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Perspective Piece

Diversity and Discrepancies in Water-related University Rankings: Is There a Need for More Consistency or Is There Value in Breadth?

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Access to clean water is an urgent and socially relevant global issue, as recognized by the U.S. National Academy of Engineers and most other global scientific agencies. Universities directly inform advances in this domain, serve as a training ground for practitioners who address challenges in water supply and quality, and more broadly educate scientifically literate citizens. However, it is challenging for students seeking information on university degree programs such as Hydrology or other water-focused areas to find consistent information about programs, in part because of the disciplinary diversity of this subject. Ranking systems typically focus on more traditional departmental groupings (i.e., geosciences, civil & environmental engineering, public health, etc.). While special rankings do occur for water science and engineering related programs, they are topically incorporated within various categories, including “Hydrology and water resources”, “Water resources engineering”, “Water treatment and sanitation”, “Environmental and health sciences”, and others that span traditional departments and have multiple homes within and across institutions. These may involve categories that are absent at a particular university that has strengths in the co-listed category. For instance, our home institution of Colorado School of Mines (or “Mines”) offers well regarded degrees and/or research programs in Environmental Engineering, Civil Engineering, Geophysics, Geology, and Hydrology, but lacks Public Health or Health Sciences degrees. Ultimately, water-focused domains of study fall outside of traditional degrees, groupings, and associated metrics leading to challenges in assessing strengths across both disciplines and degree programs.

Several ranking systems exist that rate universities based on their strength in a specific discipline, including water resources, but the metrics for each are quite different. Ranking systems are based on multiple factors including prestige of faculty members and publications, research funding, number and impact of publications, search engine traffic, international visibility, graduates in positions of influence, patent generation, perception by peer institutions, and financial sustainability, among others. The *QS World University Rankings* (QS), for example, is a ranking of the world’s top universities (not degree programs) produced by Quacquarelli Symonds, that synthesizes peer rankings from thousands of scholars, academics, and recruiters in conjunction with Scopus citations, faculty/student ratios, and staff and student numbers. The *Times Higher Education World University Rankings* (THEWU), on the other hand, assesses universities using five categories: teaching, research, citations (research influence), salary of graduates, and international reputation based on surveys. Another influential ranking system is the *Academic Ranking of World Universities* (ARWU), also known as "*Shanghai Ranking*", which is based on quality of education, faculty, and research output, among others. Beginning in 1983, *U.S. News & World Report* publishes an annual set of rankings of American colleges and universities that are based upon data from surveys that the organization collects from each institution, as well as opinions from faculty members and staff from other schools. This was expanded in 2014 to include *Best Global Universities*. As a synthesis approach, the *Aggregate Ranking of Top Universities* sums the QS, THEWU, and ARWU world ranks, excluding institutions that do not have a distinct rank in those three systems. Some educational institutions (e.g., *United Nations University* (UNU)) also publish their own ranking. Other international ranking systems include the *Center for World University Rankings*, the *Leiden Ranking*, the *G-factor*, the *Global University Ranking*, the *Nature Index*, the *Professional Ranking of World Universities*, the *Reuters World's Top 100 Innovative Universities*, the *Round University Ranking*, the *SCImago Institutions Rankings*, the *University Ranking by Academic Performance*, the *Webometrics Ranking of World Universities*, and the *Research Center for Chinese Science Evaluation Ranking at Wuhan University*.

With an increased visibility toward global issues on water availability and quality, there is growing interest in undergraduate and graduate degrees in water-related areas. In this sense, though the QS and many other ranking systems do not consider "water" as a searchable topic of interest, both THEWU and ARWU develop a global ranking system for some water topics. In contrast, the prominent *U.S. News and World Report Graduate Program Rankings* no longer includes specialties of hydrology or water resources science and engineering. Table 1 shows some water-related global university rankings for 2020, wherein one can see differences across similar ranking categories. Higher ranking universities such as The University of Arizona and Texas A&M appear under the Shanghai and UNU rankings, but are not even listed within THEWU. In contrast, UNC Chapel Hill appears under the THEWU ranking system, but is not mentioned by the other two. Similar situations are shown for other educational institutions such as Wuhan University and the University of Colorado at Boulder. While different evaluation metrics can explain some of this, it also highlights discrepancies in binning water related programs across "Water resources" versus "Clean water and sanitation", which in this example necessitates very different foundational approaches and expertise.

National ranking systems also exist in the U.S. such as the *Forbes College Rankings* (which is based on student satisfaction, post-graduate success, student debt, graduation rate, and academic success). Other national ranking systems are based on factors such as faculty publications, annual fundraising, graduation rates, student's future earnings, affordability, internet appearance, and even athletics, nightlife, and campus quality. Examples include the *Council for Aid to Education*, the *Daily Beast's College Rankings,* the *Economist'*s *Best Colleges,* the *Objective College Ranking*, the *Money's Best Colleges*, the *Princeton Review Dream Colleges*, the *United States National Research Council,* the *Faculty Scholarly Productivity Index*, the *Top American Research Universities*, the *Washington Monthly College Ranking*, the *TrendTopper MediaBuzz College Guide*, the *American Council of Trustees and Alumni,* and the *Niche College Rankings*, among others. Additionally, websites such as *universities.com* (which considers average tuition cost, student-teacher ratio, and number of enrolled students), or *stateuniversities.com* (which is only based on the number of enrolled students) provide each year a ranking of educational institutions available nationwide to learn about different professional fields. A ranking of the top-10 U.S. universities from these two websites is included in Table 2, considering different water-related topics; discrepancies among sites and categories are clear.

As one can see, another source of confusion is the diverse factors that go into ranking such as cost of tuition, student-teacher ratio, or popularity metrics. However, these factors do not address the quality of the technical, discipline-specific education that is better suited for overall university or college rankings. As an example, the University of Illinois Urbana-Champaign is ranked as one of the world's best universities in water education (see Table 1), but it does not even appear in the U.S. top-10 list from Table 2. Similarly, University of Pennsylvania is listed #1 at universities.com under the "Hydrology and water resources" search, and #7 on stateuniversities.com, but the institution is not included in the international ranking systems (see Table 1). Another good example is Mines, which regularly appears in worldwide and U.S. lists (see Tables 1 and 2). Based on research accomplishments (i.e., grants and peer-reviewed publications), Mines is strong in hydrology and water resources engineering, but while it currently plays a leading role in treatment technologies, it is not included within the top 50 in the THEWU "Clean water and sanitation" international list despite being listed at positions 40 (not shown) and 22 in the Shanghai and UNU lists, respectively (see Table 1).

The above analysis shows a few of the discrepancies across U.S. and international ranking systems which can partially be explained by a blurring across traditional categories and evaluation metrics. While discipline-specific ranking systems have inherent flaws, there is growing interest in hydrology, water resources, water and wastewater treatment, and other water-related programs in association with increasing environmental concerns and a rising need for professionals in this important area. To this end, a rating system and clearer definition of the discipline should be carefully considered and implemented for both undergraduate and graduate programs. Students seeking water-related careers should have more options than to look at rankings based on "civil and environmental engineering", "public health" or "geosciences". Rather, we propose the creation of a more specific, transparent, "Water" ranking system that could better encompass the inherent diversity across this topic. This could be extended to associated sub-disciplines such as "hydrology", "treatment", "watershed management", "water resources", "water policy", and others. Similarly, a new "Water" ranking system should consider student-centric outcomes such as job placement and salary five years after graduating, among the other key factors previously listed such as research productivity and teaching. While analysis across different ranking domains can be used to inform prospective students, it is unnecessarily confusing and confined by traditional groupings and in some cases less relevant evaluation metrics. Rather our call to the academic community is to think about (and work on) key metrics needed to create a consistent and accurate ranking system for universities and programs that focus their efforts on water sciences and engineering. This evaluation needs to embrace the diversity and richness within this theme so as to best inform future students and practitioners.

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Table 1. Top 25 water-related universities globally across three different ranking systems for 2020.

Ranking	Shanghai Ranking ("Water resources")	United Nations University (UNU) ("Water resources")	Times Higher Education World University Rankings (THEWU) ("Clean water and sanitation")
1	Swiss Federal Institute of Technology Zurich (ETH)	University of Arizona	University of North Carolina at Chapel Hill
2	University of Arizona	Swiss Federal Institute of Technology Zurich (ETH)	Tongji University
3	Beijing Normal University	Delft University of Technology	Western Sydney University
4	Texas A&M University	University of California, Berkeley	Indian Institute of Technology Kharagpur
5	The University of New South Wales	The University of New South Wales	York University
6	Hohai University	Texas A&M University	Aix-Marseille University
7	Tsinghua University	Beijing Normal University	Anna University
8	Wuhan University	University of California, Davis	University of Auckland
9	University of Illinois at Urbana-Champaign	University of Bristol	Middle East Technical University
10	University of Bristol	Hohai University	University of Strathclyde
11	Delft University of Technology	University of Illinois at Urbana-Champaign	Tunghai University
12	University of Colorado at Boulder	Flinders University	RMIT University
13	Flinders University	Tsinghua University	Charles Turt University
14	University of California, Davis	University of Colorado at Boulder	King Mongkut's University of Technology
15	University of California, Irvine	University of California, Irvine	Metropolitan Autonomus University
16	University of California, Berkeley	The University of Texas, Austin	University of Wollongong
17	The University of Texas, Austin	University of Wageningen	Penn State University
18	The University of Queensland	University of Saskatchewan	Hindustan Institute of Technology and Science
19	Wageningen University & Research	Swiss Federal Institute of Technology Lausanne	University of Indonesia
20	University of Saskatchewan	The University of Queensland	Hiroshima University
21	Northwest A&F University	Wuhan University	University of Jaén
22	Princeton University	Colorado School of Mines	Kyung Hee University
23	University of Padua	Stanford University	An-Najah National University
24	Utrecht University	Oregon State University	University of Girona
25	Swiss Federal Institute of Technology Lausanne	University of Padua	Queensland University of Technology

Table 2. Best U.S. universities in 2020, from *universities.com* and *stateuniversity.com*, considering the two available water topics ("Hydrology and water resources" and "Water resources engineering").

	universities.com		stateuniversity.com	
Ranking	**"Hydrology and water resources"**	**"Water resources engineering"**	**"Hydrology and water resources science"**	**"Water resources engineering"**
1	University of Pennsylvania	University of Southern California	Texas A&M University, College Station	University of Nevada, Reno
2	University of California, Davis	Villanova University	Colorado School of Mines	University of Minnesota, Twin Cities
3	Rensselaer Polytechnic Institute	University of Minnesota, Twin Cities	University of Arizona	University of New Mexico, Main Campus
4	Boston University	Illinois Institute of Technology	University of Rhode Island	University of Southern California
5	University of Texas, Austin	University of Idaho	University of California, Santa Barbara	Oregon State University
6	Colorado School of Mines	University of Delaware	University of California, Davis	Villanova University
7	University of California, Santa Barbara	University of Nevada, Reno	University of Pennsylvania	University of Buffalo
8	Texas A&M University, College Station	Oregon State University	Vermilion Community College	Michigan Technological University
9	Brigham Young University, Provo	Michigan Technological University	New Mexico Institute of Mining and Technology	Central State University
10	University of New Hampshire, Main Campus	University of New Mexico, Main Campus	Boise State University	Gateway Technical College

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Integrating Cultural Perspectives into International Interdisciplinary Work

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Abstract: There are well-established methods for working in interdisciplinary natural resource management settings, but place-based cultural differences are often poorly integrated into interdisciplinary projects. Intercultural adequacy is necessary to ensure that water management strategies are acceptable within the local contexts of water users. In this study we followed four cohorts of graduate students from Canada, Chile, Cuba, and the United States that participated in an international graduate-level water resource management course hosted at the Universidad de Concepción in Chile. The North American students participated in post-experience surveys and interviews to assess changes in their interdisciplinary and intercultural comfort levels. The interviews and survey identified factors that enhanced or detracted from their progress towards integrating disciplinary and cultural differences into their work. Though course material promoted interdisciplinary collaborations across various disciplinary cultures, participants noted that traditional methods of integrating did not adequately bridge differences in place-based cultural worldviews. We propose a framework developed during the experience to integrate place-based cultural differences into all phases of the interdisciplinary research and natural resource management processes.

Keywords: *intercultural adequacy, water management, collaboration, education, water resources*

Water resource management impacts natural, social, and economic systems. Water managers must consider impacts on all systems (Grigg 2016) through interdisciplinary lenses. Applying an interdisciplinary approach in water resource management allows for the incorporation of different disciplinary viewpoints and understandings to develop concrete management solutions to specific problems. Working in interdisciplinary groups poses many challenges, however. Disciplinary language barriers disrupt communication (Cosens et al. 2011; Repko 2012). Disciplinary methodologies vary (Repko 2012), which can be frustrating and often culminates in a lack of trust between disciplines and research group members (Heemskerk et al. 2003; Eigenbrode et al. 2007; Cosens et al. 2011).

The interdisciplinary literature has established methods to create a synthesis of understanding by weaving together relevant disciplinary knowledge (Newell 2001; Cosens et al. 2011). The process aides in understanding complex problems in natural sciences, social sciences, and the humanities (Newell 2001). We propose fostering intercultural adequacy by adding culturally focused discussions into interdisciplinary methodology. We define intercultural adequacy as the process of integrating place-based cultural views, discussions, and understanding into the interdisciplinary process

Research Implications

- This research highlights the importance of integrating cultural perspective into water management;
- Provides a method to include cultural discussion in the interdisciplinary water management process; and
- Identifies pathways to improve interdisciplinary and intercultural collaboration in water management.

so that individuals can work across cultural differences. Intercultural adequacy incorporates cultural contexts into natural resource research and management. The term intercultural adequacy mirrors interdisciplinary adequacy, where Cosens et al. (2011) recognize that it is highly unlikely for individuals to become experts in more than one discipline—or in the present context, for cultural learning to translate into competency (Zotzmann 2016).

We follow the method of interdisciplinary investigations and integration presented by Cosens et al. (2011), which begins by building disciplinary adequacy from each represented field to overcome disciplinary barriers (Cosens et al. 2011; Repko 2012). Disciplinary adequacy requires building a basic understanding of the methodologies, assumptions, and terminology from the various disciplines represented on the interdisciplinary team. With an understanding of the differing disciplines, the interdisciplinary team can foster disciplinary trust through interactive exercises such as the *Toolbox for Philosophical Dialogue* (Toolbox; Eigenbrode et al. 2007). The Toolbox is a series of prompts that facilitates dialogue to identify and address philosophical differences and similarities among disciplines from biological to physical to social sciences. Conceptual models or diagrams then can be constructed to aid interdisciplinary teams to create a simplified representation of the system of study (Heemskerk et al. 2003). The conceptual model can serve as a platform to develop complex integrating questions that cannot be answered using a single discipline approach (Thompson Klein 1991; Newell 2001; Cosens et al. 2011). Developing an integrating question and designing a conceptual model allowed team members to narrow the scope of their project, create a communication platform for ideas (Heemskerk et al. 2003), and continually check the focus of their working hypotheses. Figure 1 presents a flow chart of this interdisciplinary process.

Working in an interdisciplinary space also requires intercultural awareness (Muratovski 2017; Thompson Klein et al. 2018) and intercultural competency (Sarmento 2016). In 2018, the Association for Integrative Studies expanded its mission statement to explicitly include cultural diversity as an integral component of interdisciplinarity (Thompson Klein et al. 2018). Currently, there is multiplicity in definitions of intercultural study in the interdisciplinary literature. In some cases, the interdisciplinary literature focuses on differences between disciplinary cultures (Reich and Reich 2006; Thompson Klein et al. 2018)—even with relatively narrow differences such as between the humanities and the arts (Lotrecchiano and Hess 2019). Other articles stress the need for understanding place-based cultures and practices (e.g., Egidiussen Egekvist et al. 2016) and integrating cultural based ways of knowing into research designs (Morgan 2006; Sterling et al. 2017). The movement of adding intercultural discussions into the interdisciplinary process is still relatively new. Literature about interdisciplinary studies and intercultural studies still remains largely separated.

Disciplinary and place-based culture are defined differently. Disciplinary culture is the difference between the norms and practices of one discipline versus another within the academic community (Reich and Reich 2006). Place-based culture is defined as beliefs, customs, lifestyles, and arts of a particular society or group. Place-based culture is often tied in place and time to landscapes themselves, and must be interpreted in relation to context, history, and power (Swensen et al. 2013). Natural, family, and social experiences may additionally be incorporated into an individual's cultural worldviews.

