Interdisciplinary Research (IDR) Origination Awards

Project Title: Transforming water education to address the global water crisis

Principal Investigators

Name (PI listed first)	Department	College
Benjamin W. Abbott	Plant and Wildlife Sciences	Life Sciences
Ryan S. Nixon	Teacher Education	School of Education
Keely Song Glenn	Dance	Fine Arts and Communications
Daniel P. Ames	Civil and Environmental Engineering	Engineering
Elizabeth Gibbons Bailey	Biology	Life Sciences
Greg Carling	Geological Sciences	Physical and Mathematical Sciences
Joshua LeMonte	Geological Sciences	Physical and Mathematical Sciences
Richard Gill	Biology	Life Sciences
Bryan G. Hopkins	Plant and Wildlife Sciences	Life Sciences

Track: Track One

Abstract: Improving water security through sustainable management depends on an accurate understanding of human-water interactions. However, pervasive misconceptions of the water cycle persist among policymakers and the public, including where water comes from, how humans affect it, and how much is available for use. In a world where water mismanagement kills millions and causes trillions in economic damages each year, correcting water misconceptions has graduated from an academic exercise to a planetary priority. Here, we propose to transform how the water cycle is taught through three interrelated activities: **1**. Create images, animations, performances, and interactive software that integrate current hydrological understanding from local to global scales, **2**. Explore the effect of improved water cycle representations on elementary teacher instruction and undergraduate knowledge, and **3**. Flood the world with the pedagogical products from activities 1 and 2 using traditional and novel dissemination channels. Our interdisciplinary team will combine cutting-edge hydrological, educational, and social sciences with innovative artistic design and outreach to transform how we teach water. Funds will be used to recruit a postdoctoral fellow, engage 25 undergraduate students in mentored research, and cover teacher participation stipends. These activities will lead to up to 9 external funding applications, the creation of open-source images and software, at least 7 peer-reviewed publications, the development of an interdisciplinary "global water" course, and high-profile community outreach.

Summary of Plans for External Funding: We will implement a two-tiered approach for securing external funding. First, we will prepare several large proposals ($450,000 to $850,000): the NSF ECR Program in the spring of 2022, the NSF CAREER Program in the summer of 2022, the NASA Terrestrial Hydrology program in the fall of 2022, and the Spencer Foundation in the spring of 2023. Feedback from two initial NSF proposals was positive, but reviewers requested evidence that the hydrological teaching tools could be effective without traditional in-person trainings. The IDR funding would allow us to measure these effects, greatly strengthening our proposals and positioning us for success. Second, we will submit smaller proposals to allow short-term continuation of the project and expansion of the research activities at BYU. These proposals will focus on specific products (e.g. municipal- to national-level water cycle syntheses, interactive modeling components, and local outreach activities) and will be submitted to organizations, including the Utah DWQ, NEA, CUAHSI, the Sloan Foundation, and Soil Science Society of America. Each of the principal investigators will lead at least one proposal, creating a diverse funding base. We will revise and resubmit the proposals until successful. IDR support will allow us to further establish BYU as a world leader in water research and leverage BYU's unique combination of artistic, technical, and scientific expertise to address one of the greatest challenges facing humanity.

1. Overview: Though humans now dominate many of Earth's great cycles, the causes and consequences of these changes are poorly understood by policymakers and the public[1–3]. For example, climate change is routinely blamed for water shortages actually stemming from local mismanagement, watershed practices that have been debunked for decades are still widely applied, and some experts dispute whether there is a global crisis at all[4–6]. Some of this misunderstanding comes from inherent complexity in hydrological and societal systems (Fig. 1), but some of it is a consequence of distorted and inaccurate teaching materials and techniques[1,7,8]. The water cycle is one of the first great cycles with which many people engage during their basic education[1,9]. **Flaws in water education could therefore undermine efforts to improve water security and cultivate scientific literacy**[9,10].

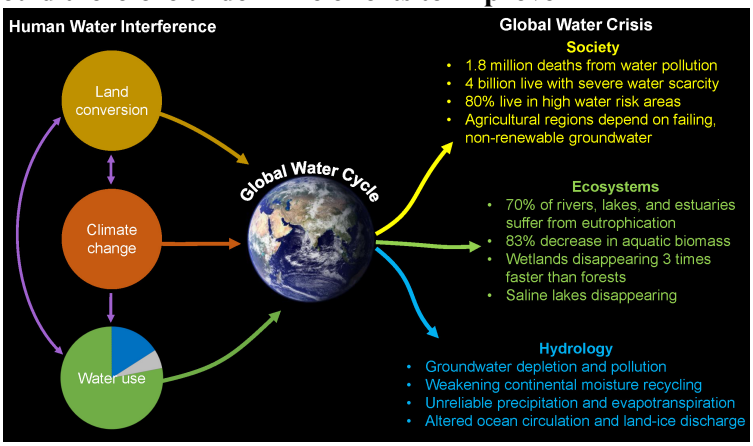

Figure 1. Types of human interference with the global water cycle and dimensions of the global water crisis. Adapted from[5].

In the absence of direct experience with large-scale hydrological processes, education forms the basis of our valuation and management of the global water cycle[4,11–13]. Though water teaching materials may not be intended as comprehensive and quantitative representations of the entirety of hydrological science, they effectively play that role for many educators, policymakers, and researchers, which increases the societal stakes of systematic inaccuracies[1,12]. Water cycle materials explicitly and implicitly teach core scientific principles, including conservation of mass, the reality that human activity can cause global-scale changes, and the concept that distant processes can have acute, local effects (e.g. upstream withdrawals or pollution affecting downstream communities, and teleconnections between local climate and ocean circulation or deforestation). Unfortunately, poor educational materials on hydrological science currently hinder formal and informal learning about the water cycle (Section 2)[5,12–14]. **Water illiteracy is so pervasive that most people do not know where rain comes from, and educational materials are so poor that the answer to that question is wrong in most diagrams**[1,5]. Because humans dominate critical components of the hydrosphere[15–17], it is urgent to cultivate understanding of the water cycle.

We propose to improve water education through three complementary research activities (Fig. 2). **First**, we will integrate correct hydrology into images, animations, and other teaching tools, including static visualizations, performance art, and interactive software. We will develop highly customized and scalable materials to catalyze personal reflection and high-level understanding, building on existing expertise and funding at BYU (e.g. the NSF-funded HydroShare, HydroLearn, and CZO projects; creative work by BYU Contemporary Dance Theatre, BYU ARTS Partnership, and BYU Kinnect Dance). **Second**, we will investigate the impact of these improved water cycle representations on college students' knowledge of the water cycle and elementary teachers' water cycle instruction. This will contribute to fundamental understandings about the influence of scientific representations, testing our hypothesis that improved materials can substantially enhance water teaching through informal channels. **Third**, we will disseminate the most effective teaching materials produced in Activity 1 through peer-reviewed publications and public platforms (e.g. USGS Water Science School, Wikipedia, Pinterest, CUAHSI, SlideShare, etc.). This will elevate the profile of research at BYU and, more importantly, flood the teaching world with high-quality, open-source materials to improve water literacy in public and professional spheres.

2. Background and need for work: Human activity alters the water cycle in three distinct but interrelated ways (Fig. 1). First, humans have disturbed approximately three-quarters of the Earth's ice-free land surface through agriculture, urbanization, deforestation, and wetland destruction[18]. These disturbances alter evapotranspiration, groundwater recharge, river discharge, and precipitation at continental scales[19–21]. Second, climate change is disrupting patterns of water flow and storage at local to global scales[22–26].

Third, humans appropriate water through livestock, crop, and forestry use of soil moisture (*green water use*), water withdrawals (*blue water use*), and water required to assimilate pollution (*gray water use*)[1,17,27]. These human water uses have confounded efforts to model regional and global water circulation[10,28,29]. More importantly, **human mismanagement has created a global crisis of water quantity and quality that kills millions or people each year[30] and threatens many ecosystems worldwide**[31–34].

The global water crisis is defined fundamentally by human beliefs about societal water demands and natural limits of sustainably-available water[5,7,35–37]. The multiple interactions between society and the hydrologic cycle limit the utility of disciplinary water research for problem solving, but does provide an opportunity to improve water management and scientific literacy through interdisciplinary research and action[7,14]. Indeed, the water cycle is a central topic of science curriculum around the globe, where it is used to teach disciplinary principles such as physical phase changes (e.g. evaporation and condensation), as well as "systems" concepts such as emergent properties and teleconnections[38–40].

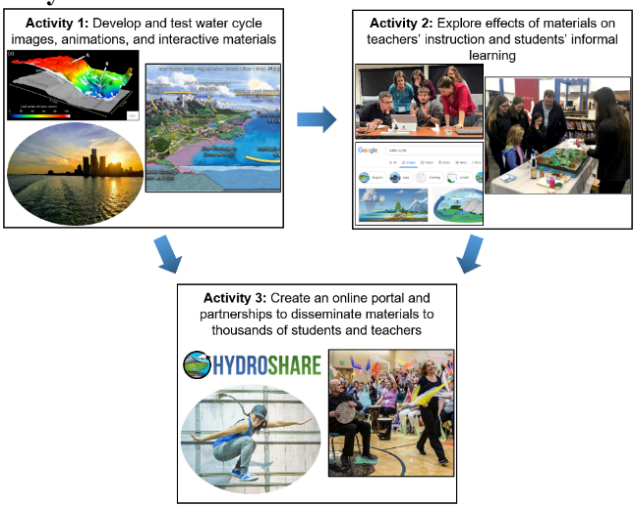

Figure 2. Relationships among the 3 main project activities. Research and outreach activities will be fully integrated to allow iterative improvements.

In Utah, the water cycle is primarily taught in the 5th grade. The state standards focus on water movement in the Earth system and the interactions of physical systems that create weather patterns. These standards are helpful, but they do not adequately integrate relations among water, human society, and ecosystems. Furthermore, teachers tend to emphasize memorizing the steps of the water cycle instead of developing students' understanding of the systems involved[39,41]. This is understandable because elementary teachers often do not have lengthy experience with the science topics they are responsible for teaching[42]. Without adequate subject matter knowledge and materials, teachers are unlikely to effectively teach their students the complex socioecological topics included in the elementary science curriculum[41,43].

The challenge of effectively teaching water complexities is not confined to elementary school. A comprehensive analysis of water cycle diagrams across educational levels found that only 15% of diagrams integrate humans with the water cycle and less than 2% show any sign of climate change or water pollution, two of the central causes of the global water crisis[1]. **The omission of humans and associated change from technical and non-technical water cycle diagrams is deeply problematic because it implies that one of our most essential and threatened resources is not influenced by our actions**. This obscures some of the most urgent socioecological crises, including water security and water justice[16,44–46], loss of aquatic biodiversity[47,48], and freshwater and coastal eutrophication[27,49]. Even for the "natural" components of the water cycle, water cycle diagrams distort or omit central water concepts[1].

Providing teachers with better representations to catalyze deeper understanding is needed to achieve national and state goals, as well as to improve water literacy and water management generally[8,50,51]. Specifically, creating accurate and engaging water materials would support the new vision of science teaching presented in the *Framework for K-12 Science Education*[52], a national curriculum document which led to the development of the new science standards in Utah. The new vision focuses on core scientific ideas, including the water cycle, by making sense of real-world phenomena. This vision encourages students to engage in systems thinking to build their disciplinary scientific knowledge and interdisciplinary application of evidence and values. Systems thinking has also been emphasized as a core concept for biological literacy at the college level as described in *Vision and Change in Undergraduate Education*[53]. The water cycle provides an ideal context to catalyze systems thinking in K-12 teachers and students, college biology professors and students, and the public, because it provides numerous, accessible phenomena to consider, it links many core ideas, and it requires considering boundaries, connections, and internal interactions[9,54].

Widespread scientific understanding of individual and linked systems is an important academic and societal goal because most socioecological challenges of our day are intractable without an understanding of uncertainty, emergent properties, and time lags[55–57]. For example, systems thinking has been identified as crucial for policymakers and the public to address food and water security, pollution and pandemic public health, climate change, and loss of biodiversity[1,2,30,58,59].

