Pacific Northwest NATIONAL LABORATORY

Idaho National Laboratory

PNNL-29471

Water Innovation and R&D Concept Exploration and Preliminary Assessment

Water Scoping Project Report Deliverable

December 2019

RS O'Neil[1]
TM Harris[1]
TM Mosier[2]

[1] Pacific Northwest National Laboratory
[2] Idaho National Laboratory

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, **makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights**. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062
www.osti.gov
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
or (703) 605-6000
email: info@ntis.gov
Online ordering: http://www.ntis.gov

PNNL-29471

Water Innovation and R&D Concept Exploration and Preliminary Assessment

Water Scoping Project Report Deliverable

December 2019

RS O'Neil[1]
TM Harris[1]
TM Mosier[2]

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99354

[1] Pacific Northwest National Laboratory
[2] Idaho National Laboratory

Abstract

Pacific Northwest National Laboratory and Idaho National Laboratory produced a cursory review and initial framework to support the US Department of Energy's Water Power Technologies Office (WPTO) in considering options for program development related to water. The laboratories provided a suite of tools – rationales, evaluation criteria, and visual maps – as well as R&D concepts that could be applied at various scales over short- and long-term time horizons.

By design the effort was not intended to be a comprehensive or detailed analytical exercise, rather an exploratory project guided by DOE interactions and direction. This report summarizes the work provided to WPTO and is not intended for broad distribution.

Summary

To expand the potential range of research and uncover new avenues of opportunity for positively impacting the hydropower sector, the Water Power Technologies Office funded a small scoping task in FY19. Provided in this report are the principal results of the task: ten research and development concepts that adopt a water perspective, by which we mean are primarily designed to advance a water outcome but also offer benefits for the hydropower program mission space, and an evaluation framework for the concepts.

These ten R&D concepts are captured in Section 2:

- **Use-oriented forecasting.** A systematic assessment of the value of forecasting accuracy for informing specific water–hydropower decisions at multiple timescales.
- **Water and snow monitoring.** Improved integration of remote-sensing and in-situ measurements to increase information for water-hydropower decision making.
- **Rural water supply and treatment systems.** Reinvestment to meet immediate needs for improved municipal water services while also providing much broader community, environmental, and resilience benefits.
- **Improved metrics and sensors.** Development of rugged, reliable, and accurate sensors; potentially also includes data analysis platforms.
- **Networks for water technology development.** Organize and leverage laboratory capabilities for water technology and R&D in partnership with industry.
- **Water resiliency.** Holistic approaches and technologies to water efficiency to reduce risk and vulnerabilities of less secure water environments.
- **Water as DER.** Utilize the emerging distributed energy resources (DER) business model and transactions to illustrate water as a potential energy resource.
- **Alternative markets for small hydropower.** New value propositions, co-benefits and specialized markets for small-scale hydropower development.
- **System-wide environmental benefits.** How can coordination or river regulation from hydropower yield net environmental benefits?
- **Water and power co-design.** Coordinated design that acknowledges the coupling, capabilities, and criticality of infrastructure that integrates water and power systems.

To review these R&D concepts, evaluation criteria and mission-based rationales were created. The purpose of the criteria is to reflect on the value of the concept to the program:

- **Demonstrated and measurable impact.** Example impacts are more energy, improved water or ecological objectives, improved value of hydropower.
- **Scalability.** Is the solution possible in many locations and scales, or is it limited in its application?
- **Achievability for level of effort.** Is it possible for R&D to reach an impact within reasonable timeframes and funding mechanisms?
- **Unique role of DOE.** How does support from DOE influence the likelihood of the R&D?
- **Proximity to DOE mission and programs.** Relationship to Water Power Technologies Office mission and the guiding rationales, relationship to the Water Security Grand Challenge.

The purpose of the rationales is to reflect on the nexus of the concept to hydropower program goals:

- **Enable Outcomes.** Hydropower is a critical enabler of non-power benefits, especially to water conditions (quality, quantity, resiliency, and ecology).
- **Replication**. Hydropower solutions are replicable in the greater water management industrial sector.
- **Water Barrier**. DOE cannot achieve hydropower goals without addressing a challenge related to water conditions.
- **Fuel.** Water availability and predictability are important as the fuel for electric loads and production.
- **Water Quality.** Enhancement to water conditions is achieved through hydropower growth.

In order to delimit the role of the U.S. Department of Energy among agencies and funders, this report provides an overview of federally funded water programs and the associated mission spaces of those programs. This material is presented in Section 3 with supporting detail in Appendix A.

In Section 4, the report supplies foundational challenges to water system innovations. The function of this section is to offer a high-level context on what issues are relatively immobile or deeply embedded in the water innovation landscape. These are identified as the following, and are not intended as a comprehensive list:

- Existing water infrastructure
- Legacy water policies
- Public-private partnership support
- Siloed water uses
- Inefficient water allocation
- Policy, data, and R&D gaps
- Change from historic patterns

The project team additionally attended seminal water sector conferences and reached out to experts in the field to understand opportunities for water technology innovation and R&D. Certain of these activities extend naturally into FY20; what interviews and outreach occurred in FY19 is documented in this report.

Acknowledgments

The authors wish to thank the contributions of the Water Power Technologies Office Hydropower Program staff in sponsoring and providing feedback to this project, in particular Alejandro Moreno, Hoyt Battey, Mark Christian, Marisol Bonnet, Simon Gore, Madden Sciubba, and Tim Welch.

Acronyms and Abbreviations

AMO	Advanced Manufacturing Office
AWWA	American Water Works Association
CEATI	Centre for Energy Advancement through Technological Innovation
DER	Distributed Energy Resources
EPA	(U.S.) Environmental Protection Agency
GMLC	Grid Modernization Laboratory Consortium
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Association
NRECA	National Rural Electric Cooperative Association
NREL	National Renewable Energy Laboratory
PBE	Powering the Blue Economy
R&D	Research and Development
ROI	Return on Investment
USDA	United States Department of Agriculture
USDOE	United States Department of Energy
WECC	Western Electricity Coordinating Council
WEFTEC	Water Environment Federation's Technical Exhibition and Conference
WPTO	Water Power Technologies Office

Contents

Figures

1.0 Introduction

The purpose of this report is to provide context, background, and findings for an initial task to scope potential water R&D concepts for the Water Power Technologies Office (WPTO). The task also includes several outputs in addition to the R&D concepts that are informative unto themselves, such as a federal water funding landscape, fundamental challenges in addressing water issues, and interviews with water experts on topic that they see as ripe for progress.

The results of this task should be considered as a step along a path. They are not an endpoint, nor are they comprehensive. Rather, they create the basis for thinking more holistically about water research in the context of water power and they provide a set of examples (the R&D concepts) for taking next steps into this space.

1.1 Origin of the Work

The original motivation for this task came in two forms: top-down, using the Water Security Grand Challenge[1] as a framework for considering broader applications and mechanisms to address water-based issues; and bottom-up, as the Irrigation Modernization[2] concept illustrated how hydropower development has a unique value proposition as a critical enabler to water infrastructure solutions. The question was: what other potential business models, use cases, or R&D could be employed to address water more broadly and simultaneously advance WPTO mission space?

In December 2018, DOE approved a PNNL/INL memo outlining a scoping task to better understand the water/water-power nexus as it relates to WPTO, using the two above-outlined motivations as lenses. The task was intended to capitalize on the specific expertise, backgrounds, and professional relationships of the authors. As a result, the bulk of the task is in presenting a range of tools and concepts generated from the authors.

1.2 A Different Perspective

Energy-water nexus solutions tend to advance technology trajectories for either the energy or the water system. For example, solutions either design energy technology to be less dependent on water or increase water availability for energy production.

This scoping effort used a broader lens for thinking about water in the context of water power systems. A useful paradigm for conceptualizing this broadening perspective is by transitioning from thinking about water as a constraint to thinking about water as a co-optimized parameter in the combined system. In particular, the water power industry often treats the fuel resource – water – as a constraint rather than a dynamic component of the system. This paradigm shift opens a larger solution space for identifying water technologies that improve water power performance as well as advance solutions for water-based objectives, such as improved ecology, efficiency, or resiliency.

[1] https://www.energy.gov/eere/water-security-grand-challenge
[2] https://www.energy.gov/eere/water/articles/new-way-modernize-irrigation-infrastructure-and-generate-renewable-energy

One paradigm for thinking about the proposed approach is to expand the ways we think about water as it relates to water power technologies. This increases the technology and innovation solution space.

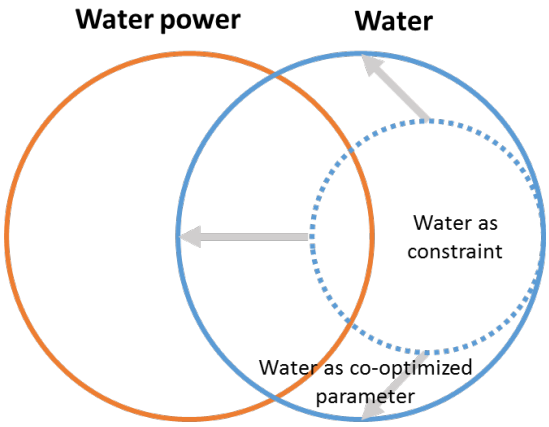


Figure 1. Overlap between Water and Water Power landscapes.

This scoping effort identified potential areas of research and inquiry that could advance the WPTO mission through improved understanding and utilization of water, along with a supporting suite of criteria and barriers by which to evaluate and organize future research topics. Some of the selected R&D options are immediately actionable as standalone projects, while others require more in-depth planning and development.

1.3 Project Deliverables

The deliverables of this work are both tangible – i.e. concrete areas for further investigation – and broad and forward thinking – i.e. a framework to organize and evaluate existing and prospective research and development investments in water relevant to WPTO. The primary outcome of this effort was to deliver a report that explores a series of potential R&D investment options, broader water technology solutions, and next steps for WPTO considering the broader scoping lens.

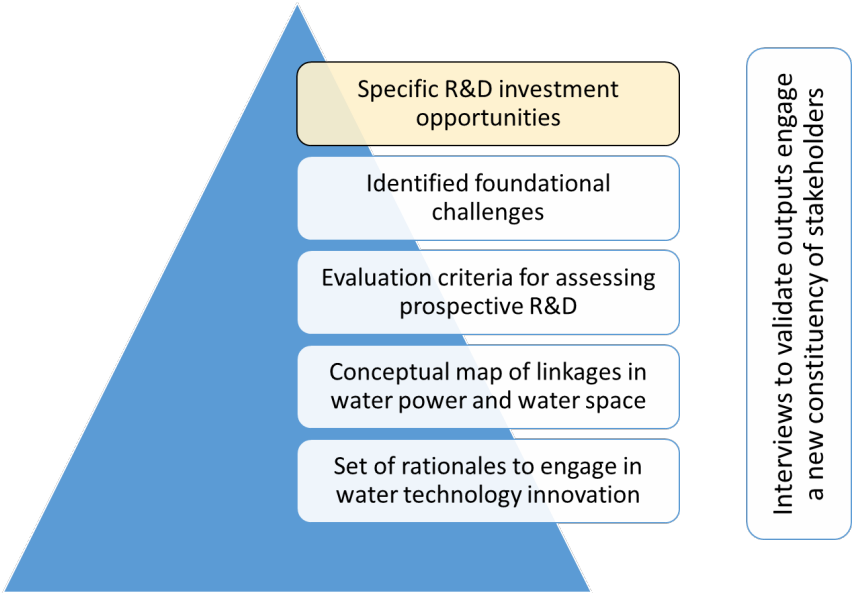


Figure 2. Conceptual outline of outputs.

There are six sets of deliverables provided by this task:

1. R&D Concepts [detailed in Section 2]
2. Mission Rationales [Section 1.4]
3. R&D Concept Evaluation Criteria [Section 1.5]
4. Conceptual Maps [Section 1.6]
5. Interviews and Outreach [Section 1.7]
6. Foundational Challenges [detailed in Section 4]

1.4 Water R&D Mission Rationales

This new lens for exploring opportunity in water systems requires us to think about water broadly and holistically with respect to achieving WPTO mission goals. The team created a set of "rationales" to explain the connection between the R&D concept and the WPTO mission space.

An example of a rationale for irrigation modernization: in order to achieve the energy goal of higher deployment of low-head small-scale hydropower technologies, it may be essential to first find high-value applications of hydropower within larger opportunities to improve rural water resilience, enhance water delivery infrastructure, and provide environmental benefits. The "rationale" here, then, is that in order to meet our hydropower deployment objective within water infrastructure, we first must improve the business model for water infrastructure upgrades.

Here we present other, similar rationales that demonstrate a connection between WPTO mission and important water R&D activities.

- **Enable Outcomes.** Hydropower is a critical enabler of non-power benefits, especially to water conditions (quality, quantity, resiliency, and ecology).
- **Replication**. Hydropower solutions are replicable in the greater water management industrial sector.
- **Water Barrier**. DOE cannot achieve hydropower goals without addressing a challenge related to water conditions.
- **Fuel.** Water availability and predictability are important as the fuel for electric loads and production.
- **Water Quality.** Enhancement to water conditions (quality, quantity, resiliency, and ecology) is achieved through hydropower growth.

It is not necessary for a given R&D concept to be strongly connected to every rationale. Rather, they should be well-aligned with at least one rationale. A strong connection to multiple rationales indicates closer proximity to existing portfolio of WPTO work.

These rationales are scored on a scale of 0 to 5 for each of the R&D concepts (example in Figure 3). The scores are a byproduct of author judgement and are meant to enable a partial comparison between R&D concepts. Of note, the rationales do not include several factors that may be important to fully rank and compare R&D concepts, such as expected impact for a given level of effort.

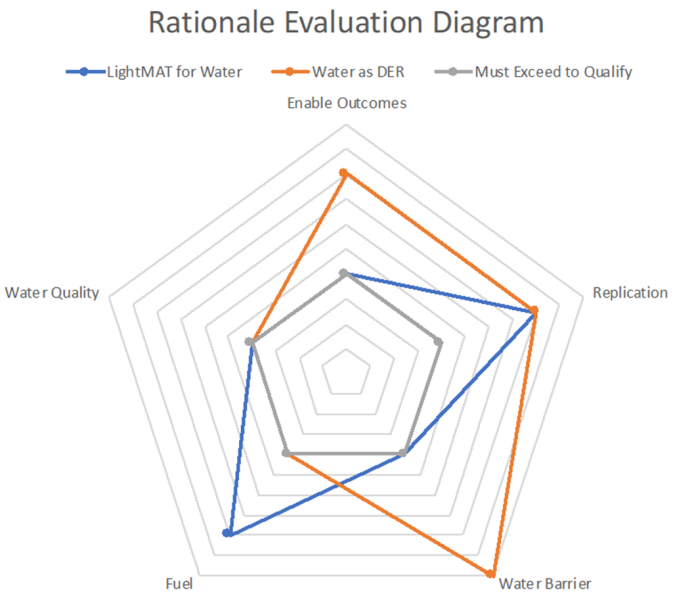


Figure 3. Example rationale scores.

1.5 Evaluation Criteria for Water R&D Concepts

The purpose of the evaluation criteria is to provide a mechanism for WPTO to weigh water R&D concepts. Using these criteria, WPTO could categorize, qualitatively prioritize, or assess concept maturity and urgency.

The criteria will be applied to the specific R&D investments that we recommend as appropriate for future consideration by WPTO.

- **Demonstrated and measurable impact.** Example impacts are more energy, improved water or ecological objectives, improved value of hydropower.
- **Scalability.** Is the solution possible in many locations and scales, or is it limited in its application?
- **Achievability for level of effort.** Is it possible for R&D to reach an impact within reasonable timeframes and funding mechanisms?
- **Unique role of DOE.** How does support from DOE influence the likelihood of the R&D?
- **Proximity to DOE mission and programs.** Relationship to Water Power Technologies Office mission and the guiding rationales, relationship to the Water Security Grand Challenge.

