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**Cover photo:** *Measuring water level in monitoring well by Moroccan and Egyptian students around San Angelo, Texas Photo taken 2012.* Credit:Fryar et al. JCWRE, August 2024.
**Back cover photo:** *Inside Busch Stadium - St. Louis, MO*. Credit: Jackie Gillespie

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# Aligning Audience Needs with Scientists' Information in the Complex Harmful Algal Bloom Outreach to Engagement Continuum

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**Abstract:** Algae, an important foundation of aquatic ecosystems, can become a nuisance or harmful when it grows in excess. Many government agencies have a role in monitoring, responding to, and confirming a harmful algal bloom (HAB). HAB scientists have important information to share, however, given the complexities of HABs, which often involve decoupled drivers from observed impacts, presents challenges to outreach and engagement. Understanding key audience information needs can help scientists prioritize key science communication and engagement opportunities to maximize the impact of such efforts. Scientists may need additional science communication training or support for scientist-community partnerships. This will be evermore important into the future with the likely range expansion of HABs due to climate change.

**Keywords:** *harmful algal blooms, science communication, outreach to engagement continuum, scientists, audiences*

Algae is an important foundation to the aquatic ecosystem and is dependent upon nitrogen or phosphorus (EPA 2024a). However, too much nutrient input can produce too much algae, resulting in nuisance algal blooms that often contain toxins (i.e., cyanotoxins, etc.) that cause them to be labeled harmful (EPA 2024a). Harmful algal blooms (HABs) occur in inland waters, the Great Lakes, and around the world (Carmichal and Boyer 2016). HABs are expected to increase in frequency due to warming temperatures and abundant nutrient inputs from point sources (e.g., wastewater treatment plants) or nonpoint sources (e.g., agricultural, residential, or commercial land uses) (Carmichal and Boyer 2016; EPA 2024b). In the Great Lakes region, this means range expansion to northern parts of lakes Michigan-Huron and Superior, as well as inland waters of the Upper Midwest. Through direct or indirect exposure, HABs can have many impacts on aquatic ecosystems, human and animal health (e.g., livestock or companion animals), as well as recreational activities such as swimming, fishing, boating, or kayaking (Hird and Baden 2023).

In the Great Lakes region, harmful algal blooms are annually persistent in Lake Erie's western basin (Stumpf et al. 2012). On August 2, 2014, a half million residents of Toledo, OH and the surrounding area woke to a message that they should not use their drinking water starting immediately due to the presence of algal toxins in the municipal water. It took three days to resolve the issues and restore safe municipal water supply. While it has been nearly a decade since that event, HAB risk remains because of available nutrients. Point sources of wastewater treatment, resuspended legacy phosphorus in Western Lake Erie, and excess agricultural nutrients from the surrounding watershed are driving Western Lake Erie basin's HABs. In response, nutrient reduction targets were established, and much progress has been made. The agricultural community is a leader

**Research Implications**

- Key audiences of lake associations and local governments need information on general aquatic ecology and the role of algae, harmful algal bloom (HAB) monitoring and responses, and treatment options. Making the information visual and easily shareable on social media will improve the likelihood of its use.
- HAB scientists rate science communication highly, so ample opportunity exists to bridge the science policy implementation gap. However, scientists do not have to do it all. When they understand the needs of key audiences, they can prioritize efforts for effective science communication to maximize the impact of their work.
- Coordinating with local governments who have shared responsibility for HAB responses can be useful to overcome unintentionally providing misleading information on who has what role in HAB monitoring and response.
- Resources are available to help scientists on the continuum of outreach to engagement, including science communication training or facilitating partnerships.

in recommending the 4R system to help cropping systems producers determine the right fertilizer to use, at the right rate, at the right place, and at the right time (Bruulsema et al. 2009) to achieve nutrient reduction targets. However, additional research is needed to address remaining questions such as predicting HAB occurrence and toxicity, who is most at risk, what information they need, etc.

The Great Lakes Center for Fresh Waters and Human Health (hereafter Great Lakes Center) was established with funding from the National Institute of Environmental Health Sciences (NIEHS) and the National Science Foundation (NSF) in 2018. The Great Lakes Center is a collaborative effort among ten research institutions to understand and prevent toxic algal blooms. Community engagement cores are common in the NIEHS funded centers with the purpose of fostering university-community partnerships, conveying community voice to researchers, and producing innovative and culturally appropriate research translation outputs (NIEHS 2023). The range of relationships between university researchers and communities can be described as a continuum from lower levels to higher levels of community participation. Lower levels may be referred to as outreach (e.g., alert or inform), with higher levels referred to as engagement (e.g., collaboration or co-create) on the continuum (Carson et al. 2022). At different stages on the continuum, public participation achieves different purposes, is organized in different ways, and employs different techniques–all aligned to achieve community and university results. Community is defined as entities beyond college or university campuses, who share an identity defined by geography, identity, affiliations, interests, professions, practice, faith, family, or circumstance and include multiple intersections of community identity (Ife 1995; Mattessich and Monsey 1997; Wenger 1998; Marsh 1999; Wenger et al. 2002; Fraser 2005; Gilchrist 2009; Doberneck 2022). Public engagement requires specificity and nuanced understanding of "the public audiences" so that outreach and engagement efforts are effective.

One of the Great Lakes Center community engagement goals was to conduct a stakeholder needs assessment for the Great Lakes and environmental health literacy to inform general outreach information needs. Given the challenges of decoupled sources of excess nutrients from likely impacts of HABs now or in the future, it is important to understand the perspectives and needs of the people who are likely experiencing impacts from HABs or responding to HABs in Western Lake Erie and more generally throughout the Great Lakes region, including inland waters. Each audience has a specific communication mode, preferred content, and evidence for credibility, accessibility, and timeliness (Baron 2010; Bogenschneider and Corbett 2010; Doberneck et al. 2017). Clarifying the audience, their information needs, when they need the information, and their preferred format to receive information in are all important aspects of oceans and human health community engagement (Carson et al. 2022). Two audiences in particular are notable because of their unique roles and interests: (1) lake associations, representing waterfront homeowners, and (2) local governments, including drain and water commissions, lake improvement boards, etc. Segmenting the public into specific groups based on what they have in common can lead to more effective science communications and outreach strategies. In HAB work, for example, scientists would use different strategies to reach K-12 teachers (community of profession/practice), recreational boaters (community of interest), or homeowners on inland lakes (community of circumstance). Outreach goals informed by the end user and strategies in alignment with their preferences will help reduce failures, including eroding time and trust (Carson et al. 2022). Effectively achieving outreach goals also depends on the preparation and skill of the science communicator. In the context of science relevant for society, as in the case of HAB researchers, they may be asked to communicate about their research or do so because of their interest in informing policy or practice. In other cases, a HAB researcher may collaborate with others to produce important public health monitoring information such as the case of Lake Champlain community science for cyanobacteria (Vaughan et al. 2021).

In this manuscript, we start with the end in mind and: (1) describe information needs from key audiences likely impacted by or responding to HABs, (2) document HAB scientists' interests in and approaches to science communication, (3) align audience information needs with scientists' assets in two recommended practice case examples, and (4) conclude with training and support opportunities for HAB scientists.

## Methods

Three open-ended group interviews were held with four individuals total representing key audiences of lake associations (i.e., waterfront homeowners). One open-ended group interview was held with four individuals from agencies responsible for responding to HABs. The agency representatives had public health or natural resource management expertise but were not conducting research. Both sets of interviews were conducted during February - May 2021 (Appendix A; IRB #5273). They were asked three basic questions about what they already know about HABs, what types of data and figures are and are not useful to them, and what do researchers need to know in order to successfully communicate with them, along with several follow-up probing questions. Interviews were conducted and recorded using Zoom video conferencing software. The recording audio was used in the analysis, which consisted of one of the authors conducting a thematic analysis (Sovacool et al. 2023). Thematic analysis involves identifying emergent themes and patterns from the data that might overlap and lack consistency, yet tell an important story (Rubin and Rubin 2005; Sovacool et al. 2023).