3. Project goals and approach: In this context, we propose to develop new materials about the water cycle, to test their effectiveness through informal learning activities, and to disseminate the most effective materials through a network of partnering organizations.

3.1. Activity 1: Creation of art and an online, interactive water cycle model. The postdoc will work with Ames, Gill, Hopkins, and 10 undergraduate students to create static and dynamic materials to teach core hydrological, societal, and systems concepts. Leveraging the unique combination of technical, scientific, and artistic expertise shared by the PIs of this project, we will develop low-tech diagrams that can be translated and distributed globally, live and recorded performance art to reach less technical audiences, and an interactive online application integrating hydrology with societal water management and use. We include an example diagram below (Fig. 3), which we created with BYU undergraduates as an example of how design principles and accurate hydrology can correct errors that undermine water literacy (e.g. temporal variability, human-water interactions, and unintended consequences of land use).

To overcome the challenges of representing temporal change (e.g. seasonality and climate change) and links between human management and water availability, Ames, Gill, and Carling will work with the postdoc and undergraduate students to create an interactive numerical model with adjustable climate, ecosystem types, and human drivers. This cutting-edge model will be distributed via an educational web application based on the NSF-funded HydroShare project and as a learning module in the forthcoming HydroLearn project. We will use our open source Tethys Platform environment to create interactive visualizations to facilitate education in both traditional and workshop environments.

3.2. Activity 2: Effects of new materials on knowledge and instruction. Nixon and Bailey will supervise the postdoc on the science education component of the project, which explores the effect of improved water cycle representations on the elementary teacher instruction and undergraduate student knowledge.

Elementary teachers: We focus on elementary teachers because we know their instruction reflects their knowledge of science concepts[60]. Many professional development programs, where experts provide instruction for teachers, have been developed over the years to help teachers improve their instruction and knowledge[61]. While these programs have an important role in teachers' learning, they are expensive, short-lived, and challenging to scale up[62]. We are interested in exploring and supporting the continuous professional learning that teachers experience outside of the formal framework of professional development[63]. Based on prior observations[64], we hypothesize that external representations such as diagrams can improve teacher subject matter knowledge and consequently the quality and accuracy of their instruction. We will test this hypothesis with detailed observations and interviews with ~10 fifth-grade teachers. Specifically, we will address three questions: 1. What aspects of the water cycle are teachers emphasizing in their instruction, 2. How does their instruction change after becoming familiar with improved water cycle teaching materials, and 3. How does their instruction in both cases align with the representations they use?

Figure 3. Example of how a static representation of the water cycle can communicate temporal variability and consequences of human activities. Images, animations, and software that teach central truths about the water cycle will be evaluated for effectiveness quantitatively and then shared freely through the project website and public platforms.

Following best practices in teacher observation[65–67], we will gather longitudinal qualitative and quantitative data (e.g. video recordings, detailed interviews, and interactive testing) before and after introduction of the new teaching

materials. This analysis will involve identifying codes and patterns throughout the data corpus in relation to the research questions. We will test how teaching materials influence emphasis in instruction, conceptual completeness, and likelihood of linking content with other systems, including human demand. *Undergraduate biology students:* Undergraduate science education—for majors and nonmajors—influences long-term scientific literacy, personal environmental behavior, and likelihood of professional and civic engagement[68–72]. We will test the effectiveness of various water materials (e.g. diagrams, interactive software, and graphic novels) on undergraduate biology students' systems thinking about the environment. Specifically, we will ask: 1. How often do undergraduate students include humans when hypothesizing causes of water cycle disruption or proposing potential solutions, 2. Are they more likely to integrate society in their mental models when instructors use the revised materials from Activity 1, and 3. What specific materials and approaches catalyze the most meaningful learning?

After identifying the most promising materials from Activity 1 with eye tracking, social media pilots, and concept retention, we will investigate our questions with students enrolled in an introductory biology course for non-majors at BYU. Past enrollment suggests we will have 250 – 400 students, which is sufficient for the factorial regression analyses we will use in this study. Building on our previous research[1,67,73], we will implement a longitudinal manipulation, with a pre-survey placing each student on the revised new ecological paradigm scale[74], which characterizes attitudes toward the environment and humans' relationship with it. We will randomly assign students to one of four groups with different versions of an online module on the water cycle. Factorial combinations include general human integration (e.g. depiction of land use) and specific examples (e.g. groundwater salinization).

All students will then take an identical assessment containing three items: 1. Conceptual drawings of the water cycle, 2. A list all fluxes they can think of that affect water pools, and 3. Hypothesized causes and potential solutions to specific water problems. We will categorize student responses based on depiction of humans, consideration of interactions within and among systems, and scientific accuracy. Using chi square tests of homogeneity and binomial logistic regression, we will quantify effects of the new materials and pre-survey new ecological paradigm score. This student-oriented experiment will complement the teacher-oriented observations, generating strong evidence about effectiveness.

3.3. Activity 3: Disseminating the most effective water materials to educators and learners worldwide. Integrating the products and findings from Activities 1 and 2, we will distribute the most effective new materials via academic and public channels. We will leverage the two recently funded NSF CZO network grants (Carling and Abbott) as well as through the Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI) program (Ames and Abbott) to expand project reach. All resources will be freely available for anyone with internet access. In addition to peer-reviewed publications in science education journals, we will post new water cycle materials to public platforms, including Pinterest, Wikipedia, and SlideShare, three of the most commonly accessed resources by teachers[75,76]. Our initial outreach efforts have been highly successful. Our revised diagram on the water cycle page of Wikipedia has been viewed and downloaded nearly a million times, and we are now partnering with the USGS to overhaul its Water Science School, one of the most widely accessed water educational resources globally.

We will also create or expand several platforms for these materials. To move beyond simple mastery of concepts, Glenn, LeMonte, and Abbott will lead the creation of an animated Ebook that incorporates water cycle lesson plans for elementary students, still images, water dance films, research articles, and commercial activism vignettes highlighting hydro-social interactions. The Ebook will encourage scientific and artistic reflection by providing the opportunity to read, hear, see, and hopefully feel the power of the water cycle corporally and emotionally. This collaboration will blur the boundaries between art and science, moving beyond textbooks and lectures into the human psyche. Working with BYU Contemporary Dance Theatre, the BYU Kinnect Elementary outreach program, and the BYU Arts Partnership, we will connect with 480 teachers during weekly arts integration courses and through a summer conference. Performances integrating Activities 1 and 2 will serve 20 schools with a reach of ~15,000 students.

These partnerships and early successes will magnify the impact of this research and demonstrate credibility to funding agencies, which are increasingly valuing public outreach as well as basic research.

4. Expected project outcomes:

- **Planned external funding proposals:** Leveraging the entire faculty team and postdoctoral fellow, we will submit up to 9 external proposals. We will continue submitting and resubmitting until we secure funding for at least three large projects (>$450,000) and four or more medium and small projects. Detailed plan for securing external funding, including table of target RFPs is included after references.
- **Planned scholarly articles** (journal in italics, lead author in parentheses*): **1.** Exposing invisible water flows to shore up global water security. *Nature* (Abbott). **2.** Making mechanistic hydrologic models accessible to K-12 students and teachers. *Environmental Modelling & Software* (Ames). **3.** Warming the water: using interactive hydrologic software to engage and educate. *Science Education* (Gill). **4**. Relationship between instruction and representational use. *Teaching and Teacher Education* (Nixon). **5.** Thriving in the Chaos: Collaboration and Innovation between Dance and Science. *National Dance Education Organization* (Glenn). **6.** Bringing agricultural water into the Anthropocene. *ASA, CSSA, SSSA* (Hopkins). **7.** How human effects are forgotten if not included in classic water cycle diagrams. *CBE-Life Sciences Education* (Bailey). *Postdoc will lead/co-lead several of these papers depending on expertise and background.
- **Experiential learning for at least 25 undergraduates.** We have a deep commitment and strong record of involving undergraduates. The minimum number of undergraduates who will participate: 10 on Activity 1 (A1; creating materials), 11 for A2 (quantifying impact), and 4 for A3 (outreach and education). The postdoc will coordinate undergraduate contributions in collaboration with all faculty. This exercise will provide interdisciplinary training and opportunities across most colleges on campus.
- **Creation of an interdisciplinary course on Global Water.** Building on the concepts developed during this interdisciplinary research project, we will develop an introductory-level course on Global Water. The course will be cross listed in Geology and Plant & Wildlife Sciences and co-taught by Carling and LeMonte, with guest lectures from members of the IDR team. The course will build on a previous class taught by Carling in Fall 2018 titled “Water in West”. Depending on the outcome of the GE revisioning, we may apply for GE certification of this course given its problem-oriented structure.
- **Develop a web application for interactive visualization of the proposed water cycle model.** We will use our existing open source Tethys Platform environment to create an interactive visualization of the new water cycle models to facilitate education in both traditional and workshop environments. The web application will be deployed at the Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI) HydroShare.org web portal and will be shared with water scientists and educators globally through CUAHSI newsletters and a proposed CUAHSI webinar.

5. Project timeline:

			2021		2022			2023
Item	**Activity**	**Lead**	**Summer**	**Fall**	**Winter**	**Summer**	**Fall**	**Winter**
Creation of new water cycle materials	A1	Abbott						
Presentation of initial models for feedback	A1	Hopkins						
Teacher observations and interviews	A2	Nixon						
Testing the impact of new water cycle representations in college biology	A2	Bailey						
Interactive water cycle web application	A3	Ames						
Online learning module	A3	Gill						
Ebook, performance, video, outreach	A3	Glenn						
New "Global Water" course	A3	Carling/LeMonte						
External funding submissions (see funding plans for proposal titles and funders)	A1-3	All		P1	P2	P3	P4-6	P7-9
Publication submissions	A1-3	All		1	2	3	4,5	6-7

Budget

Purpose/item	**Amount**
Overall Project	
Postdoctoral support (80% of salary for 24 months)	$96,000
Activity 1	
Undergraduate student salary (supplemented with mentored research hours)	$4,000
Activity 2	
Undergraduate student salary (supplemented with mentored research hours)	$3,000
Stipends for participating teachers (~$400 each)	$4,000
Transcription costs	$500
Data collection equipment and eye-tracking time	$2,000
Activity 3	
Performances and curriculum development (e.g. water dance film and eBook production)	$5,500
Web design and data-visualization integration	$1,000
Undergraduate student salary (supplemented with mentored research hours)	$4,000
Total	$120,000

Narrative

Postdoctoral salary: The bulk of our proposed budget goes to hiring a postdoctoral researcher to coordinate the project personnel and activity. Based on the experience of the faculty team, this large investment will have immense payoffs in research productivity, student involvement, and frequency and richness of the inter-faculty collaborations. Specifically, having an experienced researcher dedicated full-time to this project will ensure rapid progress, efficient communication, and deep integration across undergraduate, postdoc, and faculty levels. Following the NSF Research-Coordination-Network model, this project will provide world-class opportunities for the postdoc's professional development, cultivating future partnerships within and beyond BYU. The remaining 20% of the postdoc's salary will be covered with existing water research grants (e.g. Abbott, Carling), further expanding synergy and opportunity.

Student wages: The second largest item on the budget is undergraduate wages. We view collaboration with students as a major force-multiplier and mechanism to advance science and society. Involving students in professional-level projects will provide experience learning opportunities for employed and mentored students. The extensive involvement of students will also support the project goals of generating and disseminating broadly relevant and effective teaching materials. The PI team has a strong record of successful integration of undergraduate and graduate students in various types of research, art, and professional activity (see biosketches), including preliminary research on this topic.

Teacher stipends: To ensure a representative sample of active elementary school teachers, we will provide compensation for their time devoted to this project (e.g. data collection and adapting instruction). This compensation follows research guidelines and norms, which will be approved during the Institutional Review Board (IRB) assessment prior to research activities. We anticipate the time commitment to be about 8 hours per teacher.