Each R&D concept should meet a minimum level in all criteria. However, concepts should not necessarily be prioritized based on their average criteria rank because the selection for further investments should be based on more granular information, such as the type of impact desired.

1.6 Conceptual Maps

PNNL and INL each developed a complementary conceptual map template, referred to respectively as “Orb” and “Tile”. These maps are useful in two ways: to represent the elements of a known concept and explore new concepts. Additionally, a goal is for the conceptual maps to reveal where there are crucial gaps or how an unexpected adjustment to the scope may add significant value. Almost all R&D concepts can be appropriately represented by both conceptual maps.

The conceptual map will provide a more comprehensive structure of WPTO-related water innovation and a visual demonstration of how the R&D concepts fit within that picture. The purpose of this map is to give WPTO a sensibility about how closely linked the R&D concepts are, how well they represent diversity or clustering along certain parameters, and how to indicate where remaining white space may be.

PNNL and INL did not create conceptual maps for each R&D concept presented in Section 2. The orb conceptual map is a visually intense representation of relationships and interdependencies, which is a useful descriptor of the concept once fully developed. The tile conceptual map is useful in the *development* of R&D ideas by switching permutations of tiles but is not insightful in its final form once the concept is determined.

1.6.1 Orb Conceptual Map

The orb conceptual map is designed to represent flows of mass and energy within a system. As such, it is well suited to identify the locations within a system where a tangible R&D concept may reside. The orb conceptual map can also serve as a valuable communication tool since it is visually intuitive and enables a before and after comparison.

The level of detail used in an orb map depends on how it will be used. The most "zoomed out" version is essentially a flow chart tracking the interactions of mass and energy for multiple sectors. A granular version could focus on the attributes of a single plant. The example orb conceptual map shown in Figure 4 displays a useful level of detail for mapping a well-defined R&D concept. The detail is exemplified by a focus on connection between major devices in a given system (in this case water conveyance infrastructure for agriculture).

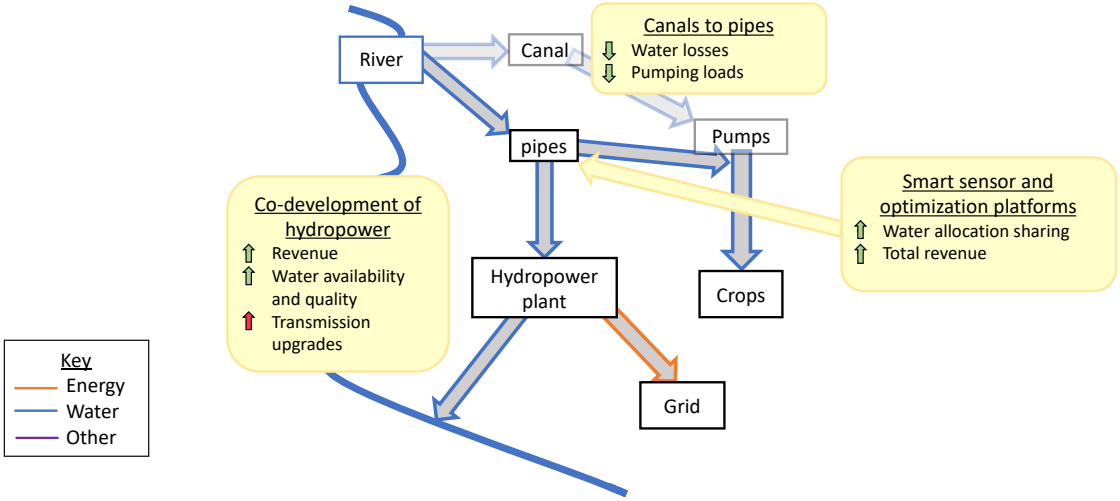


Figure 4. Orb conceptual map example for irrigation modernization.

1.6.2 Tile Conceptual Map

The "tile" conceptual map is a functional contrast to the orb chart. Instead of representing relationships between identified components to illuminate a known system, it is a tool to engineer new solutions through juxtaposition of many potential components in order to find the workable system. An example tile map is provided below, where selection of certain groups of tiles will combine to make different technical concepts as well as different elements of that technical concept. Each grouped area – sector, value, work – has several components within it that we refer to here as a "tile"; there are no correct number of tiles or orders.

The benefits of this conceptual map are that it illustrates unique combinations through selecting different sets of "tiles;" and that it allows exploration of unexpected pairings to find new R&D spaces. Every R&D concept has an associated "recipe" of tiles, though once identified, the map tool has lost most of its value, as it will appear as a list rather than as a visual explanation.

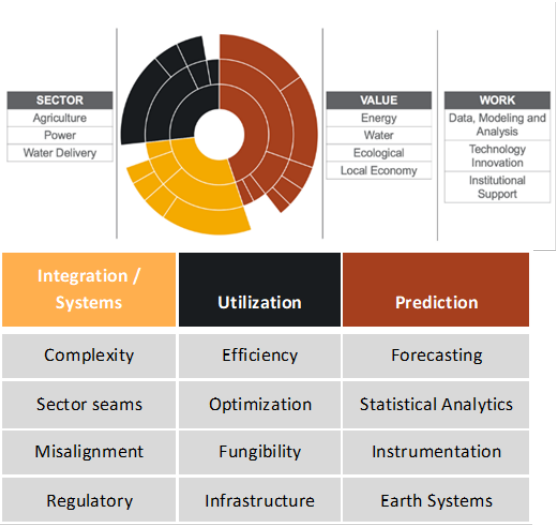


Figure 5. Tile conceptual map example

1.7 Interviews and Outreach

To complete this project, the authors conducted outreach to water sector expertise with diverse perspectives who understand research and energy challenges in order to provide additional technical perspectives to the project. Interviews were sought with entrepreneurs, funders, innovators, and resource managers that focus on water with some insight into clean energy and hydropower. These interviews provided a sense of priorities and context and motivations that shaped the R&D ideas indicated below.

1.7.1 Interview Consultations

The project team had numerous informal conversations with state and federal agencies, universities and national laboratories, industry practitioners, technology developers, accelerators, foundations, river conservation organizations, and others working in the water R&D innovation space. Takeaways from these conversations:

- The energy-water nexus is a tired topic. For many, it was cycling back the clock to talk about the junction of interests – but when the conversation focused on priorities for water R&D and innovation, there was a change in engagement and the opportunity landscape. This speaks to the need for new, big themes that can encompass energy objectives and still allow open thinking about water technology solutions.

- There is a need for more public-minded funding agents in the water R&D space. Water technology lacks patient and knowledgeable investors that can handle long cycles (patient capital) and development risks, focused on strong public benefit in place of obvious market ROI.

- Water technology solutions are in need. As a largely public and fragmented sector with little capital and significant human health and safety requirements, there is a low risk tolerance and slow adoption for new technologies. The water sector lacks the research infrastructure and long-term funding support that is present in the energy sector. In

addition to technology solutions, pathways for demonstration to scaled adoption are required for impact.

1.7.2 Conference Outreach

The project teams attended two conferences: Water Environment Federation's Technical Exhibition and Conference (WEFTEC, September 2019, Chicago, Illinois, focused more on wastewater) and American Water Works Association (AWWA, June 2019, Denver, Colorado, focused more on drinking water).

WEFTEC

Key takeaways from the WEFTEC conference related to Water Power's interest in critical technology and R&D requirements:

- The water and wastewater utility sector has similar characteristics to the hydropower industry: aging infrastructure, demographics, slim margins, risk averse, robust consulting support sector, iterative technology advancement, prepping for climate change largely in the form of extreme events.
- Integration between water and power is not common or really considered, in crisis or in configuration, in order to maintain independent control of systems.
- DOE focus should be on long-term and cross-disciplinary solutions, beyond the acute problems that the water and waste-water sector faces today and that its support sector can resolve.
- There may be an opportunity to focus on small rural municipal water supply systems in the short term. Water supply and irrigation systems have several similarities, and are also under-resourced, so our involvement could have a meaningful impact in geographically distributed communities across the U.S., for example, there are case studies where small investments have had major impact on water systems in areas such as Alaska and rural Arizona.
- The research community in the water sector is not as centrally organized or as federally dominant as in the energy sector. It is not clear that US DOE is seen as a significant player and experienced poor attendance at its talks.
- Two notable and new policies: the Water Infrastructure Improvement Act enables integrated wastewater and stormwater management[3] and watershed-based permitting (EPA) enables consideration of all stressors within a hydrologically defined drainage to achieve environmental outcomes.[4]

AWWA

Relevant themes at the American Water Works Association[5] annual conference included advanced metering infrastructure (AMI) for water, hydropower, climate change,

[3] https://www.congress.gov/bill/115th-congress/house-bill/7279
[4] https://www.epa.gov/npdes/watershed-based-permitting
[5] The American Water Works Association is an international, nonprofit, scientific and educational society dedicated to providing total water solutions assuring the effective management of water. Founded in 1881, the Association is the largest organization of water supply professionals in the world. The membership includes over 4,300 utilities that supply roughly 80 percent of the nation's drinking water and

emergency preparedness, water loss reduction and generally how to reduce energy costs for water utilities.

- *Advanced Metering Infrastructure for water.* The water industry is looking to piggyback water onto electric Advanced Metering Infrastructure (AMI). In one system offered by Itron, the AMI can detect leaks in the water distribution network through a sensor on customer AMI meters. These can also be used to spot when people are using water during curtailment periods. Over-pressurizing water systems in an attempt to manage energy use to support grid operations can create more leaks. Leaks are part of what are referred to as "non-revenue water," by water utilities. Non-revenue water is water that is "lost" before it reaches the customer. It includes physical losses (leaks) as well as apparent losses (such as through meter inaccuracies). There is a push to reduce non-revenue water, a form of system efficiency.
- *Risk assessments and emergency response plans.* The U.S. Environmental Protection Agency regulates water utilities in America based on its mandate to enforce the clean water and safe drinking water laws. On October 23, 2018, America's Water Infrastructure Act (AWIA) was signed into law. AWIA requires all community water systems serving more than 3,300 people to develop or update risk assessments and emergency response plans.[6] The law specifies components that the risk assessments and ERPs must address and establishes deadlines. An "all hazards" approach must be used, and they must look at natural disasters and malevolent acts. Applicable standards include AWWA G440 (Emergency Preparedness Practices)[7] and G430 (Security Practices for Operation and Management) standards and RAMW-J100 (Risk and Resilience Management of Water and Wastewater Systems).
- *Climate risk to water utilities*. There are many climate change risks to water utilities. Many treatment plans are in low coastal areas (especially wastewater treatment plants) at risk of inundation from storm surge and sea-level rise, which could inundate pump stations and electrical gear. Saltwater intrusion into drinking water supplies is another concern as sea levels rise and groundwater resources are depleted. More intense spikes in wastewater volumes from storm events, increased sediment load from storms and fires, and pro-active power outages to reduce chance of wildfires, as in California, were all indicated as significant risks.
- One objective of conference attendance was to understand more about water R&D for this sector. Based on information gleaned at the conference, it seems that most national level water research is being conducted through the Water Research Foundation. The U.S. EPA regulates water utilities nationally but conduct significant research. The California Energy Commission is also involved in large scale research efforts through its EPIC program, such as the Stantec research projects related to in-conduit hydropower potential in California and general considerations for battery storage at water and wastewater treatment plants. National guiding documents and manuals are developed by the two large water related professional organizations in the United States: American Water Works Association (focused mostly on drinking water) and the Water Environment Federation (focused more on wastewater).

---

treat almost half of the nation's wastewater. Our 51,000 total members represent the full spectrum of the water community: public water and wastewater systems, environmental advocates, scientists, academicians, and others who hold a genuine interest in water, our most important resource. https://www.awwa.org/About-Us

[6] https://www.federalregister.gov/documents/2019/03/27/2019-05770/new-risk-assessment-and-emergency-response-plan-requirements-for-community-water-systems

[7] https://www.awwa.org/Store/Product-Details/productId/62471757

U.S. EPA online resources:

- EPA Power Resilience Guide for Water and Wastewater Utilities. https://www.epa.gov/sites/production/files/2016-03/documents/160212-powerresilienceguide508.pdf
- Drinking Water and Wastewater Resilience. www.epa.gov/waterresilience.
- EPA's CREAT tool – Climate Resilience and Awareness Tool. https://www.epa.gov/crwu/creat-risk-assessment-application-water-utilities

2.0 R&D Concepts

This work identified specific R&D concepts, investment opportunities, broader technological solutions, and next steps for consideration by WPTO. These R&D concepts range from tangible – i.e. concrete areas for further investigation – to broad and forward thinking – i.e. a framework to organize and evaluate existing and prospective research and development investments in water relevant to WPTO.

Some concepts require more in-depth and targeted scoping to build confidence that they are ready for more significant investment. However, other concepts are sufficiently mature and therefore ready for immediate consideration as R&D investment opportunities. Some activities are not unique to WPTO and are appropriate for joint efforts as identified.

This work was not intended to be a thorough and comprehensive suite of options. Instead, the team strove for diversity in project character, technical discipline, and stakeholder viewpoints, so that WPTO will have a starting point and a reasonable spectrum for considering further investments. The team also did not intend to provide laboratory-specific solutions. Where reasonable, the authors pre-scoped the topics quantitatively; however, much of the analysis was qualitative due to the nature of this exercise.

The following 10 R&D concepts were identified by the team for further investigation and potential implementation by the WPTO and reported in the following 10 subsections:

- **Use-oriented forecasting.** A systematic assessment of the value of forecasting accuracy for informing specific water–hydropower decisions at multiple timescales.
- **Water and snow monitoring.** Improved integration of remote-sensing and in-situ measurements to increase information for water-hydropower decision making.
- **Rural water supply and treatment systems.** Reinvestment to meet immediate needs for improved municipal water services while also providing much broader community, environmental, and resilience benefits.
- **Improved metrics and sensors.** Development of rugged, reliable, and accurate sensors; potentially also includes data analysis platforms.
- **Networks for water technology development.** Organize and leverage laboratory capabilities for water technology and R&D in partnership with industry.
- **Water resiliency.** Holistic approaches and technologies to water efficiency to reduce risk and vulnerabilities of less secure water environments.
- **Water as DER.** Utilize the emerging distributed energy resources (DER) business model and transactions to illustrate water as a potential energy resource.
- **Alternative markets for small hydropower.** New value propositions, co-benefits and specialized markets for small-scale hydropower development.
- **System-wide environmental benefits.** How can coordination or river regulation from hydropower yield net environmental benefits?
- **Water and power co-design.** Coordinated design that acknowledges the coupling, capabilities, and criticality of infrastructure that integrates water and power systems.

2.1 Use-oriented forecasting.

Use-oriented forecasting develops forecasting information and products based on the ways that water is used at multiple spatial and temporal scales.

A wide variety of organizations – including hydropower owners and operators – conduct or utilize forecasting of weather or water resources. Despite active research and operational forecasting programs, there is a lack of systematic knowledge of the incremental value of forecasting improvements, and the extent to which improvements in forecasting would enable improved water–hydropower tradeoffs. Further, most forecasting products are developed independent of the myriad of ways that water is used. For example, the value of water for hydroelectric generation determined by power marketing and trading groups, but reservoir forecasting and operations are typically carried out in a separate group; these boundaries between decision makers are larger if non-generation uses of water are also considered.