Understanding and acceptance of cultural differences is a process. Responses to exposure to other cultures can be described on a continuum, where individuals may begin with denial, defense, and minimization of other cultures—especially if the cultural differences are overwhelming (Hammer 2012)—before accepting or adapting to the foreign culture (Figure 2). Individual or group development across the continuum to an intercultural mindset, or open acceptance of cultural differences, is aided by supportive interactions with people from different cultures (Hammer 2012). Hammer and Bennett (1998) propose an Intercultural Development Index (IDI) that is often used to assess the progress towards the intercultural sensitivity of students in international immersion experiences. In the interdisciplinary,

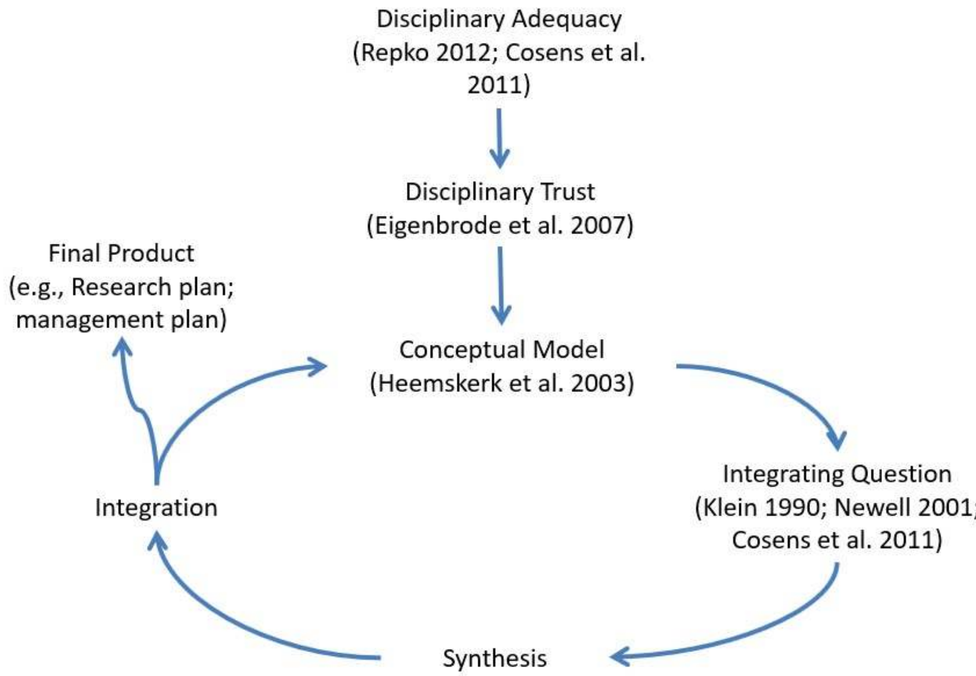

Figure 1. Overview of the interdisciplinary process presented in Cosens et al. (2011).

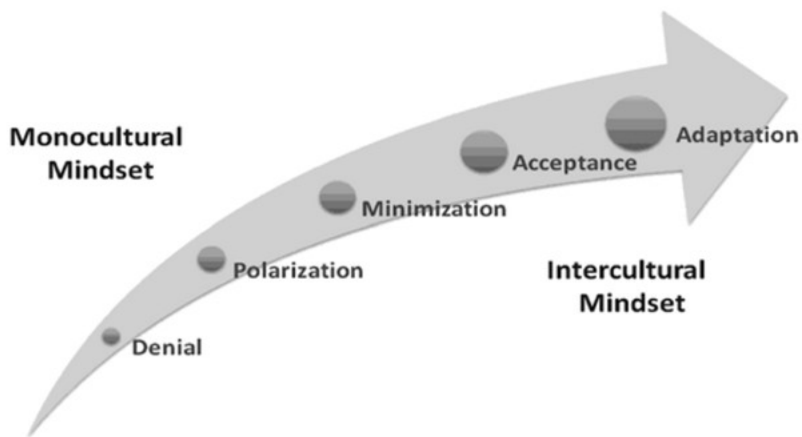

Figure 2. Intercultural Development Continuum: Growth from a monocultural to an intercultural mindset follows a continuum through Bennett's (2001) steps of denial, polarization, minimization, acceptance, and adaption. Integration is the ideal that lies beyond adaptation. Source: Hammer 2012.

intercultural context, individuals need to move across the cultural continuum for each of the cultural differences faced, such as disciplinary and place-based cultural differences.

Specific methodologies can further close the gap between disciplinary cultures by facilitating the establishment of trust within interdisciplinary teams. Existing tools do not address differences in place-based cultures, however. Allen et al. (2014) note that interdisciplinary initiatives commonly fail because of a lack of a methodology that fosters internal group dynamics and allows for group engagement and social learning. Graduate fellows in an interdisciplinary program between the United States and Costa Rica (NSF Award Number 0903479, 2012-2019) found that the lack of method(s) to integrate both disciplinary culture and place-based culture into the research process hindered team progress (Morse et al. 2007; J.D. Wulfhorst, personal communications, 5-Jan-2017).

One proposed path to bridge cultural differences and foster cultural understanding is to encourage diverse forms of intercultural dialogue and engagement (Crossley 2008; Jackson 2009). Outcomes should lead to useful integration of cultural differences and commonalities to allow for the development of shared visions, goals, or directions (Crossley 2008; Smit and Tremethick 2013; Wiek et al. 2013), now known as intercultural competence (Sample 2013). Given the term's complexity, however, there is a lack of consensus in how to operationalize intercultural competency (Wahyudi 2016). Furthermore, Zotzmann (2016) questions whether it is, "theoretically sensible and ethically desirable to conceptualize the outcomes of intercultural learning as 'competence'" (p. 252). In this manuscript, we therefore prefer the term intercultural adequacy, which parallels interdisciplinary adequacy in interdisciplinary literature (e.g., Cosens et al. 2011).

As part of an Integrative Graduate Education and Research Traineeship (IGERT) fellowship program at the University of Idaho (NSF Award Number 1249400), graduate students participated in an interdisciplinary/intercultural experience in Concepción, Chile. The course was listed as WR 604: Int'l Water Issues; we refer to it hereafter as the Water Issues course. Graduate students came from engineering, natural sciences, social sciences, and law backgrounds from Canada, Chile, Cuba, and the United States. Students were assigned into groups of intentionally diverse disciplinary and cultural compositions. Teams were tasked with developing a water resource management plan for the Río Laja and Río Biobío systems. After the course, North American students were interviewed and completed a survey to assess whether the course changed the participants' perceived comfort working in interdisciplinary and intercultural settings. Analysis of the interviews and surveys identified factors that helped or hindered working across cultural and disciplinary bounds.

Whether talking about disciplinary or placed-based culture, there is no clear path in the literature to include cultural discussions in the interdisciplinary process. The objective of this paper is twofold. First we present factors that helped or hindered working in an interdisciplinary/intercultural setting; then we propose an addition to the interdisciplinary process that facilitates intercultural adequacy and cultural integration within natural and water resource management and research.

Methods

Course Context and Research Setting

The Water Issues course curriculum was taught in collaboration with Universidad de Concepción and Universidad Católica de la Santísima Concepción. The approximately three-week course was designed to integrate graduate students from various disciplinary and cultural backgrounds—law, social science, natural science, and engineering—to take part in this unique interdisciplinary experience aimed at understanding different perspectives on watersheds and watershed management. The course was offered during winter break in four consecutive academic years from 2014 to 2018. The course was divided into three dimensions: field trips, lectures, and teamwork—the proportion of time spent in each facet of the course varied year to year.

Students participated in a tour (field trip) of the Río Biobío and Río Laja Basins from the mouth of the river into the Pacific Ocean to the headwaters of both river systems. The field trip, which lasted three days on average, provided background information on the physical, geographical, and cultural settings. Time was spent with Indigenous members in Pehuenche communities, and on their lands. The field experience familiarized participants with the complexities of the Río Biobío and Río Laja Basins systems and provided social time to foster teamwork.

A week of lectures provided historical, ecological, and hydrological context, an overview of Chilean water policy and management, and regional political issues of the Río Biobío and Río Laja. Professors from the corresponding universities lectured to provide "disciplinary adequacy"—a basic understanding of the methodologies, assumptions, and terminology from each discipline (Cosens et al. 2011)—within the context of the Río Laja and Río Biobío systems. Question and answer sessions following the disciplinary lectures further facilitated cross-disciplinary communication. The lectures and question sessions were intentionally structured to allow students to understand better the importance of the current state of the watersheds, as well as the active research within each basin. The course delved into the complexities of the interdisciplinary process by presenting complex experiential case studies that link multiple disciplines.

Students were divided into working groups by the faculty, who intentionally populated each research team with diverse disciplinary and cultural representation. All groups had at least one student who could speak both English and Spanish and served as a group translator. Groups were tasked with developing water resource management plans to increase the ecological and water yield sustainability of the systems. In the context of this course, sustainability was never defined. Each team had to work out what they meant by sustainability across their disciplinary understanding. Plans were required to integrate engineering, ecological, legal, and operational recommendations. The professors leading the course allowed the students to find their own paths to accomplish the course project. However, professors encouraged students to work through the interdisciplinary process outlined in Cosens et al. (2011) (Figure 1) before attempting the interdisciplinary integration activities. Each group had to develop a presentation and a final report that was co-authored and co-presented by all students in the team. This paper focuses on the intercultural dynamics of the collaboration processes rather than the products from the course.

To facilitate disciplinary trust, student groups participated in a modified version of the Toolbox exercise. The Toolbox prompts were translated into Spanish for the Water Issues course, so that Spanish-speaking students could engage in the exercise in their native language, understanding, and perspectives. The Toolbox exercise allowed for team members to see behind the curtain of other disciplinary cultures by discussing the fundamental principles and assumptions used in each field through guided dialogue—taking students beyond disciplinary adequacy, developing disciplinary trust, following the interdisciplinary collaboration process (Figure 1). Groups were encouraged to develop a conceptual model and an integrating question to focus the team efforts to improve the sustainability of the river systems.

Data Collection: Surveys and Interviews

Following participation in the Water Issues course, the North American students from the four successive cohorts were asked to participate in a post-course survey and interview. Participation in this study was entirely voluntary, and no compensation was provided. Twenty-three out of twenty-five North American students who completed the course participated in the survey. Twenty-two of these were IGERT fellows, one of whom was a fellow in a similar IGERT program at another university. One student was from a university in Canada. We were unable to survey and interview the South American students due to institutional hurdles and lack of financial support—this is a limitation to our study since we were only able to evaluate insights from the North American half of the student cohorts. We do, however, include in our results some observations that our Chilean colleagues offered during and after the experience.

The survey and semi-structured interview format were designed using Hammer and Bennett's (1998) IDI. Questions were organized into three categories, following Medina-López-Portillo (2004): individual student experience, external course dynamics, and student decisions. Individual student experience questions built an understanding of participants' previous years in interdisciplinary work, immersion experiences abroad, proficiency in other languages, and personal experiences in the course. External course dynamics questions were designed to get the participants' viewpoints on the content provided by the organizers and instructors in the Water Issues course. External course dynamics factors included pre-trip orientation, lecture topics, and the amount of time spent in classroom lectures and field trips. The third section was focused on understanding choices made by students during the course, such as the extent of contact and immersion efforts with their international colleagues.

The survey component collected background information using quantitative Likert-scaled responses via the online Qualtrics™ survey platform. Potential identifiers were removed, and respondents were randomly assigned an identification number to preserve confidentiality.

The survey instrument proved useful by collecting data for quantitative analysis. Participants were asked to complete the survey instrument before their interviews.

Interviews followed the developmental interview process described by Hammer (2012), which leads to more robust survey data in the IDI context. The core intent of the semi-structured interviews was to explore students' collaborative experiences to learn how they negotiated disciplinary and place-based cultural differences in their team science efforts. Students were asked to provide details of specific incidents of cultural differences that impacted the group project, how they navigated the situation, and their perceived outcomes (Hammer 2012). By asking similar questions in multiple forms, the combination of surveys and interviews allowed for triangulation (i.e., asking similar questions from different angles) of responses to cross-check for consistency.

One researcher conducted all interviews. The interview duration averaged 30 minutes with a minimum and maximum of 20 and 33 minutes, respectively. Interviews were administered in person, by phone, or by video conferencing, and were recorded. One participant responded to the questions in writing from a remote location. Additional interview questions emerged during the first few conversations and were carried forward through subsequent interviews. Transcripts of responses were coded into an expanded matrix of questions. Direct references to other members of the cohorts were removed to preserve confidentiality. Respondents' names were replaced by matching identification numbers on interviews and surveys. Statements were aggregated by question to discover trends in responses for qualitative dimensions of this study.

Additionally, respondents were asked to plot themselves on a 2 x 2 matrix (-5 to +5 scale) of interdisciplinary comfort level (y-axis) and intercultural comfort level (x-axis). The matrix was designed to gauge respondents' degree of both cultural and disciplinary comfort in collaborative research after this international experience. Matrix results were added to the quantitative dataset. Correlation analyses were performed on the variables of interest using Spearman's rho, a non-parametric test commonly used with ordinal data to test for rank correlation. Results are reported following Cohen (1988), where moderate correlations occur between (+/-) 0.30 and 0.50, and high correlations are greater than 0.50 or less than -0.50. Positive correlations indicate factors that improved interdisciplinary and intercultural comfort and negative correlations indicate factors that hindered comfort.

Results

After completing the course, interview participants indicated how comfortable they were working in an interdisciplinary, intercultural setting prior to the course versus after. Respondents plotted themselves on a Cartesian coordinate system in comfort level working in interdisciplinary (x-axis) and intercultural (y-axis) settings (Figure 3). Comfort level is plotted using a Likert Scale from negative five, meaning no experience or comfort, to positive five, meaning extremely comfortable. Participants experienced an increased comfort level working across disciplines of 1.9. The students experienced an average comfort increase of 2.1 working across cultures because of their Water Issues course experience in Chile.

The interdisciplinary comfort level before the trip correlated positively (moderate significance) with both age of participant at time of trip and years of experience in interdisciplinary research. Age and years of experience in an interdisciplinary setting were highly correlated, as expected. Interdisciplinary comfort after participation in the course had a moderate correlation in the positive direction with the helpfulness of the interdisciplinary activities (i.e., the Toolbox exercise), respondents' age at the trip, and time spent in lectures. There was a moderate negative correlation between current interdisciplinary comfort levels with time spent in field trips (i.e., the more time in the field, the lower the interdisciplinary comfort). Change in interdisciplinary comfort was positively correlated (moderate significance) with the percent composition of North American students within a working group, group social time, and time spent in lectures. Interdisciplinary comfort was negatively correlated (moderate significance) between personal time spent previously in other countries and time spent with Indigenous people in Chile.

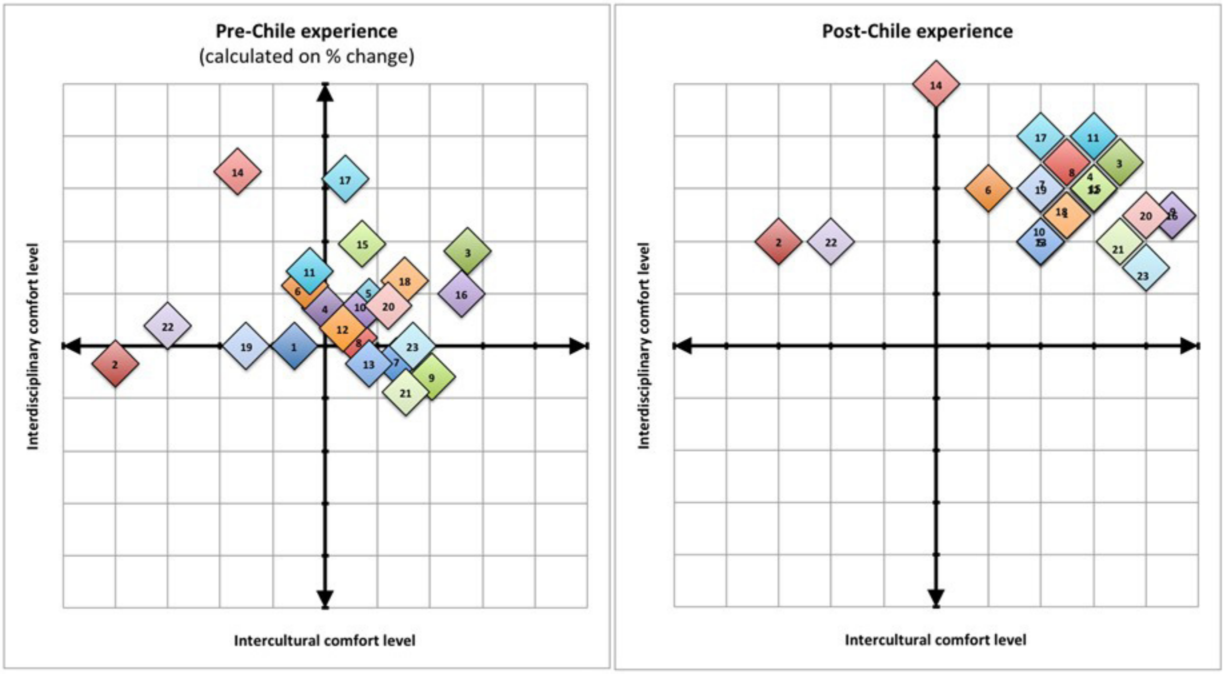

Figure 3. Participants' self-evaluations of comfort working in an interdisciplinary (on the x-axis), intercultural (on the y-axis) setting.