Twelve Great Lakes Center scientists were interviewed April - June 2020 (Appendix B; IRB #3910). They were asked 13 open-ended questions, ranging from inviting the scientist to describe their: research; its outcomes; audiences of their research; how they reach their audience; who they work with; how they rank science communication; training needs; what support they needed from the Great Lakes Center community engagement core; what skills; preferred mode and timing of training is preferred; snowball referral to other potential interviewees; and anything else they would like to add. Zoom interviews were conducted and recorded and transcripts were produced. Analysis was completed by one of the authors of this manuscript who reviewed transcripts to identify emergent themes from the interviews (Rubin and Rubin 2005). The other authors reviewed the themes and corresponding descriptions throughout the writing process.

## Results

### What Do Key Audiences Need, When, and How?

Key audiences have specific needs, regardless of what information is being received, heard, or shared by scientists. Two audiences in particular are notable because of their unique roles and interests: (1) lake associations, representing waterfront homeowners, and (2) local governments, including drain and water commissions, lake improvement boards, etc.

Both audiences need information on the importance and complexity of algae. It is an important base of the aquatic food web. However, if too much, it becomes a nuisance at best and harmful with cyanotoxins at worst. They also need information on algae identification, lake-nutrient management, and long-term strategies for reducing the likelihood of algae becoming nuisance or harmful. Late winter is the best time to provide this information.

Lake associations need information on understanding the trophic state of their lake and appropriate nutrient management for it. Additionally, lake associations want information on how HABs likely impact property values and perception of the lake. During the summer or fall, when suspected algal blooms are more likely to occur, they need just-in-time resources such as who to contact, testing procedures, treatment options, and how to screen environmental firms. Because local health departments decide when and where to post signage alerting people about the presence of HABs, communication about why they are making those decisions, as well as when county health departments decide to remove the sign, would be beneficial to lake associations.

For lake associations, visual communication, such as social media-ready text, graphics, and brief videos, along with 1-2-page fact sheets on algae and additional resources are the preferred communication approaches. There is much confusion about the roles and responsibilities among state, county, and municipal governments, resulting in people not understanding the different roles and unintentionally providing unhelpful information. Therefore, coordinating with local governments would be an effective approach to facilitate the various entities becoming acquainted with each other, understand their role, and what resources on HABs they can provide to lake associations when asked.

### Scientists' Intended Audiences and How They Are Reaching Them

Almost all Great Lakes Center respondents (n=11) described the main output of their research as scientific papers and informing public policy and natural resource managers. The intended audience for their research ranged from other researchers or scientists, specifically bloom toxin forecasting scientists, policy makers, science communicators who provide information to stakeholder groups (e.g., fisheries, tourism, or watershed groups), broader community, general public, news media, anglers, and natural resource managers (e.g., fisheries, land, general agencies).

Respondents identified outreach efforts as including attending annual professional meetings, writing perspective pieces in major publications, inviting people to collaborate, and utilization of traditional media (e.g., press releases, local television and radio broadcasting, such as *Great Lakes Now* or *The [Toledo] Blade*). Respondents also utilize digital media such as websites and social media (e.g., Facebook and Twitter, now called X). Respondents also described traditional outreach materials, such as flyers, one-page fact sheets, or visual infographics. Traditional outreach presentations, such as a student talk at an event, attending small group meetings, or responding to stakeholder inquiries were described as well. Inviting the intended audience to partner with and participate in community science (e.g., charter boat captain study, coast guard sampling, customized data reports) was also described as other outreach efforts.

Respondents noted that the public health and clinical health fields (e.g., public health officials or researchers, toxicologists, emergency room doctors, and pharmaceutical or drug developers) are important audiences, but one that they have not communicated with much. Other audiences including water infrastructure managers, farmers, lake associations, and students (i.e., high school or college) were described by some respondents. Most scientists surveyed were primarily in communication with one or two stakeholder groups, rather than all of the stakeholders identified.

### Scientists Working Along the Outreach to Engagement Continuum

Respondents rated science communication highly (average = 4, standard deviation = 0.9 on a 1-5 scale with 1 = low priority and 5 = high priority) compared to other research priorities, such as publishing papers, presenting at conferences, processing samples, applying for funding, etc. Three-quarters of Great Lakes Center respondents indicated science communication skills as a high priority need. These included translating research results for broader audiences, communicating risks and hazards, choosing what to talk about with the public, and how to frame the significance of their work. Moreover, scientists described the need for support to format data sheets for citizen science efforts or to create fact sheets or white papers about human health issues for the public. Respondents also expressed a desire to have an outreach or engagement professional observe a training or lab tour (where algal toxins are analyzed) and provide feedback on what aspects help participants learn about algal science and laboratory procedures. Similarly, some respondents also indicated an interest in having someone evaluate the long-term impacts of their outreach efforts.

Multiple scientists mentioned that their outreach to certain groups grew by working through organizations like Ohio Sea Grant or state environmental agencies. For others, people from local organizations would recognize the scientist's name and contact them directly about interpreting their data. Other scientists described leveraging existing resources, such as their department's communications staff members, to widen their reach. Without partnerships with communications professionals, scientists would not have adequate time, capacity, or funding to do their own outreach. Still, others described finding key allies within the community and to utilize them as communicators to their neighbors and friends to share relevant information. Finally, some respondents recommended coordinating communication within the Great Lakes Center and among the other NIEHS/NSF Oceans and Human Health Centers for consistent messages. The outcomes of such efforts would be amplifying colleagues' work, facilitating conversations about the tools researchers need to do their work, and reminding scientists that communicating with the public is important.

## Discussion

The good news is that key audiences likely affected by or responding to HABs do want information that scientists can provide. Scientists do not need to do multiple types of activities along the outreach to engagement continuum themselves. While there are some general education messages about algae as an important foundation of aquatic ecosystems, nuanced messages such as algae is good, when not too much and depending on appropriate nutrients, are also needed. If scientists, science communicators, or boundary spanning organizations ask their key audiences (or partners) what their information needs are, when they would like to receive it, and in what format they need it, they can maximize the impact of limited resources (adapted from Carson et al. 2022). Essentially this is being strategic about outreach and engagement activities, similar to the 4R approach of right time, right place, right amount, right type of fertilizer needed (Bruulsema et al. 2009). Below, we describe two recommended practice case examples.

### Suggested Practice Example 1: Providing Needed, Timely Information to Lake Associations (i.e., Waterfront Homeowners).

Lake associations are officially comprised of waterfront property owners for the purpose of maintaining the quality of the inland lakes. They often have a variety of goals for lake management, including monitoring, treatment, fish stocking, aquatic habitat, etc. In the winter months (i.e., January - April), they want general information on aquatic and lake ecology, HAB research, specifics about their lakes, and long-term management and treatment options. Reaching them at the statewide annual conference (i.e., Michigan Lakes and Streams Association meeting) is recommended since representatives from multiple lake associations can access the necessary information and share with their respective lake association members. While conferences often have traditional formats, presenters can also provide algae fact sheets (1-2 pages) along with directions for digital access of resources, such as social media-ready text, graphics, and brief videos, on algae, HABs, and additional resources. Keep the audience in mind, making it easy for them to access and share the information. When a probable HAB outbreak occurs, likely in July - August, lake associations also need access to resources to visually identify the species, determine who to contact, testing procedures, treatment options, and how to screen environmental firms. Additionally, lake associations also need to know why decisions about posting signs alerting HABs are made and when it is appropriate to remove the sign.

**Suggested Practice Example 2: Supporting Scientists with Communication and Engagement Skills.**

It is promising that HAB scientists rated science communication skills as a high priority. To support this interest in having their research make an impact on policy and practice, scientists should consider additional training in science communication (Table 1) or engagement and partnerships (Hunnell et al. 2020). If scientists are not comfortable conducting direct outreach to the public, they can work with their university or departmental communications staff to make sure the important ideas emerging from their research are shared with the public. Institutional communications staff can create figures for cover articles in high-profile journals, as well as work with the communications office to send out press releases or other information about their recent research.

