WATER IN GEOSPATIAL HIGHER EDUCATION: A DISCUSSION OF LESSONS LEARNED

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Abstract. Geospatial technologies and geographic methods are foundational skills in modern water resources monitoring, research, management, and policy-making. Understanding and sustaining healthy water resources depends on spatial awareness of watersheds, land use, hydrologic networks, and the communities that depend on these resources. Water professionals across disciplines are expected to have familiarity with hydrologic geospatial data. Proficiency in spatial thinking and competency reading hydrologic maps are essential skills. In addition, climate change and non-stationary ecological conditions require water specialists to utilize dynamic, time-enabled spatiotemporal datasets to examine shifting patterns and changing environments. Future water specialists will likely require even more advanced geospatial knowledge with the implementation of distributed internet-of-things sensor networks and the collection of mobility data. To support the success of future water professionals and increase hydrologic awareness in our broader communities, teachers in higher education must consider how their curriculum provides students with these vital geospatial skills. This paper considers pedagogical perspectives from educators with expertise in remote sensing, geomorphology, human geography, environmental science, ecology, and private industry. These individuals share a wealth of experience teaching geographic techniques such as GIS, remote sensing, and field methods to explore water resources. The reflections of these educators provide a snapshot of current approaches to teaching water and geospatial techniques. This commentary captures faculty experiences, ambitions, and suggestions for teaching at this moment in time.

INTRODUCTION

The intersection between geospatial theory and water resources in higher education is well established (Miller & Guertin, 1999; Wilson et al. 2000; Johnson 2016). Water is an inherently interdisciplinary area of study and broadly utilizes geospatial technologies to support hydrologic education in geography, engineering, forestry, biology, ecology, and numerous other disciplines (Tarboton et al. 2011; Evenson et al. 2012). We are interested in examining the specific ways geographic theory can help students better understand the hydrologic landscape and its relevance in our lives. How does geography provide unique vantages for considering water in terms of scale, pattern, and space? How can tools such as geographic information systems (GIS) and remote sensing provide a better understanding of water? How can practitioners apply geographic theory to address practical issues in water resources?

Geospatial techniques and geographic theory provide a methodological framework to understand our world through investigation of fundamental spatial concepts: place, scale, distance, resolution, distribution, movement, region, change, process, spatial association, and sustainability (VCA 2014). Learning objectives in geospatial education include training in "hard skills" such as spatial data fluency, data management, and spatial information science. Complementary "soft skills" include critical thinking, promotion of student creativity, and stimulation of life-long learning. Moreover, geospatial and geographic paradigms for understanding human-environment interactions, environmental governance, natural hazards, and nature-society politics provide key contextualizing frameworks for implementing these skills. To meet these objectives, geospatial educators incorporate a broad array of teaching approaches. Faculty utilize formal lectures, computer-based lab exercises (e.g. GIS), class discussions, applied projects, service learning, and field experiences. We consider various learning objectives and evaluate educational methods to bolster geospatial water resource instruction.

DISCUSSION

To structure our investigation of water in geospatial higher education, we identified three core questions and considered the influence of these ideas within our classrooms:

1. GEOSPATIAL THEORY & WATER RESOURCES

Core Question - How can educators employ geospatial theory to help students better understand water in terms of scale, connectivity, and spatial thinking?

1.1 SPATIAL THINKING

Spatial cognition (awareness) and spatial thinking (problem-solving) are two different but connected concepts. Current K-12 curriculum standards in the United States do not typically prioritize location-based thinking and students often describe a sense of placelessness and lack of location awareness (Metoyer et al. 2015; Verma 2015). Educators often utilize a mental maps exercise where students are asked to draw a map from their personal experience and knowledge of a place. However, these mental map activities focus on spatial cognition rather than deeper **spatial thinking**. While spatial thinking skills are often underdeveloped, these capabilities are core to applying geospatial theories in problem-solving. More could be done in the design of learning experiences to promote spatial thinking abilities.