Post-course intercultural comfort (i.e., after the Water Issues course) was positively correlated (strong significance) with personal time spent in other countries previously, but negatively correlated (moderate significance) to time spent in lectures during the Chilean experience. The change in intercultural comfort levels because of the trip demonstrated weak positive correlation with group social time and weak negative correlation with time spent in other countries. While the level of fluency in another language showed a strong, positive correlation with time spent in other countries, the correlation was low with cultural comfort indices. Following participation in the Water Issues course, students increased their comfort working in both interdisciplinary ($p = 0.0006$) and intercultural ($p = 0.0007$) settings at an α level of 0.05. Table 1 summarizes the results of the correlation analysis form the survey results.

Discussion

Of the twenty-three North American students, twenty-one of them had previous experience and course work that explicitly taught how to collaboratively work across disciplinary divides. The average age among the North American cohort when they participated in the Water Issues course was 31, and many had extensive experience working in interdisciplinary settings. Those experiences and backgrounds with formal training were brought into group negotiations in the Water Issues course. Furthermore, the University of Idaho's IGERT program pointedly recruited interdisciplinary students, which was reflected in the relatively high interdisciplinary comfort levels reported by the participants.

Numerous interviewees specifically mentioned barriers to disciplinary adequacy, however. For example, one respondent felt that "engineers struggled to grasp what the biologists were saying." Through various forms of language and disciplinary translation within the group, others were able to understand the biological concerns better, even though the disciplinary trust was never fully achieved. To facilitate disciplinary adequacy, some groups turned to scholarly literature outside their respective fields. Not all groups had the same perspective or difficulties integrating. One respondent stated, "differences (are) in tools, rather than disciplines."

Hammer and Bennett's Intercultural Development Continuum (Figure 2) shows the process that individuals undertake to develop intercultural mindsets. Working across disciplinary bounds follows a similar continuum. During the Water Issues course, each student joined the course with their own experience and progress working through interdisciplinary and intercultural continuums. Their experiences were brought into the course and leveraged to aid in the class project. The post-survey results do not account for the students' pre-course experience and comfort levels. However, the experience aided in further developing the skillset and comfort necessary (as shown by the results of the correlation analysis) to further progress individuals across disciplinary and cultural continuums.

Results of the interviews and the correlation analysis show that the best methods to facilitate interdisciplinary efforts were to: 1) have a formal instructional setting, and 2) allow for open discussion of disciplinary differences within teams. A key component in the group discussions—as one interviewee stated—was to allow for "open and honest" conversations and to be "willing to debate both intellectually and jokingly, and share and listen." The open dialogue allowed members to "discover how each member viewed things to get beyond that sticking point." Interestingly, all the participants who mentioned the different interdisciplinary processes in the interview reported a high level of interdisciplinary comfort (average of 8.5 out of 10) following the Water Issues course. The high level of interdisciplinary comfort allowed groups to apply interdisciplinary tools to overcome interdisciplinary hurdles.

Many of the students had previously studied or lived in immersive international settings. Eight considered themselves competent or fluent in at least one other language. Six additional students felt they could "get by pretty well" in another language. Twelve had at least some knowledge of Spanish. The previous intercultural comfort that these students brought to the course helped move them across the Intercultural Development Continuum (Figure 2).

In contrast to the interdisciplinary process, however, students were not provided with methods to embrace intercultural differences in the Water Issues course. The curriculum provided on-site cultural experiences in Chile, but did not address other influential program components identified in IDI literature to increase intercultural adequacies, such as: pre-departure and re-entry preparation, cultural mentoring, and reflection on intercultural experiences (Jackson 2009; Hammer 2012; Egidiussen Egekvist et al. 2016). Bennett (2010) laments that a major impediment to intercultural learning in studies abroad is the "failure as international educators to be knowledgeable protagonists of intercultural learning" (p. 446). Indeed, we discovered that for most of the Water Issues cohorts, our interviews were the first time they had been asked to reflect on the experience—in some cases this was four years later.

It is therefore no surprise that the need to integrate cultural consideration into interdisciplinary research was not discussed in the context of the course, which was one impetus for this study. Interviewees were asked if any cultural differences or barriers occurred while working on the group project. Eleven respondents out of the twenty-three either implied or explicitly stated that cultural differences arose while working on the international teams; ten mentioned that they did not notice cultural differences. Two of the interviewees stated that either they or members from their group had previously spent time in Chile, which may have increased intercultural adequacy between team members.

Results showed that people who self-reported feeling more comfortable working across cultures were less aware of the existence of cultural differences; this falls in line with the Dunning-Kruger effect of being ignorant of one's own ignorance (Dunning 2011). Participants who observed distinct cultural differences, self-reported an average cultural comfort level of only 6.7. In contrast, the individuals who claimed that they did not notice cultural differences responded with a higher average cultural competence, 7.7. However, one student who self-reported an experience of severe culture shock was well aware of their own limitations and ranked their intercultural comfort the lowest of the cohort. Both survey and interview results suggest that time spent in social settings helped to foster intercultural comfort, whereas formal, lecture-based settings inhibited comfort in working across cultures.

Differences also arose among all the groups around the idea of how rivers should be managed—

these are issues that are neither clearly disciplinary nor completely cultural—and were evident in the surveys and interview transcripts. As an example, one interviewee noted that:

> *People in Chile don't have the same perspective on the environment than we [Americans] do; Americans came in with "dams are bad" while Chileans wanted to make their country great through the development of hydropower*.

In the authors' working group, the North American students advocated for limiting or even removing dams from riverine systems to allow for the restoration of natural processes. Being from the Columbia River Basin, the North American students have seen how dams, over time, have become the primary contributor to ecological consequences, such as a large decline in salmon populations. In contrast, Chilean students appreciated the importance of dams in their economy. The Chilean students were in favor of installing additional infrastructure, with limits, to hold water for future use, including electricity generation and irrigation. Further, while Chilean academic communities embrace the importance of biodiversity and species preservation, the endemic species within the Laja and Biobío River systems are not iconic species and do not occupy preeminent cultural status, such as salmonids do in the American Pacific Northwest. Many interviewees discussed differences between the native species located in the Biobío and Laja River systems compared to the Columbia River. One American interviewee stated that the Chilean rivers lacked native "charismatic megafauna" within the river systems like the iconic salmon in the rivers of the Pacific Northwest.

Within the Chilean river system, many of the endemic species are dissimilar to endemic species that the American counterparts find in their river systems. The North Americans were interested in preserving endemic species, but one observed that:

> *Chilean culture doesn't have the connection with the fish, especially because the endemic fish are small galaxids[1] and of no particular cultural value*.

Some students struggled with the differing viewpoints regarding endemic species between the salmon and steelhead in the Pacific Northwest to the small fish species in the Chilean rivers. One interviewee stated that, "we Americans had to get over it," meaning the North American students had to grasp and understand differing cultural views on endemic species. To ensure that the proposed outcomes from the class project were favorable within the Chilean setting, the North American students needed to re-evaluate their ideas about dams and fish to include the cross-cultural perspective of both the locals and North American students.

Proposing a Methodological Framework

While working on the group project, our team (the co-authors) was able to work through the beginning steps of the interdisciplinary process of building disciplinary adequacy, facilitating disciplinary trust, and developing a conceptual model of the system. For these steps we drew on our lecture and field trip notes, our individual specialties, generous use of a white board, and the previous experiences of interdisciplinary experience of two group members. However, we had trouble building a conceptual model and could not agree upon an integrating question. Our progress was at an impasse.

Through conversation we realized that the North American students and the Chilean students had different cultural perspectives on dams and river operations (as elaborated above). The underlying differences on dams crosscut both disciplinary and cultural differences, contexts, and perspectives. Reflecting on the interdisciplinary objectives of our course, we realized there was a gap in the process: there was no discussion of cultural differences. At this point in the interdisciplinary process (building a conceptual model and developing an integrating question), we were able to facilitate a supportive conversation regarding the different cultural views of dams. The resulting integrating question allowed for a solution with reasonable regionally relevant ecological compromises, rather than an absolutist approach.

In the synthesis phase of our project, an unexpected but particularly interesting cultural impasse occurred over the definition of time. The

[1]Adult *Galaxias maculatus* specimen average only 10.5 cm (Froese and Pauli 2017).

future, in Euro-American culture, is typically represented in a discrete time frame. As an example, management plans will have a time horizon of five, ten, or even 30 years. Our Chilean colleagues had a different understanding of what it meant to even articulate a time horizon. To explain the Chilean concept of the future, our colleagues told the folklore story of Pedro Urdemales (Memoria Chilena n.d.). In the story, Pedro promises his soul to the devil, payable tomorrow. Whenever the devil comes to collect, Pedro tells him that he promised to pay tomorrow; but it is currently today. Thus the idea of tomorrow—or the future—remains an indefinite concept that can always be pushed onward. In essence, there are different views of timelines between the North and South American cultures. By revisiting the cultural context throughout the interdisciplinary process, we were able to blend both the North and South American students' perspective into our process. We designed our management schemes to reflect the cultural difference by not defining specific periods, but in casting the solutions on relatively "short," "moderate," and "long-term" time horizons.

Figure 4 demonstrates the addition of cultural-based discussions to build cultural adequacy during the interdisciplinary process. By adding cultural discussions, we were able to collaborate on an international interdisciplinary research/management project. Our group did not experience place-based cultural differences until we started developing a conceptual model of the water management issue. Other teams encountered process-slowing issues at other times in the cycle. It is prudent to check the intercultural adequacy of the members frequently, and iteratively, throughout the interdisciplinary process. Revisiting the cultural context of the interdisciplinary process at every step ensures that place-based cultural perspectives are being addressed throughout the process so that the integrative results are meaningful in the regional context and local communities.

While the Water Issues course took place with students between North and South America, the overarching theme of intercultural adequacy applies to water management throughout the United States. For example, in the arid west Native American tribes play a critical role in water management in numerous basins e.g., Pyramid Lake Paiute Tribe in the Truckee River Basin, California/Nevada (Cosens 2003); Yakima Nation in the Yakima River Basin (Graham 2012). The cultural value of water and fisheries can differ largely from the cultural value of water for farmers and power producers (e.g., Freeman 2005). Building intercultural adequacy can help bridge between cultural viewpoints and further support the intercultural aspects of integrated water resource management.

Conclusion

The international collaborations of faculty at the University of Idaho with their counterparts at Universidad de Concepción and Universidad Católica de la Santísima Concepción made a space for a creative interdisciplinary, intercultural experience. Results from the interviews and surveys conducted in this research suggest that increased time in formal settings, such as lectures, aids in increasing interdisciplinary collaboration. In contrast, however, more time in informal situations and team interactions was needed to foster intercultural learning and collaboration. Balance is needed between time spent in formal and social/informal settings to work effectively across intercultural and interdisciplinary bounds.

The Water Issues course improved students' comfort level working across interdisciplinary and intercultural boundaries. A short, culture-focused immersion course can facilitate individuals' comfort in working across boundaries. Groups working across cultural and disciplinary boundaries could benefit by starting their experience in a similar setting. Our findings have broad applicability in interdisciplinary and intercultural settings. Water resource management interlinks numerous disciplinary fields and binds cultures together. Interdisciplinary and intercultural education programs train the next generation of natural resource managers who need to blend complex needs of society and the environment. Collaborators in fields like water resource management must learn how to work across disciplinary and cultural divides including ideologies and cultural philosophies, as demonstrated in our different working approaches to space (e.g., landscapes, dams, and biota) and even to time. People and landscapes should be interpreted

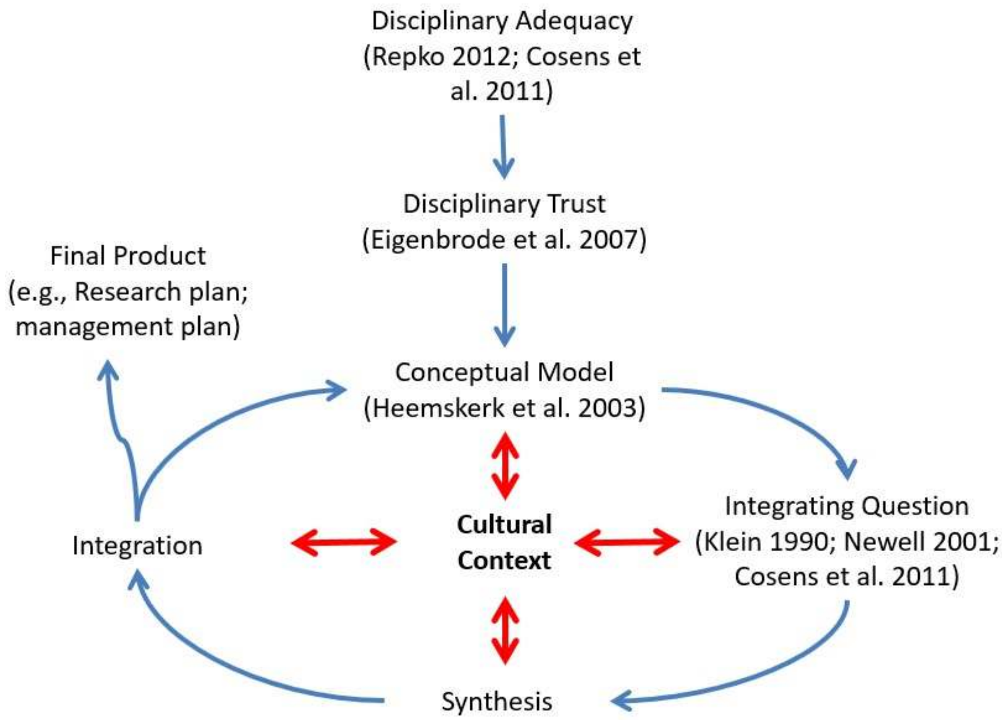

Figure 4. The interdisciplinary process presented in Cosens et al. (2011) with the addition of cultural discussion feedback loops throughout.

with context and history (Swensen et al. 2013) to understand place-based and heritage cultural perspectives. Groups need to develop intercultural adequacy when working on interdisciplinary teams with members from different countries and bioregions, and acknowledge that perspectives on natural systems can differ.

Trust and understanding take time to build. More activities than just working together are needed to overcome intercultural adequacy. Good facilitation and support before, during, and after a study visit aid in developing intercultural competencies (Jackson 2009; Egidiussen Egekvist et al. 2016). Getting to know teammates' stories, such as where each person came from, further links conversations back to the connections between people and the local environments (Allen et al. 2014). In the intercultural setting, our research found that there is value in moving away from traditional lecture-style presentations to more personal interactions to foster intercultural adequacy. Social interaction time helps "move the emphasis of the research discussions away from just the technical issues (how to do it) towards the aims (what to do and why)" (Allen et al. 2014, p. 11).

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Flood Hazard Awareness at Old Dominion University: Assessment and Opportunity

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Abstract: Building resilience to flooding is a commitment of several universities; however, student interest in flood education programs is unclear. The goals of this research are three-fold: 1) to determine the origin of flood messaging on the Old Dominion University (ODU) campus, 2) to assess on-campus flood awareness, and 3) to evaluate the interest in additional flood education. This study evaluates student awareness of flooding via a survey of ODU students and contextual analysis of University warning messages. Many students experienced reduced access to campus as a result of flooding and expressed an interest in additional flood information. Some students reported receiving flood-related information through in-class instruction or orientation-based programming. However, the content varies in detail, and ODU could formally integrate additional resources into outreach and flood education programming. These findings could support the development of a campus wide flood awareness program at ODU and other universities.

Keywords: *flood, risk perception, survey, hazards, education, resilience*

Students often have limited situational awareness about flood risk around the universities they attend (Williams et al. 2017; Ponstingel et al. 2019). Additionally, students may experience elevated risk due to a limited financial capacity and lack of familiarity with local emergency management systems (Burningham et al. 2008; Hung et al. 2016). These conditions affect an individual's ability to understand flood impacts or associated risks (Burningham et al. 2008). Individuals who perceive a low risk are less likely to invest time or financial resources in precautionary measures, such as planning alternate routes or purchasing flood insurance (Lopez-Marrero 2010; Hung et al. 2016). The flood-related information received from universities does not fully prepare them for or eliminate their anxiety about flooding (Williams et al. 2017; Ponstingel et al. 2019). Improving risk communication by integrating flood-related messaging throughout the university as a coordinated program could improve student preparedness and outcomes by adjusting risk perception (Birkholz et al. 2014; Ponstingel et al. 2019).

Research Implications

- Old Dominion University students who experienced reduced access to campus because of flooding are interested in additional flood hazard awareness.
- Opportunities to strengthen flood-related material from classes and orientations supports the development of a coordinated campus-wide program.
- Since courses and orientations do not convey consistent or comprehensive flood risk information, flood-related warnings should assume no pre-existing flood knowledge.

