)

The Community Questionnaire

- 10 open-ended questions, wealth of insights, highlights the thoughtfulness of our community
- **319 responses!**

<https://bit.ly/water-cycle-science-questionnaire>

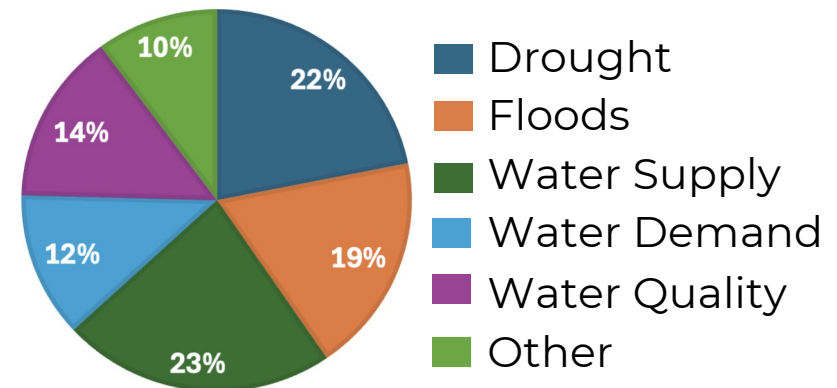
0% Survey Completion

NASA Water Cycle Science Opportunities

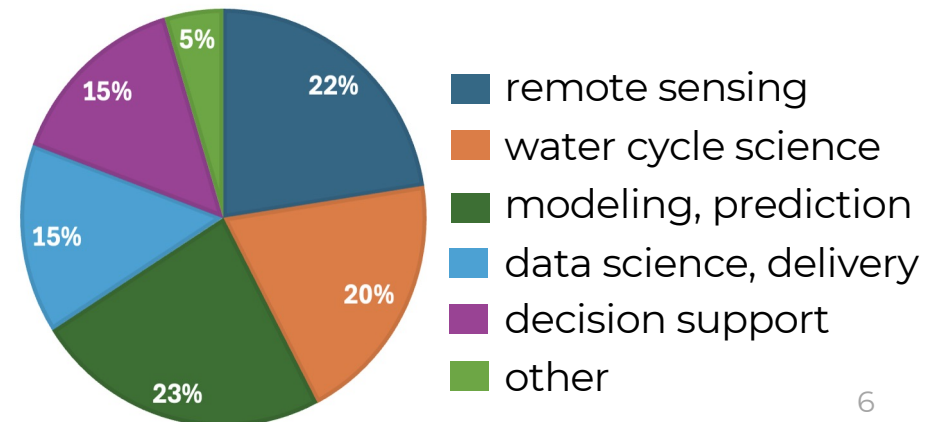
NASA's water cycle science community has made remarkable progress since the writing of the last [NASEM Decadal Survey in 2017](#), but as a community, we've also learned where assumptions were wrong, where technology surprised us, and where society's evolving needs outpaced NASA's ability to fund and implement new Earth Observing missions.

Our team was funded by NASA's Terrestrial Hydrology Program to aggregate and synthesize insights from those familiar with NASA's capabilities in water cycle science, to envision what is possible in this next decade: Where are the highest leverage points for societal benefit? How should NASA maximize impact of existing ground-airborne-satellite and Earth System modeling assets, and partner in new and innovative ways with other federal agencies.