"Use-oriented forecasting" would assess the value of forecasting information for specific water-hydropower decisions at multiple temporal and spatial scales. Key to this approach is beginning with the end-uses of water, assessing the value of the water for these specific uses, and then working backwards towards the characteristics of the forecasting product. Key characteristics may include time-variance of accuracy,

Work in this area could take many forms. A more substantive approach would be ongoing collaboration with entities such as NOAA and NCAR who create forecasting tools. A more modest, but still useful, approach would be development of periodic benchmarks and whitepapers to support industry.

WPTO is funding an initial project under its HydroWIRES program that will assess the value of forecasting for specific electricity sector services. This project will insert specific types of errors into water forecasting inputs to production cost models to assess the value of different types of forecasting improvements. It will also survey industry forecasting products to understand the types of errors that are present. Note that this project is advancing power-system uses of forecasting, but not addressing the value or water and forecasts for non-power sectors.

WPTO is also beginning to engage with CEATI's Hydropower Operations and Planning Group, which is working with its members to enhance forecasting products. There are many companies and research institutions that produce water forecast products. Two notable government-funded entities that develop and improve forecasting products are NOAA and NCAR. NOAA's mission is operational in nature, whereas NCAR's mission is to improve process understandings that lead to improved models of climate and water, which enhance our ability to produce accurate forecasts.

Use-oriented forecasting is tightly aligned with several areas of WPTO's mission (**Error! Reference source not found.**). Engagement in this topic could help hydropower owners and operators better utilize their plants as part of a broader system. The principles are highly reproducible across sites, although the value of forecasting for specific purposes will vary greatly.
In its broad form, forecasting is a very large and mature field that is conducted or used by most hydropower owners and operators across the U.S. Yet, use-oriented forecasting that accounts for sensitivities in ways that the forecast product will be used are much less mature. For

instance, even the limited use in which forecast products are tailored to electricity market conditions is at a proof-of-concept phase.

Use-oriented forecasting is a relatively concrete concept that could complement WPTO's existing hydropower portfolio. A moderate investment would be sufficient to demonstrate the benefits through targeted case studies. The case studies could be used to socialize the concept with relevant stakeholder groups to motivate uptake by industry, both individual entities and professional organizations such as CEATI. DOE has a strong role in this topic because it involves diverse stakeholders, is a relatively novel paradigm, and many of the values associated with water utilization are not monetized. Non-monetized values are often challenging for markets to solve, therefore creating a need for government involvement.

2.2 Water and snow monitoring.

Improved integration of remote-sensing and in-situ measurements to increase information for water-hydropower decision making.

In-situ water and snow monitoring are critical for decision making, but stations are being removed because they are expensive to maintain and operate. At the same time, other forms of data, such as satellite imagery, are becoming cheaper and more prevalent; computing resources and analysis tools are also proliferating. All three can be better used in coordination.

The potential value of snow and water information is also increasing, driven by increasing demands for water and changing utilization of hydropower.

This concept seeks to increase our awareness of water in-stream and in the mountains through combining new – advanced computing – and time-tested – in-situ observations. For instance, through understanding which stations are critical and if advancements in sensors and communications can reduce cost.

Some initial efforts are being made in this area by academia and the private sector (notably Upstream Tech[8]). There is a role for the federal government given that it owns and operates in-situ measurement sites, principally, the US Geological Survey's (USGS) stream gauge system. Notable technology investments include the US Bureau of Reclamation's (USBR) challenge launched in spring 2019: "Lowering the Cost of Continuous Streamflow Monitoring," conducted in partnership with USGS.[9]

In November 2019, WPTO issued an SBIR/STTR to support innovative water sensors and data analytics to advance this very goal. From that announcement, "Our ability to understand, account, and predict water conditions will be greatly improved by tools that can cost-effectively create precise or real-time datasets over large physical areas, or continuously process very large datasets such as satellite imagery. These tools can advance our ability to understand hydropower potential and simultaneously advance other water uses such as assessing streamflows and watershed/land-use conditions that drive streamflows."

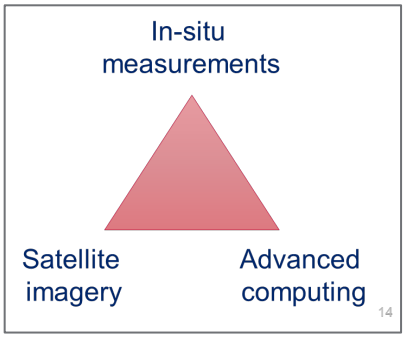


Figure 6. Three components to improved monitoring.

[8] https://upstream.tech/
[9] https://www.usbr.gov/research/challenges/streamflow.html

2.3 Rural water supply and treatment systems.

Reinvestment in rural municipal water systems has the opportunity to meet immediate needs for improved municipal water services while also providing much broader community, environmental, and resilience benefits.

Rural water supply and treatment systems share many similarities with irrigation systems, including the challenges and opportunities. Much of the infrastructure is past its design life (or recapitalization has not kept pace with needs), the system operates under constrained financial margins, and technology advancements are incremental. Rethinking and reinvesting in these systems has the potential to transform the infrastructure's role within the community, both advancing their core objectives while also providing broader benefits. These benefits may include environmental enhancements, net energy gains, improved water utilization, and advancements in resilience of the integrated water and power system.

Rural municipal water systems provide more opportunity for rethinking the system "from the ground up" than large municipal systems. Rural systems are more isolated and contain fewer components, and overall tend to be simpler with respect to their design. There is also a large need to modernize these systems to meet their core objectives. For example, USDA Rural Development is working with communities in Arizona that currently have cesspools. This need to modernize provides substantial opportunity to redesign the system and have material impact on communities that are geographically dispersed across the U.S.

Rural water supply and treatment systems share the same relationships and rationales as irrigation modernization: it is more about water and broad objectives, but hydropower generation and net energy usage is a valuable dimension of the work. The paradigms and tools developed under this topic would also be highly reproducible, likely on a regional basis where system types and water solutions are more similar.

There is a robust industry engaged in water supply and treatment. This industry and the communities they are serving tend to be focused on incremental advancements to "their system" (water supply and treatment infrastructure). There is extensive academic work on improvements to the technologies employed by industry, but little academic work on redesign of these systems.

Other entities, such as USDA Rural Development, are engaged in supporting these types of community water systems.

There is some literature and "proof-of-concept" on transformational redesign of water systems, but little of this is explicitly focused on rural water supply and treatment systems. DOE's role would be to provide broader thinking on the possibilities of redesigning these systems through the lens of integrated systems capable of advancing outcomes along a broad set of dimensions.

For rural communities, engagement in this topic would have a large impact. Scalability is high because there are many similarities between water supply and treatment systems across the U.S. The systems are simple enough that impact is achievable, and DOE could have a significant role in providing forward looking guidance and demonstration of how to solve the challenges of today while also preparing for the future.

2.4 Improved metrics and sensors.

Development of rugged, reliable, and accurate sensors; potentially also includes data analysis platforms.

Environmental objectives are often assessed through overly simplified metrics that can be broadly applied rather than targeted metrics that account for complexity of local ecological systems.

Sensors may seem simple, but accurate measurements are critical for optimally utilizing a reservoir, municipal pipe, or irrigation canal. Many hydroelectric plant operators manage their assets conservatively because their measurement systems have high uncertainty and they want to ensure they do not violate license agreements. Integration of sensors with analysis tools and platforms can also increase confidence in system state and performance.

This concept is provided as a single topic to ensure alignment of inputs (better equipment and tools) with outputs (improved system-level outcomes). Improving sensors is a very mature topic, but it is also an area where industry continues to express interest. Improving metrics is active but less mature.

DOE has a role to play through WPTO and its Advanced Manufacturing Office (AMO).

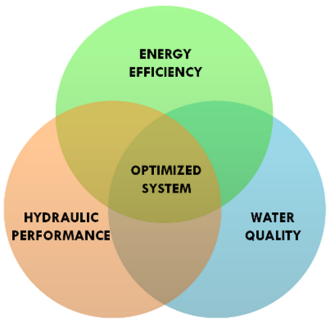


Figure 7. System optimization for water.

2.5 Networks for water technology development.

Organize and leverage laboratory capabilities for water technology and R&D in partnership with industry.

There is an existing ecosystem of incubators and accelerators to support water technology innovation. The WPTO hydropower program is a part of that system, for its investments in sensors and data acquisition, analytics, and other water technologies. However, because the WPTO program efforts are designed for hydroelectric industry applications, lateral applications into the water sector can be overlooked.

To connect program investments to water technology R&D more broadly, and to understand roles and fit with the water technology investment ecosystem, WPTO could support the creation of water technology development networks.

There are many models and structures for water technology accelerator partnerships. One model is the Desalination Hub recently funded by the EERE Advanced Manufacturing Office, a laboratory-led consortium for a suite of R&D efforts related to water re-use.

Another concept is modeled after the Lightweight Materials Consortium, or LightMAT.[10] This concept would organize and leverage laboratory capabilities for water technology and R&D in partnership with industry. As with LightMAT, the laboratories would self-organize into a consortium of capabilities, with these capabilities expressed in published program materials. As with LightMAT, laboratory administrators would work closely in concert with DOE management to issue regular calls on specific water technology topics and make subsequent selections as a team. All successful applicants for partnership would utilize a standard CRADA. This concept is elastic to available funding and multiple Office contributions.

LightMAT is an established and successful EERE Vehicles Technologies Office program now in its 4th round of calls. The singular umbrella under which all of the LightMAT work is conducted: that lowering the weight of the materials used in car manufacture will reduce fuel requirements, thereby reducing the energy requirements within the transportation sector. A similarly broad scope for water technology partnerships could be water security with specific calls related to energy nexus topics.

A favored title for this activity is the WaterPOOL Consortium.

WaterPOOL Consortium

It is difficult to rate the performance of this concept against mission rationales without identifying the associated purpose for the consortium. However it is plain that once operational, such a consortium would by design offer a relational benefit to the water sector from solutions developed in the energy sector, and that its primary activity would be to improve an outcome for water conditions.

[10] See https://lightmat.org/.

To execute this type of consortium, several relationships are required and foundational to the effort. The first is to understand that there is industry pull for these types of partnerships; that the laboratories would offer a specific technical leverage point that is useful to solution providers in the water industry. A second essential scoping element is to identify the conceptual umbrella that makes the consortium purpose clear. A third piece is the laboratories, developing some minimum sensibilities about laboratory capabilities that can be leveraged and the ability of those laboratories to cooperate. Finally, the Office structure and patronage should be developed to assure that there is enough funding to support an activity in this area.

This concept is already an active and successful operational model within US DOE EERE, so the concept is identified here as a program model from which we can borrow. The impact is not well defined without an organizing purpose for the consortium. As identified above, the concept is scalable to various funding levels and contributors; utilizes an existing program model; leverages the depth of national laboratory technical capabilities; and serves a close nexus to the Water Security Grand Challenge due to the alternative approach to recruiting and funding industry partnerships.

2.6 Water resiliency.

Holistic approaches and technologies to water efficiency to reduce risk and vulnerabilities of less secure water environments.

This concept is intended to encompass a broader set of opportunities to increase water and power resilience.

Each stage of water management – point of withdrawal, pumping loads to move water, gravity systems and conveyances, impoundments and pondage, discharge, and utilization – offers an opportunity for higher efficiency, avoided losses, and multiple uses with the same water. By reducing losses, tuning the energy requirements of equipment to its purpose, using sensors to apply the precisely correct amount of water for the proper use, technologies can help water users meet objectives and maintain a more reliable, resilient water system.

The concept of resiliency – the ability of a system to withstand and recover from disruptions – is increasingly important for both the water and the power sectors. There is an emerging understanding of the interdependencies between the two sectors and how disruptions in one sector may have consequences for the other. Similar questions and considerations appear in discussions regarding electric system-natural gas interdependencies and transmission and distribution coordination. As in these analogs, there is not so much a notable “seam” between the operation of the water and power systems. Rather there are radically different physical, economic, and institutional realities in operating the interdependent systems.
This topic area investigates system optimization, interdependencies, and opportunities to design and build cooperative infrastructure for greater resiliency outcomes. To what degree is bulk power sector reliability and resiliency linked to water availability and how does water availability change the timing, character, and location of electric loads? Can the water sector increase its own resiliency by adopting power sector techniques and technologies for resiliency? Are there opportunities in both the electric and water distribution infrastructure to combine systems in a way that makes both sectors more successful, more resilient, less costly? More traditional versions of energy-water nexus for resiliency would consider how to install back-up generators at wastewater treatment plants or consumptive/non-consumptive water uses and temperature sensitivity with effluent or discharge at specific power plants.

Resiliency can be considered at varying functional scales. Irrigation resiliency would consider rural economic resiliency, as part of water resiliency. At the community scale, resiliency investments could be cooperatively linked across R&D organizations or across EERE (Vehicles for EV charging infrastructure, Solar for specialized urban applications, Buildings for load-based resiliency, Bioenergy for alternative fuel supply for heavy-duty or light-duty fleets and flex fuels, and so forth).

Other resiliency concepts that are a high priority for the water sector include:

- Infrastructure. Changing delivery requirements, mounting maintenance obligations and capitalization challenges.
- Safe and secure drinking water. Assuring viable supplies, emerging treatment techniques and contaminants, as well as mobility of available water.
- Long-term outlook and availability. Managing changing hydrologic conditions and derivative effects on systems, economies, and infrastructure.
- Technology solutions. Future of water on a medium to long-term, low-TRL technologies needing stewarded research and development programs.
- Resiliency. System-level and non-linear problems are difficult to analyze, extended period of disruptions, maintaining public sanitation and health.
- Disruptions. Utilize emerging resiliency scenario, planning and valuation practices borrowed from electric utility sector ("water black start"), and meet new EPA regulations that require emergency plans and risk assessments.
- Runoff, storage, and transport. Runoff not just managing for combined sewer overflows (CSOs) and changing storm intensities, but managing volumes for reuse. There is a strong parallel between water and energy storage – e.g. emerging energy models for distributed storage.
- Integrated systems. Both power and water are centralized systems that draw on a few large resources and convey that resource over linear rights-of-way to homes and businesses for just in time use, supplied by a utility on a rate basis, that is considered essential for human health and habitation. There is a direct interface between natural supply and developed infrastructure.

At its simplest form, water resiliency is protecting water delivery and management from the insecurity of water availability. This could serve as a key principle for the laboratory consortium concept outlined in 2.5 above. Its origin is the Irrigation Modernization project, in which the modernization effort reduced leakages and increased certainty and effectiveness of water delivery, so that when the district experienced a dry year, the farmers were insulated from consequences.

2.7 Water as DER.

Utilize the emerging distributed energy resources (DER) business model and transactions to illustrate water as a potential energy resource.

Distributed Energy Resources (DER) are a broad term to capture energy technologies such as solar, demand response, and energy storage that are within the distribution system, including behind-the-meter. In the last ten years, business models, regulations, and technologies to coordinate, control, dispatch and compensate DERs have undergone a radical shift in maturity.

Water systems have enormous and specialized potential to participate as DER, as load and as potential generation. Water systems are everywhere, co-located with electrical infrastructure and similar linear distribution networks.

With the rise of DER business models, technologies and revenue opportunities, we now have a framework to take advantage of the ubiquity of water delivery and the potential for water to deliver critical and locational energy benefits.

WPTO is investing in a technical assistance project at PNNL to support the California Public Utilities Commission's evaluation of water supply, treatment, delivery, and wastewater management processes as distributed energy resources. See forthcoming PNNL report: "Water as a Distributed Energy Resource for California."

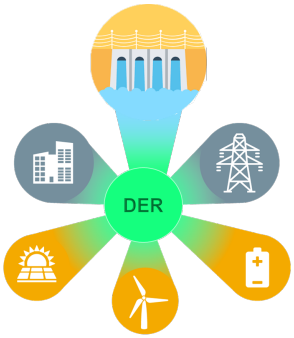


Figure 8. Distributed energy resource options.