Knocke and Kolivras (2007) found that young people perceive less flood risk than other age groups and benefit from increased understandings of floods and related emergency guidance. A four-year study by Ponstingel et al. (2019) found that overall student flood risk perceptions were low but increased with time spent at university and age, which may reflect knowledge gained. Students with a more comprehensive understanding of flood risk were more likely to take precautions but also reported anxiety associated with limited preparedness. To increase Texas State University's flood knowledge, promote preparedness, and moderate social amplification of risk, campus-wide educational outreach was recommended (Oliver-Smith and Hoffman 2019; Ponstingel et al. 2019). The suggested program included heuristic principles, which state that multimodal flood information such as university email, public news outlets, social media, and combinations thereof improve student risk perception and reduce negative impacts, such as missed classes or car stranding (Mussweiler et al. 2004; Yamamura 2010; Harvatt et al. 2011).

The values and mutual interests of information sources influence how risks are managed and characterized (Moser and Ekstrom 2011; Johnson and Covello 2012). For example, universities typically monitor the National Weather Service (NWS) and comply with resultant weather-related closures and evacuation orders issued by the local government to ensure local student safety. Universities may go beyond simply issuing warnings to also provide for basic needs, transportation, and counseling services to ensure student well-being. However, if the goals and outcomes of institutional flood management efforts are not clearly communicated, students may not perceive the threat accurately (Fatti and Patel 2013; Ponstingel et al. 2019). For example, university warnings are important in preparing students for floods; however, students express that neither those nor city efforts are sufficient, and some experience frustration with university warnings when bad outcomes occur (Ponstingel et al. 2019). Campus and community education strategies may incorporate existing community networks such as civic organizations and business associations to improve flood risk perceptions and trust (Storr et al. 2017; Tierney 2019). The NWS also offers community educational opportunities focusing on severe weather (e.g., SKYWARN Spotter Training) and flood outreach (e.g., Turn Around Don't Drown).

The ability to deal with disturbances, such as flooding, remains low without adequate risk communication (Lopez-Marrero 2010). Proactive hazard education increases resilience at the individual and community level. Dufty (2008) states that flood risk education should extend beyond awareness and preparedness to develop adaptive capacity. Engaging communities in a participatory education process from design to evaluation increases willingness to implement protective measures and contributes to more holistic flood resilience (Dufty 2008; Muro and Jeffrey 2008; Charalambous et al. 2018). Activities, such as flood simulations, reduce anxiety and improve understandings of risk (Bosschaart et al. 2016; Bathke et al. 2019). Utilizing interactive maps to assimilate risk data also helps overcome powerless feelings (Houston et al. 2019; Sanders et al. 2020). In developing comprehensive flood-related literacy, both short-term guidance and long-term knowledge building are important. Specific skills include identification of flood zones and protective actions that individuals and communities may take (Burningham et al. 2008). This is particularly relevant with respect to regional flooding in "hotspots" like southeast Virginia (Sallenger et al. 2012) which intersect both short-term weather phenomenon (e.g., hurricanes, heavy rain events) and long-term climate impacts (e.g., sea level rise). This study builds upon Ponstingel et al. (2019) and utilizes the Old Dominion University (ODU) campus to ask 1) What sources of flood information exist on campus?, 2) How personal experience and available information shape student flood awareness?, and 3) What additional flood education is of interest?

Study Area

A metropolitan campus of nearly 25,000 students, ODU is in Norfolk, Virginia, one of the seven cities commonly referred to as Hampton Roads (i.e., Norfolk, Virginia Beach, Chesapeake, Newport News, Hampton, Portsmouth, and Suffolk). The University is a minority serving institution with a large commuter population. Situated near the world's largest Navy base, many students are also affiliated with the military and represent a more transient student population when compared to other institutions of similar size.

Located at the mouth of the Chesapeake Bay with the Atlantic Ocean to the east and a multitude of interlaced rivers and creeks, the University and greater Hampton Roads region regularly experience flooding. In the 19th and 20th centuries, many creeks and wetlands were filled and used for development purposes (Spanger-Siegfried et al. 2014). Adding to the complexity, over the last 80 years, Norfolk has observed twice the average global rate of sea level rise (SLR) due to land subsidence caused by geologic factors and groundwater depletion (Eggleston and Pope 2013). Consequently, land-use and geographic features affect the local hydrologic dynamics, and routes to campus go through multiple flood zones (Figure 1). In addition to tidal cycles that contribute to flooding, the area is often impacted by tropical cyclones, nor'easters, and heavy rain events that put commuters at risk (Allen and Allen 2019; Ponstingel et al. 2019). Sweet et al.'s (2018) analysis also showed sunny day flooding events accelerating throughout the region. While much of this flooding is considered *nuisance flooding*, everyday life certainly can be disrupted by a heavy rain event, a minor tropical cyclone, or a nor'easter. Together, short-term weather phenomena along with more long-term climate impacts, such as SLR, compound risk and help explain why ODU and the Hampton Roads region have a unique opportunity and heightened necessity to engage with students to increase flood-related resilience (Kleinosky et al. 2007; Li et al. 2013).

Yusuf et al. (2018b) facilitated community discussions focused on the resources needed to address flooding in Hampton Roads. The study showed that individual perceptions of flood risk improved through learning across public, private, and non-profit sectors. However, behavioral changes to facilitate adaptation, such as individual investments into flood-proofing, remained controversial (Yusuf et al. 2018b). This

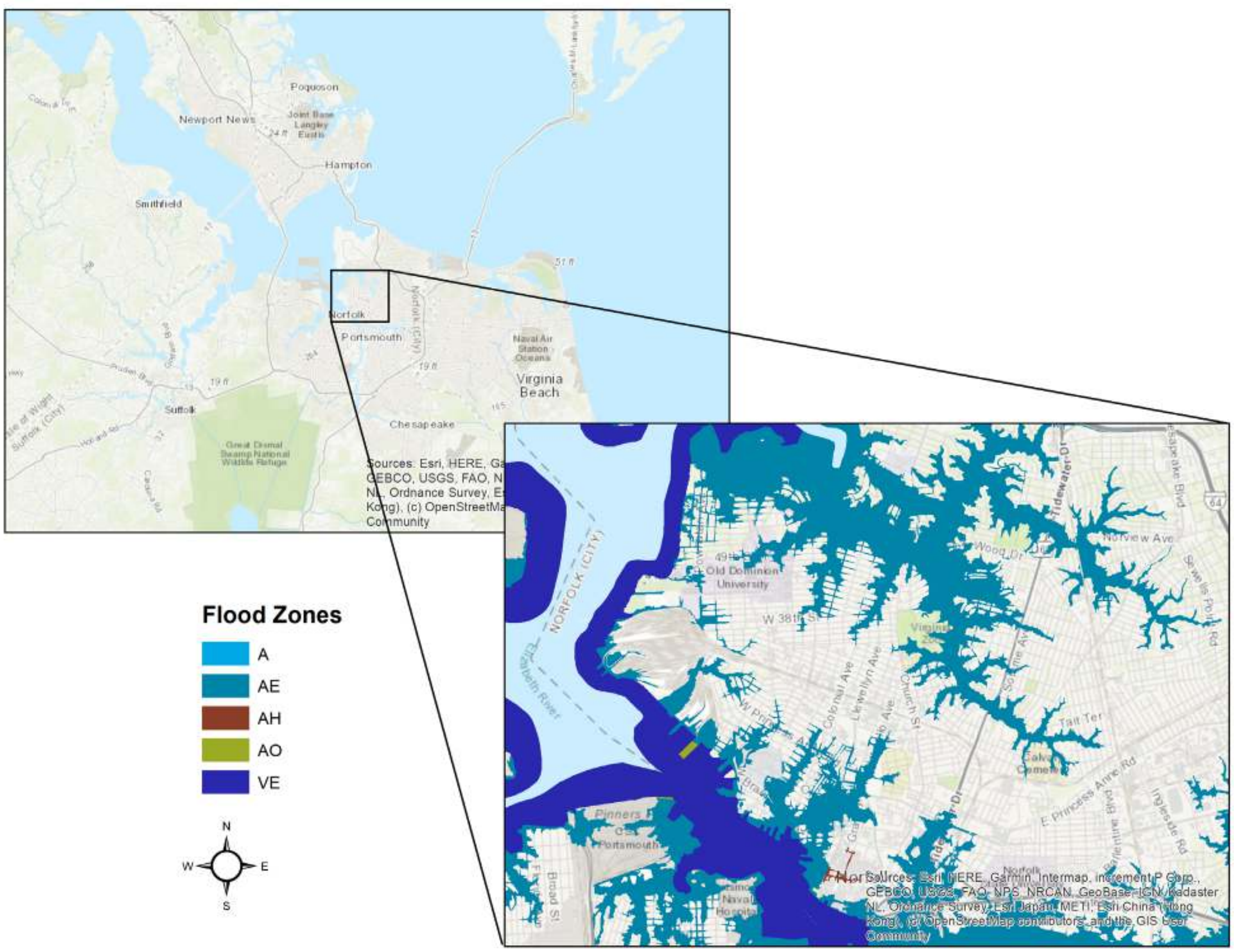

Figure 1. Federal Emergency Management Agency Flood Zones in Norfolk inset from Hampton Roads (adapted by authors from HRPDCGIS 2019). Flood zone descriptions can be found at https://www.fema.gov/glossary/flood-zones.

is consistent with Harvatt et al.'s (2011) study in England where participants externalized the responsibility for flooding associated with SLR but ascribed the responsibility to address other types of flooding to an individual level. The Commonwealth Center for Recurrent Flooding Resilience (CCRFR), ODU's Institute for Coastal Adaptation and Resilience (ICAR), and The Hampton Roads Forum engage stakeholders in dialogues, research, and policy-making efforts to mitigate current and future flooding. These regional partners present opportunities for ODU to better inform perceptions and behaviors associated with flood hazards, risk, and impacts on campus and throughout the community.

Methods

Student receptivity is critical to establishing a comprehensive flood awareness program at a university. This study included a student survey and a separate content analysis of University warning messages from 2015 – 2019. The ODU Arts and Letters Human Subjects Committee declared the study exempt research (Package 1502472-1) on October 7, 2019. The survey questions drew upon student experiences with flooding and consider the origin, availability, and receipt of flood-related information. The warning messages provided context regarding the frequency and severity of and guidance for flood events affecting campus operations. The influence of information and experiences upon risk perception and interest in additional flood-related education was assessed using mixed methods.

Survey Design

The online survey of 28 multiple choice and open-ended questions was distributed using Qualtrics software (Appendix 1). It required approximately 10 minutes to complete. The survey built upon student flood perception questions posed by Ponstingel et al. (2019) and addressed community specific flood hazards and management expectations identified by Allen and Allen (2019) and Yusuf et al. (2018b). The survey included demographic and geographic questions outlining student areas of study, student standing, commuter status, and prior residence. A series of flood experience and perception questions followed focusing on how many classes were missed due to flooding, damage and injuries incurred, as well as, perceived flood risk, contributors to flooding frequency and severity, and responsibility for management. Terms used in the survey did not include any definitions or examples. The survey concluded with questions about flood information received or of interest including orientation materials and course content.

Participant Recruitment

The ODU Office of Institutional Effectiveness and Assessment provided a representative sample of 1007 randomly selected graduate and undergraduate students (~4.25% of total student population) who completed at least one course on campus. Demographic characteristics of the recruitment pool appear in Appendix 2. A total of 110 individuals, 10.9% of the sample, consented to and participated in the online survey. Students received email invitations along with multiple follow-up reminders from the research team to complete the online survey. The survey link was available between November 12 and December 12, 2019, which coincided with the end of hurricane season.

Survey Analysis

Survey results were analyzed using both qualitative and quantitative approaches. Simple statistical tests conducted in Qualtrics included frequency counts and percentages. Crosstabulation determined significant relationships ($p < 0.05$) with a 95% confidence interval between commuter status, student status, experiences, or perceptions and the source of additional information of interest. Chi-squared and pairwise z-test statistical tests evaluated the difference in expected and observed frequencies. For example, the relationship between each type of student status (freshman, sophomore, etc.) and commuter status was tested using z-tests. Chi-square tests were used to assess the relationship such as that between classes missed due to flooding and interest in additional flood education through classes or orientations.

Qualitative data from open ended questions were manually analyzed to further explore what key messages were received in orientation and classroom instruction. Themes emerged from the data. For example, the information received in classes or orientations was either behavioral guidance, scientific explanation, or a combination of both. Selected quotes were included to illustrate how students characterized the information received in courses and orientations. Areas where reliable flood information already exists may be expanded to improve flood awareness across campus.

Geographic analysis was also conducted to provide detail for tailoring an ODU flood awareness program to the array of experiences students bring with them to campus. Zip code data were mapped using ESRI ArcMap to show where students resided prior to attending ODU. Zip codes within Hampton Roads, Virginia, the Commonwealth of Virginia, and the United States were selected in ArcGIS to determine frequencies and percentages of flood perceptions based on student origin.

University Warning Message Collection and Analysis

The University and Student Announcements communicate advisories that warrant significant action. Strategic Communication and Marketing sends out ODU Alerts advising on the status of the University for weather-related hazards. From 2015 – 2019, 24 flood-related alert messages notified ODU students. The data contextualize the flood experiences and information reported in student surveys and provide insight as to the type of messaging sent by the University during flood events. It is beyond the scope of this study to determine if students received all of these messages. Descriptive text indicating the origin and severity, as well as the recommended action for each event was manually coded based on hazard type, advisory source, and operating changes to generate and organize themes and identify connections between them from the data. Quotes were included to elaborate upon behavioral recommendations in the advisories.

Results

Participant Characteristics

Demographic information included prior residence, on- or off-campus residence, commuter status, and class standing. Figure 2 shows the zip codes provided within the United States for residence location prior to attending ODU. Of the surveyed students, 65.1% commuted. Z-tests showed a statistically significant relationship between student status and commuting, with commuting occurring at the highest rates amongst juniors, graduate students, and seniors. Table 1 outlines the break-down of student standing and College. Like other universities with majority commuter populations, ODU may benefit from flood awareness programming that promotes identification of alternate routes in advance of a flood (Ponstingel et al. 2019). A transient, military community, Hampton Roads prioritizes the transportation network, and the identification of alternative routes is not only valuable to students but also the greater community

Collective Experience with Floods at the University

This survey conducted two months after Hurricane Dorian, likely featured some enhanced awareness because the storm impacted ODU and the greater Hampton Roads; though, as stated in the ODU Alerts, the campus *did not experience serious impacts*. Tidal flood events, such as highest annual tidal cycle which occurred in October 2019, may influence participants, but these nuisance events were typically not the subject of ODU advisory messages.

Between 2015 and 2019, ODU sent 24 notifications of changes in operating posture in anticipation of or response to tropical systems; few specifically focused on flooding (Table 2). The collective results indicated what flood hazard experiences students may have shared during their time at ODU. There were no records to indicate which students experienced these events or received the messages.

All advisories had common components: 1) the name of the weather system or general hazard category, such as flood, 2) the actions taken on campus from monitoring, to delays, to closures, 3) recommended behavior, and 4) contact information for campus emergency management. Beyond these commonalities, the descriptions of risk and behavioral recommendations varied. One advisory described the flood level as *shallow*.

Another notice stated that there would be *some flooding*. Alerts in 2019 incorporated language to suggest appropriate behavior, such as *avoid driving through or walking in flooded areas*, and *turn around, don't drown*. Similar guidance issued in 2015 stated: *do not drive through flood water or into running water* and *remember not to drive around barricades or through floodwater*. Notices associated with the mandatory evacuation in 2018 offered planning support for students in residence halls and guidance on which zones ordered to evacuate, where to go, and what to bring. Hazards overlapping with the fall holiday breaks in 2015 and 2016 involved recommendations to stay or go home with friends and family, which assume an understanding of driving in flood conditions as well as evaluating safe structures. Nine ODU notifications advised the campus community to *use their best judgement,* typically discussed in the context of traveling to or from campus. Six alerts recommended to *use* or *exercise caution*.

Additional outlets suggested for monitoring the approaching hazard appeared in 13 notifications including ODU's webpage, ODU's social media, local news channels, 511 (travel information phone number), Google's map application, and National Oceanographic and Atmospheric Agency's All Hazards Radio. Links to preparedness resources from ODU or Virginia's Department of Emergency Management, including evacuation zones, were provided in five instances. In four communications, the text included NWS forecasts (e.g., warnings, outlooks). Opening these links, however, required additional action, which students may or may not be willing to take.

Alert language occasionally invoked external scientific organizations or relayed University pride. Despite the inclusion of NWS warnings and guidance, terminology did not reflect collaborations with state and local agencies until 2019. This addition may improve credibility. The term "MonarchReady" once encouraged readers to prepare in 2015 and 2016. Drawing on the University identity of Monarchs, this tactic may inspire a sense of community and connection that motivates students to rely on campus resources and promote additional flood awareness.