Similarly, to support scientists' interest in effective engagement, boundary spanning organizations, such as Sea Grant, Great Lakes Center community engagement cores, or others, can connect scientists with key audiences seeking their relevant science-based information. These professionals can help scientists discern what the best communication approach is for their work, create templates or communication materials using data provided by scientists, assess scientists' efforts, and facilitate partnerships among different groups. Collaborating with partner organizations requires the long-term investment as it involves regularly attending meetings and learning more about the needs of the group before figuring out what gaps in communication or information availability may exist. For example, an online dashboard focusing on

**Table 1.** Science communication training and other resources, 2023.

| Name | Resources |
|---|---|
| COMPASS<br>https://www.compassscicomm.org/ | Trainings<br>Message Box Toolkit |
| Alan Alda Center for Communicating Science<br>https://aldacenter.org/ | Trainings |
| American Association for the Advancement of Science-Public Engagement<br>https://www.aaas.org/programs/public-engagement | Toolkit<br>Trainings<br>Fellows Programs |
| Advancing Research Impact in Science<br>https://researchinsociety.org/ | Webinars<br>Annual Summit<br>Fellow Program<br>Small Grants<br>Awards |
| Portal to the Public<br>https://popnet.instituteforlearninginnovation.org/ | Workshops for researchers to learn informal science education teaching techniques to use at museums, zoos, aquariums, and science centers |
| Scholars Strategy Network<br>https://scholars.org/ | Workshops for researchers to communicate with policy makers |
| The Conversation<br>https://theconversation.com/us | Workshops and online platform for researchers to communicate with journalists |
| Association of Science Communicators<br>https://www.associationofsciencecommunicators.org/courses-training-opportunities/ | Workshops<br>Trainings |

human health risks from HABs was an innovative science communication output of the Great Lakes Center partnerships. Eventually, the approach leveraged additional funding and was transferred to inland counties to identify areas where people are at greatest risk from HABs because of the likely prevalence and expansion of HABs due to climate change (EPA 2024b).

Moreover, boundary spanning for engagement with and coordinating among multiple governmental levels are important. Michigan is a local (or home-rule) government comprised of 1,240 townships, 275 cities, 258 villages, 14 planning and development regions, 83 county governments with an equal number of drain commissioners (Michigan Legislature 2010), and over 1,000 intercounty drainage systems with governing boards (MDARD 2022). There are multiple levels of government involved with local water resource issues contributing to a complex and sometimes confusing operating environment, even for those who work within those roles. Helping local units of governments work together to anticipate the occurrence of HABs and respond when HABs do occur is extremely helpful.

## Conclusion

Algae is an important foundation of aquatic ecosystems, however, when growth becomes excessive, the algae may become nuisance or harmful to humans or animals. Understanding key stakeholders' information needs is an important step in aligning science communication messages, timing, and format. Moreover, this information will help scientists and other science communicators prioritize the information available to what is relevant and timely for its audience since they have expert knowledge about HABs. Scientists may need some additional support in how to effectively communicate timely, relevant, and nuanced information to key audiences, especially for lake associations (e.g., waterfront homeowners) and local governments. Training and coaching scientists is key so that they can specialize in communication with a particular audience or a particular method of communication, and also help focus and frame their outreach to engagement activities, just like their scientific discipline. Supporting scientists on facilitating or leveraging partnerships is also beneficial in the likely expansion of HABs due to a changing climate. A growth opportunity through partnering with public health officials, medical researchers and clinicians, veterinarians, and livestock farmers could be an important future direction for One Health (CDC 2024) outcomes.

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## Appendix A. Great Lakes Center for Fresh Waters and Human Health informal needs assessment interview questions for stakeholders, 2021.

1. What do you already know about HABs?
   a. What causes them, why are they harmful, etc.? We can provide 5 "must know" facts about HABs if needed.
   b. Have you sought information on HABs before? If so, where? What was helpful?
   c. If you've had a HAB/nuisance algae, who did you contact?
2. What types of data/figures are useful to you? Which are not?
   a. What is your most requested type of information?
   b. What kinds of outreach products do you use most frequently?
   c. Have any of your constituents/customers commented on a particular outreach product (i.e. Have you had positive/negative feedback on something you've distributed?)
   d. (Understanding the informational needs of these groups).
3. What do researchers need to know in order to successfully communicate with you right now?
   a. What is the most useful product to you to help you reach the rest of your constituency? Pamphlets, powerpoint, video clips, panel discussion (with Q&A?) radio/ TV ad, newspaper article, billboards?
   b. Timing of the products (WHEN is it helpful to know this information?)

## Appendix B. Great Lakes Center for Fresh Waters and Human Health research communication and engagement interview questions for scientists, 2020.

1. Will you describe your research within the scope of the Great Lakes Center for Fresh Waters and Human Health in 2-3 sentences? That is, give me your "elevator pitch".
   a. How would you describe yourself using an "-ist" term? i.e. microbiologist, ecologist, etc.
2. What are the ultimate outcomes of your research project?
   a. Manuscripts to scientific journals, law/ policy implications, land management?
3. Who is the intended audience of your study and/or results?
   a. Scientific community, land managers, community partners, anglers, recreational communities, health professionals
4. How do you currently reach your intended audience? In your opinion, which have been the most successful?
   a. Professional society meetings, reports, flyers, mailings, informational presentations, press releases, white papers, community forums

5. Who are the stakeholders in your work? And do they differ from what you consider your "community" with which you like to engage?

6. How do you currently engage your stakeholders in your work? Does that differ from how you engage your "community"?

7. On a scale of 1 to 5 (1 being low priority, 5 being high), how do you rank communicating your results to the public among your other study priorities?

8. (ASK ONLY IF ASSOCIATED WITH CENTER) How would you like to interact with the CEC? That is, are there particular aspects of your work with which the CEC may be able to help? (generate "wishlist")

9. What concepts would you like to expand on in a training?

    a. Science communication, community engagement

10. What hard skills would you hope to gain through a training?

    a. Meeting facilitation, conflict resolution, creating an effective presentation/one-pager

11. What format do you prefer in a training? What timing works best for you?

    a. In person, webinar, pre-conference session at an existing meeting, online module

12. Is there anyone that you suggest we interview?

13. Is there anything else that you would like to add? Any question you wish I had asked?

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# Skills Development in Hydrologic Sciences for Cohorts of Graduate Students from Morocco, Egypt, Türkiye, and Indonesia

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**Abstract:** In developing countries in Africa and Asia, meeting challenges of water scarcity and pollution has often been hampered by shortcomings in higher education, including insufficient research productivity and funding, lack of opportunity for university graduates, and a mismatch between university activities and societal needs. To address these issues, we developed novel programs integrating technical instruction and preparation for professional practice in hydrology for cohorts of graduate students from Morocco and Egypt (2012–2013) and from Türkiye and Indonesia (2013–2014). Students participated in an initial online course and a follow-up workshop featuring geographic information systems (GIS), remote sensing, and hydrologic modeling with internet-based data sets. Field activities in the USA (first cohort) and in the students' home countries (second cohort) included stream gauging, measurement of water levels in wells, water sampling, and measurement of hydrochemical parameters. A subsequent online course focused on research ethics, preparing proposals and publications, and presenting findings to technical audiences and the public, culminating in presentations at conferences in the USA. Participants mentored other students at their home institutions and at K-12 schools in Türkiye and Indonesia. Participant feedback during and after the programs tended to be strongly positive, and participants have continued to engage with project leaders and mentor students in their home countries and the USA. Our modular, hybrid approach offers a template for students in hydrology and related fields to develop relevant skills and engage internationally.