Performance and curriculum development: These funds will support the production costs of the videos and interactive materials (e.g. eBook, graphic novels, etc.), potentially including a filmographer, editor, gaffer/grip team, digital designer, music composer and rights, and a co-producer/director. These activities will increase competitiveness of proposals and directly reach thousand students and teachers via existing collaborations (Fig. 2).

Web design and data-visualization: Funds are requested for web design and data hosting to set up the online portal and interactive water cycle model. Specifically, this will support the server costs, technician time, and technical support fees as we transform the static and animated materials into a hydrologically accurate interface where students can adjust parameters and observe the consequences.

1. Abbott, B. W. *et al.* Human domination of the global water cycle absent from depictions and perceptions. *Nat. Geosci.* **12**, 533–540 (2019).
2. Adler, R. W. Coevolution of Law and Science. *Columbia J. Environ. Law* **44**, 1–66 (2019).
3. Wine, M. L. Climatization of environmental degradation: a widespread challenge to the integrity of earth science. *Hydrol. Sci. J.* **65**, 867–883 (2020).
4. Ellison, D., N. Futter, M. & Bishop, K. On the forest cover-water yield debate: from demand- to supply-side thinking. *Glob. Change Biol.* **18**, 806–820 (2012).
5. Abbott, B. W. *et al.* A water cycle for the Anthropocene. *Hydrol. Process.* **33**, 3046–3052 (2019).
6. Wine, M. L. & Davison, J. H. Untangling global change impacts on hydrological processes: Resisting climatization. *Hydrol. Process.* (2019) doi:10.1002/hyp.13483.
7. Linton, J. Modern water and its discontents: a history of hydrosocial renewal. *Wiley Interdiscip. Rev. Water* **1**, 111–120 (2014).
8. Keys, P. W. *et al.* Invisible water security: Moisture recycling and water resilience. *Water Secur.* **8**, 100046 (2019).
9. Cardak, O. Science Students` Misconceptions of the Water Cycle According to their Drawings. *J. Appl. Sci.* **9**, 865–873 (2009).
10. Sivapalan, M. & Blöschl, G. The Growth of Hydrological Understanding: Technologies, Ideas, and Societal Needs Shape the Field. *Water Resour. Res.* **53**, 8137–8146 (2017).
11. Schmidt, J. J. Historicizing the hydrosocial cycle. *Water Altern.* **7**, 220–234 (2014).
12. Fandel, C. A., Breshears, D. D. & McMahon, E. E. Implicit assumptions of conceptual diagrams in environmental science and best practices for their illustration. *Ecosphere* **9**, 1–15 (2018).
13. Linton, J. Is the Hydrologic Cycle Sustainable? A Historical–Geographical Critique of a Modern Concept. *Ann. Assoc. Am. Geogr.* **98**, 630–649 (2008).
14. Budds, J., Linton, J. & McDonnell, R. The hydrosocial cycle. *Geoforum* 167–169 (2014).
15. Richey, A. S. *et al.* Uncertainty in global groundwater storage estimates in a Total Groundwater Stress framework. *Water Resour. Res.* **51**, 5198–5216 (2015).
16. Rockström, J., Falkenmark, M., Lannerstad, M. & Karlberg, L. The planetary water drama: Dual task of feeding humanity and curbing climate change. *Geophys. Res. Lett.* **39**, L15401 (2012).
17. Hoekstra, A. Y. & Mekonnen, M. M. The water footprint of humanity. *Proc. Natl. Acad. Sci.* **109**, 3232–3237 (2012).
18. Ellis, E. C., Klein Goldewijk, K., Siebert, S., Lightman, D. & Ramankutty, N. Anthropogenic transformation of the biomes, 1700 to 2000: Anthropogenic transformation of the biomes. *Glob. Ecol. Biogeogr.* 586–606 (2010) doi:10.1111/j.1466-8238.2010.00540.x.
19. Gordon, L. J. *et al.* Human modification of global water vapor flows from the land surface. *Proc. Natl. Acad. Sci. U. S. A.* **102**, 7612–7617 (2005).
20. Rost, S., Gerten, D. & Heyder, U. Human alterations of the terrestrial water cycle through land management. *Adv. Geosci.* **18**, 43–50 (2008).
21. Wang-Erlandsson, L. *et al.* Remote land use impacts on river flows through atmospheric teleconnections. *Hydrol. Earth Syst. Sci.* **22**, 4311–4328 (2018).
22. Milly, P. C. D., Cazenave, A. & Gennero, C. Contribution of climate-driven change in continental water storage to recent sea-level rise. *Proc. Natl. Acad. Sci.* **100**, 13158–13161 (2003).
23. Durack, P. J., Wijffels, S. E. & Matear, R. J. Ocean Salinities Reveal Strong Global Water Cycle Intensification During 1950 to 2000. *Science* **336**, 455–458 (2012).
24. Haddeland, I. *et al.* Global water resources affected by human interventions and climate change. *Proc. Natl. Acad. Sci.* **111**, 3251–3256 (2014).
25. Huang, J., Yu, H., Guan, X., Wang, G. & Guo, R. Accelerated dryland expansion under climate change. *Nat. Clim. Change* **6**, 166 (2016).
26. Li, F. & Lawrence, D. M. Role of Fire in the Global Land Water Budget during the Twentieth Century due to Changing Ecosystems. *J. Clim.* **30**, 1893–1908 (2016).

27. Heathwaite, A. L. Multiple stressors on water availability at global to catchment scales: understanding human impact on nutrient cycles to protect water quality and water availability in the long term. *Freshw. Biol.* **55**, 241–257 (2010).
28. Fan, Y., Li, H. & Miguez-Macho, G. Global Patterns of Groundwater Table Depth. *Science* **339**, 940–943 (2013).
29. Van Loon, A. F. *et al.* Drought in the Anthropocene. *Nat. Geosci.* **9**, 89–91 (2016).
30. Landrigan, P. J. *et al.* The Lancet Commission on pollution and health. *The Lancet* **0**, (2017).
31. Famiglietti, J. S. The global groundwater crisis. *Nat. Clim. Change* **4**, 945–948 (2014).
32. Mekonnen, M. M. & Hoekstra, A. Y. Four billion people facing severe water scarcity. *Sci. Adv.* **2**, e1500323 (2016).
33. Wurtsbaugh, W. A. *et al.* Decline of the world's saline lakes. *Nat. Geosci.* **10**, 816 (2017).
34. Kümmerer, K., Dionysiou, D. D., Olsson, O. & Fatta-Kassinos, D. A path to clean water. *Science* **361**, 222–224 (2018).
35. Oki, T. & Kanae, S. Global Hydrological Cycles and World Water Resources. *Science* **313**, 1068–1072 (2006).
36. Savenije, H. H. G., Hoekstra, A. Y. & van der Zaag, P. Evolving water science in the Anthropocene. *Hydrol. Earth Syst. Sci.* **18**, 319–332 (2014).
37. Falkenmark, M., Wang-Erlandsson, L. & Rockström, J. Understanding of water resilience in the Anthropocene. *J. Hydrol. X* **2**, 100009 (2019).
38. Ben-zvi-Assarf, O. & Orion, N. A study of junior high students' perceptions of the water cycle. *J. Geosci. Educ.* **53**, 366–373 (2005).
39. Márquez, C., Izquierdo, M. & Espinet, M. Multimodal science teachers' discourse in modeling the water cycle. *Sci. Educ.* **90**, 202–226 (2006).
40. Wiek, A. & Larson, K. L. Water, People, and Sustainability--A Systems Framework for Analyzing and Assessing Water Governance Regimes. *Water Resour. Manag. Dordr.* **26**, 3153–3171 (2012).
41. NRC, N. R. C. *Ready, Set, SCIENCE!: Putting Research to Work in K-8 Science Classrooms*. (2007). doi:10.17226/11882.
42. Van Driel, J., Berry, A. & Meirink, J. *Research on science teacher knowledge*. (Routledge, 2014).
43. Sadler, P. M., Sonnert, G., Coyle, H. P., Cook-Smith, N. & Miller, J. L. The Influence of Teachers' Knowledge on Student Learning in Middle School Physical Science Classrooms. *Am. Educ. Res. J.* **50**, 1020–1049 (2013).
44. Linton, J. & Budds, J. The hydrosocial cycle: Defining and mobilizing a relational-dialectical approach to water. *Geoforum* **57**, 170–180 (2014).
45. Ellison, D. *et al.* Trees, forests and water: Cool insights for a hot world. *Glob. Environ. Change* **43**, 51–61 (2017).
46. Keys, P. W., Wang-Erlandsson, L., Gordon, L. J., Galaz, V. & Ebbesson, J. Approaching moisture recycling governance. *Glob. Environ. Change* **45**, 15–23 (2017).
47. Dudgeon, D. *et al.* Freshwater biodiversity: importance, threats, status and conservation challenges. *Biol. Rev.* **81**, 163 (2006).
48. Vörösmarty, C. J. *et al.* Global threats to human water security and river biodiversity. *Nature* **467**, 555–561 (2010).
49. Galloway, J. N. *et al.* Transformation of the Nitrogen Cycle: Recent Trends, Questions, and Potential Solutions. *Science* **320**, 889–892 (2008).
50. Creed, I. F. & van Noordwijk, M. *Forest and Water on a Changing Planet: Vulnerability, Adaptation and Governance Opportunities*. 192 (2018).
51. Hoekstra, A. Y., Chapagain, A. K. & van Oel, P. R. Progress in Water Footprint Assessment: Towards Collective Action in Water Governance. *Water* **11**, 1070 (2019).
52. NRC, N. R. C. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. (2011). doi:10.17226/13165.
53. Brewer, C. A. & Smith, D. *Revised-Vision-and-Change-Final-Report.pdf*. 82 https://live-visionandchange.pantheonsite.io/wp-content/uploads/2011/03/Revised-Vision-and-Change-Final-Report.pdf (2009).