2.8 Alternative markets for small hydropower.

New value propositions, co-benefits and specialized markets for small-scale hydropower development.

There is an opportunity to advance the small hydropower value proposition by investigating markets, other than bulk electricity, in which non-energy drivers create opportunities for small-scale hydropower development. Existing WPTO strategies support technology and siting advances. This approach will investigate other drivers and markets to illuminate co-benefits, business cases, and specialized markets in order to articulate other systems and environments which may increase the value proposition for small hydropower.

Alternative value propositions fundamentally change the design paradigm for small hydropower. Realizing new value and revenue streams require thinking about hydropower facilities from the perspective of alternative end-uses in combination with the existing operational requirements and constrains of the facility. Understanding these market environments will not only influence business cases but also technology design and purpose.

The essential element of this approach is not to simply seek out environments where it is technically feasible to consider hydropower and conduct assessments of technical potential, but to reach into the environments to understand how decisions are made, what solutions are required, to evaluate the circumstances under which hydropower is a candidate to enable a bigger solution.

A markets-based co-benefit approach, similar to *Powering the Blue Economy* (PBE), may be needed to illustrate paths forward for small hydropower. Recent developments and proposal structures illustrate how hydropower is not the principal motivation of the project, but a critical enabler of a larger suite of benefits. Following the PBE model would start with an illustrative markets-based report to organize the program and draw in new constituencies and partners.

Example co-benefits and alternative markets:

- Historic preservation
- Irrigation modernization
- Upgrades to water and wastewater facilities
- In-river ecological improvements
- Recreation (both moving water and ponded water)

WPTO has sponsored a workshop in partnership with the National Rural Electric Cooperative Association (NRECA) in early 2020 to explore alternative business cases for rural electric cooperatives in the United States.

2.9 System-wide environmental benefits.

How can coordination or river regulation from hydropower yield net environmental benefits?

A dam's ability to regulate a river is considered an environmentally harmful feature of hydropower. Yet what if that same control can be used to maximize ecological objectives – what could it do? And how could market-based tools and incentives, rather than regulatory minimums and standards, enable greater coordinated outcomes for ecological function? Control may be especially crucial for river managers, as precipitation and seasonal runoff change river conditions, raising questions about water temperature, species ranges, and habitat.

This concept considers new business models and transactive structures for enhancing environmental systems, market incentives for increasing environmental performance above a regulatory standard, virtual water trading and water quality credits. What signals and structures will the hydropower sector need in order to engage? If the value of energy is decreasing and the value of capacity and flexibility is increasing, the electricity market will shift to pay for the physical capacity to hold water or provide ramping and other short-term services. If we expect a significant shift in operational pressures away from traditional generating patterns, how can we ensure the environmental balancing is sync with these new realities?

It is possible to imagine scenarios in which the plant-by-plant minimum-standards based regulation hinders our ability to see large-scale win-wins, within a greater span of river or an entire basin. In place of running operational model to a least-cost objective with associated greenhouse gasses, as we might in today's common production cost modeling environment, how could we operate the electric system for water, to illustrate the value of hydroelectric coordination and flexibility benefits, even resiliency to drought?

These questions have a shadow twin in assessing water risk to electric reliability. Two new WPTO research investments will investigate the dynamics of water risk – at the utility level (NREL-led GMLC project) and at the interconnection level (WECC) to look at the reliability and risk of water across several aspects of electric grid performance, including resource adequacy.

There are clear partnerships with these projects, as well as entities engaged in environmental markets, water markets, and associated incentives, trading hubs and credits, which have yet to be meaningfully applied to hydroelectric plants. (Note: There has been some explicit upper Colorado River Basin incentives to leave water in the river to ensure large federal hydroelectric facilities in the lower Colorado will have additional water for generation.)

It is also clear that hydroelectric plants, through their licensing processes and through the sensors and data streams that operating them entails, offer unusually valuable insight into river conditions and forecastable conditions, such as streamflows. The data hub of hydropower is another catalyst for environmental value, a nodal network of real-time information that is presently disconnected. What can DOE do to link these data streams and deliver more public value?

2.10 Water and power co-design.

Coordinated design that acknowledges the coupling, capabilities, and criticality of infrastructure that integrates water and power systems.

Water and energy are both critical infrastructure and have significant tie-points. For example, municipal and irrigation water uses require significant pumping and often include some amount of storage. Analogously, water is used in many electricity generation processes, such as for cooling in thermal generators and as a direct fuel for hydropower.

Despite these crossovers, most existing water and energy infrastructure is designed without considering the impacts and possibilities created by the coupling. In reality, the coupling creates vulnerabilities (for example due to emerging cyber threats) and possibilities (for example utilizing modified water processes to meet electrical system needs and vice versa).

Work under this concept would develop and utilize a design framework that promotes co-design of infrastructure that includes water and power components. The framework would begin by considering the possible benefits and vulnerabilities to each system created by the infrastructure. The design framework would then develop the controls, communications, and physical considerations that promote integrated system capabilities while balancing these against financial performance. The optimization exercise described above would also be constrained by regulatory requirements and appropriate scale and footprints for design. Because most water infrastructure is already constructed, the opportunity for optimization and co-design is largely around incremental or modular investments in the water sector, or reconstruction of existing facilities, as opposed to entirely new systems.

Water and power co-design as a paradigm is highly reproducible; as a practice it requires in-depth understanding and consideration of the specific water and power systems and their coupling. The overarching goal is improved power and water system performance. This objective may or may not include hydropower but would still yield net electric system benefits. The timing is also very good for this topic because there is growing recognition of the need for reinvestment in America's water infrastructure.

Co-design of a specific water and power system would be a good fit for the Water Security Grand Challenge (WSGC) because essentially all couplings between power and water systems are ripe for improvements. For instance, specific prize topics could be scoped within municipal water supply, irrigation infrastructure, desalination plants, or groundwater pumping and recharge.

The key partnerships and stakeholder groups are principally those who would be involved in the design and development process. These stakeholder groups will depend on the specific system being assessed. What varies is bringing them together during the design phase to create systems that perform better with respect to each system and do not introduce vulnerabilities to either system due to the coupling. DOE's Advanced Manufacturing Office.

The reasons for utilizing water and power system co-development are increasing. The concept itself, though, is not particularly novel. There is a growing literature and body of work demonstrating the benefits of water and power system co-development.

The potential impact of investments in this area are large. The magnitude of the impact is guided by the recognized need for large-scale re-investments in segments of the U.S.'s water infrastructure, the cost-savings associated with right-sized designs, increasing value of certain grid and water services, and emerging threats to these systems (e.g. cyber vulnerabilities caused by the inherent coupling of these systems).

The solutions are relatively scalable because design principles developed for one coupled system can be applied to others. Achievability is ranked slightly lower simply because of the magnitude of the challenge and the corresponding larger level of investment, both in design and construction, required to have an impact. DOE has a large role in this space, though, to help accelerate innovations that will improve water and energy system performance.

3.0 Existing Water Investment Programs

The purpose of this the water investment report is two-fold: to provide the U.S. Department of Energy's Water Power Technologies Office (WPTO) with a reference point for various funding, research, and development investments in water innovation across a spectrum of US Government agencies and non-profit and non-governmental organizations; and to support the Water Scoping project research team assess DOE gaps and opportunities for advancing water R&D.

3.1 Methodology

The initial task of this project was to develop a matrix that evaluates significant agencies, large foundations, and other organizations that invest in water technology and water efficiency research and innovation. The matrix represents the mission of these organizations related to water R&D, including the program scope, priorities, and links for more information. This matrix was designed to indicate where there is ample investment and where there are notable funding gaps. Not included in the scope of this water research and innovation scoping review were technologies related specifically to water power technologies.

Searches were completed using Grants.gov, Google, Google Scholar, and other relevant sites. A comprehensive list of US Government departments, agencies, and other organizations was compiled and used along with search terms including "water," "water research," and "water innovation". The timeframe of water research and investment projects included were future, ongoing, and recent (>2016) postings of funded research projects and results. Provided in the spreadsheet matrix (as attached), general topic areas were assigned to each project for context (namely infrastructure, quality, supply, wastewater, resilience, agriculture, watershed, disaster, conflict, and advisory).

For the purposes of this scoping exercise, a "water research and innovation investment" was defined as the allocation of resources towards modernizing, establishing, or integrating new methods, ideas, or products related to water systems. Not included were investments to improve already established methods, ideas, or products, or investments to include regulation, oversight, and management activities.

In addition to the organized reference information, the team assigned scores from 1-10 based on apparent relation to the water scoping project (1 – low, 10 – high). Water related investments below a relation score of 5 were not considered relevant to this project, therefore scores from 1-4 were not included. The more that the investment was aimed at modernizing, establishing, or integrating new methods, ideas, or products related to water systems the higher the score (e.g. the $10.7M USDA Water Availability and Watershed Management investment "to develop new and improved technologies for managing the Nation's agricultural water resources" was assigned the highest score of 9, while the $235M FEMA Pre-Disaster Mitigation investment "to reduce the risk to individuals and property from… non-flood hazards" was assigned the lowest score of 5).

3.2 Water Innovation Funding, Research, and Development Investments

This memo reports US Government and Non-Government water innovation and research opportunities and projects in separate sections. The projects described as organized based on

primary agency involved. The majority of the projects and opportunities, and investment totals located stemmed from the US Government, most significantly for natural disaster and emergency mitigation, management, and resilience. As stated above, only water research and investment activities aimed towards modernizing, establishing, or integrating new methods, ideas, or products were included in this scoping exercise.

3.2.1 US Government Departments, Agencies, and Organizations

Federal investments in water research and development range in size. The Department of Interior (DOI), EPA, and USDA invest in a large number of small water innovation projects. However, in the current fiscal year Congress appropriated over $7 billion for water research and development, most of which went DHS/FEMA, USACE, DOT, and HUD. Other Government water projects included NOAA, Department of State, and USAID.

3.2.1.1 Department of the Interior (DOI)

The DOI funds water-related activities in several of its suborganizations including the USGS, Bureau of Reclamation, and Bureau of Land Management (BLM) related to advisory, supply, infrastructure, conflicts, and quality.

- The USGS is investing over $7.8 million in the National Water Census to "systematically provide information that will allow resource managers to assess the supply, use, and availability of the Nation's water"[11].

- The Bureau of Reclamation invested $26.5 million in 2018 towards their WaterSMART (Sustain and Manage America's Resources for Tomorrow) program to assist regional and local entities to "implement actions to increase water supply through investments to modernize existing infrastructure and attention to local water conflicts"[12]. The WaterSMART program utilizes this funding to offer 50/50 cost shares to water or power delivery authorities for projects that contribute to water supply reliability in western states.

- The BLM operates several ongoing programs addressing water research and innovation, however, no specific funding amounts were published. The primary water-focused BLM program is their Soil, Water, and Air Program that "leads efforts to assess and restore water quality conditions"[13]. Other BLM work that relates to water are their Resource Advisory Councils (RAC) to assist in developing BLM initiatives and proposals[14] and their Oregon-Washington Partnerships to enhance the agency's capacity to deliver services[15]. There are 37 BLM RACs in place and consists of 10 to 15 citizen-based council members to serve as sounding boards for initiatives, regulatory proposals and policy changes, with each member representing diverse interests in local communities.

[11] https://water.usgs.gov/watercensus/funding.html
[12] https://www.usbr.gov/watersmart/weeg/index.html
[13] https://www.blm.gov/sites/blm.gov/files/WaterResourceProgramStrategy.pdf
[14] https://www.blm.gov/get-involved/resource-advisory-council
[15] https://www.blm.gov/get-involved/partnerships/featured-partners/oregon

3.2.1.2 Environmental Protection Agency (EPA)

Several EPA activities and projects related to water were located through this process related to infrastructure, water quality, resilience, and watershed management.

- The EPA's National Center for Sustainable Water Infrastructure Modeling Research is a new project being developed in collaboration with several universities and institutes for the "preservation and advancement of modeling tools for infrastructure analysis and management"[16].

- EPA's Clean Water State Revolving Fund (CWSRF)[17] and Water Infrastructure and Innovation Act (WIFIA)[18] both provide low-cost financing for water infrastructure projects totaling over $6.5 billion starting in 2018. There are additional programs that contribute to infrastructure investments, such as the Drinking Water SRF.[19]

- The EPA also recognizes exceptional projects funded by CWSRF annually through the Performance and Innovation in the SRF Creating Environmental Success (PISCES) program[20].

- Along the same lines the EPA hosts the Water Infrastructure and Resiliency Finance Center for "helping communities make informed decisions" related to drinking water, wastewater, and stormwater infrastructure[21].

- Finally, the EPA hosts a website on a variety of Water Topics and research related to the Clean Water Act and Safe Drinking Water Act[22].

3.2.1.3 Department of Agriculture (USDA)

The USDA has at least 2 water research activities related to supply, quality, agriculture, and watershed management. The USDA in a joint program with the EPA funded over $10M in 2016 towards Critical Water Research on rural and agricultural watersheds under the AFRI Water for Food Production Systems Challenge Area and "focuses on multidisciplinary systems approaches, which integrate new technologies and strategic management that solve water availability and quality challenges in food production systems"[23]. The USDA also continues to fund Water Availability and Watershed Management (NP #211) since 2011 "to develop new and improved technologies for managing the Nation's agricultural water resources"[24]. An example

---

[16] http://worldwater.byu.edu/grants/ncimm-a-sustainable-center-for-crowd-sourced-water-infrastructure-modeling/
[17] https://www.epa.gov/cwsrf
[18] https://www.epa.gov/wifia
[19] https://www.epa.gov/dwsrf
[20] https://www.epa.gov/cwsrf/pisces
[21] https://www.epa.gov/waterfinancecenter
[22] https://www.epa.gov/environmental-topics/water-topics
[23] https://www.usda.gov/media/press-releases/2016/05/17/usda-announces-107-million-available-critical-water-research
[24] https://www.ars.usda.gov/natural-resources-and-sustainable-agricultural-systems/water-availability-and-watershed-management/

project is titled “The Use of Treated Municipal Waste Water as a Source of New Water for Irrigation”[25].

3.2.1.4 Department of Homeland Security (DHS)

The Department of Homeland Security has two substantial funding opportunities in 2019 related to disaster mitigation and recovery. The DHS Pre-Disaster Mitigation program provides FEMA with over $235 million to “reduce the risk to individuals and property from natural hazards”[26] not including floods but including other water hazards. The DHA Flood Mitigation Assistance program deals exclusively with flood mitigation to “reduce or eliminate the risk of repetitive flood damage”[27]. The DHS also assigns the EPA as the designated Sector-Specific Agency for the Water and Wastewater Systems Sector of the Critical Infrastructure Sector under Presidential Policy Directive 21[28]

3.2.1.5 US Army Corps of Engineers (USACE)

The Energy and Water Appropriations Bill, “Investing in American Infrastructure”, provides over $7.3 billion for a wide variety of water supply and infrastructure projects including $7 billion to USACE[29]. The America’s Water Infrastructure Act of 2018 further authorized approximately $3.8 billion to provide “key tools to support the development of water infrastructure”[30]. Furthermore, USACE has many ongoing projects related to water, including the Institute for Water Resources (IWR) “to analyze and anticipate changing water resources management conditions, and to develop planning methods and analytical tools”[31]. USACE also provides the US Army with the Access to Water Resources Data - Corps Water Management System (CWMS) to enhance the USACE’s “water control management mission by utilizing visualizations and reports to provide continuous assessment, awareness, and effective decision support of lock and dam project”[32].