Challenging students to envision the spatial configuration of their local waterways can be an enlightening exercise and interrogates any preconceived notions of expertise. Furthermore, comparing student awareness of local hydrology with the awareness of others can provide insight and push students to recognize not only their knowledge deficits but also the wide diversity in perceptions and environmental knowledge, demonstrating how different social, cultural, and economic contexts shape the everyday relationships and knowledge about water that people maintain. Much as cognitive maps of urban space can elucidate differences in place-based knowledge held by different classes and social groups (Knox et al. 2016), discrepancies in cognitive maps of local hydrology reflect economic practices and socio-ecological relations. For example, children in an agrarian community who contribute to shepherding may have intensely detailed spatial and temporal knowledge of the movement and storage of water in the landscape (Katz 1991), whereas urban youth may be limited in their knowledge about water to experiences in specific spaces of recreation, transportation, or industry.

It is also crucial to provide students with a working terminology to employ in spatial understanding and problem-solving. Fundamental to examining water resources are common concepts such as scale, pattern, and distribution, however, broader geographic concepts such as site and situation, spatial interaction, distance function, and others are equally important. Educators should invest time in allowing students to freely **explore maps** and interactive GIS interfaces to familiarize students with spatial thinking. Examination of maps encourages students to cognitively build an imagined space and provides a mental framework to analyze the configuration of water resource infrastructure, natural riparian systems, and the physical environment. This can also allow for insight regarding interconnected processes and promote contextual understanding.

Ask students to consider *how* people **produce space**. How does the construction of a bridge diminish the relative distance between sites on different sides of a river? How can the impoundment of water behind a dam alter a hydrological space and connectivity, both up and downstream? How do such transformations reconfigure spaces of economic and environmental flows? Representation of different spaces within our culture influences the way we conceive and exploit water resources. Cultural values and discourses about the environment also guide management decisions. The hydrosocial cycle is a useful tool that geographers have developed to better understand how the production of space integrates with perceptions, consumption, and governance of water resources (Linton & Budds 2014). The hydrosocial cycle demonstrates that all social relations are connected to water, and, conversely, that all epistemologies and practices used to manage water resources tend to reflect the social, economic, and other power relations of the human contexts in which they are conceived. Developing pedagogy that explores the geographical concept of the production of space can emphasize the value of interrogating the ways water resources are made legible, calculable, and manageable in relation to specific social and cultural norms and hegemonies.

To stimulate spatial thinking, conduct a guided pre-investigation and pre-staging of the environmental context before fieldwork analysis. This challenges students to build a mental conception of a location and then **validate** those assumptions (e.g. ground-truthing spatial point data) through their own **real-world experiences** such as hiking, traveling, or navigating independently. Consider "functional spaces" such as species habitats to help students visualize the spatial configuration and composition of a landscape within the framework of other subject-matter expertise, such as ecology. The overall pattern of a landscape helps guide and shape natural processes which in turn determine the composition and configuration of a given landscape. The composition and configuration of a landscape dictates the resulting distribution of the plant and animal communities seen, which is often of great interest to those studying the organisms which inhabit these areas. Examining functional space pushes students to use spatial knowledge in conjunction with other subject-matter expertise.

1.2 SCALE

Scale is a fundamental geographic concept and is an essential consideration when interpreting information, examining structural processes, or designing a research plan. It is vital that students understand that as the scale of study increases (or decreases) the processes affecting the system that is being studied will also change. For example, while local-scale erosion of the area next to a building where a downspout flows may rely on the same processes as rill and gully formation on the hillslope-scale, the processes that produce regional-scale features (i.e., drainage networks) are significantly different and independent from the local- and hillslope-scale processes (Phillips 1999).

Scale is also a vital consideration when teaching **spatial resolution**. Students must understand the influence of raster pixel size and the limitations caused by "mixed pixels" in land cover analysis. The **modifiable areal unit problem**, which is related to the spatial resolution of the data, can be exacerbated in dynamic systems such as water bodies in terms of scaling and zoning. The method used to convert point data to pixel regions affects all subsequent analyses including scale, connectivity, and the concept of the minimum mapping unit when landscape or climate co-variables are used in combination with water remote sensing datasets. MAUP problems can produce contradictory results when data are analyzed at different scales creating confusion in drawing firm conclusions. Hands-on practice allows students to understand the importance of these spatial decisions. Merging and aggregating data at different resolutions and capturing the ambient conditions at a point in time is a critical problem. Demonstrate these principles by physically collecting data and encouraging students to link water quality point measurements to geospatially derived datasets.

In addition to spatial scale, investigate the influence of **temporal scale**. While hydrologic data such as stream gage height is recorded every 15 minutes, some water quality data are sampled only a few times each year at infrequent, irregular intervals. Awareness of these limitations is crucial for students who will then interpret the water landscape using this information. An example of this issue occurs when examining different water bodies. Coastal areas are extremely dynamic due to tidal influences and wave action. In contrast, smaller ponds may be relatively stable with more homogenous conditions and longer residence times.