**Keywords:** *exchanges, hybrid curriculum, hydrology, international, mentoring, training*

As noted by USAID (2006, p. 107), the "availability of water impacts food production and nutrition, city development and growth, income generation and livelihood, and human health and hygiene." Inadequate access to clean water and sanitation is a particular problem in many countries within a belt that extends across North Africa, the Middle East, South Asia, and East Asia, which USAID (2006) defined as the Asia and Near East (ANE) region. In the arid to semi-arid Middle East and North Africa, absolute water scarcity is a primary problem (USAID 2010; Borgomeo et al. 2020), whereas in humid, tropical Southeast Asia, water pollution from unsewered areas and agriculture is a greater concern (WWAP 2012). The ANE region largely overlaps with member states of the Organisation of Islamic

**Research Implications**

- A modular, hybrid training course promoted development of technical and "soft" skills for groups of graduate students in African and Asian countries.
- Students rated field data collection and conference participation as the most worthwhile activities.
- Five-year post-program surveys and continued engagement by participants affirmed the programs' sustained impact.

Cooperation (OIC). Islamic World Educational, Scientific and Cultural Organization (ICESCO) (2003) articulated the importance of integrated water resources management, institutional and research capacity building, and international cooperation for member states.

Among the 17 Sustainable Development Goals (SDGs; United Nations 2022), SDG 6 emphasizes water ("Ensure availability and sustainable management of water and sanitation for all") and SDG 4 emphasizes education ("Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all"). Challenges in meeting SDG 6 affect the attainment of SDG 4 and *vice versa* (Hanley 2024). In various OIC countries, problems in higher education have included insufficient research productivity and funding, lack of opportunity for university graduates, and a mismatch between university activities and societal needs (USAID 2010; Lindsey 2011). The Federation of Universities of the Islamic World (FUIW) (2007) recognized the need for higher-education institutions to contribute to sustainable development and noted that research in water resources and the environment is a priority.

We created novel, hybrid programs to help young hydrologic scientists and engineers in selected OIC countries within the ANE region develop technical and professional skills through collaborating with each other and with U.S. colleagues. These two programs stemmed from the U.S. Department of State's Building Opportunity out of Science and Technology (BOOST) initiative and built on existing research collaborations. For two binational cohorts of graduate students, we combined technical instruction in hydrology (accessing and distributing data via shared platforms, GIS, remote sensing, hydrologic modeling, and field monitoring techniques) with preparation for professional practice (scientific ethics, writing grant proposals, and communicating science to technical and public audiences). We included online coursework, exchanges (a workshop in the USA for each cohort, and field activities by U.S. partners and the students), and presentations at a major Earth science conference in the USA. This approach provided opportunities for collaborative mentoring by U.S. and ANE faculty members, and peer mentoring through interactions between U.S. and ANE students. Program objectives included strengthening the students' communication skills, especially in English; increasing their ability to connect with the regional and global scientific communities; and positioning them to contribute as professionals in academia, industry, or government. Thereby, the participants would be empowered to build capacity in both education (through sharing their learnings with other students and members of the public) and water management in their home countries.

Our approach to designing the programs is grounded in observations from the recent literature on hydrology and Earth science education. These include the value of field learning, including team activities and field discussions (Mogk and Goodwin 2012; Iqbal and Clayton 2020), and cross-disciplinary and regionally diverse perspectives in hydrology (Wagener et al. 2010; Gleeson et al. 2012; Ruddell and Wagener 2015). Training in both "hard" skills (use of technology, such as internet resources, GIS, and modeling; Ruddell and Wagener 2015) and "soft" skills (e.g., communication and professional practice; McClain et al. 2012; Santillan-Jimenez et al. 2020) is important. Developing professional networks is particularly valuable for scientists in underdeveloped regions (Hughes 2012) and for members of underrepresented groups (e.g., women scientists; Avallone et al. 2013). We surveyed participants at various points during and after each program to assess the value of various activities.

## Program Activities and Assessment

### Cohort 1: Morocco and Egypt

For the first BOOST program, faculty from the University of Kentucky (UK; Alan Fryar), University of Georgia (UGA; Adam Milewski), and Western Michigan University (WMU; Mohamed Sultan) partnered with collaborators at three Moroccan institutions (Faculty of Sciences Ben M'sick [FSBM], Casablanca; Faculty of Sciences Semlalia, Marrakech [FSSM]; and Faculty of Sciences and Techniques, Fez [FST Fez]) and the National Authority for Remote Sensing and Space Sciences (NARSS) in Egypt (Figure 1). Collaborators recommended six students from each country based on criteria including gender (at least 50% of participants identifying as female, in response to historic discrepancies in STEM education and career opportunities; Hassan 2000), age (18–30), graduate education in a field related to hydrology, some background in remote sensing and/or GIS, and proficiency in English. In February 2012, two students each were chosen from FST Fez and FSSM, and one from FSBM; a sixth student was chosen from Faculty of Sciences Aïn Chock (FSAC, Casablanca) (Figure 1). Four Moroccan students were pursuing doctorates and two were pursuing master's degrees, all in geology; five were female and one was male. From Egypt, three students were chosen from Zagazig University (ZU; one each in geology, geography, and soil science); one each was selected from Cairo University (CU; geology), Helwan University (HU; geology), and NARSS (Figure 1). Two students were pursuing doctorates and four were pursuing master's degrees; three were male and three were female.

In April–May 2012, Milewski taught an online course on the fundamentals and principles of remote sensing, GIS, and hydrologic modeling using a series of lectures, videos, and assignments with the Moodle platform. Students completed hands-on laboratory assignments using GIS, ENVI (NV5 Geospatial, Broomfield, CO), and SWAT (SWAT 2024). Racha El Kadiri, a Moroccan Ph.D. student at WMU, served as a teaching assistant. Subsequent field activities were planned for Morocco and Egypt, but political instability precluded travel to planned sites in Egypt (south Sinai and the Eastern Desert). Instead, James Ward arranged a week of activities for the cohort in West Texas as an arid-zone analog to North Africa during June 2012. Participants stayed in a residence hall at Angelo State University (ASU) and attended lectures on geology and hydrology of the San Angelo region (Figure 2), including water use and pollution issues. Field activities included examining outcrops; gauging stream flow by wading with top-setting rods and a current meter; measuring hydrochemical parameters (dissolved oxygen, pH, electrical conductivity, and alkalinity by titration) in streams and groundwater; measuring water levels in wells and infiltration rates (using a double-ring infiltrometer) in soil; and electrical resistivity and electromagnetic surveys. Participants interacted with ASU faculty and students and with staff of government agencies, including the Railroad Commission of Texas (which regulates petroleum production), the U.S. Geological Survey, and the Upper Colorado River Authority.

Milewski and El Kadiri led an 11-day workshop for the cohort at UGA in June–July 2012. Students attended lectures with presentations of case studies. The main topics were introduction to ArcGIS (ESRI, Redlands, CA); analysis and spatial interpolation of field data; data acquisition, resources, and processing; and development of a hydrologic model using SWAT. Data collected during the field activities in Texas were mapped and spatially interpolated using ArcGIS. For the primary exercise, six groups (each containing one Moroccan and one Egyptian student) used satellite-based and field observations to construct preliminary hydrologic models of different Moroccan watersheds.