3.2.1.6 National Oceanic and Atmospheric Administration (NOAA)

There are numerous programs and collaborations related to water research administered through the NOAA. The NOAA Office of Water’s Office of Water Prediction has the mission of creating a “Water-Ready Nation” by informing “essential emergency management and water resources decisions across all time scales”[33]. NOAA National Weather Service hosts the National Water Center (NWC) that “serves as a catalyst for the Integrated Water Resources Science and Services (IWRSS) partnership” with USGS and USACE[34]. The NOAA NWC also hosts a Summer Innovators Program “which brings together graduate students, academic researchers, and National Water Center staff to work on projects designed to improve water-related products and decision-support services”[35]. And the NOAA Center for Earth Systems

---

[25] https://www.ars.usda.gov/research/project/?accnNo=432143
[26] https://www.grants.gov/web/grants/view-opportunity.html?oppId=307874
[27] https://www.fema.gov/media-library/assets/documents/168194
[28] https://www.dhs.gov/cisa/critical-infrastructure-sectors
[29] https://appropriations.house.gov/subcommittees/subcommittee/?IssueID=34796
[30] https://www.prnewswire.com/news-releases/president-signs-into-law-americas-water-infrastructure-act-of-2018-300737158.html
[31] https://www.iwr.usace.army.mil/
[32] http://water.usace.army.mil/a2w/f?p=100:1:0:
[33] https://water.noaa.gov/
[34] https://cpaess.ucar.edu/nwc
[35] https://www.cuahsi.org/education/summerinstitute/

Sciences and Remote Sensing Technologies (CREST) Theme III – Water Prediction & Ecosystem Services research tasks include drought, flood, and snow risk assessments[36].

3.2.1.7 Department of State

The Department of State has an Office of Conservation and Water in the Bureau of Oceans and International Environmental and Scientific Affairs that "coordinates the development of U.S. foreign policy approaches to conserving and sustainably managing the world's ecologically and economically important ecosystems" to include the world's water resources[37]. The Department of State also published the US Government Global Water Strategy in 2017 detailing their vision to enable "a water secure world, where people have sustainable supplies of water of sufficient quantity and quality to meet human, economic, and ecosystem needs while managing risks from floods and droughts"[38]. Of note is the description of 14 additional US Government agencies' plans to aid in achieving this global mission. However, no particular funding opportunities or investments were found in connection with any of these organizations or programs.

3.2.1.8 Other Agencies

The Departments of Transportation, and Housing and Urban Development, and Related Agencies Appropriations Bill grants over $112 billion for research and development on "storm hazard mitigation for multimodal transit hubs," "permeable pavements," and "enhanced road maintenance"[39].

3.2.2 Non-Governmental Organizations

There are numerous NGOs and non-profits that engage in a wide variety of water related research and investments. However, little information on investment size or funding opportunities was readily available. Many NGOs focus on international efforts related to improving water, sanitation, and hygiene (WASH) in developing countries including The Bill and Melinda Gates Foundation[40], UNICEF[41], Water Mission[42], and World Bank[43]. The Gates Foundation's WASH efforts are designed to "enable widespread use of safely managed, sustainable sanitation services, contributing to… gender equality outcomes," focusing on Sub-Saharan Africa, South Asia, and China. UNICEF's WASH program "focuses on the ability for children to access safe water in developing nations. Water Mission's WASH is intended to "build and implement… [WASH] solutions for people in developing countries and disaster areas." And World Bank's WASH program develops "innovative methods to fully appreciate the impacts of inadequate [water] services on human development outcomes and identify the binding constraints to service delivery".

Other non-governmental water programs include:

---

[36] https://www.noaacrest.org/research/themes/land-processes-and-water-resources
[37] https://www.state.gov/e/oes/ecw/water/index.htm
[38] https://www.state.gov/documents/organization/275842.pdf
[39] https://appropriations.house.gov/subcommittees/transportation-and-housing-and-urban-development-and-related-agencies-116th-congress
[40] https://www.gatesfoundation.org/What-We-Do/Global-Growth-and-Opportunity/Water-Sanitation-and-Hygiene
[41] https://data.unicef.org/topic/water-and-sanitation/overview/
[42] https://watermission.org/
[43] http://www.worldbank.org/en/topic/water/publication/wash-poverty-diagnostic

- the Group on Earth Observations Global Water Sustainability[44] initiative supported by NASA and NOAA,

- the Water Research Foundation's 2019 request for proposals[45] amounting to over $250,000 for projects on a variety of topics like managing water utility data to reduce consumption, practical approaches to water reuse pricing, and long-term water demand forecasting,

- the Water Research Initiative[46] that focuses on molecular and nanoscale science and engineering solutions to water management, and

- the World Bank Group Global Water Security and Sanitation Partnership (GWSP)[47] that "supports client governments to achieve the water-related Sustainable Development Goals."

3.3 Conclusion

Though not comprehensive, an informed estimate of the scope of this review suggests that the data presented here and in Appendix A covers a substantial and representative portion of US Government programs and funding opportunities related to water. Therefore, the matrix of other agency water innovation funding, research, and development, as well as this summary report, should enable sufficient perspective on where there is ample investment and where there are notable funding gaps related to water R&D and technology innovation.

[44] https://www.earthobservations.org/activity.php?id=118
[45] http://www.waterrf.org/Pages/Index3.aspx
[46] https://www.waterresearchinitiative.org/
[47] http://www.worldbank.org/en/programs/global-water-security-sanitation-partnership

4.0 Foundational Challenges to Water System Innovations

This section provides context for understanding an important dimension of the U.S. water landscape: the relevant but non-obvious factors explaining the current status of water systems. These foundational challenges are documented to help screen potential research and development (R&D) solutions to ensure they account for the relevant water landscape and existing barriers. In this way, they can be used to refine proposed R&D opportunities.

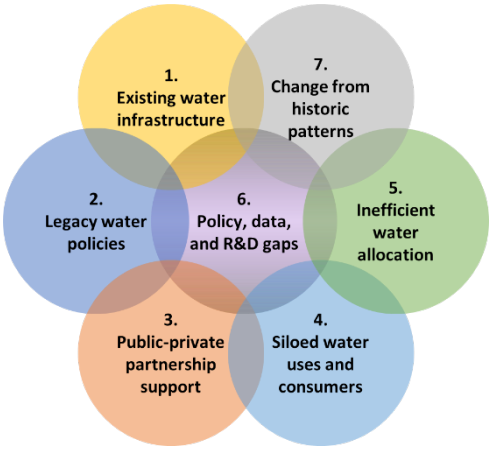
When identifying Foundational Challenges, this research utilized the following working definition:

> *A foundational challenge is a fundamental or complex issue manifesting as a possible barrier to implementing innovative solutions within the water-energy-food-climate nexus.*

These identified Foundational Challenges are intentionally broad in scope and often overlapping, encompassing the characteristics of water which prove problematic across locations, sectors, and time. Recognition of such characteristics and broad challenges to water systems may provide insight into the necessary characteristics of a given proposed solution and innovation.

Figure 9. Identified foundational challenges (not mutually exclusive)

Existing water infrastructure
Legacy water policies
Public-private partnership support
Siloed water uses and consumers
Inefficient water allocation
Policy, data, and R&D gaps
Change from historic patterns



4.1 Existing water infrastructure

Existing water infrastructure is generally large, aging, and expensive to maintain, repair, or replace.

Most infrastructure for water retrieval, distribution, refinement, and use was developed decades ago under the support of massive institutional financing and management programs such as the New Deal in the 1930s. Today, outdated and aging water infrastructure often does not meet the needs of its service population. The capital expenses required to modernize under current governance practices would require increased local taxes or water rates which mitigates refinancing and rebuilding. Furthermore, retrieval, conveyance and storage costs are the primary determinants of water price.

Maintained, refurbished, and new infrastructure is needed to improve system efficiency, operation, and resilience for our future wellbeing. Existing systems, in which capital investments are already made, appear to the stakeholders as inexpensive, despite the ever-increasing costs

of adding more and more “band aids” to maintain system functionality. The growing need for major upgrades to water systems will become more evident as the strain on systems increase with changing municipal and industrial demand patterns.

Examples

- The marginal cost of infrastructure is increasing as it ages; most water infrastructure has exceeded its expected lifetime.

- Existing aging infrastructure needs many upgrades (e.g. improved efficiency, delivery and technology) to satisfy changing water demands and changing system requirements.

Relevance to water R&D

Clear understanding and accounting of the differentiation between the pure financing problem and R&D development barriers – e.g. we know what to build but don’t have the funding versus we need more innovative solutions to revitalize our aging water systems – is needed to effectively and efficiently modernize our water system infrastructure.

References for more information

1. The Army Corps of Engineers owns and operates locks, dams, and other water infrastructure on behalf of the federal government. This study reviews Army Corps infrastructure age and maintenance costs. https://www.nap.edu/resource/13508/Corps-Infrastructure-Report-Brief-Final.pdf

2. The American Society of Civil Engineers (ASCE) issues an infrastructure “score card” for a range of civil structures including wastewater systems, inland waterways, levees, and dams. https://www.infrastructurereportcard.org/infrastructure-super-map/

3. Congressional Research Service review of needed water infrastructure investments (2010). https://fas.org/sgp/crs/homesec/RL31116.pdf

4. Short synopsis of infrastructure development: https://www.usace.army.mil/About/History/Brief-History-of-the-Corps/Water-Resources-Development/

5. This was a slogan during the water infrastructure development era: “True conservation of water is not the prevention of its use. Every drop of water that runs into the sea without yielding its full commercial returns to the nation is an economic waste.” Herbert Hoover (1926)

4.2 Legacy water policies

Existing water policies often prevent locally-driven and site-specific policy solutions.

Most existing water rights and policies were developed in the United States in the late 19th and early 20th centuries, which were very different than today in terms of water demands, social priorities, and technology landscape. [In fact the origins of water-abundant Eastern U.S. water

law is even older: Eastern riparian practices is derived from English common law practices.[48]] Where states have underdeveloped water law systems, legal precedent and judicial decisions set the practice. These legacy water policies often lead well-intentioned groups to be unable to implement solutions that meet their current needs. For example, doctrines developed in the early 1900's such as "first in time, first in right" laws often found in the Western U.S. create perverse incentives (such as being forced to use allocated water or lose it) and the common law practice of riparian water rights in the Eastern U.S. (water appropriation dictated by shore ownership) interferes with watershed-level management practices. Because water law regimes vary from state to state, market, data, and technology implementations cannot be easily reproduced without some adaptation to accommodate each state's requirements.

Modernization, innovation, and implementation of federal, regional, state, local, and international water policy and rights to promote local solutions through collaborative management have the potential to enhance water use and distribution. Refinement of water rights that include increased flexibility (e.g. water markets, decoupling water rights from land rights) and localized optimization of water withdrawal, trading, and use parameters could be effective in addressing such challenges.

Examples

- Watersheds and basins are unique. Implementation of basin-specific policy enables both enhanced localized management and enhanced collaboration between basins/regions.

- Unintended or counterproductive barriers to integration of new technology at local scales can result from well-intentioned overarching federal or regional policy.

Relevance to water R&D

Rigid, overarching, and outdated policies can hinder regional and local efforts to develop and deploy innovative structures for managing water resources in a novel way.

References for more information

1. Young and Loomis (2014). Excerpt: "Transaction costs for water management and allocation tend to be high relative to its value. Where water is plentiful relative to demand, water laws tend to be simple and casually enforced. Where water is scarce, more elaborate management systems have evolved."

2. Matthews, Paul Olen (2004). Water Resources Research. Vol 40. Fundamental questions about water rights and market reallocation. Online: http://www.geo.oregonstate.edu/classes/ecosys_info/readings/2003WR002836.pdf

[48] "Eastern Water Law: Historical Perspectives and Emerging Trends," Steven T. Miano and Michael E. Crane. *Natural Resources & Environment.* Vol. 18, No. 2 (Fall 2003), pp. 14-18. Published by: American Bar Association. https://www.jstor.org/stable/40924492

4.3 Public-private partnership support

Public-private partnerships in water systems are difficult to finance and often lack sufficient technical support.

Water system innovation and modernization requires substantial R&D and capital expenses to be implemented successfully. Much of the existing water infrastructure is considered a public good, benefiting wide swatches of communities as well as specific industries. Stakeholders – including federal and regional government, utility providers, and private businesses – must balance ongoing operation, maintenance, and repairs with adequate forward-thinking investments in water systems to be prepared for the water challenges of the future.

Mechanisms to streamline the distribution of institutional financing to local and private parties are needed. Opportunities to implement innovation and local solutions, particularly driven by public-private collaboration, should be enabled through federal systems. Federal promotion and financing to enable public-private collaboration, particularly in localized arenas, can effectively spur innovation within the private industry.

Examples

- Little incentive for public-private partnerships given current financing, permitting and returns on investments.
- Infrastructure projects are designed to have long lifespans and benefits are manifest in non-market mechanisms (e.g. resiliency and flexibility), making the economic returns on such projects difficult to quantify.

Relevance to water R&D

Opportunity to provide technological solutions and support to public-private partnerships in developing and deploying innovative technologies for clean, domestic power generation while addressing environmental and regulatory concerns.

References for more information

1. World Bank information on water public-private partnerships. https://ppp.worldbank.org/public-private-partnership/5-trends-public-private-partnerships-water-supply-and-sanitation
2. The EPA also provides general information on public-private financing. https://www.epa.gov/waterfinancecenter/leading-edge-financing-water-infrastructure
3. Short discussion related to water infrastructure and opportunities for development/ upgrade funding: https://bipartisanpolicy.org/wp-content/uploads/2016/09/BPC-Aging-Water-Infrastructure.pdf

4.4 Siloed water uses and consumers

Water users act independently of each other, even though they withdraw and return water to the same sources, resulting in barriers to system-level optimization and cost allocation.

It is difficult to track individual units of water as they move through their unique cycles of consumptive and non-consumptive uses. For example, non-consumptive water units move through multiple water conveyance systems and between various users, making it hard to allocate impacts, costs, or externalities[49] . In fact, in terms of sustainability science, water use itself is an impact. Water, being a fluid commodity, is rarely owned or possessed by a single entity over its life-cycle, making it hard to assign responsibilities when it has been used or disposed of improperly. These transitions mean that more holistic water management practices and techniques are required to track and budget for water effectively.

Innovations which enhance water management through oversight, allocation, and tracking could promote the assignment of water costs so as to deter impacts or internalize externalities. Improved sensor technologies would enable better accounting at each node in the system. Additionally, data-driven approaches to tracking (e.g. a platform that unifies monitoring of water at each location and uses by various parties) could reduce the impact

Examples

- When one user pumps groundwater (or surface water), it may alter quality or quantity available to other users. Some of the impacts can include cones of depression, increased salinity, contamination with non-naturally occurring chemicals, or changes in temperature. When groundwater pumping is not managed collaboratively and individual users are not incentivized, decreased reliability and resiliency as a result of aquifer depletion occurs.

- Because water is not privately-owned (as would be the case with a typical commodity), the classic “tragedy of the commons” occurs (e.g. water is over pumped because it is not correctly priced or total water quantity is not restricted). This results in overuse and depletion of water sources and reservoirs. Effectively some users reap disproportionately larger costs of depletion or contamination.

- Water is a universal solvent which absorbs and transports nutrients and pollution. Tracking and removing of soluble materials (and allocating cost to contamination) is nearly impossible because it diffuses through the substance.

- Governing bodies often communicate with, and assign costs to, individual water users without compensating the other water users who may be impacted.

Relevance to water R&D

If water systems are not valued properly, the value of next generation of water power technologies may go unrecognized, creating barriers to implementation.

References for more information

[49] Externalities embody the uncompensated side effects of economic activities. For example, an externality can be negative (e.g. an upstream water user pollutes which makes water unusable for downstream users) or positive (e.g. a manufacturer pumps its recycled water into surrounding aquifers, effectively recharging them for groundwater pumping).