54. Kastens, K. A. & Manduca. Earth and Mind II: A Synthesis of Research on Thinking and Learning in the Geosciences. *Geol. Soc. Am.* **486**, (2012).
55. Levin, K., Cashore, B., Bernstein, S. & Auld, G. Overcoming the tragedy of super wicked problems: constraining our future selves to ameliorate global climate change. *Policy Sci.* **45**, 123–152 (2012).
56. Arnold, R. D. & Wade, J. P. A Definition of Systems Thinking: A Systems Approach. *Procedia Comput. Sci.* **44**, 669–678 (2015).
57. Berry, H. L., Waite, T. D., Dear, K. B. G., Capon, A. G. & Murray, V. The case for systems thinking about climate change and mental health. *Nat. Clim. Change* **8**, 282–290 (2018).
58. Khan, S. *et al.* Embracing uncertainty, managing complexity: applying complexity thinking principles to transformation efforts in healthcare systems. *BMC Health Serv. Res.* **18**, 192 (2018).
59. Steffen, W. *et al.* Trajectories of the Earth System in the Anthropocene. *Proc. Natl. Acad. Sci.* 201810141 (2018) doi:10.1073/pnas.1810141115.
60. Bartos, S. A., Lederman, N. G. & Lederman, J. S. Teachers' Reflections on Their Subject Matter Knowledge Structures and Their Influence on Classroom Practice. *Sch. Sci. Math.* **114**, 125–138 (2014).
61. Luft, J. & Hewson, P. Research on Teacher Professional Development in Science. in (2014). doi:10.4324/9780203097267.
62. National Academies of Sciences, E. *Science Teachers' Learning: Enhancing Opportunities, Creating Supportive Contexts*. (2016). doi:10.17226/21836.
63. Webster-Wright, A. Reframing Professional Development Through Understanding Authentic Professional Learning. *Rev. Educ. Res.* **79**, 702–739 (2009).
64. Pande, P. & Chandrasekharan, S. Representational competence: towards a distributed and embodied cognition account. *Stud. Sci. Educ.* **53**, 1–43 (2017).
65. Creswell, J. W. *Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research*. (Pearson, 2012).
66. Woodrow, L. Reliability, Validity and Ethics. in *Writing about Quantitative Research in Applied Linguistics* (ed. Woodrow, L.) 25–35 (Palgrave Macmillan UK, 2014). doi:10.1057/9780230369955_3.
67. Nixon, R. S., Smith, L. K. & Sudweeks, R. R. Elementary teachers' science subject matter knowledge across the teacher career cycle. *J. Res. Sci. Teach.* **56**, 707–731 (2019).
68. Theobald, E. J. *et al.* Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *Proc. Natl. Acad. Sci.* **117**, 6476–6483 (2020).
69. Deslauriers, L., McCarty, L. S., Miller, K., Callaghan, K. & Kestin, G. Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. *Proc. Natl. Acad. Sci.* 201821936 (2019) doi:10.1073/pnas.1821936116.
70. Bradshaw, W. S. *et al.* A longitudinal study of attitudes toward evolution among undergraduates who are members of the Church of Jesus Christ of Latter-day Saints. *PLOS ONE* **13**, e0205798 (2018).
71. Woodin, T., Carter, V. C. & Fletcher, L. Vision and Change in Biology Undergraduate Education, A Call for Action—Initial Responses. *CBE—Life Sci. Educ.* **9**, 71–73 (2010).
72. Cordero, E. C., Centeno, D. & Todd, A. M. The role of climate change education on individual lifetime carbon emissions. *PLOS ONE* **15**, e0206266 (2020).
73. Bailey, E. G. *et al.* Learning Gains from a Recurring "Teach and Question" Homework Assignment in a General Biology Course: Using Reciprocal Peer Tutoring Outside Class. *CBE—Life Sci. Educ.* **17**, ar23 (2018).
74. Dunlap, R. E., Liere, K. D. V., Mertig, A. G. & Jones, R. E. New Trends in Measuring Environmental Attitudes: Measuring Endorsement of the New Ecological Paradigm: A Revised NEP Scale. *J. Soc. Issues* **56**, 425–442 (2000).
75. Moy, C. L., Locke, J. R., Coppola, B. P. & McNeil, A. J. Improving Science Education and Understanding through Editing Wikipedia. *J. Chem. Educ.* **87**, 1159–1162 (2010).
76. Pearce, N. & Learmonth, S. Learning beyond the Classroom: Evaluating the Use of Pinterest in Learning and Teaching in an Introductory Anthropology Class. *J. Interact. Media Educ.* (2013).

Starting in the first month of funding, we will implement a two-tiered approach for securing external funding. First, we will prepare two large proposals ($450,000 and $850,000) based on the work described above. The first will be submitted to the National Science Foundation (NSF) Education and Human Resources (EHR) Core Program in fall of 2021 or spring of 2022 depending on RFP. The second, which will have a larger purview, will be submitted to the NSF CAREER Program in the summer of 2022. Depending on the outcomes and feedback, we will revise the proposals for resubmission to EHR or submit to other programs in 2022 and 2023 (list of RFPs below). Second, we will submit a series of smaller proposals to allow continuation of the project pending success of one of our "first-tier" proposals. These proposals will focus on specific products (e.g. municipal- to national-level water cycle syntheses, interactive modeling components, and local outreach activities), which will be submitted to state agencies and larger organizations, including the Utah Division of Water Quality, NASA, NEA, CUAHSI, Sloan Foundation, MacArthur Foundation, and Soil Science Society of America. Support from the IDR program will allow us to leverage a unique combination of artistic, technical, and scientific expertise to address an urgent societal issue and secure support for high-profile research at BYU. The strong funding record of the PI team (see Current and Pending) and the intense public and administrative interest in this subject (water security, sustainability, and human water pathogens) increase likelihood of success.

More specifically, Nixon and Abbott have already submitted two related proposals to NSF programs. We received positive feedback about the potential impact of the work, but reviewers requested preliminary data demonstrating effectiveness of informal interventions (e.g. diagram dissemination, interactive online workshops, etc.). This IDR proposal was crafted to directly respond to this feedback and input from our program officers. The IDR funding will allow us to refine our research design, demonstrate the potential of these methods, and expand the purview of our interdisciplinary research and outreach. Indeed, we plan on using the IDR funds to develop a decadal research program integrating human and social sciences, natural sciences, humanities, art, engineering, and communication. This will position our team to train the rising generation of researchers and artists and generate high-profile publications, products, and proposals for years to come.

Grant program	Proposal number (for timeline) and title where applicable	Requested amount	Deadline (DL) or planned submission (PS)	Lead PI
NSF Education and Human Resources Core Research	P1. We are teaching the water cycle wrong: fixing misconceptions of water in the Anthropocene	$450,000	October, 2020 (DL)	Abbott
NSF Hydrologic Sciences	P2. Same as P1	$320,000	January, 2021 (PS)	Ames
NSF CAREER	P3. Water in the Anthropocene	$850,000	July, 2021 (DL)	Abbott
NSF Facilitating Research at Primarily Undergraduate Institutions	P4. Same as P1	$450,000	January, 2022 (PS)	Nixon
Spencer Foundation: Small Research Grant	P5. Water cycle professional development supported by new diagrams	$50,000	February, 2022 (DL)	Nixon
NSF Discovery Research PreK-12 (DRK-12)	P6. Elementary teachers' informal learning of science content with innovative water cycle materials	$300,000	November, 2022 (DL)	Nixon
NASA Terrestrial Hydrology	P7. Leveraging global hydrology products to improve water literacy and encourage systems thinking	$420,000	November, 2022 (DL)	Ames
Utah Division of Natural Resources Watershed Restoration Initiative	P8. A water cycle for Utah: Using local diagrams to improve water literacy and management	$80,000	January 2023 (PS)	Abbott
Sloan Foundation	P9. Global water stewardship; Local environmental justice	$300,000	March 2023 (PS)	Glenn

Biographical Sketch

Benjamin W. Abbott
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Brigham Young University, Provo, Utah 84602
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(a) Professional Preparation

Utah State University (Logan, UT)	Watershed and Earth Sciences	B.S. 2009
University of Alaska Fairbanks (Fairbanks, AK)	Biological Sciences	Ph.D. Dec. 2014
OSUR (Rennes, France)	Ecosystem Ecology	Postdoc 2014-2016
Michigan State University (East Lansing, MI)	Ecohydrology	Postdoc 2016-2017

(b) Professional Appointments

Assistant Professor	Brigham Young University	2017-Present
Postdoctoral fellow	Michigan State University	2016-2017
Marie Curie postdoctoral fellow	OSUR, France	2014-2016
Graduate research assistant	University of Alaska Fairbanks	2009-2014

(c.i) Relevant products:

1. **Abbott, B. W.**, K. Bishop, J. P. Zarnetske, C. Minaudo, F. S. Chapin, S. Krause, D. M. Hannah, L. Conner, D. Ellison, S. E. Godsey, S. Plont, J. Marçais, T. Kolbe, A. Huebner, R. J. Frei, T. Hampton, S. Gu, M. Buhman, S. S. Sayedi, O. Ursache, M. Chapin, K. D. Henderson, and G. Pinay. **2019**. *Human domination of the global water cycle absent from depictions and perceptions.* Nature Geoscience.
2. **Abbott, B. W.**, K. Bishop, J. P. Zarnetske, D. M. Hannah, R. J. Frei, C. Minaudo, F. S. Chapin, S. Krause, L. Conner, D. Ellison, S. E. Godsey, S. Plont, J. Marçais, T. Kolbe, A. Huebner, T. Hampton, S. Gu, M. Buhman, S. S. Sayedi, O. Ursache, M. Chapin, K. D. Henderson, and G. Pinay. **2019**. *A water cycle for the Anthropocene.* Hydrological Processes.
3. **Abbott, B. W.**, G. Gruau, J. P. Zarnetske, F. Moatar, L. Barbe, Z. Thomas, O. Fovet, T. Kolbe, S. Gu, A.-C. Pierson-Wickmann, P. Davy, and G. Pinay. **2018**. *Unexpected spatial stability of water chemistry in headwater stream networks.* Ecology Letters.
4. **Abbott, B. W.**, F. Moatar, O. Gauthier, O. Fovet, V. Antoine, and O. Ragueneau. **2018**. *Trends and seasonality of river nutrients in agricultural catchments: 18 years of weekly citizen science in France*. Science of The Total Environment.
5. Turetsky, M. R., **B. W. Abbott**, M. C. Jones, K. W. Anthony, D. Olefeldt, E. A. G. Schuur, C. Koven, A. D. McGuire, G. Grosse, P. Kuhry, G. Hugelius, D. M. Lawrence, C. Gibson, and A. B. K. Sannel. 2019. *Permafrost collapse is accelerating carbon release.* Nature.
6. Frei, R. J., **B. W. Abbott**, R. Dupas, S. Gu, G. Gruau, Z. Thomas, T. Kolbe, L. Aquilina, T. Labasque, A. Laverman, O. Fovet, F. Moatar, and G. Pinay. 2020. *Predicting Nutrient Incontinence in the Anthropocene at Watershed Scales.* Frontiers in Environmental Science.
7. **Abbott, B. W.**, V. Baranov, C. Mendoza-Lera, M. Nikolakopoulou, A. Harjung, T. Kolbe, M. N. Balasubramanian, T. N. Vaessen, F. Ciocca, A. Campeau, M. B. Wallin, P. Romeijn, M. Antonelli, J. Gonçalves, T. Datry, A. M. Laverman, et al. **2016**. Using multi-tracer inference to move beyond single-catchment ecohydrology. Earth-Science Reviews.
8. **Abbott, B. W.**, A. V. Rocha, A. Shogren, J. P. Zarnetske, F. Iannucci, W. B. Bowden, S. P. Bratsman, L. Patch, R. Watts, R. Fulweber, R. J. Frei, A. M. Huebner, S. M. Ludwig, G. T. Carling, and J. A. O'Donnell. **2021**. *Tundra wildfire triggers sustained lateral nutrient loss in Alaskan Arctic*. Global Change Biology.
9. Shogren, A. J., J. P. Zarnetske, **B. W. Abbott**, F. Iannucci, and W. B. Bowden. **2020**. We cannot shrug off the shoulder seasons: Addressing knowledge and data gaps in an Arctic Headwater.

Environmental Research Letters.
10. Natali, S. M., J. D. Watts, B. M. Rogers, S. Potter, S. M. Ludwig, A.-K. Selbmann, P. F. Sullivan, **B. W. Abbott**, et al. **2019**. *Large loss of CO2 in winter observed across the northern permafrost region.* Nature Climate Change.
11. Turetsky, M. R., **B. W. Abbott**, M. C. Jones, K. W. Anthony, D. Olefeldt, E. A. G. Schuur, G. Grosse, P. Kuhry, G. Hugelius, C. Koven, D. M. Lawrence, C. Gibson, A. B. K. Sannel, and A. D. McGuire. **2020**. *Carbon release through abrupt permafrost thaw*. Nature Geoscience.
12. Sayedi, S. S., **B. W. Abbott**, B. F. Thornton, J. M. Frederick, J. E. Vonk, P. Overduin, C. Schädel, E. A. G. Schuur, A. Bourbonnais, N. Demidov, A. Gavrilov, S. He, G. Hugelius, M. Jakobsson, M. C. Jones, D. Joung, G. Kraev, R. W. Macdonald, A. D. McGuire, C. Mu, M. O'Regan, K. M. Schreiner, C. Stranne, E. Pizhankova, A. Vasiliev, S. Westermann, J. P. Zarnetske, T. Zhang, M. Ghandehari, S. Baeumler, B. C. Brown, and R. J. Frei. **2020**. *Subsea permafrost carbon stocks and climate change sensitivity estimated by expert assessment*. Environmental Research Letters.
13. Wologo, E., S. Shakil, S. Zolkos, S. Textor, S. Ewing, J. Klassen, R. G. M. Spencer, D. C. Podgorski, S. E. Tank, M. A. Baker, J. A. O'Donnell, K. P. Wickland, S. S. W. Foks, J. P. Zarnetske, J. Lee-Cullin, F. Liu, Y. Yang, P. Kortelainen, J. Kolehmainen, J. F. Dean, J. E. Vonk, R. M. Holmes, G. Pinay, M. M. Powell, J. Howe, R. J. Frei, S. P. Bratsman, and **B. W. Abbott**. **2020**. *Stream dissolved organic matter in permafrost regions shows surprising compositional similarities but negative priming and nutrient effects*. Global Biogeochemical Cycles.