Topical Area Representation



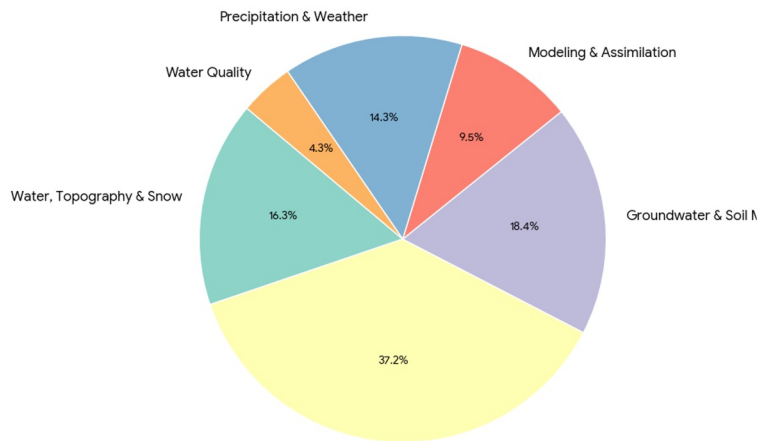
Expertise Representation



Key Community Questionnaire Insight: Valued Data and Products

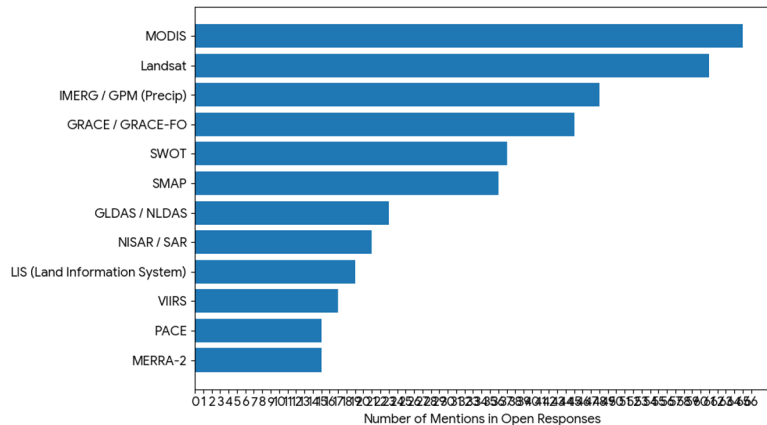


Data Mentions Grouped by Measurement Type / Specialty



Vegetation, ET & Land (Optical/Thermal)

Top Data & Models Mentioned by Community



Vegetation, ET & Land Cover (37.2%)

- o Includes: Landsat, MODIS, VIIRS, Sentinel, ECOSTRESS
- o Context: Driven by the massive "Water Demand," "Agriculture," and "Drought" users who need optical and thermal data to calculate crop stress and ET.

Groundwater & Soil Moisture (18.4%)

- o Includes: GRACE / GRACE-FO, SMAP
- o Context: The backbone of the "Water Supply" and "Initialization" communities looking for root-zone memory and aquifer depletion.

Surface Water, Topography & Snow (16.3%)

- o Includes: SWOT, NISAR / SAR, ICESat-2, SnowEx
- o Context: The "Floods" and "River Basin" managers needing high-resolution elevation, bathymetry, and inundation extents.

Precipitation & Weather (14.3%)

- o Includes: IMERG, GPM, TRMM, MERRA-2
- o Context: The fundamental forcing data required by all modelers to understand how much water is actively falling into the catchments.

Modeling & Assimilation (9.5%)

- o Includes: LIS, GLDAS, NLDAS
- o Context: Users who rely on NASA not just for raw pixels, but for structured, physics-based output that already fuses multiple sensor streams.

Water Quality (4.3%)

- o Includes: PACE, SBG (Hyperspectral)
- o Context: A smaller, specialized, emerging community waiting for next-generation spectral capabilities to diagnose algal blooms and aquatic health.

Key Questionnaire Insight: Cross-cutting Innovation Opportunities



Moving from 'raw data' to 'integrated intelligence'

1. "Digital Twin" & ML Workflows

- *The Need:* Fusing satellite and in-situ data for rapid decision support.

2. High-Resolution Earth System Models (ESMs)

- *The Need:* Bridging the gap between weather events and climate trends.

3. Next-Generation Spectral & Radar Missions

- *The Need:* Upgrading spatial/spectral resolution for inland water and soil moisture.

4. "Physically Consistent" Assimilation Frameworks

- *The Need:* Translating raw satellite pixels into usable hydrologic variables.

5. Long-Term Merged Datasets & Reanalysis

- *The Need:* Reliable, continuous forcing data for historical baselines and modeling.

High anticipation for "Landsat Next, which will represent a significant advancement," "PACE... to study inland water quality," and "NISAR in the future."

Valuing the "contribution of NASA missions to long-term merged satellite datasets," while noting reanalysis gaps ("MERRA needs improvement").

Key Questionnaire Insight: Strategic Tensions and Competing Needs



1. Latency vs. Scientific Rigor

- "Provisional" fast data (<6 hours) saves lives in disasters but risks false alarms. "Perfect" calibrated data (48 hours) is scientifically rigorous but operationally obsolete.

2. Global Baselines vs. Hyper-Local Action

- NASA excels at global, basin-scale physics, but water is managed at the street and farm level (<30m). Bridging this gap pushes NASA toward downscaling techniques that border on commercial territory.

3. Water Accounting vs. Agricultural Privacy

- Accurate hydrologic models require precise, field-level consumptive use (ET) data, but publishing this transparency triggers industry pushback over perceived "surveillance".

4. AI Speed vs. Physical Validity

- Machine learning is desperately needed to speed up processing and fill gaps, but purely data-driven AI "black boxes" often fail to obey physical laws (e.g., conservation of mass).