From September 2012 to January 2013, Fryar led an online course on soft skills for the cohort. Activities included discussions on careers in Earth sciences (followed by a reflective essay); submitting updated resumes; developing profiles on LinkedIn; and completing an online module on responsible conduct of research. During two videoconferences, the participants gave PowerPoint presentations that summarized and evaluated webinars on hydrologic topics. Fryar provided feedback on essays, resumes, and presentations. The core activity for the professional practice course was participation in the Geological Society of America Annual Meeting in Charlotte, North Carolina, November 4–7, 2012. Fryar, Milewski, and Sultan proposed a topical poster session entitled "Building Capacity for Hydrologic Science in Water-Stressed Regions

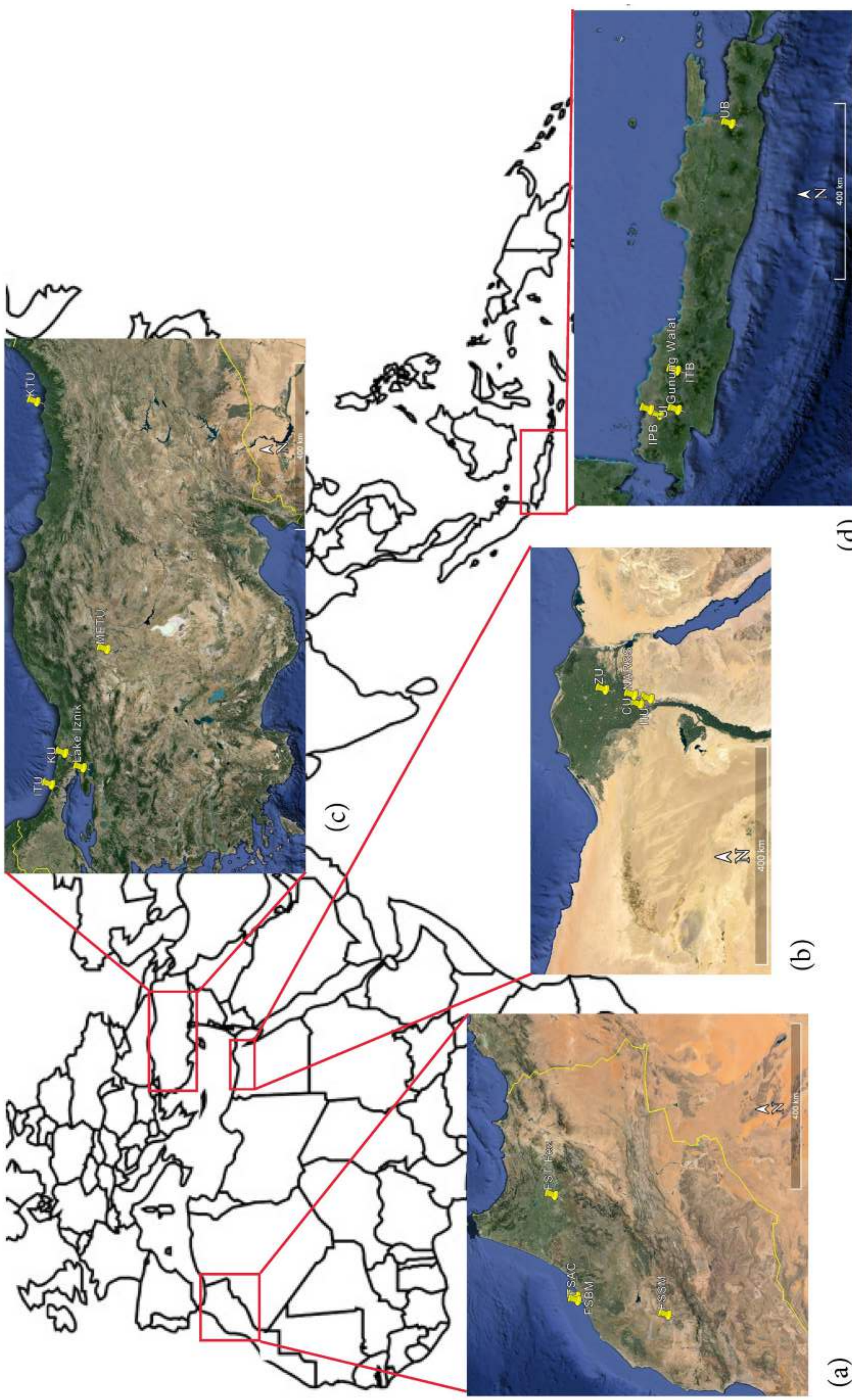


**Figure 1.** Map of participants' institutions in (a) Morocco, (b) Egypt, (c) Türkiye, and (d) Indonesia. Field sites in Türkiye and Indonesia are shown. See text for full names of institutions. Inset maps from Google Earth; base map modified from Jones (2019).

a.

b.

**Figure 2.** Field activities by Moroccan and Egyptian students around San Angelo, Texas: (a) gauging stream flow along Concho River; (b) measuring water level in monitoring well.

of the World," which included 25 presentations. Ten of the cohort participants and two of the Moroccan collaborators presented their individual research in the session; two other posters summarized the training activities (Fryar et al. 2012; Milewski et al. 2012).

Each participant was expected to spend at least 40 hours in educational outreach activities. Suggested venues included universities (through classroom teaching, in-person or online peer tutoring, and presentations) and K-12 schools and community organizations (sharing information about water use, water conservation, pollution prevention, and science as a career). The Egyptian participants generally considered their work as course and lab instructors to fulfill the outreach mandate, including teaching classes in field geology, engineering geology, hydrogeology, and use of GIS software. Two of the Egyptian participants showed videos about field activities in Texas to their classes. The Moroccan students were not employed as instructors and their outreach activities were more individual. Three participants mentored classmates at their universities in GIS, remote sensing, and hydrologic modeling; another taught a short course on those topics to a group of master's students. One participant gave a presentation and worked with a youth council in their hometown. In the most elaborate case, Mahmoud Zemzami mentored three groups of biology students (11 people total) in research projects on water quality and pollution, and lectured on geostatistics, hydrology, and technical communication. During fall 2013, as a visiting student at the University of Rouen (France), he gave lectures to five Ph.D. students (two each from Algeria and Tunisia and one from Morocco) and mentored a French Ph.D. student.

Fryar, Milewski, El Kadiri, Moroccan collaborators, and the cohort held a final meeting in Marrakech May 20–24, 2013. The group discussed the status of participants' research projects and possible ways to continue BOOST activities. The group met with staff of two regional water-management agencies (Tensift Hydraulic Basin Agency and Haouz Regional Office of Agricultural Promotion). Topics discussed included the responsibilities of each agency, opportunities for collaboration with faculty and students, and professional skills desirable for employment.

Fryar and Carol Hanley (UK) designed a series of assessments to obtain feedback from participants at five time points: at the start of the program (March 2012), after the spring online course and summer activities (July 2012), after the fall online course and GSA meeting (January 2013), at the end of the program (December 2013), and five years afterward (February 2019). The pre-program assessment consisted of three open-ended questions. In the subsequent three assessments, participants were asked to rate features of the program using two to four Likert-type questions with four choices (from poor (1) to excellent (4)) that allowed for open-ended responses, as well as strictly open-ended questions. In the 5-year post-program assessment, participants were asked to evaluate the program using three Likert-type questions with four choices (from not at all (1) to very much (4)), plus a yes/no question, all of which allowed for open-ended responses. The assessment protocol was approved by UK's Non-Medical Institutional Review Board for human-subjects research. Participants were asked to return their responses to a UK staff member, who compiled responses anonymously. Data from the Likert-type responses were collated and percentages for each response option were calculated (Table 1). NVivo software version 1.0 (Lumivero, Denver, CO) was used to look for patterns, themes, contrasts, and clusters in the qualitative data. Responses were analyzed and categorized using descriptive codes.