1. Young, Robert A., and S. L. Gray (1985). Input-Output Models, Economic Surplus, and the Evaluation of State or Regional Water Plans, Water Resources Research (Chapter 2). Vol: 21(12). Pp. 1819–1823. doi:10.1029/WR021i012p01819.

2. "Watershed Payments" is an attempt to minimize water use externalities and reassign water use costs: https://www.forest-trends.org/wp-content/uploads/imported/state_of_water_2010.pdf

4.5 Inefficient water allocation

Water markets are designed to provide universal access but not to incentivize efficient allocation for productive uses, producing a discrepancy between water's value and cost.

Governments often subsidize water systems and infrastructure to ensure that all constituents have access to clean, affordable water. Universal access to water is needed, since water is required for human existence; however, not all uses of water are equally imperative. Many uses of water are for business purposes that create profit for an individual or corporation. Subsidization of resources tends to distort the utilization of the resource for productive uses, relative to how the resource would be allocated in a free market. That is, the price to purchase water as an input to a productive use is lower than the total cost to obtain that water. This disincentives users from prioritizing efficiency of water in their processes, resulting in greater use than if water was purchased via a free market.

Alternative subsidy and cost structures could be designed to enable universal access but differentiate between necessary and optional uses of water. For example, Australia has developed a water market where entities can trade water.[50] The market includes both a digital platform for regulating the buying and selling of the resource and physical infrastructure for facilitating the market through enabling transportation of water between basins.

Examples

- Consumptive[51] versus non-consumptive[52] water use plays a large role in water availability and sustainability. It is challenging to quantify and associate costs of use when water is non-consumptive, especially when externalities are present (e.g. pollution as a result of use).

- Water conveyance costs are very high: the cost of conveyance and supply far exceeds the physical value of one unit of water because of its mass and volume characteristics.

- Natural monopolies exist for water because it offers an economy of scale to install one central conveyance system that collects, treats, delivers to customers and then collects, treats, and discharges wastewater as a single utility. While a vertically integrated system that provides all of these functions under one utility offers efficiency, the service territories and withdrawal footprints are not nearly as large or balkanized as the electric or telecommunications sector due to the physical fact of transporting the commodity.

[50] http://www.agriculture.gov.au/water/markets
[51] Consumptive: When water is removed from the immediate water environment – restricting it from use by others. For example, irrigation and municipal use are both consumptive.
[52] Non-consumptive: Use does not redirect or withdraw from the water source (e.g. hydropower, recreation).

Another contrast with the electric and telecommunications sector is that water utilities are commonly integrated with municipalities or publicly administered rather than privately held, which dramatically changes the utility capitalization profile, customer tariff design, and value of the commodity. .

Relevance to water R&D

Accurate valuation and pricing of water and its systems could help to incentivize private sector innovation and accelerate the development of markets for innovative water technologies.

References for more information

1. Cosgrove, W. J., and Loucks, D. P. (2015), Water management: Current and future llenges and research directions, *Water Resour. Res.*, 51, 4823– 4839, doi:10.1002/2014WR016869.Online: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014WR016869

2. More specific information on water markets and efficient allocation. Matthew T. Payne, & Skye Root. (2011). Water Markets in the USA. *Water Resources IMPACT, 13*(5), 6-8. Retrieved from http://www.jstor.org/stable/wateresoimpa.13.5.0006

4.6 Policy, data, and R&D gaps

Water systems are complex, inter-related and require interdisciplinary understanding, but efforts to innovate are often fragmented.

Within the federal government, for example, there are many departments and agencies with specific roles that relate to water. Many universities and civil society groups are also engaged in water, but too often are also fragmented by discipline, use, or location.[53] Fragmentation is pervasive across management, specialization, and data; all of this increases the barriers to utilizing existing and new technologies, ultimately slowing critical information exchange and diffusion of insights.

Large, cross-cutting federal investments would meaningfully accelerate the pace of water innovation and dissemination. The federal government makes large and cross-technology investments in energy, for example through the Department of Energy's National Laboratory system, but few similar national-scale centers and cross-cutting investments exist for water. Developments in digital technology, such as data tracking and decision support tools, can also enhance water utilization in and across geographical, political and managerial boundaries.

Examples

- The inability to collect and analyze data stems from barriers related to water tracking, understanding of distributed effects, and the difficulties of "big data" analysis.

[53] Some universities, notably Oregon State University, have interdisciplinary water programs to promote cross-cutting solutions.

- Siloed industries and water users create gaps in data development, dispersion, and use. Reporting mechanisms (i.e. systems to track and report water presence and use) are also fragmented.

- Limited data pertaining to new technology lifespan and impact serves as a challenge to innovation financing and implementation.

Relevance to water R&D

Critical research and development efforts (such as those completed at National Labs) are necessary to produce the data, understanding, and effective policy mechanisms to produce groundbreaking water technologies that will drive sustainable growth and economic opportunity.

References for more information

1. "A National Policy Framework to Address Drought and Water Security in the United States" 2016 White Paper from the Office of Senator Maria Cantwell https://www.energy.senate.gov/public/index.cfm/files/serve?File_id=03D88F56-1AE2-4DEE-A3EC-7CAC0E9BCF03

2. Organisation for Economic Co-operation and Development report on alternative water. http://www.oecd.org/env/resources/42349741.pdf

3. US Army Corps of Engineers Institute for Water Resources. https://www.iwr.usace.army.mil/

4.7 Change from historic patterns

Water supply trends are rapidly changing from historic patterns.

Changes to earth systems and cycles inevitably effect water's availability and quality. Continuing changes to timing and location of precipitation patterns need to be understood to make appropriate adjustments to the water system. Changing water availability is driving a need for new water infrastructure investments. For example, historically snowpack is a natural reservoir of water during winter months. In many locations this water is needed for the summer to be used for irrigation. Reductions in winter snowpack are driving a need for more seasonal storage capacity in many locations.

Exploration of changing earth patterns and their effects on current water supplies and uses is needed to adapt systems to changing water needs. In many instances water infrastructure sizing is based on empirical analysis of historic conditions. For instance, return periods for flood events are typically estimated based on empirical analysis of historic patterns. Given the long life of many water infrastructure investments, new processes and tools are needed to better set the design criteria. Water infrastructure developed to support historical demand for water, driven by both population (up and down) as well as by industries, crop selection and consumption technologies – may need to be updated to serve current and projected demands.

Examples

- The timing and location of water is dependent on physical cycles (e.g. rainfall, snowpack, man-made and natural reservoirs). Alterations to earth cycles are changing the availability of water throughout time and space.

- A lack of information regarding the challenges faced by existing facilities and how these facilities will operate under changing usage patterns.

Relevance to water R&D

Understanding changing earth systems in the context of historical production, consumption, land use change, and technological innovation patterns helps to support the United States' ability to sustainably meet its growing water and energy demands.

References for more information

1. For insight into changing water use: United States Geological Survey. 2017. Trends in Water Use in the United States, 1950 to 2010. URL: http://water.usgs.gov/edu/wateruse-trends.html

2. Dieter, C.A., Maupin, M.A., Caldwell, R.R., Harris, M.A., Ivahnenko, T.I., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2018, Estimated use of water in the United States in 2015: U.S. Geological Survey Circular 1441, 65 p., https://doi.org/10.3133/cir1441. [Supersedes USGS Open-File Report 2017–1131.]

3. Provides an example of how drought effects water permit prices – gets at the changing value of water. Petrie, R.A., and Taylor, L.O. (2007). Estimating the Value of Water Use Permits: A Hedonic Approach Applied to Farmland in the Southeastern United States. Land Economics, 83(3), 302-318. doi: 10.3368/le.83.3.30

Appendix A – Water Innovation Funding, Research and Development Programs Matrix

Data as of February 2019

Topic Key	
Advisory	Development and provision of information, models, and recommendations related to water systems
Agriculture	Water research related to irrigation and agricultural systems
Conflict	Water research related to conflict mitigation
Disaster	Water research related to natural disaters and resulting damage mitigation
Infrastructure	Water infrastructure system research
Quality	Water quality research
Resilience	Water system research related to the "comprehensive system capacity to withstand and absorb disruptions and quickly recover to the pre-disrupted condition" (Shin 2018)
Supply	Water supply research
Wastewater	Wastewater research
Watershed	Water system research related to watershed management

Department, Agency, Organization, &c	NOAA Center for Earth Systems Sciences and Remote Sensing Technologies
Project Title	Center for Earth Systems Sciences and Remote Sensing Technologies (CREST)
Relation to Project (5-9)	7
Org. Type	US Admin.
Topic	Advisory
Mission	Theme III - Water Prediction & Ecosystem Services
Priorities	Theme III Research Tasks Drought Risk Assessment Using Demand Data and Remote Sensing Products Researchers are estimating trends in natural hazards and hydrologic droughts. The goal is to develop a complete database of demand-based drought index data and real-time probabilistic forecast methods for drought quantiles. Flood Risk Assessment Using In-situ Data and Remote Sensing Data Products Work in this task involves developing a high-resolution blended precipitation product using the latest New York City urban Hydro-Meteorological Testbed (NY-uHMT) and remote sensing data for flood prediction and vulnerability mapping. Assessment and Improvement of National Water Model Development and Validation of the Snow Data Product

	This task involves development of a new snow and ice climatology product. It also involves assessment of remote sensing based forcings and their integration into the National Water Model. Researchers will also explore of the utility of the National Water Model for flash flood predictions. Monitoring Land-Atmosphere-Ocean Fluxes Research involves monitoring environmental and flux data from San Diego State University's eddy covariance flux towers and mapping regional evapotranspiration of the recent decades (2000 - 2018) for implementing the Surface Energy Balance Algorithm for Land (SEBAL) and Mapping Evapotranspiration at High Resolution Internalized with Calibration (METRIC) models in the Western United States. Development of Sensors for Unmanned Aircraft Systems (UAS) platforms for Environmental Intelligence and Satellite Product Validation Work in this task is developing a small unmanned aerial vehicle (UAV) mounted multiband microwave sensor for monitoring ocean salinity and soil moisture that is being tested in different regions in Puerto Rico. Coastal risk and vulnerability mapping using UAV and radar technologies are also areas of focus.
Links	https://www.noaacrest.org/research/themes/land-processes-and-water-resources

Department, Agency, Organization, &c	NOAA National Weather Service
Project Title	National Water Center (NWC)
Relation to Project (5-9)	7
Org. Type	US Admin.
Topic	Advisory
Mission	The NWC serves as a catalyst for the Integrated Water Resources Science and Services (IWRSS) partnership. IWRSS consists of NOAA, the U.S. Geographical Survey and the Army Corps of Engineers as its initial members. The partnership is unifying and leveraging each agency's expertise and investments to improve water resource forecasts, understand how water moves across the land and rivers and facilitate creative and informed decisions, all utilizing the best available science.
Links	https://cpaess.ucar.edu/nwc

Department, Agency, Organization, &c	NOAA NWC
Project Title	National Water Center Innovators Program Summer Institute
Relation to Project (5-9)	9
Org. Type	US Admin.
Topic	Advisory

Mission	The Summer Institute is a unique program which brings together graduate students, academic researchers, and National Water Center staff to work on projects designed to improve water-related products and decision-support services. Since the first Summer Institute in 2015, over 100 hundred students have participated in the program, which continues to play an important role in developing and refining the National Water Model.
Links	https://www.cuahsi.org/education/summerinstitute/

Department, Agency, Organization, &c	NOAA Office of Water
Project Title	Office of Water Prediction
Relation to Project (5-9)	5
Org. Type	US Admin.
Topic	Advisory, Resilience
Mission	A Water-Ready Nation Collaboratively research, develop and deliver timely and consistent, state-of-the-science national hydrologic analyses, forecast information, data, guidance, and decision-support services to inform essential emergency management and water resources decisions across all time scales
Scope	The OWP will conduct development, field support and operational functions through projects and programs that address national, regional, and local needs and are led and supported by staff in multiple offices across the country.
More Information	Other enterprise centers at the Institute's NCR office include the International Center for Integrated Water Resources Management (ICIWaRM), under the auspices of UNESCO, which is a distributed, intergovernmental center established in partnership with various Universities and non-Government organizations; and the Conflict Resolution and Public Participation Center of Expertise, which includes a focus on both the processes associated with conflict resolution and the integration of public participation techniques with decision support and technical modeling.
Links	https://water.noaa.gov/

Department, Agency, Organization, &c	EPA
Project Title	National Center for Sustainable Water Infrastructure Modeling Research
Relation to Project (5-9)	6
Org. Type	US Agency
Topic	Infrastructure, Advisory
Mission	dedicated to the preservation and advancement of modeling tools for infrastructure analysis and management, training on the use of those tools,

	and expansion of the tools to incorporate changes in the computational environment and end user needs.
Scope	This research is targeted at development of a sustainable national center for the furtherance of EPASWMM, EPANET, and other software. In support of this global and primary objective are a range of enabling objectives, including the development of a superior engine for EPA-SWMM (and potentially EPANET) hydraulic calculations, and the development of associated tools and capabilities (i.e. support for the tools, training, and related contributing activities). In the
Priorities	first year of the research program, the primary objectives were to reach out to the relevant communities, develop avenues of communication as to needs and priorities, enlist support from individuals and entities with allied interests, take steps to stabilize code from the existing products, and make progress on engine development in the form of theoretical advances and evaluation of alternative development options.
Investment Year	2017
Links	https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/recipients.display/rfa_id/593/records_per_page/ALL http://worldwater.byu.edu/grants/ncimm-a-sustainable-center-for-crowd-sourced-water-infrastructure-modeling/

Department, Agency, Organization, &c	EPA
Project Title	Water Topics
Relation to Project (5-9)	6
Org. Type	US Agency
Topic	Watershed
Mission	When the water in our rivers, lakes, and oceans becomes polluted; it can endanger wildlife, make our drinking water unsafe, and threaten the waters where we swim and fish. EPA research supports efforts under the Clean Water Act and Safe Drinking Water Act.
Links	https://www.epa.gov/environmental-topics/water-topics

Department, Agency, Organization, &c	EPA
Project Title	Clean Water State Revolving Fund (CWSRF)
Relation to Project (5-9)	5
Org. Type	US Agency
Topic	Infrastructure, Quality
Mission	federal-state partnership that provides communities a permanent, independent source of low-cost financing for a wide range of water quality infrastructure projects.