(d) Synergistic activities

1. Director of the Utah Lake Collaborative (ULC), a large and ongoing participatory science project that has involved ~4,000 participants throughout the Intermountain West. The project collaborates with the public to collect water samples from ~300 sites across seasons throughout the Utah Lake watershed to provide a comprehensive assessment of point and non-point pollution sources in a watershed suffering from eutrophication. The ULC organizes and participates in community events, including the *Utah Lake Festival*, the *Central Utah Water Festival*, the *STEM Like a Girl* series, and the *Provo River Day* event, which reach thousands of individuals each year.
2. Community, state, and national scientific service supporting outreach including scientific panels (*COVID-19; Wildfires; Drought; Air Pollution; Utah Lake; Collaborating on Air Quality: From Pollution to Solution*), environmental organizations (*Mormon Environmental Stewardship Alliance; Citizen's Climate Lobby; LDS Earth Stewardship*), and more than two dozen in-face and remote meetings with members of Utah and U.S. House and Senate.
3. Translation of science to the general public as scientific consultant and featured scientist for *Tipping Points* documentary by Unboxed media, the *Klimaatjagers* documentary (*Climate Hunters*) by Uitzendinggemist, Netherlands Public Broadcasting, and the *Yale forum on Climate Change and the Media* (2012-2020).
4. Science correspondent for the Salt Lake Tribune, Deseret News, and Provo Herald addressing issues including climate change, air quality, water security, eutrophication, sustainable development, and science ethics.
5. Reviewer for 180 papers in 50 international peer-reviewed journals, guest editor for 3 journals (2010-present), and external reviewer for 6 funding agencies, including the National Science Foundation, European Research Council, and Department Of Energy.
6. Faculty mentor for 61 undergraduates, 9 M.S. students, and 4 Ph.D. students.

BIOGRAPHICAL SKETCH

Ryan S. Nixon
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Brigham Young University 801-422-4803

(a) Professional Preparation

Weber State University	Ogden, Utah	Physics Teaching	B.S., 2009
Brigham Young University	Provo, Utah	Teacher Education	M.A., 2012
University of Georgia	Athens, Georgia	Science Education	Ph.D., 2015

(b) Appointments

Assistant Professor, Science Education 2015 – current
Brigham Young University, Department of Teacher Education
Research Assistant 2012 – 2015
University of Georgia, Department of Mathematics and Science Education
Middle school science teacher 2009 – 2012
Dixon Middle School, Provo School District

(c.i.) Closely Related Publications

Navy, S. L., Nixon, R. S., Luft, J. A., & Jurkiewicz, M. A. (2020). Accessed or latent resources? Exploring new secondary science teachers' networks of resources. *Journal of Research in Science Teaching, 57*, 184-208. doi: 10.1002/tea.21591

Nixon, R. S., Smith, L. K., & Sudweeks, R. R. (2019). Elementary teachers' science subject matter knowledge across the teacher career cycle. *Journal of Research in Science Teaching, 56*(6), 707-731. doi: https://doi.org/10.1002/tea.21524

Nixon, R. S., Toerien, R., & Luft, J. A. (2019). Knowing more than their students: Characterizing secondary science teachers' subject matter knowledge. *School Science and Mathematics, 119*, 150-160. doi: https://doi.org/10.1111/ssm.12323

Nixon, R. S., Hill, K. M., & Luft, J. A. (2017). Secondary science teachers' subject matter knowledge development across the first five years. *Journal of Science Teacher Education, 28*(7), 574-589. doi: 10.1080/1046560X.2017.1388086

Nixon, R. S., Campbell, B. K., & Luft, J. A. (2016). Effects of subject-area degree and classroom experience on new chemistry teachers' subject matter knowledge. *International Journal of Science Education*, *38*(10), 1636–1654. doi: 10.1080/09500693.2016.1204482

(c.ii.) Other Significant Publications

Nixon, R. S., Luft, J. A., & Ross, R. J. (2017). Prevalence and predictors of out-of-field teaching in the first five years. *Journal of Research in Science Teaching, 54*(9), 1197-1218. doi: 10.1002/tea.21402

Nixon, R. S., Godfrey, T. J., Mayhew, N. T., & Wiegert, C. C. (2016). Undergraduate student construction and interpretation of graphs in physics lab activities. *Physical Review Physics Education Research, 12*(1), 010104.

Nixon, R. S., & Luft, J. A. (2015). Teaching chemistry with a biology degree: Crosscutting concepts as boundary objects. In J. A. Luft & S. L. Dubois (Eds.), *Newly hired teachers of science: A better beginning* (pp. 75-85). Rotterdam, The Netherlands: Sense Publishers.

Luft, J. A., Dubois, S. L., Nixon, R. S., & Campbell, B. K. (2015). Supporting newly hired teachers of science: Attaining teacher professional standards. *Studies in Science Education*, *51*(1), 1-48. doi: 10.1080/03057267.2014.980559

Synergistic Activities

1. An internally funded project with colleagues exploring the development of science subject matter knowledge (SMK) of fifth and sixth grade teachers. For this project, I worked with three other professors (Leigh Smith, Rich Sudweeks, Ross Larsen) and employed seven undergraduate students. To date, this has resulted in one published manuscript (Nixon, Smith, & Sudweeks, 2019), two manuscripts in review, and five conference presentations. These findings have influenced the tasks I give students to develop their science SMK and the recommendations I provide for their future learning.

2. A longitudinal study that explored the prevalence and predictors of out-of-field teaching (Nixon, Luft, & Ross, 2017). This paper has been recognized as holding important implications for teacher education through the Association for Science Teacher Education's 2016 Conference Paper Award V: Implications for Research for Educational Practice. This paper has been published in one of the top science education journals and has been featured by multiple news outlets.

3. A project in which we developed a tool to support secondary science teachers' SMK development and investigated the ways it can impact teachers' thinking about science concepts in planning. This project has generated a manuscript is in review and three conference presentations. One of these presentations was to an audience of approximately 30 practicing teachers. Four undergraduate students have been employed on this project.

4. A project exploring Pinterest as a resource for teachers. In collaboration with a faculty member at Kent State University, this project employs one graduate and three undergraduate students to analyze 1,600 pins and their associated websites. Questions include: What kinds of materials are teachers seeing? What kinds of messages about science are being communicated? What science ideas are represented and what is the accuracy of these representations? This project is new enough that project products are still forthcoming.

Keely Song Glenn

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CURRENT POSITION

Assistant Professor of Dance 2018-Present
Brigham Young University, Department of Dance

EDUCATION

Master of Fine Arts, Choreography 2010
The University of Iowa, Iowa City, IA
Bachelor of Arts, Dance Education 2008
Brigham Young University, Provo, UT

CERTIFICATION

Certified Laban Movement Analyst 2018
Integrative Movement Studies, SLC, UT

CREATIVE WORKS (4)

Film:

CLAIM- A Dance Film for Pregnant Dancers 2020
- Director, Concept Developer, Producer

Jack Be Nimble (6 min.) 2019
- Director, Concept Developer, Producer

Air Transit: A Dance Film Series for Clean Air (13 min.) 2018
- Co-director/producer, choreographer, dancer, screen writer
- An Environmental Commercial Dance Activism Film

Publications:

Glenn, Keely (2019) "Creative Transformation through Witnessing and Belongingness." *Spirit of Creativity in Dance Education* Ed. Anis Nor. NusParc, 2019. (in Press)

Glenn, Keely (2019) "Personal Journey of Rehabilitation and Hip Hop." *Laban/Bartenieff movement Studies Contemporary Application* Ed. Colleen Wahl. Human Kinetics, 2019. 189-194 print.

OTHER SIGNIFICANT CREATIVE WORKS (5)

Choreography/Stage production: 2018

3 Degrees of Vulnerability (collaborator Ken Nukaya) (10 min)
- Dance Ensemble Concert

Air Transit (Part 1) (13 min) 2018
Senior Project Showcase and Faculty Works

Performance:

"The Last Mile" (3 minutes) Part 4 of *Air Transit* 2019
- assistant choreographer and performer with Tristan Gray

"Jenny Rebecca" (4 Minutes) 2018

- Choreographic Improvisation Solo at the BYU Museum of Art

"Improvisation at the Orem Museum" (30 min) 2018

- Improvisation performance with Kate Monson and Lehua Brown

AWARDS & FUNDING

BYU Gerontology Research Grant Award: Funding for *Living Stages* ($5000) 2020

- An Intergenerational Dance Performance

Laycock Center for Creative Collaboration Grant ($8625) 2020

- Collaboration research using animation/design student for a Dance Film Series

Laycock Center for Creative Collaboration Grant ($9,900) 2019

- Research collaboration between art, science, dance, and film in the permafrost region of Alaska

Women's Research Initiative Grant ($5,000) 2019

- Development and production costs for a dance pregnancy film

Fulton Travel Grant to IADMS ($2,978.85) 2018

- Co-present at the International Association of Dance Medicine and Science (IADMS) Conference in Helsinki, Finland

Laycock Center for Creative Collaboration Grant ($1000) 2018

- Development funding for CLAIM— An interactive Dance E-book on the sanctity of the Feminine

Research and Creative Activity Funds ($2000) 2018

- Attendance and Presentation at the International Conference on Dance Education
    - Kuala Lumpur, Malaysia

Creation/Production cost for *Air Transit- A Dance Film Series for Clean Air ($15,000)* *2018*

- BYU Dance Department Film and Digital Media Funding ($3,000)
- Laycock Center for Creative Collaboration Grant ($10,000)
- College of Fine Arts Film and Media Digital Grant ($2,000)

Ohio Arts Council Individual Arts Excellence Award in Choreography ($5000) 2012

- Recognizing outstanding accomplishments by Ohio Artists

CITIZENSHIP ACTIVITIES

Committee member- CFAC Diversity, Inclusion, and Accessibility Committee 2020-Present
Member of the National Dance Education Organization 2019-Present
Member of the International Association of Dance Medicine and Science 2018- Present
Advisory Board Member of the Wasatch Contemporary Dance Company 2017- Present

RESEARCH INTEREST

Collaboration and visibility of dance/movement in STEAM research

- Science: Environmental Commercial Dance Activism
- Technology: Alternative consumerism and distribution of dance collaborations through new technological mediums such as social media, E-books, and other digital platforms
- Science: Improving women's health/wellness with dance during the perinatal experience

Elizabeth Gibbons Bailey
Assistant Professor
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Liz_bailey@byu.edu

(a) Professional Preparation
A list of the individual's undergraduate and graduate education and postdoctoral training as indicated below:

Brigham Young University	Provo, Utah	Biophysics	B.S. 2008
Brigham Young University	Provo, Utah	Physiology and Developmental Biology	Ph.D. 2013

(b) Appointments
- Assistant Professor: Biology. Brigham Young University, Provo, UT (2018 – current)
- Assistant Teaching Professor: Biology. Georgetown University, Washington, DC (2017 – 2018)
- Visiting Assistant Professor: Biology. Brigham Young University Hawaii, Laie, HI (2016 – 2017)
- Visiting Assistant Professor: Biology. Brigham Young University, Provo, UT (2014 – 2016)
- Adjunct Faculty: Physiology and Developmental Biology. Brigham Young University, Provo, UT (2013 – 2014)
- Adjunct Faculty: Biology. Salt Lake Community College, Salt Lake City, UT (2013 – 2014)