Eleven of the 12 participants submitted the pre-program assessment. Question 1 asked students to describe how prepared they thought they were for graduate studies in hydrologic sciences, and to justify their responses by explaining their related prior experiences. Respondents described work they had performed during their undergraduate, master's, and (where appropriate) doctoral degree programs. Some described mini-projects and internships. Others described related coursework that was essential to the understanding of geosciences, such as chemistry and field methods. A few students named specific topics they had previously studied. Question 2 addressed participants' expectations. Most responses fell under the category of technical skills, which included learning GIS, remote sensing, hydrologic

**Table 1.** Summary of Moroccan and Egyptian participant responses to Likert-type questions on surveys.

| Assessment | Average (out of 4) | 4: Excellent/ very much | 3: Good/ moderately | 2: Fair/ a little | 1. Poor/ not at all | No response |
|---|---|---|---|---|---|---|
| *Mid-program 1* | | | | | | |
| Spring online course worthwhile | 3.27 | 4 | 6 | 1 | 0 | 0 |
| Workshop worthwhile | 3.64 | 7 | 4 | 0 | 0 | 0 |
| Field exercises worthwhile | 3.91 | 10 | 1 | 0 | 0 | 0 |
| *Mid-program 2* | | | | | | |
| Fall online course worthwhile | 3.80 | 8 | 2 | 0 | 0 | 0 |
| GSA meeting worthwhile | 4.00 | 9 | 0 | 0 | 0 | 1 |
| *End of program* | | | | | | |
| Enhanced skills in hydrologic sciences | 3.56 | 5 | 4 | 0 | 0 | 0 |
| Enhanced ability to explain scientific research | 3.33 | 4 | 4 | 1 | 0 | 0 |
| More likely to find suitable employment | 2.88 | 2 | 4 | 1 | 1 | 1 |
| Program met expectations | 3.78 | 7 | 2 | 0 | 0 | 0 |
| *5-year post-program* | | | | | | |
| Enhanced skills in hydrologic sciences | 4.00 | 6 | 0 | 0 | 0 | 0 |
| Enhanced ability to explain scientific research | 3.83 | 5 | 1 | 0 | 0 | 0 |
| Benefitted professionally | 4.00 | 6 | 0 | 0 | 0 | 0 |

modeling, and conducting fieldwork. However, many expectations also included soft skills, such as developing the capacity to work with diverse teams, improving English skills, understanding the environmental implications of water resources, and decision-making skills. In question 3, students were asked about their concerns about engaging in the program. The concerns raised included being in a new environment, learning in an intercultural environment, and applying new learning after returning home. The most common response was one of hope or anticipation.

Eleven participants responded to the first mid-program assessment, which contained three Likert-type questions and four strictly open-ended response questions. Questions 1–3 asked if the spring online course (on GIS, remote sensing, and modeling), the follow-up workshop, and the field activities were worthwhile. Thirty-six percent of participants thought the course was excellent, 55% said it was good, and 9% said it was fair. Sixty-four percent rated the workshop excellent and 36% said it was good. Ninety-one percent thought the fieldwork was excellent and 9% thought it was good. Questions 4–6 asked which part of each module (the online course, workshop, and field exercises) was most worthwhile. In each case, students mentioned multiple features. The most common responses for the online course included modeling and GIS; for the workshop, SWAT modeling was most popular. Students felt stream gauging was the most worthwhile aspect of the field exercises. Finally, students were asked to recommend changes and provide comments. The most common responses were allotting more time to complete activities and having more of the same types of activities.

Ten participants responded to the second mid-program assessment, which contained two Likert-type questions and four strictly open-ended response questions. Question 1 asked if the online professional practice course was worthwhile. Eighty percent rated it as excellent and 20% rated it as good, but comments indicated that some respondents were confused by the question (four mentioned fieldwork or other previous activities). Likewise, when asked about the most worthwhile feature of the professional practice course, 50% of respondents mistakenly listed fieldwork or other previous activities. Two respondents listed publications and authorship, while another said the webinars were most worthwhile. Ninety percent of respondents rated the GSA meeting as excellent; the rating from one student could not be determined. Four students mentioned the value of preparing and presenting a scientific poster, and four cited the benefit of networking with hydrologists and geologists from different universities and countries. When asked about the most worthwhile aspect of the conference, students most commonly listed poster and oral presentations. Regarding changes to the online professional practice course or GSA meeting, only two of the five responses were relevant. One student requested "training on research methodology and art of writing a research paper for a good journal." Another student, referring to a geology-in-industry mentor luncheon at the GSA meeting, would have liked more information about opportunities for non-U.S. citizens.

At the end of the program, nine students rated components of the program and assessed their professional growth. Fifty-six percent said that the program was excellent in increasing their hydrologic science knowledge and 44% said it was good. Likewise, 56% rated the program excellent in increasing their ability to explain scientific research to technical and non-technical audiences, while 33% rated it good and 11% said it was fair. Students highlighted improvement in English skills and in communicating with people from different cultures. Twenty-two percent of respondents thought the program gave them an excellent chance of finding employment, 44% a good chance, 11% a fair chance, and 11% a poor chance; one student did not give a numerical response. Two respondents said it was difficult to find employment in Morocco, whereas three were already working at a university and finding employment was not an issue for them. Of the students who answered the question regarding "Will you continue to mentor?" seven stated they would. Seventy-eight percent said that the program was excellent in meeting their expectations; 22% said it was good.

Six participants (three each from Egypt and Morocco), representing 50% of the cohort, responded to the 5-year post-program survey. All respondents said the program enhanced their skills in hydrologic science very much. One participant stated that the program "helped me find a new Ph.D. project and be successful in my Ph.D. journey all the way until the defense." Eighty-three percent of respondents said the program enhanced their ability to communicate scientific research very much; 17% said the program moderately enhanced their ability. All respondents said that they very much benefitted professionally from participating in the BOOST program and they had continued to mentor other students afterward.

### Cohort 2: Türkiye and Indonesia

For the second program (BOOST H2O [Helping Hydrologic Outreach]), UK and UGA faculty partnered with collaborators at four Turkish institutions (Istanbul Technical University [ITU], Karadeniz Technical University [KTU], Kocaeli University [KU], and Middle East Technical University [METU]) and two Indonesian institutions (Bogor Agricultural University, now IPB University [IPB], and University of Brawijaya [UB]) (Figure 1). Participants were selected in February 2013 following the same criteria as for the first project, except that the age range was changed to 21–35, recent graduates were eligible, and at least one alternate was chosen from each country (Table 1). Core participants from Türkiye included two students each from ITU and METU and one each from KTU and KU. Five core participants were female and five were doctoral students. A male master's student from KTU was the alternate. All were enrolled in geological engineering degree programs. Indonesian core participants included three from UB and one each from IPB, Institute of Technology Bandung (ITB), and University of Indonesia (UI); three were male and three were female. All core participants were enrolled in master's programs except the one from ITB (a recent master's graduate). Three studied water resources engineering, two studied natural resources management, and one studied civil and environmental engineering. Four men and three women were selected as alternates (five from UB; one each from IPB and UI). Two alternates from UB later withdrew.

In March–April 2013, Milewski taught the introductory online course on remote sensing, GIS, and hydrologic modeling in the same fashion as for the first cohort. In contrast to the previous year, the workshop at UGA directly followed the spring online course. From May 4 to 14, Milewski, Paul Schroeder, and students at UGA hosted core participants from Indonesia and Türkiye. Activities were similar to those of the 2012 workshop, except participants constructed preliminary hydrologic models of Turkish watersheds. Attendees also provided outlines of their individual research projects, measured water-quality and physical hydrologic parameters for a local stream, and traveled to Atlanta and to Tallulah Gorge to learn more about the geology and water resources of the region.

From May 28 to June 3, 2013, Fryar, Milewski, Schroeder, and Carmen Agouridis (UK) led field activities in the Iznik Lake basin near Gemlik, Türkiye, for the Turkish participants, including the alternate (Figure 3). The group measured water levels in wells and collected groundwater samples by bailing; measured hydrochemical parameters (pH, electrical conductivity, and alkalinity) for springs, streams, wells, and the lake; gauged stream flow; conducted geomorphic assessment (cross-sectional and bank erosion surveys and bed material characterization) of pristine and impacted streams; analyzed data; and discussed geologic and land-use contexts for observations. From June 10 to 16, 2013, Fryar, Milewski, and Agouridis led field activities around Bogor, West Java, Indonesia, with collaborators from IPB and UB (Figure 4). Attendees included six core participants and three alternates from Indonesia. Field activities were similar to those in Türkiye, but also included caving in the IPB forest (Gunung Walat), soil sampling (by hand auger) and description, a pumping test to measure aquifer properties, and an electrical resistivity survey.