Investment Year	2018
Investment Size	$1,655,202,000
Links	https://www.epa.gov/cwsrf

Department, Agency, Organization, &c	EPA
Project Title	CWSRF PISCES Program: Performance and Innovation in the SRF Creating Environmental Success
Relation to Project (5-9)	5
Org. Type	US Agency
Topic	Infrastructure, Quality
Mission	The Clean Water State Revolving Fund's Performance and Innovation in the SRF Creating Environmental Success (PISCES) program allows assistance recipients to gain national recognition for exceptional projects funded by the CWSRF.
Scope	Recognizing high achievers in the CWSRF program
Priorities	Participating state programs each nominated one project that demonstrates one or more of the following evaluation criteria: Water Quality, Public Health, or Economic Benefits Sustainability Innovation
Investment Size	NA
More Information	See CWSRF tab for list of 2018 PISCES awardees
Links	https://www.epa.gov/cwsrf/pisces

Department, Agency, Organization, &c	EPA
Project Title	Water Infrastructure Finance and Innovation Act (WIFIA)
Relation to Project (5-9)	5
Org. Type	US Agency
Topic	Infrastructure
Mission	The WIFIA program accelerates investment in our nation's water infrastructure by providing long-term, low-cost supplemental loans for regionally and nationally significant projects.
Investment Year	2018
Investment Size	$5,000,000,000
More Information	See WIFIA tab for list of 2018 projects
Links	https://www.epa.gov/wifia

Department, Agency, Organization, &c	EPA
Project Title	Water Infrastructure and Resiliency Finance Center
Relation to Project (5-9)	5
Org. Type	US Agency
Topic	Infrastructure, Resilience
Mission	The Water Infrastructure and Resiliency Finance Center is an information and assistance center, helping communities make informed decisions for drinking water, wastewater, and stormwater infrastructure to protect human health and the environment.
Priorities	The Center seeks to accelerate and improve the quality of water infrastructure: Goal 1: Research - Identify financial solutions to help communities meet infrastructure needs. Goal 2: Advise - Provide financial advice, support, and technical assistance to stakeholders. Goal 3: Innovate - Provide expertise and add value to the national water conversation. Goal 4: Network - Build relationships with government partners and stakeholders.
More Information	See Water Finance Clearinghouse tab for funding opportunities
Links	https://www.epa.gov/waterfinancecenter

Department, Agency, Organization, &c	USAID
Project Title	Local Partnerships for the Transformation of Water in Southern Africa
Relation to Project (5-9)	5
Org. Type	US Agency
Topic	Advisory, Resilience
Mission	(i) to address key challenges in the Southern Africa region and (ii) that are aligned with USAID/SA's development objectives 1. Enhanced ecosystem services; 2. Increased individual and institutional resilience; 3. Improved governance around water resource management and water security; and 4. Improved engagement of youth and local environmental champions
Scope	climate change adaptation, biodiversity conservation, agriculture, health, education and democracy and governance into a synergized and complementary development approach intended to support activities in the water resources management sector (especially in the provision of clean water and sanitation)

Priorities	improve the resilience of communities through transformative governance over water resources and increased water security for the benefit of people and ecosystems
Investment Year	2019
Investment Size	$2,000,000
Links	https://www.grants.gov/web/grants/view-opportunity.html?oppId=309834

Department, Agency, Organization, &c	House Committee on Appropriations
Project Title	FY19 Energy and Water Appropriations Bill
Relation to Project (5-9)	7
Org. Type	US Congress
Topic	Supply, Infrastructure
Mission	INVESTING IN AMERICAN INFRASTRUCTURE Provides a much-needed influx of funds into our nation's water resources infrastructure by directing $7B to the Army Corps of Engineers Addresses Western water needs by providing an additional $343M for water conservation and delivery projects, including $134M for water storage projects authorized under the WIIN Act and $99M for rural water projects
Investment Year	2019
Investment Size	$7,343,000,000
Links	https://appropriations.house.gov/subcommittees/subcommittee/?IssueID=34796

Department, Agency, Organization, &c	House Committee on Appropriations
Project Title	DEPARTMENTS OF TRANSPORTATION, AND HOUSING AND URBAN DEVELOPMENT, AND RELATED AGENCIES APPROPRIATIONS BILL, 2019
Relation to Project (5-9)	7
Org. Type	US Congress
Topic	Disaster, Infrastructure
Mission	Storm hazard mitigation for multimodal transit hubs.—The Committee encourages the Secretary to allow mitigation and weatherproofing activities on or near multimodal transportation hubs as eligible for funds administered by the Department of Transportation. This includes activities that would reduce the risk of flooding associated with natural disasters surrounding the structure such as urban trees, vegetation, passive parkland, and increased permeable surfaces and storm water control. These elements not only provide opportunities to mitigate

	transportation pollution and improve air quality but also enhance the structure's security elements and help to reduce the structure's energy use, lowering overall operating costs. Permeable Pavements.—The Committee encourages the Secretary to accelerate research, demonstration, and deployment for permeable pavements to achieve flood mitigation, pollutant reduction, stormwater runoff reduction, and conservation. The Committee encourages the Secretary to conduct comprehensive life cycle cost analyses of permeable pavements compared to non-permeable pavements. The Committee encourages the Secretary to conduct fullscale load testing to establish structural design methods for permeable pavements to enhance roadway stormwater mitigation and flood reduction. The Secretary should make findings of this research available to state and local departments of transportation. Enhanced road maintenance.—Emerging evidence suggests that stormwater runoff from federal highways has a significant effect on water quality. Relatively straightforward control options, including enhanced road maintenance and pavement sweeping, have been shown to be effective at correcting this problem but have only been tested at small scales. The Committee encourages the Department to study the effectiveness of enhanced road maintenance and street sweeping to mitigate the impacts of nonpoint source pollution on our waterways. The Water Resources Development Act of 1986 authorized the Harbor Maintenance Trust Fund as a source of appropriations for SLSDC operations and maintenance. Additionally, the SLSDC generates non-federal revenues which can then be used for operations and maintenance.
Investment Year	2019
Investment Size	$112,813,000
Links	https://appropriations.house.gov/subcommittees/transportation-and-housing-and-urban-development-and-related-agencies-116th-congress

Department, Agency, Organization, &c	BLM (DOI)
Project Title	BLM Oregon-Washington Partnerships
Relation to Project (5-9)	6
Org. Type	US Dept.
Topic	Advisory
Mission	BLM Oregon-Washington continues to place an emphasis on seeking and strategically utilizing partnerships to enhance the agency's capacity to manage public lands and deliver services for the American people.
Scope	Oregon Youth Conservation Corps American Conservation Experience Northwest Youth Corps

	Oregon Natural Desert Association The Heart of Oregon Corps Chicago Botanic Garden SOLV The Nature Conservancy of Oregon Backcountry Horsemen of Oregon Pacific Crest Trail Association
Links	https://www.blm.gov/get-involved/partnerships/featured-partners/oregon

Department, Agency, Organization, &c	BLM (DOI)
Project Title	BLM's Soil, Water, Air Program
Relation to Project (5-9)	5
Org. Type	US Dept.
Topic	Quality, Supply
Mission	leads efforts to assess and restore water quality conditions, and to manage water resources on public lands...
Scope	promote healthy watersheds, provide safe habitat for fish and wildlife, maintain drinking water sources, allow for safe recreational use of our surface water, and maintain healthy plant communities
Priorities	Reducing and limiting the discharge of pollutants and sediments into water resources. Incorporating collaborative, regional watershed assessments into BLM planning efforts to understand potential impacts to watersheds from land use decisions. Improving water quality monitoring through the National Aquatic Monitoring Framework, a component of the Assessment, Inventory and Monitoring (AIM) Strategy. Partnering with other agencies and stakeholders to design and implement landscape scale restoration projects in priority watersheds. Enhancing and then maintaining the BLM's technical expertise by supporting and training water resource specialists, such as hydrologists, ecologists, and aquatic biologists. Implementing Executive Order 13547 Stewardship of the Ocean, Our Coasts, and the Great Lakes which calls for protection, maintenance, and restoration of the health and biological diversity of ocean, coastal, and Great Lakes ecosystems and resources.
More Information	The BLM is responsible for protecting water quality based on mandates in the Federal Land Policy and Management Act (FLPMA), the Clean Water Act, and other laws and regulations. The BLM cooperates with the Environmental Protection Agency (EPA), states, and tribes who establish water quality standards, conduct assessments, and identify water bodies

	that do not meet standards. The BLM analyzes proposed uses of the public lands, and develops mitigation measures to prevent negative impacts to water quality as a result of those uses. The BLM's land health assessments require the BLM to determine if applicable water quality standards are met, or whether there is significant progress toward achieving compliance with water quality standards. Other BLM programs and directorates, such as the Riparian and Fisheries Programs and the National Landscape Conservation System and Community Partnerships Directorate, contribute routinely to the Soil, Water, and Air Program's goals and objectives for water resources. The Soil, Water, and Air Program is actively pursuing ways to integrate the goals of this strategy into all BLM programs. Quarterly issue forums are open to all BLM programs; integrated site visits are encouraged; and opportunities to pool resources for projects and training are welcomed. The Soil, Water, and Air Program is available to assist other programs with technical expertise, training programs, and projects and is anticipating learning from other programs as the aquatic aspects of the BLM's land management responsibilities are integrated.
Links	https://www.blm.gov/programs/natural-resources/soil-air-water/water https://www.blm.gov/sites/blm.gov/files/WaterResourceProgramStrategy.pdf https://www.blm.gov/programs/natural-resources/soil-air-water/water/oregon

Department, Agency, Organization, &c	BLM (DOI)
Project Title	Resource Advisory Councils (RAC)
Relation to Project (5-9)	5
Org. Type	US Dept.
Topic	Advisory
Mission	RACs are sounding boards for BLM initiatives, regulatory proposals and policy changes
Scope	The Bureau of Land Management maintains 37 chartered advisory committees located in the West. These include 30 statewide and regional Resource Advisory Councils; 5 advisory committees affiliated with specific sites on the BLM's National Conservation Lands; and two others, including the National Wild Horse and Burro Advisory Board and the North Slope Science Initiative Science Technical Advisory Panel.
Links	https://www.blm.gov/get-involved/resource-advisory-council

Department, Agency, Organization, &c	Bureau of Reclamation (DOI)

Project Title	WaterSMART (Sustain and Manage America's Resources for Tomorrow)
Relation to Project (5-9)	7
Org. Type	US Dept.
Topic	Supply, Infrastructure, Conflicts
Mission	Through WaterSMART, Reclamation will continue to work cooperatively with states, tribes, and local entities as they plan for and implement actions to increase water supply through investments to modernize existing infrastructure and attention to local water conflicts.
Scope	Water and Energy Efficiency Grants Water Marketing Strategy Grants Small-Scale Water Efficiency Projects Title XVI Desalination Basin Studies Baseline Assessments Site-Specific Pilots Applied Science Grants Cooperative Watershed Management Program Drought Program Water Conservation Field Services Program
Priorities	funding opportunities for water and energy efficiency, small-scale water efficiency, and water marketing strategy projects
Investment Year	2018
Investment Size	$26,500,000
More Information	Through WaterSMART Water and Energy Efficiency Grants (formerly Challenge Grants) Reclamation provides 50/50 cost share funding to irrigation and water districts, tribes, states and other entities with water or power delivery authority. Projects conserve and use water more efficiently; increase the production of hydropower; mitigate conflict risk in areas at a high risk of future water conflict; and accomplish other benefits that contribute to water supply reliability in the western United States. Projects are selected through a competitive process and the focus is on projects that can be completed within two or three years.
Links	https://www.usbr.gov/watersmart/weeg/index.html

Department, Agency, Organization, &c	Department of State
Project Title	U.S. Government Global Water Strategy
Relation to Project (5-9)	8
Org. Type	US Dept.
Topic	Supply, Quality, Disaster
Mission	Our vision is a water secure world, where people have sustainable supplies of water of sufficient quantity and quality to meet human, economic, and ecosystem needs while managing risks from floods and droughts.

Priorities	Strategic Objectives Access to Safe Drinking Water and Sanitation Water Resources Management Cooperation on Shared Waters Governance and Financing
Links	https://www.state.gov/documents/organization/275842.pdf

Department, Agency, Organization, &c	Department of State
Project Title	The Office of Conservation and Water in the Bureau of Oceans and International Environmental and Scientific Affairs (OES/ECW)
Relation to Project (5-9)	6
Org. Type	US Dept.
Topic	Watershed
Mission	coordinates the development of U.S. foreign policy approaches to conserving and sustainably managing the world's ecologically and economically important ecosystems, including, forests, wetlands, drylands and coral reefs, the species that depend on them, and the world's water resources.
Links	https://www.state.gov/e/oes/ecw/water/index.htm

Department, Agency, Organization, &c	DHS
Project Title	Critical Infrastructure Sectors
Relation to Project (5-9)	7
Org. Type	US Dept.
Topic	Infrastructure, Quality, Wastewater
Mission	The Water and Wastewater Systems Sector-Specific Plan details how the National Infrastructure Protection Plan risk management framework is implemented within the context of the unique characteristics and risk landscape of the sector. Each Sector-Specific Agency develops a sector-specific plan through a coordinated effort involving its public and private sector partners. The Environmental Protection Agency is designated as the Sector-Specific Agency for the Water and Wastewater Systems Sector. Presidential Policy Directive 21 changed the name of the Water Sector to the Water and Wastewater Systems Sector in 2013.
Scope	Safe drinking water is a prerequisite for protecting public health and all human activity. Properly treated wastewater is vital for preventing disease and protecting the environment. Thus, ensuring the supply of drinking water and wastewater treatment and service is essential to modern life and the Nation's economy.
Links	https://www.dhs.gov/cisa/critical-infrastructure-sectors#

Department, Agency, Organization, &c	DHS
Project Title	Flood Mitigation Assistance
Relation to Project (5-9)	6
Org. Type	US Dept.
Topic	Disaster
Mission	reduce or eliminate the risk of repetitive flood damage to buildings and structures insured under the National Flood Insurance Program (NFIP)
Scope	Advance Assistance for flood mitigation design and development of community flood mitigation projects and mitigation projects that address community flood risk for the purpose of reducing NFIP flood claim payments.
Investment Year	2019
Investment Size	160,000,000
Links	https://www.fema.gov/media-library/assets/documents/168194

Department, Agency, Organization, &c	DHS
Project Title	Pre-Disaster Mitigation
Relation to Project (5-9)	5
Org. Type	US Dept.
Topic	Disaster
Mission	implement and sustain cost-effective measures designed to reduce the risk to individuals and property from natural hazards, while also reducing reliance on Federal funding from future disasters
Scope	FEMA will prioritize competitive projects for funding by hazard and activity type to minimize duplication with the Flood Mitigation Assistance (FMA) grant program with a priority of non-flood hazard (e.g., wildfire, drought, seismic, wind) mitigation project activities over flood mitigation projects
Investment Year	2019
Investment Size	$235,200,000
Links	https://www.grants.gov/web/grants/view-opportunity.html?oppId=307874

Department, Agency, Organization, &c	USDA
Project Title	National Program 211: Water Availability and Watershed Management
Relation to Project (5-9)	9

Org. Type	US Dept.
Topic	Supply, Quality, Agriculture
Mission	(1) to conduct fundamental and applied research on the processes that control water availability and quality for the health and economic growth of the American people; and (2) to develop new and improved technologies for managing the Nation's agricultural water resources
Scope	improve water conservation and water use efficiency in agriculture, enhance water quality, protect rural and urban communities from the ravages of droughts and floods, improve agricultural and urban watersheds, and prevent the degradation of riparian areas, wetlands, and stream corridors.
Priorities	characterizing potential hazards, developing management practices, strategies and systems to alleviate problems, and providing practices, technologies, and decision support tools for the benefit of customers, stakeholders, partners, and product users
Investment Year	2011-ongoing
Links	https://www.ars.usda.gov/natural-resources-and-sustainable-agricultural-systems/water-availability-and-watershed-management/

Department, Agency, Organization, &c	USDA
Project Title	Critical Water Research
Relation to Project (5-9)	8
Org. Type	US Dept.
Topic	Watershed
Mission	joint program with EPA
Scope	Rural and Agricultural Watersheds
Priorities	AFRI Water for Food Production Systems Challenge Area
Investment Year	2016
Investment Size	10700000
More Information	This funding is available through the Agriculture and Food Research Initiative (AFRI), authorized by the 2014 Farm Bill and administered by USDA's National Institute of Food and Agriculture (NIFA). The AFRI Water for Food Production Systems Challenge Area focuses on multidisciplinary systems approaches, which integrate new technologies and strategic management that solve water availability and quality challenges in food production systems.
Links	https://www.usda.gov/media/press-releases/2016/05/17/usda-announces-107-million-available-critical-water-research

Department, Agency, Organization, &c	USGS (DOI)

Project Title	National Water Census
Relation to Project (5-9)	6
Org. Type	US Dept.
Topic	Advisory
Mission	systematically provide information that will allow resource managers to assess the supply, use, and availability of the Nation's water
Scope	The primary building blocks of the water budget are base layers of precipitation, streamflow, evapotranspiration (ET), water use, and change in groundwater storage.
Priorities	Water Use, Focus Area Studies, Groundwater, Streamflow, Environmental Flows, Drought
Investment Year	2019
Investment Size	$7,871,000
Links	https://water.usgs.gov/watercensus/funding.html