Understanding scale is also important when describing **positional accuracy** of geospatial data. The scale of analysis will determine the precision and positional accuracy needed for the vector/raster data being analyzed. Thus, the methods used to collect/georeference these data needs to be at the appropriate scale (e.g., recreation-grade GPS point locations versus survey-grade post-processed GNSS base station surveys). Repeated field-based activities teaches students that accuracy cannot be taken for granted and abundant validation is essential. When conducting field-based (or remotely sensed) change analysis it is important that students understand that they can only detect change greater than the accuracy (resolution) of their data.

1.3 PATTERN & CONNECTIVITY

Pattern and distribution of hydrologic phenomena are principal concepts. To successfully interpret hydrologic landscapes, vital skills include examination of stream networks, analysis of land use patterns, and consideration of precipitation distribution and timing. The understanding of spatial arrangement, pattern, and form also allow practitioners to evaluate how connectivity and fragmentation affect hydrologic systems. Teaching the importance of spatial patterns allows students to appreciate how local disturbances can influence an entire system depending on location and connectivity. Exploration of regional geography helps emphasize how processes on land affect the quality and quantity of water downstream.

The concept of river basins, catchments, and **watersheds** can be challenging to teach (Anandhi et al. 2017). Approaching these ideas through an interactive geospatial interface and allowing students to explore elevation models and streamflow data enhances learning, especially when students can (later) physically go to the places explored virtually. Lab exercises which emphasize the connectivity of hydrologic networks are crucial. Examination of upstream and downstream networks is a common and important practice within geospatial classes. Within specific locations of Georgia, identification of important geologic topographic features such as the Fall Line and Eastern Continental Divide can help students understand watersheds and the importance of location. Additionally, highlighting how water is shed off of campus parking lots towards storm drains and identifying where these storm drains ultimately empty provides a real world understanding of how water flows and how it actually can affect them (i.e., knowing where not to park during a large rainstorm).

2. GEOSPATIAL TECHNIQUES & WATER RESOURCES

Core Question - How can geospatial technologies (GIS, remote sensing) and geographic field experiences be designed to promote understanding of hydrologic processes?

2.1 GIS & REMOTE SENSING

GIS and remote sensing are powerful tools to help students understand and analyze water resources. Through innovative educational experiences with GIS, students gain the ability to acquire, manage, and examine geospatial hydrologic information (Mathews & Wikle 2019). GIS provides students with essential content knowledge in **data analytics** and **quantitative analysis**. Specifically, students acquire competency in spreadsheet management, data processing, and spatial statistics. Students can extract meaning from information through cartography and web map design (Manson et al. 2014). Data visualization helps students engage in the communication of science through graphic expressions such as scatterplots, time-series graphs, histograms, and box plots. These tools are essential when dealing with the diverse array of data types, including 2D and 3D hydrologic modeling data, often used in water resources research today. Geospatial technologies also provide awareness of the large variety of different data types and data sources and prepare students for applications such as hydrologic modeling.

GIS exercises increase awareness of data limitations and data precision. Exercises such as watershed and stream channel delineation are powerful examples of data creation and help students understand how data is produced. Evaluation of **data integrity** provides helpful preparation for applied water resources work. It is also important for students to **cross-validate data** such as land use and topographical models from a variety of sources. Comparing diverse datasets may uncover surprising patterns and expose unexpected spatial correlations. The opportunities for discovery and serendipity are rich within geospatial exercises and experimentation should be encouraged. Open-ended exercises asking students to brainstorm which hydrologic phenomena to map, which water quality parameters to examine, or what land use schema to utilize provide awareness about the creation of hydrologic information. Students gain an appreciation for the process of science, exploratory data analysis, and the act of knowledge formation.