During October–December 2013, Fryar led the online soft skills course, which followed the same format as that of the initial BOOST program. The core activity for the course was participation in the 2013 American Geophysical Union (AGU) Fall Meeting in San Francisco, California, December 9–13. Fryar and Milewski submitted a proposal for a technical session entitled "Building Capacity for Hydrologic Science in Africa and Asia," which was co-sponsored by the AGU Education Special Interest Group and the AGU Hydrology Section. The submissions were organized into a poster session with 13 presentations (12 from BOOST H2O participants) and an oral session with eight presentations, including two summaries of field activities by participants. Core participants attended the meeting along with two alternates (one each from Türkiye and Indonesia), who were selected following participation in the summer activities.

Outreach expectations were the same as for the initial BOOST cohort. Three participants from Indonesia and three from Türkiye mentored undergraduate and/or graduate students. Five Indonesian participants from UB and a Turkish participant (Yağmur Derin) gave presentations on water and environmental issues to groups of elementary-school students. Another Indonesian participant presented modules on theory and practice in climatology, meteorology, and hydrology to high-school students at the IPB laboratory school. Indonesian participant Faizal Rohmat spoke to high-school students about career development in fields related to Earth sciences and foreign-exchange opportunities.

The design of the assessments for BOOST H2O followed that of the initial BOOST program. Participants were surveyed at the start (March 2013), after the spring online course and summer activities (July 2013), after the fall online course and AGU meeting (April 2014), at the end (June a.

b.

**Figure 3.** Field activities by Turkish students in Lake Iznik basin, Türkiye: (a) measuring hydrochemical parameters at çeşme (hillslope spring); (b) geomorphic assessment of stream channel.

**a.**

**b.**

**Figure 4.** Field activities by Indonesian students on IPB University campus, Bogor, West Java, Indonesia: (a) description of soil samples; (b) monitoring well discharge during pumping test.

2014), and five years afterward (February 2019). For each assessment, the BOOST H2O questions were essentially identical to the BOOST questions. The qualifier "if you participated" was added to questions about the workshop at UGA, field activities, and AGU meeting, because not all students participated in all activities. A question was added to the July 2013 assessment regarding how the participant anticipated completing the outreach requirement and what kind of resources would be needed. The February 2019 assessment was sent to core participants and the one alternate from each country who attended the AGU meeting. Quantitative responses to Likert-type questions are summarized in Table 2.

Thirteen participants (out of 20 total, including the eight alternates) submitted the pre-program assessment. Most stated that they were sufficiently prepared to be comfortable with the cognitive demands of the program. Some students had related experience on projects, but many commented on the fact that they lacked preparation in some aspect of hydrologic science. These gaps included no research experience, no field experience, no experience with different techniques such as remote sensing, and only a fundamental understanding of laboratory analysis. The second question was about participants' expectations. In terms of content knowledge and skills, participants most often wanted to improve their abilities in GIS, remote sensing, and modeling. Several wanted to understand how the topics were integrated. Soft-skills expectations included being able to work with diverse types of people and professional development. Finally, 54% of respondents said they had no concerns regarding the program. One respondent predicted that the culturally diverse nature of the group would be a positive challenge.

Fifteen participants returned surveys for the first mid-program assessment. Sixty percent of respondents said the spring online course (on GIS, remote sensing, and modeling) was excellent, 33.3% said it was good, and 6.6% said it was fair. Similarly, 60% of respondents said the follow-up workshop at UGA was excellent and 20% said it was good; three did not answer the question. The field activities were rated excellent by 73.3% of respondents, good by 13.3%, and fair by 6.6%; one student did not respond. Respondents indicated that the most worthwhile aspects of the online course were GIS and/or remote sensing. Modeling was the most worthwhile aspect of the workshop; for the field activities, water-quality sampling and analyses were deemed most worthwhile. One participant commented that he/she learned "a lot of new knowledge about field data collection that previously I only knew…from books." The question about how participants would fulfill the outreach requirement of the program was broadly misunderstood. Four participants gave detailed, appropriate answers about outreach to K-12 schools. Regarding improvements or recommendations for the program, the most common response was a lack of time or the need for a more efficient use of time. Two respondents expressed concerns regarding the selection process and that some participants were not fully engaged.

Twelve participants responded to the second mid-program assessment. Forty-two percent rated the online professional-practice course as excellent, 50% rated it good, and 8% rated it fair. All respondents who attended the AGU meeting (n = 11) rated it excellent. When asked to name the most worthwhile feature of the professional-practice course, four students mistakenly conflated it with the spring online course. Relevant responses included the responsible conduct of research module, viewing or evaluating webinars, and publication ethics or plagiarism. For the most worthwhile feature of the AGU meeting, half the respondents listed poster presentations. The most commonly suggested change was that posters should have been in a hydrology session rather than an education session in order to attract more attention. Other suggestions included more careful participant selection, more student participation, making the online course more interactive, and incorporating problem-based learning in the course.

Nine students completed the final program assessment. Most (56%) said the program was excellent in enhancing their hydrologic science skills; 33% rated the program good and 11% fair in that regard. Forty-four percent of respondents rated enhancement of their ability to explain scientific research as excellent; another 44% rated the program good and 11% rated it poor. Fifty-six percent stated they had an excellent chance

**Table 2.** Summary of Turkish and Indonesian participant responses to Likert-type questions on surveys.

| Assessment | Average (out of 4) | 4: Excellent/ very much | 3: Good/ moderately | 2: Fair/ a little | 1. Poor/ not at all | No response |
|---|---|---|---|---|---|---|
| *Mid-program 1* | | | | | | |
| Spring online course worthwhile | 3.53 | 9 | 5 | 1 | 0 | 0 |
| Workshop worthwhile | 3.75 | 9 | 3 | 0 | 0 | 3 |
| Field exercises worthwhile | 3.71 | 11 | 2 | 1 | 0 | 1 |
| *Mid-program 2* | | | | | | |
| Fall online course worthwhile | 3.33 | 5 | 6 | 1 | 0 | 0 |
| AGU meeting worthwhile | 4.00 | 12 | 0 | 0 | 0 | 0 |
| *End of program* | | | | | | |
| Enhanced skills in hydrologic sciences | 3.44 | 5 | 3 | 1 | 0 | 0 |
| Enhanced ability to explain scientific research | 3.22 | 4 | 4 | 0 | 1 | 0 |
| More likely to find suitable employment | 3.44 | 5 | 3 | 1 | 0 | 0 |
| Program met expectations | 3.44 | 5 | 3 | 1 | 0 | 0 |
| *5-year post-program* | | | | | | |
| Enhanced skills in hydrologic sciences | 3.75 | 7 | 0 | 1 | 0 | 0 |
| Enhanced ability to explain scientific research | 3.75 | 7 | 0 | 1 | 0 | 0 |
| Benefitted professionally | 3.50 | 6 | 0 | 2 | 0 | 0 |

of finding suitable employment as a result of participation in the program, while 33% stated they had a good chance and 11% a fair chance of finding suitable employment. Reasons given for the increased likelihood of finding employment included the international nature of the program and the usefulness of the skills emphasized in the program. All respondents said they would continue to mentor. Regarding the most worthwhile feature of the program, the AGU meeting and field training were tied. Most of the recommendations on how to improve the program reiterated comments in the mid-program assessments. Most respondents said the program met their expectations to a high degree: 56% rated it excellent, 33% rated it good, and 11% rated it fair. One student reported changing his/her thesis topic as a result of the program.

Eight participants (four each from Indonesia and Türkiye) out of 14 contacted completed the 5-year post-assessment. Eighty-eight percent said the BOOST H2O program enhanced their skills in hydrologic science very much and 12% responded that their skills were enhanced a little. Likewise, 88% of participants said the program enhanced their ability to communicate scientific research very much and 12% said the program enhanced their ability a little. Seventy-five percent of respondents said they benefitted very much professionally and 25% said they benefitted a little from participating in the program. One participant said the program made him/her realize the importance of improving English skills. A second said, "Thanks to the BOOST H2O program I started creating my network internationally." Sixty-two percent of respondents said they had mentored others and 38% said they had not.