5. 2D Mapping vs. 3D Volumetric Reality

- Current satellites reliably map surface water extent, but predictive models are starved for 3D "Deep Storage" variables (aquifers, root-zone moisture, snow volume) that are much harder to measure from space.

Five Topical Working Groups

Drought

Amir Aghakouchak
Justin Mankin
Mark Svoboda

Members

Martha Anderson
Faisal Hossain
Laurie Huning
Flavio Lehner
Ben Livneh
Mahta Moghaddam
Jason Otkin
Christa Peters-Lidard
Roger Pulwarty
Steven Quiring
Angela Rigden
Hailan Wang
Brian Wardlow

Floods

Paola Passalacqua
Augusto Getirana
Cedric David

Members

John Bolten
Jessica Fayne
Stephanie Granger
Dave Gochis
Jim Nelson
Brett Sanders
Guy Schumann
Chaopeng Shen
Jason Regina
Andy Wood
Zong-Liang Yang

Water Quality

Steven Greb
Bridget Seegers

Members

Brian Barnes
Caren Binding
Keith Cherkauer
Heather Golden
Alex Held
Tiit Kutser
Christine Lee
Kelly Luis
Matt Ross
Blake Schaeffer
Stefan Simis
Rick Stumpf
Ryan Vandermeulen

Water Demand

Joshua Fisher
Wade Crow

Members

Wim Bastiaanssen
Michael Cosh
Pierre Gentine
Manuela Girotto
Stephanie Granger
Christopher Hain
Kyle Knipper
Alexandra Konings
Randal D. Koster
Forrest Melton
Diego Miralles
Julie Valdez

Water Supply

Carrie Vuyovich
Ethan Gutmann

Members

Ana Barros
Ali Behrangi
Clara Draper
Mike Durand
Dara Entekhabi
Christopher Frans
Paul Grogan
George Huffman
Jennifer Jacobs
Crane Johnson
Ed Kearns
Jessica Lundquist
Steve Marguilis
Reed Maxwell
Matt Rodell

Cross-Cutting Strategies across Topical Areas



[10.69925/YEUT6918](https://doi.org/10.69925/YEUT6918)

SHARED STRATEGIES FOR INTEGRATED WATER SCIENCE



FOUNDATIONAL VARIABLES



CONTINUITY



INTEGRATION



USABILITY



STRATEGIC PARTNERSHIPS

Practical approaches to achieving strategic priorities:

Elevate foundational variables: To sustain efforts, interagency coordination with buy-in at the highest level, around continuity of foundational variables.

See continuity as critical to innovation: Continuity allows for observations to keep going which allow for more innovative science, but it also allows for modernization (updating systems to do more, incorporate new technologies).

Leverage integrative approaches: an observatory approach to information is desirable with constellations and multi-mission data integration, integration frameworks for in situ, airborne, and space-based operations, and leverage modeling to fill gaps in observations wherever possible.

Consider usability from the beginning and throughout: To get to usability, need to reduce latency and mismatched scales - this requires integrating data into useful models, products, and tools that meet user needs (e.g., through deploying the WKID framework).

Share the load: innovative partnerships are key. From the onset, include multi-agency ownership of tech R&D/launch vs. off-ramps to sustain. Include private sector when there's a market. Collectively make the case for more resources.

Foundational variables

- Droughts, floods, water quality, water quantity, and water demand all rely on **key variables**.
- During the synthesis workshop we compared several existing lists of “foundational” or “essential”
- **Consistent and sustained collection** of these variables, at relevant spatial and temporal scales, would require interagency coordination with buy-in at the highest level.
- This could be achieved by supporting frameworks for **continual observing constellations**, as well as the integration of data across constellations, multi-mission programs, and in situ, airborne, and space-based platforms
- Observation gaps can be anticipated and managed through **data assimilation and modeling** wherever possible

Primary Essential Water Variables (EWVs)
Precipitation
Evaporation and Evapotranspiration
Snow (including snow water equivalent, cover, depth, freeze thaw margins)
Soil moisture, Soil temperature
Groundwater
Runoff/streamflow/river discharge
Lake/reservoir levels, water storage, and aquifer volumetric (or mass) change
Surface water extent
Bathymetry
Mass balances of glaciers and ice sheets
Water quality, including physical, chemical, and biological variables
Water use/demand (agriculture, hydrology, energy, urbanization, others)

Drought: Science Frontiers

Processes to be understood: Drought drivers, subsurface partitioning and transport, vegetation and human water coupling, evaporative demand and water-energy feedback

Information gaps prioritized:

1. Snow Water Equivalent (SWE) and Snow Hydrology
2. Root-Zone Soil Moisture
3. Terrestrial Water/Groundwater Storage at higher resolution
4. Human-Coupled Fluxes and Consumptive Use



Leads:

Amir AghaKouchak (UC Irvine)
Justin Mankin (Dartmouth)
Mark Svoboda (Nat'l Drought Mitigation Center)

A key takeaway:

Drought is fundamentally an emergent, temporary process resulting from **interactions among all terrestrial water storage compartments and human water use.**

Need an intentional blend of integration frameworks (available immediately) and hardware investments (long-term priorities). For example, an **integrated multi-domain water storage framework** could bring together existing observations through physics information AI/ML and land surface models.