Individual Flood Experiences

The majority of students (60.8%) either had a class canceled or were unable to attend a class as a result of flooding. Eighty percent of those who experienced a cancelation or absence due to flooding perceived Norfolk to have high flood risk; of those that did not, 88.1% perceived Norfolk to have high flood risk. Chi-squared tests showed no statistically significant relationship between missed class and flood risk perception. Of total

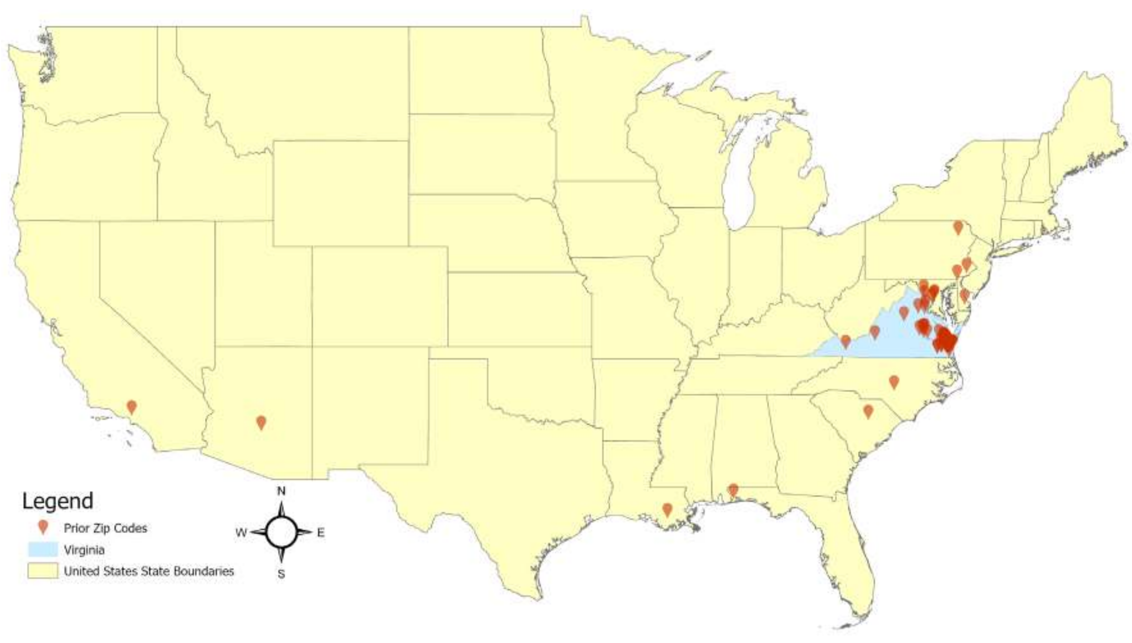

Figure 2. Prior zip codes of Old Dominion University students.

survey participants, 63.8% experienced flooding resulting in a canceled or missed class more often than once a year but few experienced property damage (14.3%) or injury (9.57%). Even with a small percentage of students reporting damage or injury, it is important to increase perceived risk to reduce future occurrences because most students encounter flooding.

Flood Risk Perceptions

The perception that Norfolk is prone to floods generally increased with student status during the undergraduate degree but then declined among graduate students (Table 3). The perception of Norfolk being flood prone increased by 31.8% from freshman to senior standing, whereas 5.7% fewer graduate students perceived Norfolk as flood prone than seniors. A chi-square test showed no statistically significant relationship. While the vast majority (96.7%) of students perceived that Norfolk has high flood risk, no students that provided prior residence information from outside Virginia thought Norfolk was a high flood risk area.

Only 19.4% of participants noted the relationship between flooding and SLR. When asked which climate change influenced weather-related hazards affect Hampton Roads only 28.1% noted flooding, 27.3% hurricanes, and 15.4% nor'easters. Students identified precipitation (37.9%) as major causal factors to flooding (Table 4) but did not significantly differentiate between other factors such as tidal processes, SLR, or storm surge. The low range of variation may indicate that students perceive that these factors are related, which is critical to understanding coastal hazards whether that awareness is from experience or information absorption. Few students acknowledged the relationship between flooding and climate change from either orientation or class information as well. Only one participant described the main

Table 1. Participant characteristics.

Residence Prior to Attending ODU (%)				
Norfolk	Hampton Roads (excluding Norfolk)	Virginia (excluding Hampton Roads)	United States (excluding Virginia)	International
7.22	62.89	15.46	12.37	Not Applicable

Student Standing (%)				
Freshman	Sophomore	Junior	Senior	Graduate Student
17.27	20.91	18.18	18.18	25.45

College (%)					
Arts and Letters	Business	Education	Engineering	Health	Sciences
31.40	11.63	8.14	8.14	18.60	22.09

Table 2. ODU Alerts, 2015-2019 (developed by authors from ODU Alert messages).

Year	Event(s)	Action
2019	Hurricane Dorian	Closure
2018	Hurricane Florence	Evacuation
	Tropical Storm Michael	Partial electrical failure
2017	Unnamed Tropical System	Coastal flood advisory
2016	Hurricane Matthew	Flash and coastal flood warnings
	Tropical Storm Hermine	Class cancelation
2015	Hurricane Joaquin	Route/schedule modification
	Wind driven high tide	Route/schedule modification

message of information received in class as, "Sea level rise caused by climate change [is] having a huge effect on Hampton Roads." Since perceptions of risks associated with climate change are highly politicized, particularly in the United States (Lorenzoni and Pidgeon 2006; Whitmarsh 2011; Brulle et al. 2012; Lee et al. 2015), a balance of messages, materials, and delivery methods could improve student perceptions regarding risk, the intersection of climate change and flooding, and student capacity to mitigate adverse outcomes.

Interest, Responsibility, and Sources of Information

There is a continued need for the University to expand flood-awareness initiatives. Only 8.3% of participants identified students as responsible for developing their own flood awareness. Students suggested emergency and flood managers were largely responsible for increasing awareness followed by administration and faculty (Table 5).

Of the students surveyed, 36.8% of participants reported receiving flood information in class. Students gained flood-related resources from three of the six University Colleges (i.e., College of Sciences, College of Arts and Letters, and College of Education & Professional Studies), and received this information in a wide-variety of courses including but not limited to Biology, Oceanography, Psychology, Political Science, Geography, and Human Development. Although some general education courses reach a broad set of students, this study suggests that there is a need to increase and formalize the cross-curriculum integration of flood information across the University.

Participants reported receiving information about emergency management and weather in Norfolk at incoming freshman orientation as well as transfer and graduate student programming. Twenty-five point four percent of respondents received flood information in orientations. This low percentage may be associated with inconsistent messaging or recall but indicates room for improvement. One student also reported a flood studies orientation associated with the community work of Yusuf et al. (2018b).

Participants' summaries of the main messages from classes explained more than those of

Table 3. Perception of flood risk by student standing.

	--Norfolk Has High Flood Risk (%)--		
Student Standing	**Yes**	**No**	**No Response**
Total Student Body	80.9	4.5	14.6
Freshman	63.2	10.5	26.3
Sophomore	78.3	8.7	13.0
Junior	75.0	0.0	25.0
Senior	95.0	0.0	5.0
Graduate Student	89.3	3.6	7.1

Table 4. Factors causing flooding.

Factor	Percent
Rain	29.13
Snow	8.74
Tides	18.12
Storm Surge	24.60
Sea Level Rise	19.42

Table 5. Perceptions of responsibility for student flood awareness raising.

Responsible Party	Percent
Emergency Managers	28.68
Flood Managers	29.06
Administrators	19.62
Faculty	12.45
Students	8.30
Other	1.89

orientations, which were more warning and action oriented. Students reported receiving flood risk messages including "It floods here"; and "Norfolk is sinking" in orientations. Emergency contact, warning alert information, and action recommendations were also reported from orientations, such as "don't drive through flood waters" and "get to higher ground." These terms connect with suggested NWS best practices. Although the orientation messages do not provide a foundation for the complex science behind SLR, they may improve the receipt of more general flood warnings and resultant behaviors for vehicle protection. Participants' summary statements of course messaging associate a range of attitudes with the human-environmental interactions contributing to flooding from, "That it is a problem that we have to come together to try and solve for our future" to "We've killed our wetlands so water floods now."

There is both room for and interest in improved outreach to the ODU campus with flood awareness information. Approximately half of the students wanted to learn more from some education outlet. Chi-squared tests showed statistically significant relationships between reduced access to classes from flood events and interest in additional flood information in orientation and courses. By addressing knowledge gaps and providing additional context and information, a coordinated flood awareness program may improve general understanding by also improving resilience to flood impacts.

Discussion

Pairing behavioral advice with best judgement recommendations minimizes the flood knowledge needed to reduce risk (Montz et al. 2017). Since ODU already invests in building community resilience and producing warnings in conjunction with city, state, and federal partners, implementing a flood awareness campaign could leverage these resources to benefit University emergency management by improving warning message content as well as students' understandings of and reactions to messages. Students perceive that the responsibility for management falls upon emergency and flood managers yet interest in flood education remains high, thereby, positioning ODU to complement its flood awareness offerings with existing government resources, a capacity also indicated by Yusuf et al. (2018a).

The types of material presented in orientations and classes influence attitudes toward the problem. Covi and Kain's (2016) study of Hampton Roads shows that framing and visualization increase understanding of the complex and politicized connections between climate change and SLR. For example, interactive maps increase urgency to protect homes and interest in capacity building amongst community members and government agencies (Hutton and Allen 2020; 2021). To create flood resilience, students need to see the socio-ecological connection and be able to identify ways to adapt (Adger et al. 2005).

With only 19.4% of ODU respondents noting a relationship between flooding and SLR, there is an opportunity to improve climate literacy. Whereas warmer world temperatures do not directly cause flooding, warmer temperatures enhance the probability of extreme events as the capacity for air to hold water increases with temperature. Recent studies indicate changes in historical precipitation (e.g., Allen and Allen 2019) and the role anthropogenic climate change has on flood events (e.g., Kirchmeier-Young and Zhang 2020). Norfolk, due to both natural and anthropogenic factors, is sinking, but the seas are also rising as a result of heat-trapping gases warming the planet. Consequently, SLR in Norfolk is a greater hazard than for many other coastal areas. These factors indicate that the interconnected dimensions of climate impacts and flood risk should be more effectively communicated across multiple modes.

Aytur et al. (2015) show that it takes several months and multiple means of education from interactive activities to conversations with scientists to raise awareness of how flood risk and climate change are intertwined. On the one hand, geography courses involving water resources, for example, address the human-environmental interactions associated with flooding through climatology (Pease et al. 2019). Enrollment in a course with flood-related content is not required at ODU or many universities as a general education requirement, which shows in that only 36.8% of students reported receiving flood information from a class. On the other hand, the short duration and large amount of content presented at required orientations may reduce retention. Only 25.4% of ODU students reported receiving flood information in orientations. Comparisons between information provided and retention are beyond the scope of this study but merit additional research. A framework with both interdisciplinary and disciplinary learning is needed to establish a broad foundation, offer practical flood management solutions (Grigg 2019), and adjust the range of views on flood risk.

Conclusions

The results of this study identify an area of opportunity to increase climate literacy and interconnected flood-impacts at ODU. This case study of ODU assesses: 1) sources of flood-related information on campus, 2) the role of information and experience in student flood awareness, and 3) what additional education is of interest. Over the past five years, the campus received several flood-related warnings about hurricanes, tropical storms, and tides that rely upon pre-existing flood knowledge that is not thoroughly conveyed to students through orientations or course curriculum. Reported receipt of flood information in orientations and classes was low. Classes that did address flood risk had more information about natural and human systems than orientations, which provided contacts and behavioral advice.

The large majority perceived Norfolk to have flood risk regardless of personal experiences on campus. However, few students noted the connection between flooding and climate change impacts. Most students experienced flooding while attending ODU. Although local experience matters, risk perception at ODU, unlike some other universities (i.e., Texas State), was not related to missing classes due to flooding. Interest in receiving additional flood awareness information was associated with missing a class due to flooding.

Students expect emergency and flood managers to raise flood awareness more so than administrators, faculty, or themselves. Balancing the messengers, means, and amount of information received over time is important for making human-environmental connections and fostering resilience. These findings will prepare flood prone universities to develop more comprehensive risk perception evaluation and integrate awareness programs to increase knowledge of, readiness for, and resilience to hazards.

Limitations and Future Research

The full relationship between the information received and increased resilience among ODU students requires additional exploration. This study features limitations regarding sample size and terminology. A relatively small participant count (n = 110) may influence the results. Student interpretations and understanding of terms such as hurricane and nor'easter may not be sufficient to differentiate between terms. These exploratory results, however, illuminate areas for future research.

This survey could be expanded in size and scope and conducted annually to determine changes in flood awareness availability and perception longitudinally amongst a larger percent of the student population. More detailed iterations could collect the information available in classes and orientations and determine how much information is sufficient, specific types of information of interest, the role of social networks, a timeline for distribution in relation to the student standing, variation in flood risk perception at the graduate level, and motivations for coordination between campaigns. Such longitudinal studies could also examine: 1) existing emotional, social, and demographic relationships with risk perception, and 2) the current range of preparedness behaviors implemented by students. If a program was to be developed and started during that time, it would also be a way to determine behavioral change and efficiency, and assess reactions to specific warning texts or modes of presentation to refine offerings. Finally, comparative studies could allow for robust regional flood awareness programs connecting universities with their surrounding community.

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Appendix 1. Survey Materials

Recruitment Email

Subject: Flood Hazard Awareness Questionnaire

Dear ODU Student,

Please consider answering this "Flood Awareness among Old Dominion University Students" questionnaire linked here https://odu.co1.qualtrics.com/jfe/form/SV_6gRkAmwox9KiTqZ.

The questionnaire should require no more than 10 minutes to complete.

No identifying information is requested, nor will it be included in the analysis of the responses.

Responses will be used to assess Old Dominion University (ODU) students' awareness, experiences, and perceptions of floods. Results will contribute to awareness raising activities on-campus, presentations at professional conferences, and publications in academic journals.

Your participation is voluntary. You may choose not to fill-out the questionnaire, skip questions in the questionnaire, or stop the questionnaire at any time with no consequence. If you chose to take the questionnaire, please only do so once.

Additional participant information is provided on the introductory page of the questionnaire.

Sincerely,
Drs. Michael Allen and Nicole Hutton

Survey Questionnaire

Thank you for your interest in the "Flood Hazard Awareness among Old Dominion University Students" study.

The questionnaire should require no more than ten minutes to complete. Most questions will be yes or no. Some will be multiple choice or fill in the blank. Questions will collect consent, as well as flood experience and perceptions.

Your participation is voluntary. You may choose not to fill-out the questionnaire, skip questions in the questionnaire, or stop the questionnaire at any time with no consequence. If you chose to complete the questionnaire, please do so by November 30, 2019.

Your name, student number and/or any other identifying information is not requested, nor should it be provided in any responses to protect your anonymity. No grade may be assessed by any instructor based on the answers to the questionnaire.

No risk of harm is expected from the questionnaire; however, should the questions cause any unsettling feelings or emotions, please contact the ODU Office of Counseling Services at 757-683-4401.

If you have any questions or concerns, please contact Dr. Michael Allen (Principal Investigator) at mallen@odu.edu, Dr. Nicole Hutton (Co-Investigator) at nhuttons@odu.edu, or Dr. Randy Gainey (Chair of the Arts and Letters Human Subjects Review Committee) at rgainey@odu.edu.

Do you understand the information provided to you about this study?
☐ Yes
☐ No

Do you consent to participate in this study?
☐ Yes
☐ No

What is your student standing?
☐ Freshman

☐ Sophomore
☐ Junior
☐ Senior
☐ Graduate Student

Are you a campus resident?
☐ Yes
☐ No

Where did you live prior to attending ODU? (Zip code)

Are you a commuter?
☐ Yes
☐ No

Do you have a declared major?
☐ Yes
☐ No

Display This Question:
If Do you have a declared major? Yes Is Selected

What is your major?

Has street flooding ever caused a class cancellation or affect your class attendance in the time you have been a student at ODU?
☐ Yes
☐ No

Display This Question:
If Has street flooding ever caused a class cancellation or affect your class attendance in the time...Yes Is Selected

How often has street flooding caused you to miss class or cause one of your classes to be canceled?
☐ Less than once a year
☐ Once a year
☐ Once a semester
☐ Multiple times each semester
☐ Monthly
☐ Weekly
☐ Daily
☐ Multiple times each day

Have you experienced damage to your residence or other property as a result of flooding in the time you have been a student at ODU?
☐ Yes
☐ No

Display This Question:
If Have you experienced damage to your residence or other property as a result of flooding in the ti...Yes Is Selected

What part(s) of your property was damaged as a result of flooding in the time you have been a student at ODU? (select as many as apply)
☐ Yard
☐ Building
☐ Vehicle
☐ Parking area
☐ Clothes
☐ Other

Do you consider Norfolk as having a high flood risk?
☐ Yes
☐ No

How do you receive warnings, if at all, about flooding in Norfolk? (select as many as apply)
☐ Text
☐ Email
☐ Call
☐ News
☐ Social Media
☐ Other
☐ I do not receive warnings

What factor(s), if any, do you perceive to cause flooding in Norfolk? (select as many as apply)
☐ Rain
☐ Snow
☐ Tides
☐ Storm surge
☐ Sea level rise

How often have you experienced flooding in the past year?
☐ Never
☐ Once a year
☐ Twice a semester
☐ Multiple times each year
☐ Monthly
☐ Weekly
☐ Daily
☐ Multiple times each day

Have you or someone you know been injured in a flood?
☐ Yes
☐ No

Who should be responsible for flood risk awareness at ODU? (select as many as apply)
☐ Flood management experts
☐ Emergency management experts
☐ Faculty
☐ Administrators
☐ Students
☐ Other

Has climate change affected the frequency and/or intensity of any of these events in Norfolk: (select as many as apply)
☐ Floods
☐ Hurricanes
☐ Droughts
☐ Earthquakes
☐ Tsunamis
☐ Tornados
☐ Heatwaves
☐ Nor'easters

☐ None of the above

Have any of your ODU course materials alerted you to flood risks in Norfolk?