## Discussion

### Cohort Comparisons

The overarching goal of the BOOST and BOOST H2O programs was to help selected graduate students in Morocco, Egypt, Türkiye, and Indonesia enhance their technical skills in hydrology and their ability to communicate scientific research. Responses from Likert-type questions and qualitative data provided by participants indicate that this goal was met. At the start of each program, participants expressed similar expectations and concerns (e.g., learning in an intercultural environment). During each program, almost all respondents rated the online course on GIS, remote sensing, and modeling as excellent or good. A majority of respondents rated the workshop at UGA (60–64%) and field activities (73–91%) as excellent. Almost all respondents rated the online course on professional practice as excellent or good, but some students confused activities from it with activities from other parts of the program, so ratings for that course may not be valid or reliable. All respondents who provided numerical scores rated the GSA and AGU meetings as excellent. At the end of each program, almost all respondents rated the program as excellent or good in increasing their hydrologic science knowledge and their ability to explain scientific research. A majority (56–83%) said the program was excellent in meeting their expectations. However, only 22% of the BOOST respondents thought the program gave them an excellent chance of finding employment, while 56% of the BOOST H2O respondents did. This divergence in the perceptions of the two cohorts regarding the program's effectiveness in aiding their search for employment may be a consequence of differing job availability between countries. Five years later, nearly all respondents said that participation in the program had very much enhanced their skills in hydrologic science (88–100%) and research communication (83–88%). One student in each cohort reported changing his/her thesis topic as a result of the program. Most or all of the respondents (75–100%) said they had benefitted very much professionally from the program, and a majority had continued to mentor others. A word cloud (Figure 5) shows recurring terms in student responses for both programs.

We recognize challenges and opportunities for improvement in the design and execution of both programs. Respondents from both cohorts recommended more time to complete activities. Field activities varied somewhat between cohorts (in particular, geomorphic surveys were added for BOOST H2O), based on availability of personnel and/or equipment. BOOST participants met with staff of government agencies (in Texas and Morocco), whereas BOOST H2O participants did not, except for two students from METU who attended a meeting along with U.S. project personnel in Ankara, Türkiye. We did not anticipate that placement of the AGU poster presentations within an education session would limit the exposure of the students' research. Because of the shorter grant duration and lesser funding for the BOOST H2O program, we did not hold a final in-person meeting for the second cohort, in contrast to the first cohort. Because English was not the participants' first language, and the program evaluators did not speak Arabic, Indonesian, or Turkish, some of the assessment questions proved to be ambiguous and the responses were difficult to interpret.

Although all participants came from OIC countries in the ANE region, there was greater cultural affinity between students in the first cohort (Moroccan and Egyptian, who were Arab and North African) than in the second cohort (Turkish and Indonesian). All Moroccan participants and three of the six Egyptian participants were geology students. There was less disciplinary overlap between the Turkish participants (geological engineering students) and Indonesian participants (water resources engineering, civil engineering, and resource management students). The sequence of summer activities may have promoted closer connections among the first cohort (with field work in Texas followed immediately by the workshop at UGA) than among the second cohort (with


**Figure 5.** Word cloud showing recurring terms in participant responses.

a 2- to 4-week gap between the workshop and field activities, which were conducted separately in Türkiye and Indonesia). In the first cohort, all participants attended activities in the USA, whereas only the core participants and two alternates in the second cohort did so. Each of these differences could have contributed to the disengagement observed among some students in the second cohort, which was not noted for the first cohort.

Given the limited duration (15 to 21 months) and number of participants in each program, effecting systemic changes in hydrologic education in the targeted countries was beyond the scope of BOOST and BOOST H2O. Rather, the programs provided a holistic, interdisciplinary approach to hydrologic education that the participants could transmit within their institutions and beyond, through mentoring and other outreach activities. Broader implementation of this approach is constrained by limited resources in institutions in the Global South, but online access to free, high-quality instructional materials can mitigate this constraint (Hughes 2012; Ke et al. 2023).

**Follow-on Activities and Engagement**

In 2020, Milewski, Fryar, Hanley, El Kadiri (now at Middle Tennessee State University [MTSU]), and Charlotte Garing (UGA) were awarded a grant through the U.S. National Science Foundation (NSF) International Research Experience for Students program. Our Dryland Recharge Assessment in Morocco (DReAM) program builds on our BOOST and BOOST H2O experiences. Differences include (1) the participation of three annual cohorts of five students each; (2) the selection of U.S. rather than non-U.S. students; (3) the inclusion of undergraduate as well as graduate students; and (4) the participation of students in fields adjacent to hydrologic sciences and engineering (e.g., international agricultural development). Students apply through an NSF-affiliated online portal and participants are selected after review of applications by DReAM faculty. As in the previous programs, a 2-month spring online course focuses on GIS and remote sensing, and a 3-month fall online course focuses on scientific communication, research ethics, and other aspects of professional practice. However, the 1-week workshop following the spring course is also virtual and focused on preparing for field activities in Morocco. Students spend four to five weeks in Morocco during May–June with DReAM faculty, one or two U.S. peer mentors, and Moroccan collaborators. Activities have included deploying thermistor arrays to measure infiltration; measuring water levels in wells; gauging stream and spring flow; sampling groundwater and surface water for chemical analyses; and sampling soil (for textural analyses) and sediment (to estimate maximum stream velocity). Participants have also met staff of water-management agencies; visited dams, reservoirs, and irrigation systems; and visited a museum highlighting the role of water in Moroccan history. The first two DReAM cohorts (2022 and 2023) are developing an ArcGIS StoryMap (ESRI 2024), to which the 2024 cohort will contribute. During the program, participants record their experiences in digital journals and complete assessments in Qualtrics software (Qualtrics, Provo, UT), which enables text entry, the ability to choose multiple answers, Likert matrices, and multiple-choice options. We also assess the development of participants' intercultural awareness during the program by administering the Intercultural Development Inventory (IDI LLC, Olney, MD) to each cohort at the beginning and end of the program.

Beyond assessments, the instances of participant engagement with us following the conclusion of the BOOST and BOOST H2O programs provide evidence of their impacts. After completing his doctorate, Moroccan participant Zemzami was a Fulbright Scholar with El Kadiri at MTSU (2016–2017). Schroeder coauthored two papers with one of the Turkish participants (Ünal Ercan et al. 2016; 2022), and Fryar coauthored a paper on salinization of groundwater in the Nile Delta with two Egyptian participants (Nosair et al. 2021). At the invitation of Indonesian participant Jadfan Sidqi Fidari, Fryar, Milewski, and Agouridis delivered online lectures in the Groundwater Sustainable Development and Water Resources Management training program at UB in 2021. Zemzami accompanied DReAM participants in the field in Morocco during summers 2022–2024. Indonesian participant Rohmat and Turkish participant Derin discussed professional development with DReAM participants as part of the fall online course.

## Conclusions

The BOOST and BOOST H2O programs were designed to establish a robust, adaptable training framework for young hydrologic scientists and engineers in the ANE region. Our vision was to cultivate a diverse set of hard and soft skills in participants, enabling them to become mentors, network effectively regionally and globally, and excel as hydrologic professionals. Despite the challenges inherent in executing 15- to 21-month projects with 12 to 18 participants from varied educational and cultural backgrounds and navigating unforeseen obstacles such as the security situation in Egypt, the programs have been largely successful. Participant feedback has been strongly positive, reinforcing the value of our efforts. The enduring engagement among participants and their continued mentorship of students both in their home countries and the USA highlights the long-term impact of these programs. The subsequent development of the DReAM program further demonstrates the adaptability and relevance of our modular, hybrid curriculum across different student demographics in hydrology and related fields.

Moreover, these programs have set a precedent as a multi-country collaborative model that not only focuses on hydrologic skills but also integrates advanced technologies like GIS and remote sensing. The inclusion of soft skills training, particularly in scientific communication, enhances this model's potential for fostering scientific collaboration and workforce development. This holistic approach has established a scalable blueprint that could be replicated in other regions and disciplines, signifying a significant step forward in the global scientific community's efforts to address complex environmental and hydrologic challenges.

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