GIS also allows for analysis of **change over time** at short and long-term temporal scales. Advancements in remote sensing such as cyber-physical systems-based frameworks (such as CyanoTracker), cloud computing, and increased access to mass quantities of data enrichen opportunities for students to engage with this information. The availability of high spatial and temporal resolution datasets such as the European Space Agency's Sentinel-2A and B (10-20m), and Planet Labs (3m) multispectral datasets allows for frequent water quality monitoring and mapping. Crowdsourcing and citizen science are often integrated with remote sensing modelings to target water bodies with persistent environmental issues. For example, CyanoTracker integrates remote sensing, crowdsourcing, and cloud computing to generate early warning information on toxic harmful algae in GA waters (Mishra et al. 2020). Similarly, innovative mobile applications such as HydroColor and CyAN can help lay citizens acquire water quality data using their mobile phones to monitor turbidity in their local waters (Schaeffer et al. 2018).

The selection of GIS software influences student experience. While advanced geospatial software offers powerful analytical capabilities, introductory level students and non-science majors may benefit from a **simple interface** to promote focused learning (Hammond 2019). In geospatial courses, students should be given abundant time to explore software and obtain advanced skills through repeated exposure to more complex programs. These interfaces also provide compelling **immersive visualization** capabilities. If field-based experiences are not feasible, visualizations can transport students to different locations and help develop their understanding of water resources through interactive virtual reality experiences.

2.2 GEOGRAPHIC FIELD EXPERIENCES

Field experiences are a critical aspect of geographic education and curriculum design should prioritize these activities. Link real-world phenomena with geospatial data to help students understand that data is merely a representation of reality and is therefore inherently limited.

Field experiences can also generate beneficial **active learning** opportunities (Bradbeer et al. 2004). Collaborating with students when designing geospatial field experiences helps students learn how to ask scientific questions (McKee & Hashemi-Beni 2020). Rather than learning through a traditional didactic approach, inquiry-based learning methods challenge students to hypothesize and test their expectations. These experiential learning practices stimulate the long-term retention of information (Mountrakis and Triantakonstantis 2012; Freeman et al. 2014).

Essential field techniques that should be prioritized in geospatial water education include measuring stream channel cross-sections and streamflow, navigating a terrain using a topographic map, mapping dynamic river networks, and identifying ephemeral and perennial streams. Field exercises include **source-to-stream** experiences where students follow a tributary from the headwaters downstream through multiple land use types. Another field-based experience is GNSS data collection and investigation of the accuracy and data limitations based on location (proximity to buildings and amount/distribution of tree cover, etc.). It is also vital to recognize the limitations of a purely technical approach. Field experiences must provide opportunities to use **qualitative experiences**, conversations with local people and lived interactions to understand the importance and value of water.

3. APPLICATIONS OF WATER GEOGRAPHY

Core Question - How can educators apply geospatial technologies and strategies to promote interdisciplinary examination of water resources and a more holistic conception of the link between water and place?

3.1 INTERDISCIPLINARY EXPERIENCES

Geospatial students typically specialize in an additional concentration to supplement theoretical geographic knowledge. Integrating a geospatial curriculum with **core concepts from water science** allows students to actively learn scientific principles and a specialized field of study through data analysis and spatial problem-solving. Applying geographic tools to address multi-faceted water resource problems is intuitive as geography and water resources are both inherently interdisciplinary (Pease et al. 2019).

Combining multiple data sources from a variety of hydrologic disciplines within a GIS allows students to cross-validate and **explore connections**. For example, combining hydrologic networks with demographic data may provide surprising insights about environmental justice, water access, and equity. A profound example of these kinds of insights can be found in Debbage (2019), which not only demonstrates disproportionately high urban flood risk for racial and ethnic minorities in the Charlanta megaregion but also shows how different ways of connecting demographic and flood risk data produce different measures of such disparity. A powerful exercise along these lines can be built around the EPA's EJScreen tool, which allows students to explore spatial relationships between demographic variables and environmental indicators such as the National-Scale Air Toxics Assessment, Toxic Release Inventory, and Discharge Monitoring Report, among others. Similar exercises can be developed to showcase local examples, such as overlaying a map of race in the Atlanta metro with a map showing recreational access points to the Chattahoochee River. As you move south and west from Lake Lanier across the metro area, an abundance of access points for the Chattahoochee abruptly ceases as soon as you cross the color-line where the neighborhoods become majority Black. The use of data from a variety of fields of study also provides students with a more holistic conception of the watershed as environment, society, infrastructure, political boundaries, and other data layers can deepen our understanding of water systems.