☐ Yes
☐ No
☐ I don't know

Display This Question:
If Have any of your ODU course materials alerted you to flood risks in Norfolk? Yes Is Selected

What is the name of the course(s) from which you received materials related to local flood risk? (list all that apply)

Display This Question:
If Have any of your ODU course materials alerted you to flood risks in Norfolk? Yes Is Selected

What was the key message of the course material related to flood risk that you received?

Do you wish you learned more about local flood risk in courses?

☐ Yes
☐ No

Have any of ODU orientations alerted you to flood risks in Norfolk?

☐ Yes
☐ No
☐ I don't know

Display This Question:
If Have any of ODU orientations alerted you to flood risks in Norfolk? Yes Is Selected

What was the topic of the orientation in which you received materials related to local flood risk? (list all that apply)

Display This Question:
If Have any of ODU orientations alerted you to flood risks in Norfolk? Yes Is Selected

What was the key message of the orientation material related to flood risk that you received?

Do you wish you learned more about local flood risk in orientations?

☐ Yes
☐ No

Appendix 2. Sample Characteristics

Ethnicity	**%**
African American	33.57
Asian	4.27
Hispanic	9.04
Native American	0.10
Native Hawaiian / Pacific Islander	0.30
Non-Resident Alien	4.07
2 or more	7.45
Unknown	1.49
White	39.72

Gender	**%**
Female	52.63
Male	47.37

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Natural Characteristics and Human Activity Influence Turbidity and Ion Concentrations in Streams

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Abstract: All 54 km of the West Fork of the White River (WFWR) were on Arkansas's 303(d) list of impaired waterbodies for turbidity, total dissolved solids (TDS), and sulfate for many years. This study identifies which river segments fail to meet applicable water quality standards (WQS) and investigates possible anthropogenic or natural sources of pollutants. We also evaluated a larger dataset of 119 sites in the Boston Mountains and Ozark Highlands ecoregions, compiled from the Arkansas Department of Environmental Quality online database. In the WFWR, water samples were collected once or twice a month at nine sites from June 2014 through June 2018. Median values for turbidity, TDS, sulfate, and chloride ranged from 1.8 to 10.8 NTU, 40.8 to 151.3 mg/L, 3.5 to 27.9 mg/L, and 3.2 to 5.5 mg/L, respectively, and generally increased from upstream to downstream ($p < 0.05$). Violations of the water quality standard for the parameters of interest varied by site, but generally occurred in the downstream portion of the WFWR, where land use, riparian soils, and underlying geology change. In the larger dataset, turbidity, TDS, sulfate, and chloride concentrations were all significantly greater in the Ozark Highlands than the Boston Mountains ecoregion ($p < 0.05$). Anthropogenic activities influence dissolved ion concentrations across these study sites, while geology and riparian soils may be important factors for differences in sulfate and turbidity.

Keywords: *total dissolved solids, sulfate, chloride, water quality standard, watershed management*

Research Implications

- Sulfate concentrations in the West Fork White River (WFWR) abruptly increased where primary and secondary shales dominate the subsurface geology along the river corridor, aligning with river sections that exceeded the State's water quality standard (WQS).
- Site-specific WQSs in streams should consider changes in underlying geology to account for chemical contributions from these natural sources.
- Base-flow turbidity levels were relatively high at the two most downstream sites on the WFWR, where the natural riparian soils had high erositivity indices and thus a natural tendency to contribute inorganic solids to the stream.
- WQSs for turbidity and subsequent plans to address exceedances should consider riparian soil type and erosivity.
- Watershed land use and underlying geology influence physico-chemical properties of streams.

Over 600,000 of the 1.1 million miles of streams assessed in the United States are identified as impaired, meaning they are unable to support one or more of their designated uses (USEPA 2017). In the U.S., the Clean Water Act requires states to identify streams, rivers, and lakes to be placed on the 303(d) list of impaired waterbodies. States must develop water quality standards (WQS) and assessment methodologies to evaluate waterbodies for a variety of pollutants. Sediments, turbidity, total dissolved solids (TDS), sulfate, and chloride are some of the common water quality parameters listed for non-attainment across the U.S. (USEPA 2018a).

Excessive amounts of sediment and high levels of turbidity can negatively impact water quality by changing the physical, chemical, and biological characteristics of streams and rivers. Sediment transport to drinking water supplies can reduce water storage capacity due to infill and result in increased treatment costs (Holmes 1988). In streams, increased sediment can negatively impact aquatic life by reducing light penetration, filling channels, and possibly releasing bound pollutants such as metals and nutrients. Sediment deposition can increase habitat homogeneity (Jones et al. 2012), reduce interstitial refugia for aquatic organisms (O'Callaghan et al. 2015), increase macroinvertebrate drift (Bilotta and Brazier 2008), and clog gills of animals (Bruton 1985; Bilotta and Brazier 2008). All of this can result in changes in the biological community of a stream system (Fossati et al. 2001; Jones et al. 2015) and degradation of the waterbody's intended use(s).

Sediments and turbidity can be transported from the watershed or can originate from within the fluvial channel. Turbidity relates to catchment land use, where urban and agricultural land can increase turbidity in receiving streams (Ryan 1991; Wood and Armitage 1997; Brett et al. 2005). Urban areas might show a decrease in overland sediment transport due to large areas of impervious surfaces such as roads and parking lots (Wolman 1967). However, urban land use indirectly influences sediment transport by increasing peak flows during storm events, leading to increased channel erosion (Trimble 1997; Nelson and Booth 2002), which can be the predominant source of sediments and turbidity in some streams (Simon and Klimetz 2008; Mukundan et al. 2015). In fact, Van Eps et al. (2004) showed that stream bank erosion was the primary source of sediments to the West Fork of the White River (WFWR), the focus of the current study.

Sulfate and chloride make up a large portion of the dissolved minerals, salts, and ions in water. Increasing ion concentrations have been shown to change algal community structure in streams (Potapova and Charles 2003), potentially affecting food web dynamics. Even low-level increases in dissolved ions might negatively impact stream macroinvertebrates due to osmoregulatory and physiological stress (Freitas and Rocha 2011; Tyree et al. 2016). Increases in ionic concentrations definitely influence the biological community and ecosystem functions, but how these changes relate to the waterbody's designated use(s) is more challenging.

Dissolved ions naturally occur in streams and vary with watershed soils and geology (Griffith 2014), but anthropogenic activities such as urban development and agricultural activities can increase ion concentrations, especially sulfate and chloride, in surface waters (Herlihy et al. 1998; Zampella et al. 2007; Wright et al. 2011). Effluent discharges from industrial or municipal wastewater are sources of sulfate and chloride (Fitzpatrick et al. 2007). Sulfate and chloride concentrations in streams are also influenced by road salts, fertilizers, animal waste, and rainwater (Khatri and Tyagi 2015).

In Arkansas, approximately 8,875 km of streams are listed as impaired, including the entire 54 km-long WFWR. The WFWR is a major tributary to the White River, which forms the drinking water supply, Beaver Lake, for almost half a million people in northwest Arkansas. Turbidity, TDS, and sulfate concentrations violate the applicable WQS in the WFWR. The objectives of this study were to: 1) evaluate base-flow water quality from the headwaters to the most downstream portion of the WFWR; 2) compare these data against the applicable WQS to identify which part(s) of the stream actually violate the standards; and 3) consider possible landscape or in-stream sources of these problem pollutants, whether human-caused or naturally occurring. The goal of this paper is to help watershed managers target problem areas for improvement and allow regulators to make data-driven decisions on water quality impairment issues. Here, we point out how these decision-makers should consider underlying geology and land use, among other considerations, when addressing water quality impairments.

Methods

Study Sites

The WFWR watershed is a 322 km^2 sub-watershed of the Upper White River Basin, in northwest Arkansas (Figure 1). The WFWR is approximately 54 km long, with headwaters near the small town of Winslow in the Boston Mountains ecoregion. The river flows north into the Ozark Highlands ecoregion where it enters into the White River in the more populated city of Fayetteville. Of the nine sites where samples were collected, the six most upstream sites are located in the Boston Mountains, while the three most downstream sites are located in the Ozark Highlands ecoregion. Geology in the Boston Mountains is dominated by sandstone, limestone, siltstone, and shale (Woods et al. 2004). The Ozark Highlands consist of soluble and fractured geology and are dominated by shale, limestone, and dolomite (Woods et al. 2004). The karst topography of the Ozark Highlands allows for net subsurface transfer of water and minerals to surface waters (Hays et al. 2016).

Land use in the WFWR watershed is predominately forested (66%), with approximately 20% pasture and 14% urban (ANRC 2018). Land use varies across sites (Table 1; Figure 1), where percent forest generally decreases and percent urban generally increases from upstream to downstream. While there is one small municipal point-source wastewater discharge in the watershed (design flow is 0.1 million gallons per day), the downstream portion of the watershed also has several industrial sites permitted by the State for stormwater runoff discharges (ADEQ 2018).

Water Sampling and Analysis

In this study, water samples were collected 18 times per year for four years at nine sites along the WFWR during base-flow conditions (see Figure 1). The sample collection schedule met or exceeded the requirements for sample frequency and duration needed to properly evaluate the WQS. Samples were collected from the thalweg using an alpha type sampler or manually from within the stream channel. Water samples were returned on ice to the Arkansas Water Resources Center Water Quality Lab (AWRC WQL, or Lab) and analyzed for turbidity (WTW Turb 550 Turbidity Meter), TDS (Mettler Toledo AX205), and sulfate and chloride (Thermo Scientific Dionex ICS-1600) according to standard methods (AWRC 2018). The Lab is certified by the Arkansas Department of Environmental Quality (ADEQ) for the analysis of water samples, including all parameters analyzed for this project.

Turbidity, TDS, sulfate, and chloride for the WFWR study sites were evaluated against the applicable WQS for Arkansas (APCEC 2015). For turbidity, the WQS states that:

- The limit “should not be exceeded during base flow (June to October) in more than 20% of samples,” and
- “should not be exceeded during all flows in more than 25% of samples taken in not less than 24 monthly samples.” Here, “all flows” values apply to data collected throughout the year.
- The limit for turbidity is specific to ecoregion and months sampled, where the limit for the Ozark Highlands ecoregion is 10 and 17 NTU for “base” and “all flows,” respectively; the limit for the Boston Mountains ecoregion is 10 and 19 NTU for “base” and “all flows,” respectively.

The WQS for TDS, sulfate, and chloride is site specific to the WFWR and states that:

- The stream “will be listed as non-support when greater than 25% of samples exceed the applicable criteria.”
- The site-specific limit for TDS is 150 mg/L.
- The site-specific limit for sulfate and chloride is 20 mg/L.

Percent exceedances of the water quality limits were calculated and reported for turbidity, TDS, sulfate, and chloride.

In a separate analysis to better understand how ecoregion might influence stream water quality, data were acquired from the ADEQ Water Quality Monitoring online database for an additional 110 sites throughout the Boston Mountains and Ozark Highlands ecoregions. The database was accessed in October 2018 and the date range searched was from June 1, 2014 through June 30, 2018. Data were used for a site if at least eight observations were available for each parameter and these observations were collected over the course of at least two years. The geometric means were calculated for each site in order to reduce the influence of outliers and used for subsequent analysis. Land use and land cover (LULC) data for these additional 110 sites were estimated using the Model My Watershed application from the

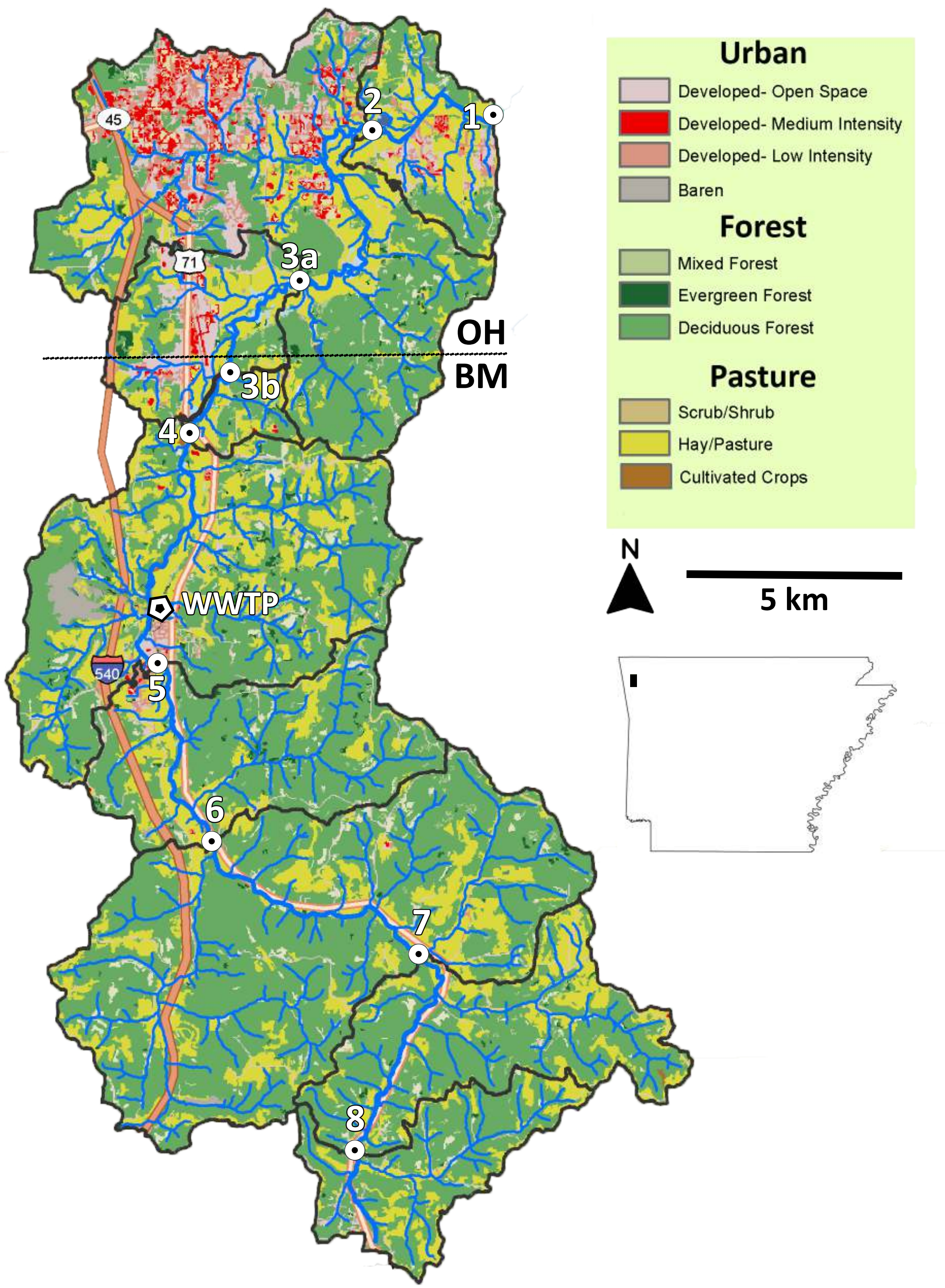

Figure 1. Map of AWRC study sites on the West Fork White River in northwest Arkansas, land use land cover, and delineations of site drainages. Sites are indicated by white circles with inner black dots; the West Fork wastewater treatment plant is indicated by a white pentagon with inner black pentagon; and the ecoregion boundary is indicated by a dotted line, with Ozark Highlands (OH) and Boston Mountains (BM) labels provided.

Table 1. Information for AWRC study sites on the WFWR, including site ID, distance downstream (Dist. Down.), site description, coordinate location (Lat. and Long.), ecoregion (Eco.), and land use (forest = %F; pasture = %P; urban = %U; pasture plus urban = %P+U).