Department, Agency, Organization, &c	US Army Corps of Engineers
Project Title	Institute for Water Resources
Relation to Project (5-9)	7
Org. Type	US Org.
Topic	Advisory, Resilience
Mission	created in 1969 to analyze and anticipate changing water resources management conditions, and to develop planning methods and analytical tools to address economic, social, institutional, and environmental needs in water resources planning and policy.
Scope	IWR strives to improve the performance of the USACE water resources program by examining water resources problems and offering practical solutions through a wide variety of technology transfer mechanisms. In addition to hosting and leading USACE participation in national forums, these include the production of white papers, reports, workshops, training courses, guidance and manuals of practice; the development of new planning, socio-economic, and risk-based decision-support methodologies, improved hydrologic engineering methods and software tools; and the management of national waterborne commerce statistics and other USACE Civil Works information systems. IWR serves as the USACE expertise center for integrated water resources planning and management; hydrologic engineering; engineering risk assessments; conflict resolution and public participation; and waterborne commerce data and marine transportation systems.
Priorities	Coasts Collaboration and Conflict Resolution Civil Works Planning and Policy Support Economics Emergency Management

	Flood Risk Management Hydrology ICIWaRM- International Center for Integrated Water Natural Resources Management Support Environment Navigation Regulatory Risk Analysis IWR Training Value to the Nation Water Supply
More Information	IWR's Hydrologic Engineering Center (HEC), located in Davis, CA specializes in the development, documentation, training, and application of hydrologic engineering and hydrologic models. IWR's Navigation and Civil Works Decision Support Center (NDC) and its Waterborne Commerce Statistical Center (WCSC) in New Orleans, LA, is the Corps data collection organization for waterborne commerce, vessel characteristics, port facilities, dredging information, and information on navigation locks. IWR's Risk Management enter is a center of expertise whose mission is to manage and assess risks for dams and levee systems across USACE, to support dam and levee safety activities throughout USACE, and to develop policies, methods, tools, and systems to enhance those activities.
Links	https://www.iwr.usace.army.mil/
Additional Details	Program Direction: Water Resource Trends and Emerging Issues Support on CW Strategic Plan Policy Development Support National Studies Click here to collapse content Problem Solving: Investment Decision Support Methods and Models Multi-Objective/Integrated Water Resource Management (IWRM) Plan Formulation Socio-Economic Analyses Environmental Evaluation Global Climate Change Technical Assistance and Capacity Development Click here to collapse content Partnering: Collaborative Planning Public Involvement Alternative Dispute Resolution National Interface International Outreach Click here to collapse content H&H Methods and Models: Surface Hydrology Hydrologic Statistics River Hydraulics Ecosystem Function Models

	River Forecasting Reservoir Systems and Water Management

Department, Agency, Organization, &c	USACE
Project Title	America's Water Infrastructure Act of 2018
Relation to Project (5-9)	7
Org. Type	US Org.
Topic	Infrastructure
Mission	The authorization of an estimated $3.8 billion in new Army Civil Works projects, the Fiscal Year 2019 appropriations of $7 billion and the emergency supplemental funds of $17.4 billion, will give the U.S. Army Corps of Engineers (USACE) key tools to support the development of water infrastructure in this Nation
Links	https://www.prnewswire.com/news-releases/president-signs-into-law-americas-water-infrastructure-act-of-2018-300737158.html

Department, Agency, Organization, &c	USACE
Project Title	Access to Water Resources Data - Corps Water Management System (CWMS
Relation to Project (5-9)	7
Org. Type	US Org.
Topic	Advisory
Mission	The United States Army Corps of Engineers (USACE) is responsible for operating and maintaining more than 700 lock and dam projects nationwide. The Access to Water Resources Data - Corps Water Management System (CWMS) Data Dissemination tool supports the USACE water control management mission by utilizing visualizations and reports to provide continuous assessment, awareness, and effective decision support of lock and dam projects, which in turn reduces risks to people, property, and the environment.
Links	http://water.usace.army.mil/a2w/f?p=100:1:0:

Department, Agency, Organization, &c	Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI)
Project Title	Universities Allied for Water Research
Relation to Project (5-9)	7
Org. Type	US Admin.

Topic	Advisory, Infrastructure
Mission	CUAHSI's mission is to advance water science by: Strengthening interdisciplinary collaboration in the water science community, To empower the community by providing critical infrastructure, and To promote education in the water sciences at all levels
Links	https://www.cuahsi.org/about/what-is-cuahsi/

Department, Agency, Organization, &c	State of Washington Water Research Center (WRC)
Project Title	Research Projects
Relation to Project (5-9)	8
Org. Type	WA Center
Topic	N/A
Mission	https://wrc.wsu.edu/project/category/research-projects/
Priorities	https://wrc.wsu.edu/project/category/seed-grants/
Links	https://wrc.wsu.edu/

Department, Agency, Organization, &c	Bill and Melinda Gates Foundation
Project Title	Water, Sanitation & Hygiene
Relation to Project (5-9)	5
Org. Type	NGO
Topic	Wastewater
Mission	Enable widespread use of safely managed, sustainable sanitation services, contributing to positive health, economic, and gender equality outcomes for the world's poorest.
Scope	Solving the sanitation challenge in the developing world will require breakthrough innovations in technologies as well as systems that are practical, cost-effective, and replicable on a large scale. Sub-Saharan Africa — As African cities and towns continue to grow, especially within informal settlements, governments are acknowledging the need for innovative sanitation solutions that are less expensive and faster to deploy than building and operating sewer systems and wastewater treatment plants. South Asia — Sanitation is a significant challenge for most South Asian countries, but many are now aggressively driving inclusive national sanitation strategies that prioritize safe sanitation. India, in particular, provides a global model for sanitation reform through the government's Swachh Bharat Mission and a growing network of sanitation operators and utilities practicing Fecal Sludge Management.

	China — The Chinese government's Toilet Revolution, promising the rapid scaling of safe sanitation approaches for the country, presents a strong opportunity for the adoption of new technologies within the rural and public toilet markets in China, particularly in areas facing water scarcity issues.
Priorities	Promoting policies and practical steps that governments can take now to establish safer sanitation through Fecal Sludge Management (FSM)—a sanitation strategy that does not require sewers; Investing, alongside governments in our priority geographies, in city-wide inclusive sanitation to accelerate the adoption of safely managed sanitation at the city level, particularly focused on slums and informal settlements that are typically underserved; Investing in technologies, such as the reinvented toilet and the omni-processor, that can radically change the way municipalities and households manage human waste affordably, at scale, and with little or no need for water and electricity; and Conducting research to help the sanitation sector develop data and evidence about what works.
More Information	Transformative Technologies & Commercialization The flush toilet and central sewer systems are considered by many consumers and governments around the world to be the gold standard for safe sanitation. However, decentralized sanitation systems incorporating technologies like the reinvented toilet present alternatives that can be safer, more resilient, more cost-effective, and environmentally-friendly. Since 2011, the Gates Foundation's Reinvent the Toilet Challenge has worked with leading engineers and scientists to design low-cost toilets that do not require connections to the electrical grid, water supply, or sewers.
Links	https://www.gatesfoundation.org/What-We-Do/Global-Growth-and-Opportunity/Water-Sanitation-and-Hygiene

Department, Agency, Organization, &c	Group on Earth Observations (GEO)
Project Title	GEO Global Water Sustainability (GOEGLOWS)
Relation to Project (5-9)	7
Org. Type	NGO
Topic	Advisory
Mission	This Initiative consolidates the positive elements of the water activities in the first phase of GEO and ensures that strong coordination and commitment is in place for links between data, information, knowledge, and applications and policy.

Scope	This Initiative is intended to facilitate the use of Earth observation assets to contribute to mitigating water shortages, excesses and degraded quality arising from population growth, climate change and industrial development.
Priorities	Enhancing Global Water Sustainability (Sustainable Development Goals; water scarcity and access; climate change; cold regions; user engagement); Minimizing Basin and Regional Risk (integrated water prediction including floods and droughts; transboundary issues and Integrated Water Resources Management; Water-Energy-Food-Environment-Health Nexus; Climate Change Adaptation); Essential Water Variable (EWV) Understanding (water quality and use; water cycle Variables); Earth Observations, Integrated Data Products and Applications, and Tool Development; Data Sharing, Dissemination of Data, Information, Products, and Knowledge; User Engagement, Capacity Building, and AmeriGEOSS.
More Information	Supported by NASA and NOAA
Links	https://www.earthobservations.org/documents/work_programme/201802_geo_global_water_sustainability_update.pdf https://www.earthobservations.org/activity.php?id=118

Department, Agency, Organization, &c	The Water Research Foundation
Project Title	Current RFPs
Relation to Project (5-9)	7
Org. Type	NGO
Topic	Advisory
Mission	Water Research Foundation (WRF) is the leading not-for-profit research cooperative that advances the science of water to protect public health and the environment. Governed by utilities, WRF delivers scientifically sound research solutions and knowledge to serve our subscribers and stakeholders in all areas of drinking water, wastewater, stormwater, and reuse.
Scope	Managing Water and Wastewater Utility Data to Reduce Energy Consumption and Cost (project #4668) Incentives for Green Infrastructure Implementation on Private Property (project #4684) Rates and Mechanisms of Lead Phosphate Formation, Aggregation, and Deposition for More Efficient Corrosion Control (project #4686) Project Delivery Performance Evaluation and Decision Support Tool for Water and Wastewater Capital Projects (project #4685) Practical Condition Assessment and Failure Probability Analysis of Small Diameter Ductile Iron Pipe (project #4661) Challenges and Practical Approaches to Water Reuse Pricing (project #4662)

	Defining Optimum Security and Communication Methodologies for Intelligent Water Networks (project #4670) Building-Scale Treatment for Direct Potable Water Reuse & Intelligent Control for Real Time Performance Monitoring (project #4691) Long-Term Water Demand Forecasting Practices for Water Resources and Infrastructure Planning (project #4667)
Priorities	Dual Plumbing Costs For Buildings Utilizing Non-Potable Water Reuse Compiling Evidence of Pathogen Reduction through Managed Aquifer Recharge and Recovery Identifying the Amount of Wastewater That is Available and Feasible to Recycle in California Assessing the State of Knowledge and Impacts of Recycled Water Irrigation on Agricultural Crops Evaluation of a Validation Protocol for Membrane Bioreactors Based on a Correlated Surrogate to Achieve Pathogen Credit for Potable Reuse
Investment Year	2019
Investment Size	>$250k
Links	http://www.waterrf.org/Pages/Index3.aspx

Department, Agency, Organization, &c	Water Mission
Project Title	Water Mission
Relation to Project (5-9)	5
Org. Type	NGO
Topic	Quality, Wastewater
Mission	We design, build and implement safe water, sanitation and hygiene (WASH) solutions for people in developing countries and disaster areas. We have 300 staff members around the world in permanent country programs combatting the world's water scarcity crisis, using innovative technology and engineering expertise to break through the global water crisis.
Scope	Water Mission is committed to ongoing learning and improvement to ensure the integrity of our promise to deliver lasting benefits for the people and communities we serve. Our product innovation and program evaluation initiatives – both in the laboratory and in the field – continuously enhance our water treatment and pumping technologies, technical design and community development approach. Additionally, we share our knowledge and best practices for the Water, Sanitation and Hygiene (WASH) sector.
Priorities	Solar Water Pumping Sustainable WASH Management Remote Monitoring & Innovative Technology Measuring Holistic Impact
Links	https://watermission.org/

Department, Agency, Organization, &c	Water Research Initiative
Project Title	Water Research Initiative
Relation to Project (5-9)	5
Org. Type	NGO
Topic	Advisory
Mission	The premise of this initiative is that a cooperative combination of the innovative technical resources in molecular and nanoscale science and engineering of Ben-Gurion University (BGU) in Israel with the University of Chicago (UChicago), the Argonne National Laboratory (ANL) and others in the greater Chicago area will create new, scalable tools and processes for water production, purification, preservation and re-use deployable in many regions of the globe
Scope	Through the Water Research Initiative (WRI), scientists and engineers are developing new membrane technologies, new catalytic processes for eliminating organic chemicals, anti-fouling surfaces to enhance the lifetime of water treatment equipment, novel methods to monitor underground water movement and innovative smart grids for urban water management. The Water Research Initiative (WRI) is guided by three major themes - Catalysis, Separations, and Hydrological Connectivity - each of which is comprised of multiple collaborative projects.
Priorities	Biofouling control by zwitterionic polymer brushes Separations Catalytic wet oxidation Catalysis Membrane-biofilm nexus Separations Self-assembled functional membranes Separations Smart water landscapes Hydrological Connectivity Timescale of groundwater transport Hydrological Connectivity
Links	https://www.waterresearchinitiative.org/

Department, Agency, Organization, &c	UNICEF
Project Title	Water, Sanitation and Hygiene (WASH)
Relation to Project (5-9)	5
Org. Type	UN Org.
Topic	Quality, Wastewater
Mission	WASH is the collective term for Water, Sanitation and Hygiene. Due to their interdependent nature, these three core issues are grouped together to represent a growing sector. While each a separate field of work, each is dependent on the presence of the other. For example, without toilets, water sources become contaminated; without clean water, basic hygiene practices are not possible.
Scope	

Priorities	Water UNICEF's work in water focuses on the ability for children to access safe water, the quality of the water they can access and the journey they must take to collect it. UNICEF is at the forefront of exploring innovative ways to access water, and building climate resistant infrastructure. More on water Sanitation For sanitation, UNICEF works to ensure access and use of basic toilets and ways to separate human waste from contact with people. One important area of work for sanitation is to end the practice of "open defecation," and facilitate community-led initiatives to build, maintain and use basic toilets. More on sanitation Hygiene UNICEF's work in hygiene is aimed at nurturing good hygiene practices, especially handwashing with soap. Although it sounds simple, this act is essential to prevent disease and the health of children. More on hygiene
Links	https://data.unicef.org/topic/water-and-sanitation/overview/

Department, Agency, Organization, &c	World Bank
Project Title	Water Supply, Sanitation, and Hygiene (WASH) Poverty Diagnostic Initiative
Relation to Project (5-9)	6
Org. Type	UN Org.
Topic	Quality, Wastewater
Mission	Over the past three years, it has assessed the relationship of poverty, time, physical space and social space with drinking water, sanitation and hygiene, as well as the knock-on effects on a person's life cycle. It was not designed just to answer the "What?" but to also look at the "So What?" and "Now What?" After all, water is life. And that is both a very simple and very complex relationship.
Priorities	To better understand this relationship, this initiative undertook multidisciplinary research - developing innovative methods to fully appreciate the impacts of inadequate services on human development outcomes and identify the binding constraints to service delivery. Supported by the Swedish International Development Cooperation Agency (SIDA), the initiative is a large-scale partnership between the World Bank's Water, Poverty, Governance, Health, Nutrition & Population teams and these countries. This work is especially relevant for the SDG era and as countries look to harness their precious WASH resources for maximum impact.
Links	http://www.worldbank.org/en/topic/water/publication/wash-poverty-diagnostic

Department, Agency,	World Bank Group Water Global Water Security and Sanitation Partnership (GWSP)

Organization, &c	
Project Title	Global Water Security and Sanitation Partnership (GWSP)
Relation to Project (5-9)	6
Org. Type	UN Org.
Topic	Advisory
Mission	The GWSP supports client governments to achieve the water-related Sustainable Development Goals through the generation of innovative global knowledge and the provision of country-level support.
Links	http://www.worldbank.org/en/programs/global-water-security-sanitation-partnership

Pacific Northwest National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354
1-888-375-PNNL (7665)

www.pnnl.gov