Read more:

[10.69925/XYOC6054](https://doi.org/10.69925/XYOC6054)



Drought: Information Needs



Measurement/ Processes	Target Resolution and Latency	Existing Spaceborne Observations	Gaps and Technical Limitations
Snow Water Equivalent (SWE) and Snow Hydrology	~1 km spatial resolution Weekly temporal interval Low latency (<1 week)	MODIS, VIIRS (optical snow cover area); passive microwave arrays	Fifteen existing gridded products show major disagreement over catchment-scale SWE trends. Optical tools only see snow extent, while passive microwave (~25 km) fails in steep mountain terrain.
Root-Zone Soil Moisture	Sub-10 km spatial footprint 3–5 day temporal return Root-zone depth tracking	SMAP, SMAP L4, NISAR, ESA BIOMASS (P-band SAR; potential direct RZSM retrieval)	SMAP and NISAR primarily provide surface or near-surface soil stocks. Earth observation lacks operational capacity to measure the transport of water down to the water table. BIOMASS (P-band) offers potential direct RZSM sensing but cannot transmit over...
Terrestrial Water Storage Change	Basin scale (~100 km); Weekly to monthly intervals; High mass sensitivity.	GRACE, GRACE-FO	Coarse spatial resolutions do not support process-level understanding of subsurface water transport at societally relevant local scales.
Human- Coupled Fluxes and Consumptive Use	Field scale (<30–100 m) 1–2 day temporal interval Low operational latency	ECOSTRESS, Landsat TIR, NISAR OpenET	Existing drought monitoring frameworks struggle to decouple natural ecohydrological drought stress from localized human extraction and irrigation.

Floods: Science Frontiers

Processes to be understood: Geometric controls, surface water dynamics, land-surface conditions, precipitation that drives flash floods

Information gaps prioritized:

1. Flood plain and river bathymetry
2. High-res flood dynamics during events
3. Antecedent land-surface conditions in complex terrain
4. High-resolution extreme precipitation characterization



Leads

Paola Passalacqua (ETH Zürich)
Cédric David (NASA)
Augusto Getirana (NASA)

A key takeaway:

High-resolution flood modeling will remain bottlenecked by the physical template; **we cannot solve for inundation if we do not solve for geometry.**

Closing these gaps requires a move away from "satellite-only" data toward a **hybrid ecosystem** that integrates space, airborne, and commercial terrain products into trusted workflows.

Read more:

[10.69925/UBEA6800](https://doi.org/10.69925/UBEA6800)



Water Quality: Science Frontiers

Processes to be understood: Primary production and species composition, sediment transport and land-water connectivity, aquatic biogeochemistry

Information gaps prioritized:

1. Spatial-spectral-temporal matching
2. In situ calibration and validation infrastructure
3. Data downlinks and interconnected data systems
4. Increased modeling and non-optical domains



Leads

Bridget Seegers (NASA)
Steven Greb (UW Space
Science & Eng.)

A key takeaway:

Satellites bolster available measurements to inform water quality decisions in **public health** and **environmental monitoring**.

Advancements would come through a constellation of satellites that provide a **water quality suite** of integrated datasets. Yet, progress also requires **strategic community coordination on validation methods, equipment, training and modeling**.

Read more:

[10.69925/WAXL4673](https://doi.org/10.69925/WAXL4673)



Photo Credit: Norman Kuring, [NASA](#)

Water Supply: Science Frontiers

Processes to be understood: Seasonal storage reservoirs, precipitation distribution and phase partitioning, water storage partitioning, water supply losses

Information gaps prioritized:

1. Snow Water Equivalent (SWE)
2. Precipitation over complex terrain and high-altitude
3. Terrestrial and Groundwater Storage at higher spatial resolution
4. ET and Other Water Losses



Leads:

Ethan Gutmann (NSF-NCAR)
Carrie Vuyovich (NASA)

A key takeaway:

Future efforts to better characterize water supply (including SWE) should build missions to fill specific gaps and frameworks to leverage available data in a **multi-sensor modeling approach**.