Site ID	Dist. Down. (km)	Site Description	Lat.	Long.	Eco.	%F	%P	%U	% P + U	Area (km^2)
1	45	Mally Wagnon Road	36.0539	-94.0833	OH	59.7	25.7	13.6	39.4	318.3
2	40	Dead Horse Mtn Road	36.0506	-94.1189	OH	60.8	24.9	13.4	38.3	303.1
3a	32	Tilly Willy Bridge (CR69)	36.0158	-94.1408	OH	64.3	26.2	8.7	34.9	236.3
3b	29	Fayetteville Airport	35.9944	-94.1628	BM	66.0	25.5	8.0	33.5	220.9
4	27	Baptist Ford	35.9814	-94.1739	BM	67.1	25.3	7.1	32.4	214.8
5	19	Riverside Park	35.9281	-94.1844	BM	71.3	22.5	6.0	28.5	157.1
6	13	Woolsey Bridge	35.8867	-94.1692	BM	71.6	22.9	5.4	28.3	125.3
7	6	Brentwood Mountain	35.8594	-94.1100	BM	68.5	25.8	5.6	31.4	47.9
8	0	Slicker Park	35.8144	-94.1300	BM	67.4	24.9	7.6	32.5	17.7

WikiWatershed initiative (Stroud Water Research Center 2017). Land use classifications were condensed into three categories – urban, forest, and pasture. There is essentially no row-crop agriculture in the watershed (less than 0.1% at all sites). Grassland is grouped with pasture, where grassland across sites ranges from 2-3%, while pasture alone ranges from 20-24% across sites.

Water quality data for the WFWR were log-transformed to reduce skewness of the data prior to the analysis of variance (ANOVA). Post-hoc tests were completed using the least significant difference (LSD) to test for differences across sites (Statistix 10.0). Relationships between water quality parameters and LULC variables were analyzed using linear regression (R Core Team 2016; v. 3.3.1). Although we collected samples during base-flow conditions where groundwater may influence in-stream water quality, McCarty and Haggard (2016) show that water quality during base flow can be a reliable metric to evaluate land-use impacts. To test differences in water quality between ecoregions, an ANOVA was used on site geometric mean data (R Core Team 2016; v. 3.3.1). All statistics were considered significant at alpha = 0.05.

Results

Turbidity

Turbidity varied widely within and across all nine sites along the WFWR, ranging from 1 to 299 NTU. However, turbidity over 100 NTU was rarely observed during the flow conditions sampled at the WFWR (Figure 2a). Most of the values were less than 20 NTU, and only 4% of all the data were greater than 20 NTU across all sites.

Turbidity increased from upstream (geometric mean 2.9 NTU at Site 8) to downstream along the WFWR (ANOVA, $p < 0.01$), with particularly high values at the two most downstream sites where geometric means were just above 10 NTU. Turbidity was not significantly different between sampling sites (Sites 3b through 8) within the Boston Mountains, except at Site 3b where there was a small but significant increase in turbidity (Figure 2a). There was another small but significant increase when transitioning to the Ozark Highlands (Site 3a). However, turbidity greatly increased as we moved downstream from Site 3a (geometric mean 5.6 NTU) to Site 2 (geometric mean 10.2 NTU). The two most downstream sites had the greatest measured turbidity compared to all other sites along the WFWR ($p < 0.01$).

The two most downstream sites were also the only sites that violated the applicable WQS (Table 2; Figure 2a). During base flow, these sites exceeded the limit of 10 NTU in 47% or more of the samples collected; whereas, the limit was exceeded in 6% or less of the samples collected at the other sites. During all flows, these two downstream sites exceeded the limit for the Ozark Highlands ecoregion of 17 NTU in less than 20% of the samples collected, which did not violate the applicable WQS. The limit (i.e., 19 NTU for the Boston Mountains ecoregion) for all flows was exceeded in 6% or less of the samples collected at each of the other sites.

At the WFWR, geometric mean turbidity values increased with increasing pasture plus urban land use (28-39%) within the watershed ($r = 0.93$, $p < 0.01$; Figure 3a). However, this relationship does not exist when looking at the larger dataset of all 119 sites within these ecoregions ($p = 0.58$; Figure 3b), which spanned a larger range in land use (2-90% pasture plus urban). When sites were separated by ecoregion, there was not a significant relation between turbidity and the proportion of pasture plus urban land use within the stream's watershed in the Boston Mountains. But, there was a relatively weak decreasing relationship within the Ozark Highlands ($r = -0.33$, $p = 0.02$; Figure 3b). Overall, the geometric mean turbidity values were significantly greater in the Ozark Highlands compared to the Boston Mountains across the 119 sites, where geometric means averaged 8.7 and 2.9 NTU, respectively ($p < 0.01$).

Total Dissolved Solids

TDS concentrations were variable within and across sites, ranging from a low of 7.5 mg/L at the upstream site to a high of 266 mg/L downstream at the WFWR. TDS concentrations significantly increased from upstream (geometric mean 38.2 mg/L) to downstream (geometric mean 143 mg/L), and the biggest increase occurred between Sites 5 (geometric mean 76.6 mg/L) and 4 (geometric mean 112.1 mg/L). TDS concentrations in the WFWR steadily increased moving downstream in the four most upstream sites, but concentrations generally leveled off at the five most downstream sites (Figure 2b). The TDS concentrations at the WFWR sites were also positively correlated to percent pasture plus urban land use in the drainage area ($r = 0.75$, $p = 0.02$; Figure 3c).

While TDS concentrations were not statistically different between the five downstream sites, Sites 1 and 2 were the only sites that violated the applicable WQS. TDS concentrations exceeded the limit of 150 mg/L in 44 and 50% of the samples collected at these sites, respectively (Table 2). The other Site (3a) in the Ozark Highlands exceeded the limit in 25% of the samples collected, close to violating the standard limit in *more* than 25% of the samples collected. The two more downstream Sites (3b and 4) in the Boston Mountains exceeded the TDS limit in 19-22% of samples collected, while the more upstream sites had TDS concentrations below the 150 mg/L limit in all samples collected.

The geometric mean TDS concentrations across all 119 sites showed an increasing relation with percent pasture plus urban land use in the watershed ($r = 0.68$, $p < 0.01$; Figure 3d). When separated by ecoregion, pasture plus urban land use in the catchment explained 31 and 17% of the variability in geometric mean TDS concentrations in the Ozark Highlands and Boston Mountains, respectively ($p < 0.01$; Figure 3d). There was a change in TDS concentrations when pasture plus urban land use increased above 35% within the drainage area.

Geometric mean TDS concentrations at the WFWR sites were within the range observed in the dataset of 119 sites in the same ecoregions (26.6 to 312 mg/L). When looking at this larger dataset, there were significant differences between the ecoregions ($p < 0.01$). The average geometric mean of TDS concentrations was greater in the Ozark Highlands (171 mg/L) compared to the Boston Mountains (90.4 mg/L), which is consistent with that observed in the WFWR watershed.

Sulfate

Sulfate concentrations in the WFWR were variable from upstream to downstream, as well as within a site, and these individual concentrations ranged from 1 mg/L at the upstream site (Site 8) to over 50 mg/L at the downstream sites (Sites 1 and 2; Figure 2c). Sulfate concentrations significantly increased from upstream (geometric mean 3.8 mg/L) to downstream sites (maximum geometric mean 27.9 mg/L) at the WFWR ($p < 0.01$; Figure

2c). However, there appears to be an abrupt change in sulfate concentrations between Sites 5 and 4. When geometric means were grouped by ecoregion in the WFWR, the average geometric mean concentration in the Ozark Highlands (25.5 mg/L) was two times greater ($p = 0.05$) than that observed in the Boston Mountains (12.6 mg/L).

The only sites that violated the applicable WQS for sulfate concentrations were the five most downstream sites (Sites 1 through 4; Table 2). These sites exceeded the applicable limit of 20 mg/L for sulfate concentrations in 63% or more of the water samples collected at each site over the study period (Table 2). None of the four upstream sites (Sites 5 through 8) violated the applicable WQS, where a total of only three exceedances occurred across these sites during the study.

Sulfate concentrations at the WFWR increased with increasing pasture plus urban land use within the catchment ($r = 0.73$, $p = 0.03$; Figure 3e), although there were really two groups of data that separated between Sites 5 and 4. This positive relation between geometric mean sulfate concentrations and pasture plus urban land use in

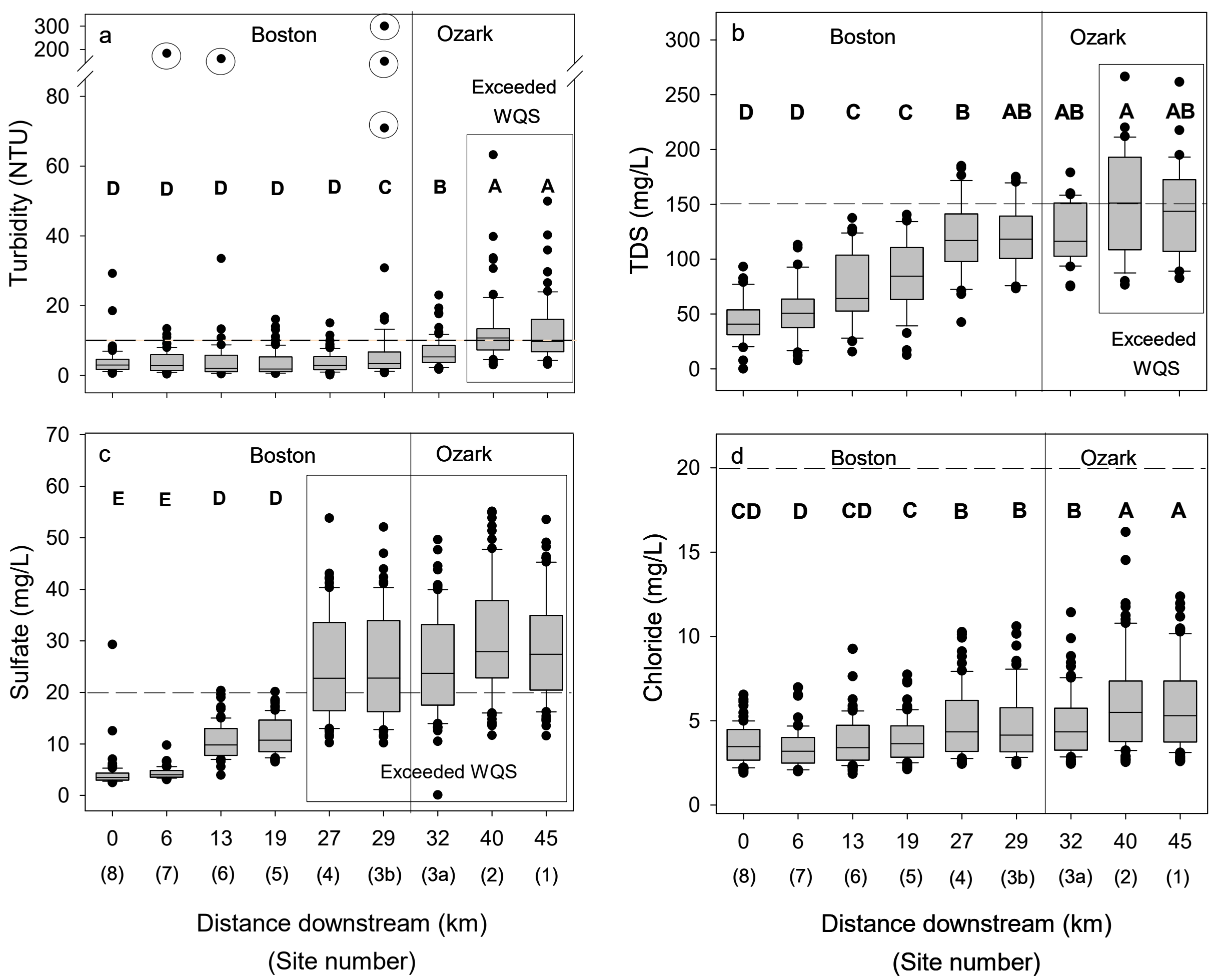

Figure 2. Box and whisker plots for (a) turbidity, (b) totals dissolved solids (TDS), (c) sulfate, and (d) chloride from upstream to downstream at the West Fork of the White River. The bottom and top of the box represents the 25th and 75th percentiles, respectively; the line inside the box represents the median value; the bottom and top whiskers represent the 10th and 90th percentiles, respectively; and the circles represent any observations that fall outside of the 10th and 90th percentile range. Horizontal dashed lines represent the relevant water quality standards (APCEC 2015) for the Boston Mountains ecoregion (left of vertical line) and the Ozark Highlands ecoregion (right of vertical line). For turbidity, the line is drawn at the "base flow" standard (data collected June 1 – October 31), but all the data are shown. Circles around five observations for turbidity identify sample events where in-stream activities with heavy equipment took place. Capital letters represent statistical differences across sites ($p < 0.01$).

Table 2. Percent exceedances of the constituent limit related to the applicable water quality standard (WQS) at sites along the West Fork of the White River. The horizontal dashed line represents the ecoregion divide between the Ozark Highlands (above) and the Boston Mountains (below). Bold values represent violations of the WQS. Constituent limits are given for turbidity (NTU), total dissolved solids (TDS; mg/L), sulfate (mg/L), and chloride (mg/L).

Site ID	Site Description	------- Turbidity ------- Base flow	All flow	TDS	Sulfate	Chloride
Site 1	Mally Wagnon Road	**47**	19	**44**	**77**	0
Site 2	Dead Horse Mtn Road	**59**	17	**50**	**79**	0
Site 3a	Tilly Willy Bridge (CR69)	6	6	25	**66**	0
Site 3b	Fayetteville Airport	6	4	22	**63**	0
Site 4	Baptist Ford	0	0	19	**65**	0
Site 5	Riverside Park	0	6	0	1	0
Site 6	Woolsey Bridge	3	3	0	1	0
Site 7	Brentwood Mountain Road	1	3	0	0	0
Site 8	L.P. Jarnagan Ball Park	1	3	0	1	0
WQS Limits	Ozark Highlands	10	17	150	20	20
	Boston Mountains	10	19	150	20	20

the catchment also was seen in the larger dataset of all 119 sites across the two ecoregions ($r = 0.59$, $p < 0.01$; Figure 3f), where the geometric mean sulfate concentrations ranged from 2 to 37 mg/L. When these data were separated based on ecoregion, pasture plus urban land use in the watershed explained 19 and 37% of the variability in geometric mean sulfate concentrations within the Ozark Highlands and Boston Mountains, respectively ($p < 0.01$). The average of the geometric mean sulfate concentrations was significantly greater ($p < 0.01$) in the Ozark Highlands (10.9 mg/L) compared to the Boston Mountains (5.3 mg/L). The spread in the geometric mean sulfate concentrations increased when the catchment had more than 30% pasture plus urban land use within it.

Chloride

Chloride concentrations were generally low and ranged from 1.8 to 16.2 mg/L across all nine WFWR sites during the study period. Chloride concentrations increased from upstream to downstream along the WFWR where the greatest concentrations were observed at the two most downstream sites, Sites 1 and 2 ($p < 0.01$; Figure 2d). None of the sites along the WFWR exceeded the limit of 20 mg/L for chloride in any of the samples collected (Table 2).

In the WFWR watershed, geometric mean chloride concentrations ranged from 3.2 mg/L at the headwaters to 5.6 mg/L downstream, and these geometric mean concentrations significantly increased with increasing pasture plus urban land use in the drainage area ($r = 0.86$, $p < 0.01$; Figure 3g). Chloride concentrations were also significantly different between ecoregions within the WFWR, where average geometric mean concentrations were 4.9 and 3.5 mg/L in the Ozark Highlands and Boston Mountains, respectively ($p < 0.01$). However, the geometric mean chloride concentrations across the WFWR were low relative to that observed more broadly across the ecoregions as seen in the 119 sites.