It is also valuable to expose students to information about water **careers** and provide opportunities to interact with **professionals** from a variety of perspectives. One way this can be achieved is through networking with local water authorities, organizations, and entities, as many are active in the surrounding communities. Other activities could include the academic department hosting seminars and/or other events inviting those professionals to share their work. Providing case studies, interacting with guest speakers, or watching recorded lectures from water professionals working in diverse specializations can help students gain awareness of different cross-disciplinary approaches (Hedberg et al. 2017).

3.2 PLACE-BASED LEARNING

Place-based education persists as a long-standing, high-impact learning methodology (Haskin 1999; Johnson 2012). In a "place-based" approach, faculty members select a specific location and dedicate a learning module or entire course to investigate the site using multi-disciplinary strategies. Students often actively research and deeply engage with the local watershed of their college campus. Exploring a local watershed through guided academic experience provides awareness of the physical setting and also incorporates an understanding of the communities, institutions, services, and policy decisions that overlap to create our environment.

Place-based exercises force students to more deeply consider the definition of "place". As Johnson (2012) states, "Place, rather than an abstract space, is a location endowed with meaning". Students consider how they perceive a local area and investigate how story, history, and context lead to the creation of "place". It is important to discuss native lands, the history of colonization, and the human influence on physical spaces. It is also valuable for students to consider which hydrologic spaces are "natural", "artificial", or "controlled" spaces (Fath & Beck 2005). How does our conception of nature affect our actions regarding water management, planning, and use?

3.3 COMMUNITY BASED EDUCATION & SERVICE-LEARNING

The value of water resources is intrinsically linked to local communities (Liguori et al. 2021). The health of water systems affects and is affected by the people that rely on these vital resources. To provide students with a comprehensive understanding of water, geospatial educators must address both the physical and social aspects of hydrology. Service-learning approaches allow students to actively experience the connection between people and water while also assisting the community and engaging with applied problem-solving.

Teaching strategies such as **community-based education** promote student learning by forming reciprocal and mutually beneficial partnerships between academic institutions and community members (Hawthorne et al. 2018). These service-oriented approaches can incorporate learning strategies such as collaborative projects, undergraduate research, common intellectual experiences, and community-based learning; all **high-impact practices** that increase student retention and engagement (Kuh 2008).

Theoretical approaches such as **sociohydrology** specifically examine the interactions and feedbacks between water and people (Di Baldassarre 2019). To apply these ideas within a geographic approach, **community geography** includes "collaborations between academic and public scholars resulting in mutually beneficial and co-produced knowledge" (Shannon et al. 2020). To best serve communities, it is also valuable to share technological knowledge with community members. **Citizen science** approaches allow community members to directly contribute their knowledge and experiences (Buytaert 2014). If possible, it is helpful to use local, multi-generational knowledge so that students gain awareness of the importance of partnerships and multiple perspectives. **Collaborative mapping** projects also provide powerful opportunities to build geospatial partnerships.

Experiential, active learning increases student engagement and improves the long-term retention of information (Qualters 2010). It is valuable to connect students to something relevant in their lives. When students can investigate issues they personally care about, they will become more passionate about the course and want to develop the geospatial skills to help them succeed (Pawson et al. 2006; Ursavas & Aytar 2017).

CONCLUSIONS

Linking geospatial concepts and hydrologic subject matter creates extraordinary opportunities for higher education students and educators. Geospatial technology provides a powerful toolset for the analysis of water resources and strengthens student's critical thinking and quantitative reasoning skills. In addition to technical geospatial training, students benefit from engaging with a strong conceptual framework in geographic theory to properly utilize geospatial techniques and to understand the integrated human-environment hydrologic system (Murphy 2007). Applied exercises in water geography and geospatial technology allow students to practice asking spatial questions and applying the scientific method to solve problems. Students receive a strong foundation in spatial data science to carefully evaluate and utilize hydrologic information.

The ideas captured here represent current reflections based on the teaching experiences of numerous faculty. However, to better understand the role of water in geospatial higher education, we recommend additional pedagogical inquiry. Primarily, it is vital to validate teaching practices and assess teaching efficacy (Baker et al. 2015). In addition, the creation of a centralized statewide repository for geospatial course materials would help educators share teaching resources and lessons learned.

The ability to think geospatially gives students a new perspective about water resources. Students are empowered with the ability to ask geographic questions and gain a more holistic understanding of hydrologic processes. Geospatial technologies such as GIS, remote sensing, and field methods provide a robust technological foundation while geospatial theory provides students with a profound new perspective to understand our vital and dynamic water systems.

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