(c) Publications
Closely Related
- **Bailey EG**, Greenall RF, Tullis MM, Williams K. The long-term retention benefits of frequent cumulative versus non-cumulative testing depend on students' reasoning skills. PLOS ONE *(accepted pending minor revisions).*
- Williams K, Wasson SR, Barrett A, Greenall RF, Jones S, **Bailey EG**. Teaching Hardy-Weinberg equilibrium using population-level Punnett squares: Facilitating calculation for students with math anxiety. CBE-LSE *(in press)*.
- **Bailey EG**, Greenall RF, Baek DM, Morris C, Nelson N, Quirante TM, Rice NS, Rose S, Williams KR. Female in-class participation and performance increase with more female peers and/or a female instructor in life sciences courses. CBE-LSE 2020; 19(3), ar30. DOI: 10.1187/cbe.19-12-0266
- **Bailey EG**, Baek D, Meiling J, Morris C, Nelson N, Rice N, Rose S, Stockdale P. Learning Gains from Recurring 'Teach and Question' Homework Assignment in an Introductory Biology Course for Non-Majors: Utilizing Reciprocal Peer Tutoring Outside of Class. CBE-LSE 2018; 17: ar23. DOI: 10.1187/cbe.17-12-0259
- Jensen J, **Bailey, EG**, Kummer T, Weber K. Using Backward Design in Education Research: A Research Methods Essay. J. Microbiol. Biol. Educ. October 2017; 18(3). DOI: 10.1128/jmbe.v18i3.1367
- **Bailey EG**, Jensen J, Nelson J, Wiberg HK, Bell JD. Weekly Formative Exams and Creative Grading Enhance Student Learning in an Introductory Biology Course. CBE-LSE 2017; 16(1): ar2. DOI: 10.1187/cbe.16-02-0104

Other
- Moulton ER, Hirsche KJ, Hobbs ML, J. Schwab M, **Bailey EG**, Bell JD. Examining the effects of cholesterol on model membranes at high temperatures: Laurdan and Patman see it differently. BBA-Biomembranes 2018; 1860(8):1571-1579. DOI: 10.1016/j.bbamem.2018.05.013

- **Gibbons E**., Murri M., Grabner A., Moss E., Campbell L.E., Nelson J., Judd A.M., Bell J.D. Ionomycin Causes Susceptibility to Phospholipase A_2 while Temperature-Induced Increases in Membrane Fluidity Fail: Possible Involvement of Actin Fragmentation. BBA-Biomembranes 2014; 1838(10): 2607-2614. DOI: 10.1016/j.bbamem.2014.05.028
- Campbell LE, Nelson J, **Gibbons E**, Judd AM, Bell JD. Membrane Properties Involved in Calcium-Stimulated Microparticle Release from the Plasma Membranes of S49 Lymphoma Cells. The Scientific World Journal 2014; Article ID 537192. DOI: 10.1155/2014/537192
- **Gibbons E**, Pickett KR, Streeter MC, Warcup AO, Nelson J, Judd AM, Bell JD. Molecular details of membrane fluidity changes during apoptosis and relationship to phospholipase A(2) activity. BBA-Biomembranes 2013; 1828(2):887-895. DOI: 10.1016/j.bbamem.2012.08.024
- **Gibbons E**, Nelson J, Anderson L, Brewer K, Melchor S, Judd AM, Bell JD. Role of membrane oxidation in controlling the activity of human group IIa secretory phospholipase A(2) toward apoptotic lymphoma cells. BBA-Biomembranes 2012; 1828(2):670-676. DOI: 10.1016/j.bbamem.2012.09.013

(d) Synergistic Activities

- Co-Chair of Web Committee for the Society for the Advancement of Biology Education Research (SABER; 2019–present)
- Co-leader of the Graduate Teaching Fellows Program at BYU (2014–2016, 2019–Present)
- Development of Cancer Biology Course for undergraduates
- Development and testing of a reciprocal peer tutoring assignment called the “Teach and Question” (tested in my course and now being implemented and tested in a variety of courses)

Gregory T. Carling, Associate Professor of Geological Sciences

(a) Professional Preparation

Brigham Young University	Provo, UT	Geology	B.S., 2005
Brigham Young University	Provo, UT	Geology	M.S., 2007
University of Utah	Salt Lake City, UT	Geology	Ph.D., 2012

(b) Appointments

Assistant Professor, Department of Geological Sciences, BYU	2012 – 2018
Associate Professor, Department of Geological Sciences, BYU	2018 – present

(c) Selected Publications

- Rackliffe, D.R., Schaalje, G.B., **Carling, G.T.**, Rader, R.B., 2021. Spatial and seasonal variation in ecosystem metabolism are associated with aquatic macrophyte traits, shading, and water temperature in a shallow riparian pond. *Freshwater Science, in press.*
- **Carling, G.T.**, Fernandez, D.P., Rey, K.A., Hale, C.A., Goodman, M.M., Nelson, S.T., 2020. Using strontium isotopes to trace dust from a drying Great Salt Lake to adjacent urban areas and mountain snowpack. *Environmental Research Letters* 15:114035.
- Jones, E.F., Griffin, N.A., Kelso, J.E., **Carling, G.T.**, Baker, M.A., Aanderud, Z.T., 2020. Stream microbial community structured by trace elements, headwater dispersal, and large reservoirs in sub-alpine and urban ecosystems. *Frontiers in Microbiology* 11:491425.
- Checketts, H.N., **Carling, G.T.**, Fernandez, D.P., Nelson, S.T., Rey, K.A., Tingey, D.G., Hale, C.A., Packer, B.N., Cordner, C.P., Dastrup, D.B., Aanderud, Z.T., 2020. Trace element export from the Critical Zone triggered by snowmelt runoff in a montane watershed, Provo River, Utah, USA. *Frontiers in Water* 2:578677.
- Packer, B.N., **Carling, G.T.**, Veverica, T., +Russell, K.A., Nelson, S.T., Aanderud, Z.T., 2020. Mercury and dissolved organic matter dynamics during snowmelt runoff in a montane watershed, Provo River, Utah, USA. *Science of the Total Environment* 704:135297.
- Randall, M.C., **Carling, G.T.**, Dastrup, D.B., Miller, T., Nelson, S.T., Rey, K., Hansen, N., Bickmore, B.R., Aanderud, Z.T., 2019. Sediment potentially controls in-lake phosphorus cycling and harmful cyanobacteria in shallow, eutrophic Utah Lake. *PLOS ONE* 14:e0212238.
- Goodman, M.M., **Carling, G.T.**, Fernandez, D.P., Rey, K.A., +Hale, C.A., Bickmore, B.R., Nelson, S.T., Munroe, J.S., 2019. Atmospheric deposition along the Wasatch Front (Utah, USA) reflects regional playa dust and local urban aerosols. *Chemical Geology* 530:119317
- **Carling, G.T.**, Romanowicz, E., Jin, L., Fernandez, D.P., Tingey, D.G., +Goodsell, T.G., 2019. Redox conditions and pH control trace element concentrations in a meandering stream and shallow groundwater of a semiarid mountain watershed, Red Canyon, Wyoming, USA. *Environmental Earth Sciences* 78:510.
- Barkdull, N.M., **Carling, G.T.**, Rey, K., Yudiantoro, D.F., 2019. Comparison of mercury contamination in four Indonesian watersheds affected by artisanal and small-

scale gold mining of varying scale. *Water, Air, & Soil Pollution* 230:214.

- Spackman Jones, A., Aanderud, Z.T., Horsburgh, J.S., Eiriksson, D.E., Dastrup, D., Cox, C., Jones, S.B., Bowling, D.R., Carlisle, J., **Carling, G.T.**, Baker, M.A., 2017. Designing and implementing a network for sensing water quality and hydrology across mountain to urban transitions. *Journal of the American Water Resources Association (JAWRA)* 53:1095-1120.
- Johnson, W.P., Swanson, N., Black, B., Rudd, A., **Carling, G.T.**, Fernandez, D.P., Luft, J., van Leeuwen, J., and Marvin-DiPasquale, M., 2015. Total- and methyl-mercury concentrations and methylation rates across the freshwater to hypersaline continuum of the Great Salt Lake, Utah, USA. *Science of the Total Environment* 511:489-500.
- Naftz, D.L., **Carling, G.T.**, Angeroth, C., Freeman, M., Rowland, R., Pazmiño, E., 2014. Density-stratified flow events in Great Salt Lake, Utah, USA: Implications for mercury and salinity cycling. *Aquatic Geochemistry* 20:547-571.
- Naftz, D.L., Angeroth, C., Freeman, M., Rowland, R., and **Carling, G.T.**, 2013. Monitoring change in Great Salt Lake. *Eos, Transactions of the American Geophysical Union* 94:289-290.
- **Carling, G.T.**, Richards, D., Hoven, H., Miller, T., Fernandez, D.P., Rudd, A., Pazmino, E., and W.P. Johnson, 2013. Relationships of surface water, pore water, and sediment chemistry in wetlands adjacent to Great Salt Lake, Utah, and potential impacts on plant community health. *Science of the Total Environment* 443:798-811.
- **Carling, G.T.**, Fernandez, D.P., Rudd, A., Pazmino, E., and W.P. Johnson, 2011. Trace element diel variations and particulate pulses in perimeter freshwater wetlands of Great Salt Lake, Utah. *Chemical Geology* 283:87-98.

(d) Grants and contracts last five years

• 2020-2025 NSF Critical Zone Thematic Cluster	$888,941
• 2019-2021 Utah Division of Air Quality	$150,000
• 2019-2020 Tintic Consolidated Metals	$49,562
• 2019-2020 Utah Division of Water Quality	$75,735
• 2015-2019 NSF Hydrological Sciences	$267,796
• 2018-2019 Wasatch Front Water Quality Council	$30,300
• 2017-2018 Utah Division of Forestry Fire and State Lands	$29,770
• 2015-2017 Wasatch Front Water Quality Council	$56,638
• 2015-2016 Utah Division of Forestry Fire and State Lands	$39,717

***(e)* Synergistic activities**

- Member of Utah Lake Science Panel to understand impacts of nutrients on harmful algal blooms
- Frequent participation in meetings with Utah Department of Environmental Quality and Provo River Water Quality Council
- Host for summer undergraduate researchers as part of the NSF-funded iUTAH project
- Advisor for Alaska Geology Study Abroad Program

Biographical Sketch: Joshua J. LeMonte

EDUCATION

2016	Ph.D.	Environmental Soil Chemistry	University of Delaware, Newark, DE
2011	M.S.	Environmental Science	Brigham Young University, Provo, UT
2009	B.S.	Environmental Science	Brigham Young University, Provo, UT

EXPERIENCE

Brigham Young University

2020 – Present	Assistant Professor

U.S. Army Engineer Research & Development Center

2019 – 2020	Program Manager, Intelligent Environmental Battlespace Awareness
2018 – 2019	Soil & Sediment Geochemistry Interim Team Leader
2016 – 2020	Research Soil Scientist (GS 13), Soil & Sediment Geochemistry Team, Environmental Laboratory

PUBLICATIONS

Chappell, M.A.; J.M. Seiter; H.M. West; L.F. Miller; M.E. Negrete; **J.J. LeMonte**; B.E. Porter; C.L. Price; M.A. Middleton. 2020. Organic contaminant sorption parameters should only be compared across a consistent systems of linear functions. Heliyon, 6(3). https://doi.org/10.1016/j.heliyon.2020.e03511.

Wilkens, J.L.; A.D. McQueen; **J.J. LeMonte**; B.C. Suedel. 2020. Initial survey of microplastics in bottom sediments from United States waterways. Bulletin of Environmental Contamination and Toxicology, 104(1) 15-20, DOI: 10.1007/s00128-019-02762-3.

Busby, R.R.; T.A. Douglas; **J.J. LeMonte**; D.B. Ringelberg; K.J. Indest. 2020. Metal accumulation capacity in indigenous Alaska vegetation growing on military training lands, International Journal of Phytoremediation 22(3) 259-266, DOI:10.1080/15226514.2019.1658708.

Chappell, M.A.; J.M. Seiter; H.M. West; L.F. Miller; M.E. Negrete; **J.J. LeMonte**; B.E. Porter; C.L. Price; M.A. Middleton. 2019. Predicting 2,4-dintroanisole (DNAN) sorption on various soil "types" using different compositional datasets. Geoderma, 356, 113916. https://doi.org/10.1016/j.geoderma.2019.113916.