When data for all 119 sites were analyzed, geometric mean chloride concentrations also increased with increasing pasture plus urban land use in the watersheds ($r = 0.68$, $p < 0.01$; Figure 3h), where geometric means ranged from 1 to 40.5

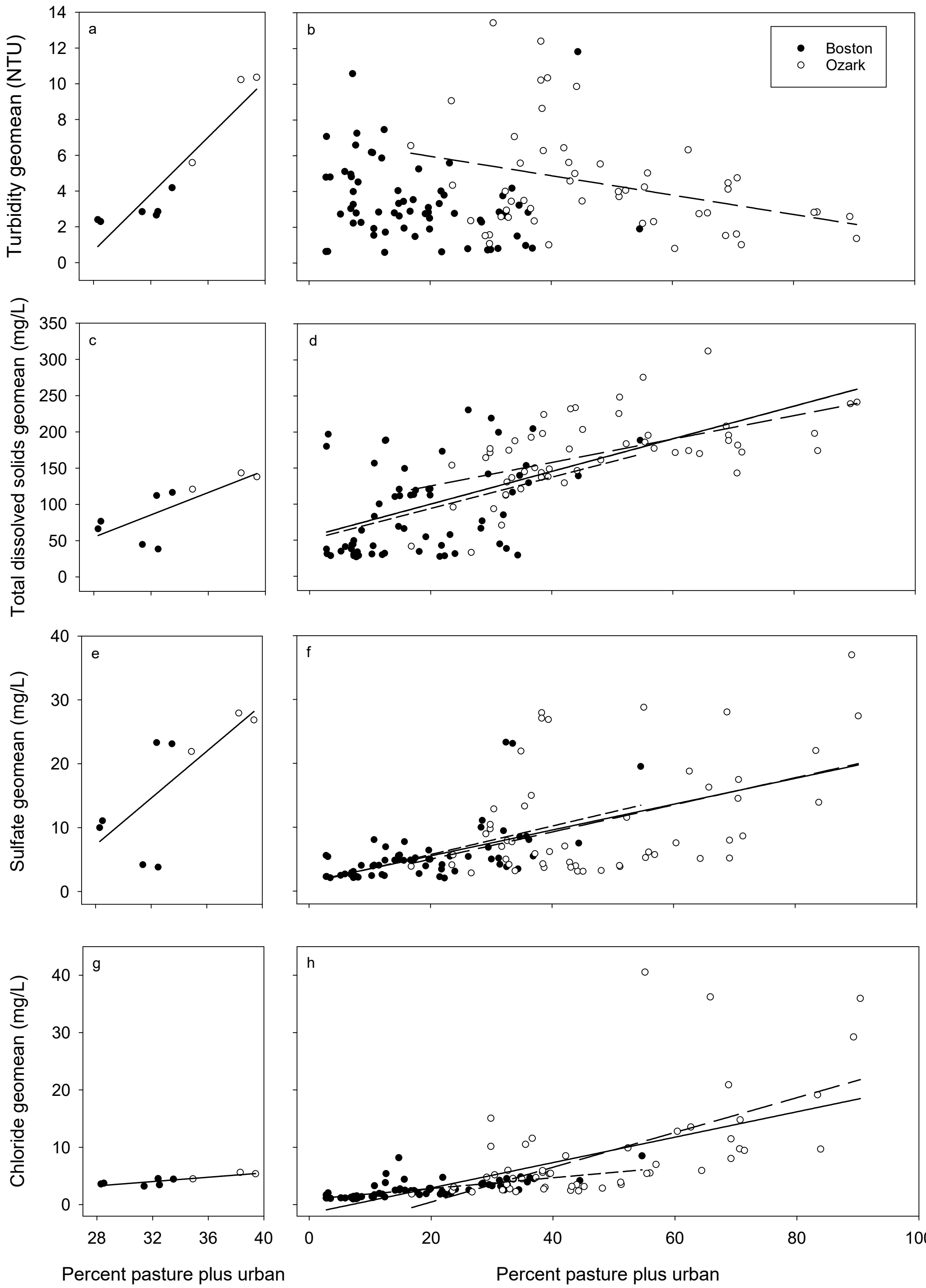

Figure 3. Geometric mean constituent concentrations versus percent pasture plus urban land use in the drainage area of study sites along the West Fork of the White River (WFWR). Panels show: (a) turbidity in the WFWR; (b) turbidity across all 119 sites; (c) total dissolved solids (TDS) in the WFWR; (d) TDS across all 119 sites; (e) sulfate in the WFWR; (f) sulfate across all 119 sites; (g) chloride in the WFWR; and (h) chloride across all 119 sites. Linear regression lines are shown for significant relationships ($p < 0.05$). Solid regression lines represent all the data, long-dashes represent data for the Ozark Highlands, and short-dashes represent data for the Boston Mountains.

mg/L across all sites. Percent pasture plus urban land use explained 46, 37, and 48% of the variability in geometric mean chloride concentrations in the entire dataset, the Ozark Highlands, and Boston Mountains, respectively ($p < 0.01$; Figure 3h). The central tendency of the geometric means also differed significantly among ecoregions, where average geometric mean concentrations were 8.9 and 2.7 mg/L in the Ozark Highlands and Boston Mountains, respectively ($p < 0.01$). The variability in geometric mean chloride concentrations with land use increased when pasture plus urban land use in the watershed was greater than 30%.

Discussion

Turbidity

Stream turbidity increased with human activities (measured as pasture plus urban land use) in the WFWR watershed, although the change in land use was relatively small (28-39%). Several studies have shown increases in stream turbidity along an increasing gradient of human activity and development in the watershed (e.g., Trimble 1997; Nelson and Booth 2002; Brett et al. 2005). Even low-level or small increases in human activity in the watershed have increased stream turbidity (i.e., agriculture plus urban land use ranged from 1-8%; Bolstad and Swank 1997). The land use change in the WFWR watershed could be influencing turbidity in the water column, although there may be other factors driving this change.

Much of the variability in stream turbidity was not explained simply by land use changes in the above-cited studies, suggesting that other factors and even natural sources more strongly influenced turbidity in those studies, as well as in the WFWR. Many states like Arkansas have ecoregion specific criteria, because ecoregions are defined by similar environmental characteristics such as climate, geology, and soil types (Omernik 1987). The turbidity data across the 119 streams support ecoregion specific criteria, because geometric mean turbidity levels were greater in the Ozark Highlands relative to the Boston Mountains. This is consistent with the downstream gradient in the WFWR, but it leaves us wondering why only the most downstream sites violated the WQS for turbidity.

In the WFWR, the primary component of turbidity is inorganic suspended solids, not organic matter (Cotton and Haggard 2011). The violation in the WQS for turbidity is likely not from increased algal growth in the water column, although we do see slight increases in sestonic chlorophyll-a concentrations (data not shown). The nutrient supply in the WFWR is relatively low, even at the most impacted site downstream (average soluble reactive phosphorus 0.003 mg/L and NO_3-N 0.228 mg/L, data not shown), and sestonic chlorophyll-a (2.0 µg/L; data not shown) would suggest that the WFWR is not eutrophic.

The change in turbidity levels along the WFWR coincides with changes in the dominant riparian soils. Cotton and Haggard (2011) showed that riparian soils change downstream, where the riparian areas around the two most downstream sites consist of Enders-Allegheny complex and Sloan, Razort, Taloka, and Pickwick silt loams. These soils have a higher erosivity index compared to most of the soils found further upstream in the riparian area (Cotton and Haggard 2011). Thus, the increased turbidity might be natural due to the change in soils or from fluvial channel erosion and instability where these soils are present.

In the WFWR, data showed that turbidity was elevated only at the two most downstream sites, spanning roughly 15% of the entire river. Yet, all 54 km have been on the State's 303(d) list of impaired waterbodies since 1998. That was, until, the State changed the way the WFWR is segmented. Ours and other studies provided scientific data that led to dividing the WFWR into two stream segments in 2018. The ADEQ segmented the river into two parts based on their identification of the ecoregion divide, between Sites 3a and 3b (ADEQ 2018). Now only the downstream segment is listed for turbidity, supporting a more focused effort to address violations of the turbidity WQS.

However, the information presented in this paper also suggests that the greater turbidity levels at the downstream sites, as well as across Ozark Highlands sites, might be driven by natural sources (e.g., riparian soil types). This leaves the question, is a limit of 10 NTU appropriate for all sites in the Ozark Highlands? Regulatory agencies should consider a variance in the WQS for select streams or reaches where the source is possibly natural (i.e., soil type in the riparian areas).

TDS, Sulfate, and Chloride

Some anthropogenic sources of ions, particularly sulfate and chloride, in watersheds include wastewater treatment effluent, industry, fertilizers, animal manures, and even road deicers (Herlihy et al. 1998; Khatri and Tyagi 2015). Many studies have shown that agricultural and urban land uses influence ion concentrations in streams, where streams draining agricultural and urban watersheds have significantly greater sulfate and chloride concentrations during base flow than primarily forested streams (Fitpatrick et al. 2007). For example, Wright et al. (2011) calculated mean sulfate and chloride concentrations in urban streams (30-70% urban land use) at 13 and 90 mg/L, respectively, which was almost twice as high as their reference streams (< 5% urban land use). The changes in ion concentrations downstream in the WFWR and across the 119 ecoregion sites fits this pattern, where sulfate and chloride concentrations increase with human activity and development in the watershed.

Chloride is naturally present in streams, and the magnitude of the concentration does vary with the underlying geology. But, chloride is an excellent conservative hydrologic tracer because it does not react physico-chemically in most freshwaters. That is why this ion often has a strong correlation to anthropogenic sources in watersheds, whether it be a signal of wastewater effluent in streams (Martí et al. 2004; Haggard et al. 2005) or nonpoint sources from the landscape (e.g., deicers; Khatri and Tyagi 2015). The sites along the WFWR did not violate the WQS for chloride, but chloride concentrations at the WFWR and across the 119 sites in the Ozark Highlands and Boston Mountains increased with pasture plus urban land use.

Rock weathering of underlying geology can influence mineral and ion concentrations of surface waters, especially at base flow when groundwater is the major source of flow. TDS and chloride concentrations gradually increased downstream along the WFWR (Figure 2), but sulfate showed an abrupt increase from Site 5 to 4, where Site 4 is approximately 3.2 km upstream of the ecoregion divide. This suggests that there may be a natural characteristic at play as the WFWR flows downstream. Indeed, King et al. (2002) developed a geologic map of the West Fork quadrangle, which brackets upstream of Site 6 and just downstream of Site 3b, and includes the abrupt change in sulfate concentrations (Figure 4). Their map shows a distinct change in the underlying geology near and just downstream of Site 5, where bedrock becomes more limestone and shale dominant, especially along the river corridor. The ecoregion boundary lies approximately 1.1 km downstream (north) of Site 3b, outside the view of the quadrangle shown in Figure 4. Relatively high sulfate concentrations can be found in streams and rivers in areas where the underlying geology is comprised of limestone (Khatri and Tyagi 2015) and shale (Cerling et al. 1989). The abrupt increase in sulfate concentrations at the WFWR might be from a natural change in the underlying geology.

The entire WFWR has been on the State's 303(d) list of impaired waterbodies for TDS and sulfate since at least 2010. After evaluating data from this study, among others, ADEQ segmented the WFWR along the State-defined ecoregion boundary in 2018. Now only the downstream portion is listed as impaired for TDS and sulfate, while the upstream portion is still listed for sulfate (ADEQ 2018). However, the segment divide occurs just downstream of Site 3b, which is approximately 9 km downstream from the change in underlying geology along the river corridor. This malalignment between the defined ecoregion boundary and the true underlying geology is likely due to insufficient data resolution when the boundaries were determined.

A sulfate limit of around 20 mg/L might be appropriate if the intent of the WQS is to preserve natural background conditions in the upstream reaches of the WFWR. However, the limit should also consider ecoregion divide, and even go further to identify variations in underlying geology. In the case of the WFWR, perhaps the ecoregion boundary should be moved to align with the abrupt change we see in underlying geology, where high sulfate materials like limestone and shale dominate. If the divide is redrawn where geology changes, then the river might be more appropriately segmented by ecoregion. The sulfate limit could then be adjusted to reflect the naturally higher concentrations expected in the Ozark Highlands compared to the Boston

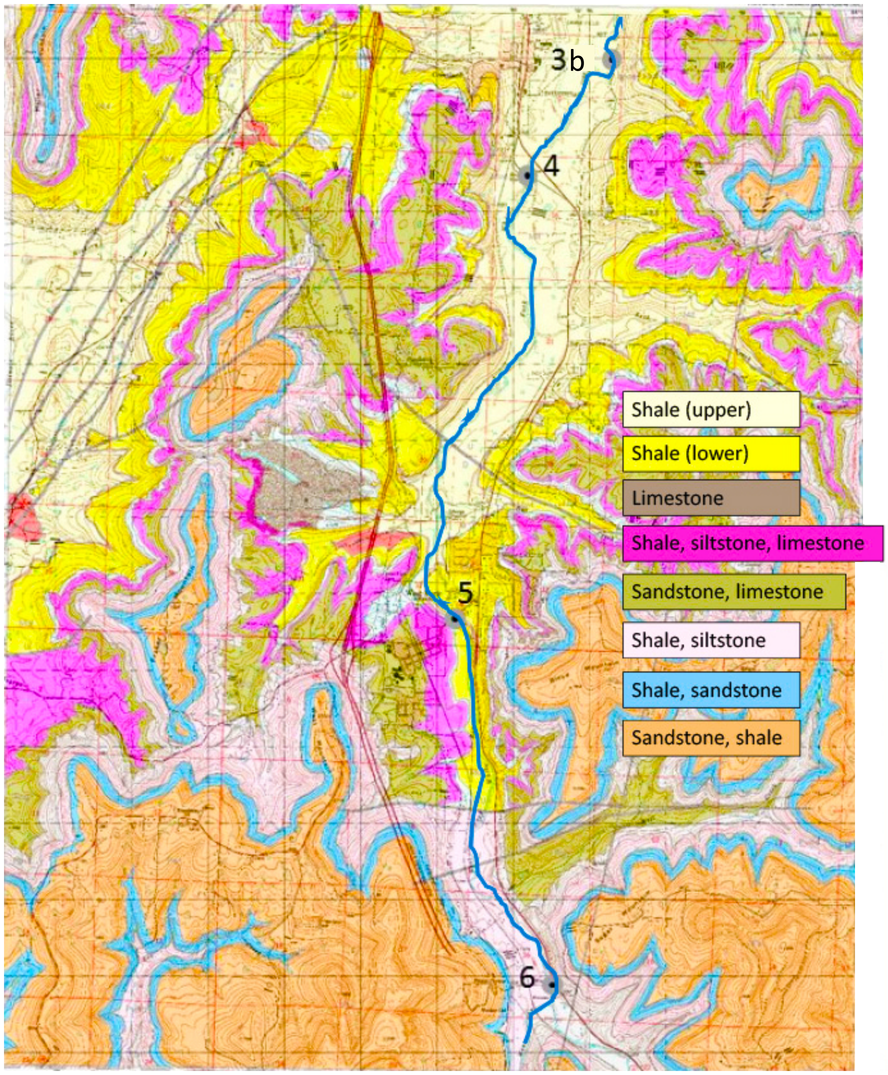

Figure 4. Map of the bedrock geology of the West Fork quadrangle, adapted from King et al. (2002). The blue line represents the West Fork White River (WFWR), which flows from south to north. The dots with numbers show sampling sites and the ecoregion divide is approximately 1.1 km downstream (north) of Site 3b.

Mountains, particularly when groundwater contribution is greater (e.g., during base flow).

The WFWR is designated for primary and secondary contact recreation; domestic, agricultural, and industrial water supplies; and aquatic life. The aquatic life use is often considered the most sensitive to increases in sulfate concentrations compared to other designated uses, and thus is the basis of the WQS in the WFWR (personal communication, Nathan Wentz, ADEQ). If the intent of the WQS for sulfate is to protect aquatic life, then the limit of 20 mg/L might be quite low. Sulfate concentrations can be as high as 129 to 262 mg/L and still protect the most sensitive species of fish, macroinvertebrates, and algae (Soucek and Kennedy 2005; Elphick et al. 2010; Table 3). In the WFWR, the greatest geometric mean sulfate concentration was 27.9 mg/L at Site 2, with a maximum observed value of 55.1 mg/L, well below the thresholds seen in the above-mentioned studies. Further, other designated uses have sulfate thresholds near the upper range for aquatic life, and even higher thresholds for industrial, irrigation, and some livestock uses (Table 3). TDS and chloride concentration thresholds to protect various designated uses are also much higher than the concentrations observed in the WFWR (Table 3; Figure 2).

Conclusions

Water quality changes from upstream to downstream in the WFWR, where turbidity, TDS, sulfate, and chloride concentrations increase as we move downstream. The entire 54-km long WFWR has long been on the State's 303(d) list of impaired waterbodies for turbidity, TDS, and sulfate. But, most of the WFWR had constituent concentrations that were within the allowable WQS limits. The results of our monitoring study led ADEQ to segment the river into two parts, such that the upstream portion has been removed from the list of impaired waterbodies for turbidity and TDS.

It can be hard to parse out the sources of increased turbidity, TDS, and sulfate in the WFWR. Our results suggest that, while these water quality variables increase with increasing human land use (e.g., pasture plus urban), riparian soil types and underlying geology also play an important role in the increasing concentrations we see. Watershed managers should consider the potential natural variability in constituent sources to waterways, such as variability due to changes in ecoregion designation. Further, when a river spans multiple ecoregions, the boundary should be drawn based on known characteristics, particularly underlying geology in the case of the WFWR. If the ecoregion boundary was drawn where the change in underlying geology occurs, then the upstream portion of the WFWR would also be removed from the 303(d) list for sulfate.

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Table 3. Threshold concentrations for TDS, sulfate, and chloride for the given designated use. Table includes the potential impact of exceeding the thresholds and the literature sources are listed.

Designated Use	Impact	-------- Literature Thresholds -------- TDS (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Sources
Aquatic life	Toxicity	-	129-262*	-	Soucek and Kennedy 2005; Elphick et al. 2010
Domestic	Taste; Laxative	500	250	250	APCEC 2015; USEPA 2018b
Industrial	Salinity	1000	500	-	Driscoll et al. 2002
Poultry	Flushing; Toxicity	-	200	150	Austin et al. 2016a
Cattle	Laxative; Toxicity	1000-2500	500	1500	Austin et al. 2016b
Swine	Laxative; Toxicity	3000	1000	250	Austin et al. 2016b
Irrigation	Salinity	-	300	142	Austin et al. 2017

*Range is for protection of the most sensitive species.

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General questions about the conference can be directed to Karl Williard (williard@siu.edu), Executive Director of UCOWR.

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