These can be **co-developed with decision-makers** to facilitate satellite data delivery that matches the explicit format, latency, and requirements of operational decision models.

Read more:

[10.69925/LCQU1962](https://doi.org/10.69925/LCQU1962)



Photo Credit: ESA

Water Demand: Science Frontiers

Processes to be understood: Variation in natural water stores, ecohydrology, consumptive use, water and energy balance closure

Information gaps prioritized:

1. Higher spatial-temporal Land Surface Temperature (LST) and Thermal Infrared
2. Surface to Root-Zone Soil Moisture
3. Vegetation Traits and Hyperspectral VSWIR
4. Near-Surface Micrometeorology



Leads:

Wade Crow (USDA-ARS)
Josh Fisher (Chapman Univ)

A key takeaway:

Closing water demand gaps requires **rethinking mission design, integrative approaches and partnerships.**

For example, **private-public partnerships** could reduce critical spatiotemporal gaps (e.g., emerging commercial smallsat like Hydrosat's daily thermal, Planet's high-frequency VNIR, Pixxel's high-resolution hyperspectral, and ICEYE's radar).

Read more:
[10.69925/SJAN6565](https://doi.org/10.69925/SJAN6565)



Photo Credit: ESA

Community Inputs on Strategic Priorities for NASA

GOALS FOR SCIENTIFIC DISCOVERY AND WATER CYCLE BENCHMARKS



DISCOVERING CHANGES



HUMAN INTERACTIONS



AUTHORITATIVE BENCHMARKS



SOCIETAL NEEDS

Valued by all working groups, reflecting enduring scientific challenges and emerging opportunities:

- 1. Discover how the terrestrial water cycle is changing**, reshaping water availability and extremes, threatening lives, infrastructure, and food security; we need reliable, timely, credible information to detect shifts, uncover mechanisms and cascading impacts.
- 2. Explore how human activities interact with the terrestrial water cycle**, including reservoir management, irrigation, groundwater pumping, land-cover change, urbanization, and inter-basin transfers, which reshape how water moves, yet difficult to simulate and predict.
- 3. Advance consistent, authoritative terrestrial water cycle benchmarks**, which provide critical continuity to detect and track changes, advance model predictions, improve interoperability, and inform AI/ML efforts.
- 4. Let societal needs shape terrestrial water-cycle science priorities**, elevating applications as design constraints from the outset, strengthening the science by demanding relevance, robustness, transparency, and clearly communicated uncertainty.



[10.69925/YEUT6918](https://doi.org/10.69925/YEUT6918)

Water Connects All of the Spheres

INTEGRATING THE EARTH'S INTERCONNECTED SYSTEMS



HYDROSPHERE



ANTHROPOSPHERE



ATMOSPHERE



BIOSPHERE



GEOSPHERE



CRYOSPHERE

The movement of water on or within the land shapes the land and affects life; life, in turn, alters the quantity and quality of water. Key terrestrial water cycle (TWC) linkages include:

Hydrosphere: Within the hydrosphere, coastal process and coupling drive variability, residence, and transport of oceanic, atmospheric water that fuels the TWC.

Anthroposphere: Human activities through agriculture, reservoirs, infrastructure, energy and transportation systems among other activities, reshape how water moves and impact water extremes.

Atmosphere: The atmosphere is a key driver of TWC processes through radiation, vapor pressure deficit, thermodynamic and biogeochemical processes in the planetary boundary layer.

Biosphere: Earth's living ecosystems impact water availability through evapotranspiration and water quality

Geosphere: Earth's surface holds water in groundwater, sub- and near-surface soils. Landform processes shape bathymetry and drive land loss or gain.

Cryosphere: Snow and ice change how water moves, especially in the mountains, in glaciers, and through permafrost.



[10.69925/YEUT6918](https://doi.org/10.69925/YEUT6918)

Conclusions and next steps

- Incredible response from the community, people keen to build science questions within context of real-world decisions
- Many common threads and opportunities for shared learning
- White papers for NASEM's RFI submitted; happy to share
- Synthesis report will be shared this fall along with various presentations sharing with NASA and the broader community



Funding provided by
NASA's Terrestrial
Hydrology Program
Grant 80NSSC25K7474

It takes a community...!

- PIs, Topical Leads, Advisors, Working Group Members
- Community questionnaire respondents (319!)
- NASA Hydrosphere, Water Resources, and other participating PMs

For all who engaged, thank you!





Thank you for sharing
your insights!

Contact:

ejs@agci.org

tls@ucar.edu

john.reager@jpl.nasa.gov

sujay.v.kumar@nasa.gov

jvano@agci.org