LeMonte J.J., Jolley V.D., Story T.M., Hopkins B.G. 2018. Assessing atmospheric nitrogen losses with photoacoustic infrared spectroscopy: Polymer coated urea. PLoS ONE 13(9): e0204090. https://doi.org/10.1371/journal.pone.0204090.

LeMonte, J.J.; J.W. Stuckey; R. Tappero; J. Rinklebe; D.L. Sparks. 2017. Sea Level Rise Induced Arsenic Release from Historically Contaminated Soils. Environmental Science & Technology 51 (11), 5913-5922. https://doi.org/10.1021/acs.est.6b06152

LeMonte, J.J., V.D. Jolley, J.S. Summerhays, R.E. Terry, and B.G. Hopkins. 2016. Polymer Coated Urea in Turfgrass Maintains Vigor and Mitigates Nitrogen's Environmental Impacts. PLoS ONE 11(1). http://dx.doi.org/10.1371/journal.pone.0146761.

TECHNICAL REPORTS

Chappell, M.A.; **J.J. LeMonte**; L.F. Miller; H.M. West; M.A. Middleton; C.R. Milller. 20XX. Environmental fate of tungsten munition beads; U.S. Army Engineer Research & Development Center Technical Report: Vicksburg, MS.

Chappell, M.A.; W.S. Shih; C.L. Price; L.F. Miller; B.N. Stevens; **J.J. LeMonte**. 20XX. Environmental life cycle assessment on CNTRENE(R) and CNT-based sensors; U.S. Army Engineer Research & Development Center Technical Report: Vicksburg, MS.

Chappell, M.A.; M. Shukla; R. Karna; H.M. West; C.L. Price; M.E. Negrete; B.E. Porter; M.A. Middleton; R. Styles; **J.J. LeMonte**. 20XX. Surface Complexation Theoretical Descriptions of the Sorption of Organic-Acid Munition Constituents on Variably Charged Surfaces; U.S. Army Engineer Research & Development Center Technical Report: Vicksburg, MS.

Chappell, M.A.; W.P. Lorentz; L.F. Miller; **J.J. LeMonte**; B.J. Lafferty. 20XX. Variable performance of the V-22 Osprey Engine Air Particle Separator (EAPS) system to remove aerosolized soil particles.; Submitted to the Department of Defense Inspector General: Vicksburg, MS.

INVENTION DISCLOSURES AND PATENTS

Chappell, M.A., Negrete, M.E., West, H.M., Middleton, M.A., Porter, B.E., Price, C.L., Stephens, B.N., **LeMonte, J.J.** 2018. UHPLC analysis of insensitive munitions, in, U.S. Army Engineer Research & Development Center, Application COE-741.

RESEARCH GRANTS

1/2021-22 Utah Division of Water Quality, $123,120, "Utah Lake Water Quality Study: Utah Lake Sediment Phosphorus Binding".

TEACHING AND MENTORING

Courses Taught: Geological Communications (Geol 230, starting Fall 2021), Geological Field Methods (Geol 420, starting Spring 2021), Geochemistry (Geol 445)

Advisor for M.S. Students: Leeza Wells (expected 2022), Christine Miller (University of Florida, expected 2021)

Undergraduate Mentoring: Primary mentor for 6 undergraduate students since 2020. Recipient of the U.S. Army Engineer Research and Development Center Award for Outstanding Achievement in Student Outreach: College and University Category (2020).

Richard A Gill

Professor
Department of Biology
Brigham Young University
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Education

PhD, Colorado State University (1998) Major: Ecology
B.S., Brigham Young University (1993) Major: Conservation Biology

Professional Experience

Postdoctoral Research Associate, Duke University (1998-2001)
Assistant Professor, Washington State University (2001 - 2007)
Associate Professor, Washington State University (2007-2008)
Associate Director, School of Earth and Environmental Sciences, Washington State University (2005-2008)
Associate Professor, Brigham Young University (2008-2019)
Professor, Brigham Young University (2019-Current)
Associate Chair, Department of Biology, Brigham Young University (2012-2019)
Chair, Department of Biology, Brigham Young University (2019-Current)

Awards and Honors

Miss EL Hellaby Trust Sabbatical Award (2016)
Alcuin Fellowship, General Education (2015 - 2017)
College of Life Sciences Teaching Award, College of Life Sciences, BYU (2011)
Karl and Mollie Butler Young Scholar, Charles Redd Center (2009)
Honors College Faculty Award, Washington State University (2007)
Young Faculty Achievement Award, College of Sciences, Washington State University (2002)

Selected Publications (Last 5 Years)

Bishop, T.B.B., RA Gill, BR McMillan, SB St. Clair. 2019. Fire, rodent herbivory, and plant competition: implications for invasion and altered fire regimes in the Mojave Desert. Oecologia DOI: 10.1007/s00442-019-04562-2

Bishop, T.B.B., SB St. Clair, R.A. Gill, Steve Petersen, Seth Munson. 2019. Spatiotemporal patterns of cheatgrass invasion in Colorado Plateau National Parks. Landscape Ecology 34 (4):925-941.

Jensen, JL, KF Manwaring, RA Gill, RS Sudweeks, RS Davies, JA Olsen, AJ Phillips, SM Bybee. 2019. Religious Affiliation and Religiosity and their Impact on Scientific Beliefs in the United States. BioScience 69 (4):292-304.

Polley, HW, M.J. Aspinwall, H.P. Collins, A.E. Gibson, R.A. Gill, R.B. Jackson, V.L. Jin, A.R. Khasanova, L.G. Reichmann, P.A. Fay. 2019. CO2 enrichment and soil type additively regulate grassland productivity, New Phytologist 222 (1):183-192. doi: 10.1111/nph.15562

Gill, RA, RC O'Connor, A Rhodes, TB Bishop, DC Laughlin, SB St. Clair. 2018. Niche opportunities for invasive annual plants in dryland ecosystems are controlled by disturbance, trophic interactions, and rainfall. Oecologia. DOI 10.1007/s00442-018-4137-z (0/3.13)

Fay, Philip, Michael Aspinwall, Hal Collins, Anne Gibson, Richard Gill, Robert Jackson, Virginia Jin, Alina Khasanova, Lara Reichmann, H. Wayne Polley. 2018. Flowering in grassland predicted by CO2 and resource effects on species abundance. Global Change Biology. 24:1771-1781 DOI 10.1111/gcb.14032 (0/8.502)

Colin L. Tucker, Theresa A. McHugh, Armin Howell, Richard A. Gill, Bettina Weber, Jayne Belnap, Edmund Grote, Sasha C. Reed. 2017. The concurrent use of novel soil surface microclimate measurements to evaluate CO2 pulses in biocrusted interspaces in a cool desert ecosystem. Biogeochemistry 135:239-249. DOI 10.1007/s10533-017-0372-3 (3/3.428)

Conner, Lafe G., Richard A. Gill, Joshua T. Harvey. 2017. Early snowmelt leads to warmer spring soil temperatures in mid-latitude aspen forest and subalpine meadow: implications for soil carbon cycling. Plant and Soil. (0/3.052)

St Clair, SB, R O'Connor, R.A. Gill, B McMillian. 2016. Biotic resistance and disturbance: rodent consumers regulate post-fire plant invasions and increase plant community diversity. Ecology 97 (7):1700-1711. (17/3.573)

Conner, Lafe G., Richard A. Gill, Jayne Belnap. 2016. Soil moisture response to experimentally-altered snowmelt timing is mediated by soil, vegetation, and regional climate patterns. Ecohydrology (2/2.852)

Gill, RA, CS Campbell, SM Karlinsey. 2015. Soil moisture controls Engelmann Spruce (Picea engelmannii) seedling carbon balance and survivorship at timberline in Utah, USA. Canadian Journal of Forest Research 45:1845-1852. 10.1139/cjfr-2015-0239 (8/1.827)

Procter, Andrew, Richard A. Gill, Philip Fay, H. Wayne Polley, and Robert B. Jackson. 2015. Soil carbon responses to past and future CO2 in three Texas prairie soils. Soil Biology and Biochemistry 83:66-75. 10.1016/j.soilbio.2015.01.012 (5/4.857)

Selected Grants

Gill, R. A. (Principal), "Preparing Indigenous Communities for Climate Change in Samoa," Sant Foundation, $14,000.00 (January 2020-December 2020)

St. Clair, S (Principal), Gill, R. A. (Co-Principal), Madsen, M (Co-Principal), Roundy, B (Co-Principal). Post-fire recovery of Great Basin sagebrush habitat using seed coating technology and herbicides to overcome abiotic and biotic limitations to native plant establishment., Joint Fire Sciences, $400,000.

Aanderud, Z. T. (Principal), Ames, D. P. (Co-Principal), Carling, G. T. (Co-Principal), Gill, R. A. (Co-Principal), EPSCOR-iUTAH-innovative Urban Transitions and Aridregion Hydro-sustainability, National Science Foundation (NSF), $1,566,023.00, (August 2012 – June 2018)

Gill, R. A. (Principal), Droughts in Dryland Regions: The Sensitivity of Grasslands and Shrublands of the Colorado Plateau to Historical and Current and Experimental Droughts, United States Geological Survey (USGS), $94,000.00, (May 2017 – May 2018)

Gill, R. A. (Principal), Authentic STEM Applications in Earth Science: Capstone Experiences in Conservation, National Aeronautics and Space Administration (NASA), $5,966.00, (April 2017 – April 2018)

Gill, R. A., "Conservation of Nearshore Fish Communities in Hawaii and Samoa: Using Underwater Video Analysis to Address Key Ecological Questions and Increase Undergraduate Involvement in Marine Sustainability," Sant Foundation, $10,000.00 (January 2017 - April 2017)

Gill, R. A., Kent Keller, C., Harsh, J. B., Thomashow, L. S., ETBC Collaborative Research: Weathering Under Cover: Role of biofilms in mineral weathering and nutrient uptake in the mycorrhizosphere, National Science Foundation (NSF), $491,421.00, (2009 – December 2013)

St Clair, S. B. (Principal), Aanderud, Z. T. (Co-Principal), Gill, R. A. (Co-Principal), McMillan, B. R. (Co-Principal), Petersen, S. L. (Co-Principal), Climate Driven invasive grass-fire cycles, United States Department of Agriculture (USDA), $419,173.00, (September 2010 – August 2013)

Gill, R.A. (Principal) and Lauenroth, W.K. Using long-term chart quadrats to evaluate plant demography in the subalpine: rescuing the Great Basin Experimental Range data sets. National Science Foundation, $68,632, (2003-2005)

Gill, R.A. (Principal) Carbon dioxide induced changes in belowground C and N cycling in grasslands. US Department of Agriculture—National Research Initiative, $90,000 (2000-2002).

BRYAN GENE HOPKINS
CURRICULUM VITAE

RANK: Professor, Brigham Young University

DEPARTMENT: Plant and Wildlife Sciences

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EDUCATION:

Degrees:

1995	Ph.D.	Agronomy	Kansas State University, Manhattan, KS
1991	M.S.	Agronomy and Horticulture	Brigham Young University, Provo UT.
1990	B.S.	Agronomy and Horticulture	Brigham Young University, Provo UT.
1988	A.A.	Horticulture	Ricks College, Rexburg, ID

Certificates:

1991-present	Certified Professional Soil Scientist (CPSSc),	Soil Science Society of America,

EXPERIENCE:

Academic Appointments:

Environment Science of Managed Landscapes, Professor, Brigham Young University, Provo, UT, 50% teaching/45% research/5% citizenship, 10 month appointment

*2012-present Professor & Director of BYU Environmental Analytical Lab

*2007-2012 Associate Professor

Soil Scientist and Cropping Systems Specialist, University of Idaho, Idaho Falls, ID, 80% extension/20% research and citizenship, 2001-2007

SCHOLARSHIP:

Publications and Presentations Summary for Bryan Hopkins

	Hopkins' Graduate Student First Author	Hopkins' Undergraduate Student First Author	Other Graduate Student First Author	Other Undergraduate Student First Author	Hopkins First Author	Co-author	Total
Refereed Journal	14	3	14		14	7	52
Editor Reviewed Journal		2		1	4	3	9
Book Chapters					4	4	8
Bulletins					12	8	20

SELECTED PUBLICATIONS:

Hopkins, B.G., K.J. Fernelius, N.C. Hansen, and D.L. Eggett. 2018. AVAIL phosphorus fertilizer enhancer: Meta-analysis of 503 field evaluations. *Agron. J.* 110: 389-398.

Jones, C. D., J.M. Stettler, S.L. Jensen, B.G. Hopkins, V.D. Jolley, D. Turner, and M.R. Stevens. 2018. Comparisons of cultivation methods for Lupinus sericeus, L. argenteus, L. prunophilus, and L. arbustus. *Native Plants J.* 19: 90-99

LeMonte, J.J., V.D. Jolley, T.M. Story, and B.G. Hopkins. 2018. Assessing atmospheric nitrogen losses with photoacoustic infrared spectroscopy: Polymer coated urea. *PLOS ONE*. 13(9): e0204090.

Smith, T.S., B.G. Hopkins, J. Gookin, and S. Thompson. 2018. Portable electric fencing for bear deterrence and conservation. *Human Wildlife Interactions.* 12(3): 309–321.

Svedin, J. 2018. Characterizing the spatial variation of crop water productivity for variable-rate irrigation management. M.S. thesis. Provo, UT: Brigham Young Univ.

Campbell C., A. Campbell, N. Hansen, B.G. Hopkins, S. Evans, E. Campbell, and D. Cobos. 2017. Comparing in situ soil water characteristic curves to those generated in the lab. *Second Pan-American Conf. on Unsaturated Soils*; 12-15 Nov. 2017; Dallas, Texas. Reston, VA; ASCE Publishing.

Carroll, D.A., II., N.C. Hansen, B.G. Hopkins, and K.C. DeJonge. 2017. Leaf temperature of maize and crop water stress index with variable irrigation and nitrogen supply. *Irrig. Sci.* 35(6): 549-560.

Fernelius, K.J., M.D. Madsen, B.G. Hopkins, S. Bansal, V.J. Anderson, D.L. Eggett, and B.A. Roundy. 2017. Post-fire interactions between soil water repellency, soil fertility and plant growth in soil collected from a burned Piñon-Juniper woodland. *J. Arid Env.* 144: 98-109. DOI:org/10.1016/j.jaridenv.2017.04.005.

Hopkins, B.G., and N.C. Hansen. 2017. Nitrogen and water interactions: Crop production systems case studies. *In Proc. of the Western Nutrient Management Conf.;* 2-3 March 2017; Reno, NV. 12:22-27. WERA-103; USDA-NIFA; Peachtree Corners, GA: International Plant Nutrient Institute. Available at: http://www.ipni.net/ipniweb/conference/wnmc.nsf/e0f085ed5f091b1b852579000057902e/ccbc3bfdb684eb ee852580e400519374/$FILE/17WNMC%20Hopkins%20pg22.pdf

Hopkins A.P., B.G. Hopkins, N.C. Hansen, and T.J. Hopkins. 2017. Interacting Water & Nitrogen. *Turf Trends*. Cleveland, OH: North Coast Media. 3 (3) 10-17.

Summerhays, J.S., V.D. Jolley, M.W. Hill, and B.G. Hopkins. 2017. Enhanced phosphorus fertilizers (Carbond P® and AVAIL®) supplied to maize in hydroponics. *J. Plant Nutr.* 40: 2889-2897. DOI:10.1080/01904167.2017.1384007.

Buck, R.L., B.G. Hopkins, B.L. Webb, and V.D. Jolley. 2016. Depth of ion exchange resin capsule placement impacts on estimation of nitrogen and phosphorus bioavailability in semi-arid, low fertility soils. *Soil Sci.* 181: 216–221. DOI:10.1097/SS.0000000000000165

Katseanes, C.K., M.A. Chappell, B.G. Hopkins, B.D. Durham, C.L. Price, B.E. Porter, and L.F. Miller. 2016. Multivariate functions for predicting the sorption of 2,4,6-trinitrotoluene (TNT) and 1,3,5-trinitro-1,3,5-tricyclohexane (RDX) among taxonomically distinct soils. *J. Environ. Manage.* 182: 101–110. DOI:org/10.1016/j.jenvman.2016.07.043

LeMonte, J.J., V.D. Jolley, J.S. Summerhays, R.E. Terry, and B.G. Hopkins. 2016. Polymer coated urea in turfgrass maintains vigor and mitigates nitrogen's environmental impacts. *PLOS ONE* 11: e0146761. DOI:10.1371/journal.pone.0146761

Hopkins, B.G. 2015. Phosphorus in plant nutrition. *In* D.J. Pilbeam and A.V. Barker (*ed.*) *Plant Nutrition Handbook.* Second Edition. Boca Raton, FL: CRC Press, Taylor & Francis Group. Ch. 3: 65-126.

Madsen, M.D., D.L. Zvirzdin, S.L. Petersen, B.G. Hopkins, and B.A. Roundy. 2015. Anchor chaining's influence on soil hydrology and seeding success in burned piñon-juniper woodlands. *Rangeland Ecol. Manage.* 68: 231-240. DOI:10.1016/j.rama.2015.03.010

Jones, M.P., B.L. Webb, V.D. Jolley, B.G. Hopkins, and D.A. Cook. 2013. Evaluating nutrient availability in semi-arid soils with resin capsules and conventional soil tests, I. Native plant bioavailability under glasshouse conditions. *Commun. Soil Sci. Plant Anal.* 44: 971-986. DOI:10.1080/00103624.2012.747609

Madsen, M.D., E.G. Coronel, and B.G. Hopkins. 2013. Soil surfactant products for improving hydrologic function in post-fire water-repellent soil. *Soil Sci. Soc. Am. J.* 77: 1825-1830. DOI:10.2136/sssaj2012.0305

Madsen, M.D., S.L. Petersen, K.J. Fernelius, B.A. Roundy, A.G. Taylor, and B.G. Hopkins. 2012. Influence of soil water repellency on seedling emergence and plant survival in a burned semi-arid woodland. *Arid Land Res. Manag.* 26: 236-249.

Hopkins, B.G., D.A. Horneck, R.G. Stevens, J.W. Ellsworth, and D.M. Sullivan. 2007. Managing irrigation water quality for crop production in the Pacific Northwest. PNW 597-E. Corvallis, OR: Oregon State University.

Benjamin W. Abbott

1. NSF Arctic System Science. Brothers, Budy, Abbott, Devlin. *Biomass Trajectories for Arctic Lake Food Webs*. $1.4 million, $320,711 to Abbott. **Pending**, 2021-2023
2. NSF Critical Zone Observatories. Perdrial, Abbott, Harpold, et al., *Collaborative Research: Network Cluster: Using Big Data approaches to assess ecohydrological resilience across scales*. $3.2 million, $357,883 to Abbott. **Funded**, 2021-2025
3. Utah Division of Natural Resources. St Clair, Abbott, Frandsen, Nelson, *Megafire impacts on terrestrial and aquatic ecosystems and management interventions to protect wildlife habitat and watershed hydrology.* $497,946. **Funded**, 2019-2023
4. NSF ANS. Abbott, Zarnetske, Shogren, O'Donnell, Bowden, Glenn, *COLLABORATIVE RESEARCH - Constraining fate and function of permafrost nutrients with direct multi-scale observations: Stream networks as indicators of watershed processes*. $1.34 million, $469,943 to Abbott. **Funded**, 2020-2022

Ryan S. Nixon

Project Name	Role	Funder	Award Amount	Period	Person-Months
Current Projects					
Development of elementary teachers' science subject matter knowledge through teaching experience	PI	BYU McKay School	$21,378	2021-2022	0
Pending Projects					
Supporting pre-service teachers to notice students' community and experience-based resources for classroom science learning	Co-PI	University of Washington College of Education	$8.624	2021-2022	0

Keely Song Glenn

1. BYU Gerontology Research Grant Award: Funding for *Living Stages*- an intergenerational dance performance. ($5,000). **Funded,** 2020
2. BYU Laycock Center for Creative Collaboration Grant: Funding for *Teleconnection—A Dance Film Journey*- Intersection of Dance & Design Faculty Fellow Research Grant. ($8,625). **Funded,** 2020
3. BYU Laycock Center for Creative Collaboration Grant: Funding for *Teleconnection—Our Distant Home*- Collaborative Research Grant to the Alaska Permafrost. ($9,900). **Funded** 2020
4. BYU Fulton Grant- BYU *CDT Screendance experience*- funding to support the BYU contemporary dance faculty and students through creative dance films during Covid-19 ($7000). **Funded** 2020

Daniel P. Ames

1. Project Title: SI2-SSI: Collaborative Research: Cyberinfrastructure for Advancing Hydrologic Knowledge through Collaborative Integration of Data Science, Modeling and Analysis
    a. Source of Support: NSF
    b. Total Award Amount: $5,000,000
    c. Award Period: 7/1/2017-6/30/2021
    d. Calendar months committed per year: 1.0
2. Project Title: 16-GEO16-0089; An AmeriGEOSS Cloud-based Platform for Rapid Deployment of GEOGLOWS Water and Food Security Nexus Decision Support Apps
    a. Source of Support: NASA
    b. Total Award Amount: $ 540,655
    c. Award Period: 1/1/2017-1/31/2022
    d. Calendar months committed per year: 1.0

Elizabeth Gibbons Bailey

1/1/20 – 12/31/21 Gender Gaps in Utah County K-12 Math and Science Classes. Internal Grant at Brigham Young University (Emmeline B Wells Grant), $25,000

Greg Carling

1/2021-26 NSF Critical Zone Thematic Cluster, $888,941 ($5.2M total including other universities), "Collaborative Research: Network Cluster: Dust in the Critical Zone from the Great Basin to the Rocky Mountains"

7/2019-21 Utah Division of Air Quality, $150,000, "Characterizing air quality impacts from exceptional events along the Wasatch Front"

Joshua LeMonte

1/2021-22 Utah Division of Water Quality, $123,120, "Utah Lake Water Quality Study: Utah Lake Sediment Phosphorus Binding".

Richard Gill

Gill, RA (PI) Adapting to Climate Change in the Developing South Pacific: Identifying Key Trophic Interactions in Post Bleaching Recovery. May 1, 2020-April 30, 2022. $15,000. Sant Foundation.

Bryan G. Hopkins

NAME (List/PD #1 first)	SUPPORTING AGENCY	TOTAL $ AMOUNT	START YEAR	END YEAR	% OF TIME	TITLE OF PROJECT
Hopkins	*Soil Science Society of America*	*$ 103,000*	Oct 2019 -	Dec-21	*9%*	North American Proficiency Testing Program
Hansen, Kerry, Heaton, Jensen, Hopkins	US-Israel Binational Agricultural Research and Development Fund: BARD Research Grant	$ 90,047	Jul 2019 -	Jun-21	2%	Spatiotemporal decision support systems for recognizing variability and managing precision irrigation
Yost, M, N.C. Hansen, G. Cardon, **B.G. Hopkins,** O. Walsh, J. Williams, H. Neibling and B. Black. Stacking	*International plant nutrition institute (IPNI)*	$ 612,805	2019	2023	2%	Stacking and intersecting nutrient and irrigation 4R's.
Yost, Hansen, Neibling, Spackman, Creech, Allen, Hopkins, Heaton, Christenson, Hunter, Hanberg	Western Sustainable Agriculture Research and Education	$ 350,000	Jul 2019 –	Jun-22	2%	Identifying Stacked Conservation Practices that Optimize Water Use in Agriculture
Hansen, Kerry, Heaton, Jensen, Hopkins	*Active: Brigham Young University*	$ 120,000	Jan 2018 –	Jan-20	5%	Integrating Remote Sensing and Spatiotemporal Statistics to Develop Prescription Maps for Variable Rate Irrigation Systems