Commentary

Empowering the Next Generation of Watershed Decision-Makers: A Pedagogical Design

Jim Perry ^{1,*} and Louise Thompson ²

¹ Department of Fisheries, Wildlife and Conservation Biology, University of Minnesota, Minneapolis, MN 55455, USA

² Natural Resource Science and Management Graduate Program, University of Minnesota, Minneapolis, MN 55455, USA; louise.thompson061@gmail.com

* Correspondence: jperry@umn.edu; Tel.: +1-612-5245-4717

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Abstract: Watershed management is the art and practice of understanding stakeholder values for ecosystem services within a watershed and instituting management practices that consider trade-offs to sustain these goods and services. Effective watershed management practices are hydrologically defined, ecosystem-based, inclusive, and integrate biophysical as well as socioeconomic decisions. The uncertainties and unpredictability of climate change create an ambiguous backdrop to the increasingly social problem of water resource management. Inequities in watershed decision-making processes often lead to the reinforcement of power and resource imbalances. Future watershed managers must be able to engage across socioeconomic and cultural boundaries to support decisions that advance water as a human right in an uncertain future. We offer a design for a graduate level, 15-week university course that uses publicly available resources to help emerging watershed leaders prepare for an uncertain future. The design is interactive and constructivist, engaging the refereed literature and leading to an increased understanding of ecosystem-based watershed management under climate scenarios, with special attention to vulnerable populations.

Keywords: watershed management; graduate education; decision-making; water resources

1. Introduction

Watershed or catchment management is the art and practice of understanding stakeholder values for ecosystem services within a watershed, then enacting management to balance trade-offs and sustain those goods and services. In any given watershed, societal goals include a range of ecosystem services; in most cases, demands compete, requiring trade-offs. Water quality, generally influenced by non-point sources, infrastructure development, and water allocation are examples of important drivers of ecosystem services. Recognition that decision-making in the face of competing values has transformed a traditionally formal, fragmented management practice into an informal, collective one, increasing the need for equitable, adaptive approaches to watershed management [1].

Informal, collective management strategies rely on participatory approaches to generate social learning [2], a process defined as the collaboration among diverse individuals and organizations to reach shared understanding for collective action [3,4]. This process engages stakeholders to identify and prioritize trade-offs to form common goals, building capacity for sustainable watershed management [5]. The practice of collective management is supported by a wide range of capacity development efforts from local to international, that suggest management based on hydrologic boundaries rather than geopolitical ones provides greater transparency and accountability [5]. An example of the increasing breadth required with this new perspective is the new US Environmental Protection Agency requirement that cities and towns offer educational programs to help residents

understand how stormwater operates at the watershed scale [6]. Using hydrologic boundaries to facilitate ecosystem-based management increases environmental awareness and responsibility, thereby increasing the likelihood of stakeholder engagement in water quality improvement efforts [6,7]. Further, engaging stakeholders in the process of managing watersheds as ecosystems ensures that management functions across political boundaries to promote collaboration, innovation, and adaptation [1,8].

While participatory approaches aim to include all stakeholders [9], they often lack representation of all social and economic conditions [10]. Deeply embedded historic, cultural, and socioeconomic inequities [11] leave decision-making weighted in favor of elite, powerful stakeholders [1]. These systemic inequities often leave watershed managers blind to socioeconomic disparities [12], extending the negative impacts of inequity to water resources [11]. As a result, vulnerable populations who face the greatest risk from climatic change are left with little to no influence on watershed management decisions [13,14]. This lack of inclusion leads to management plans characterized by limited consideration for the breadth of stakeholder livelihoods [12]; yet that consideration is a necessity for long-term climate change resilience [15]. Without inclusivity, watershed management programs often fail [16], highlighting the importance of equitable practices.

Watershed governance, the administrative processes, and institutions that uphold stakeholder values also rely on the involvement of a diverse range of stakeholders [8]. Such inclusivity is becoming vital as watershed governance is inextricably linked to water security [17], which is characterized as access to water of adequate quantity and quality and is a global necessity for societal function. As climate change threatens to exacerbate water insecurities [18], communities lacking the capacity to adapt (e.g., those who are marginalized or low income) will face risks associated with loss of livelihood, health, displacement, and food insecurity [19]. The increased water insecurity that results from inequality emphasizes the importance of incorporating water security into decision-making. Decisions that advance water security can be made through management at the watershed scale [20] if supported by inclusive, equitable watershed management [21].

As the focus of watershed management has shifted from environmental to social [5,12,22], tools and approaches that go beyond traditional watershed management training must ensue [23]. This need is reflected in the failure of plans lacking inclusion [11] and climatic sensitivity [24]. Tools and approaches failing to emphasize future climatic (and socioeconomic) uncertainty will fail to maintain water quality [24]. Long-term success is fostered through innovation, adaptation, and relational governance and is dependent on the formation of inclusive groups [5,8]. Professionals with the ability to navigate the ambiguity of future climates and engage stakeholders across socioeconomic and cultural boundaries [24,25] will become indispensable.

Developing the cadre of professionals to meet those needs requires innovative approaches to education [26]. Such approaches should incorporate educational tools that mimic water resource complexities, leading to knowledge that is transferable [26]. This view is supported by Martinez et al. [22], who argue that if universities expect to be contributors to sustainable development (and by extension, watershed management), they must be more innovative in incorporating societal necessities and demands. Traditional graduate and professional training programs rely on implicit linkage among isolated, disciplinary fields [27,28]. This siloed educational model sustains the lack of meaningful integration among scientific research disciplines [28]. Natural resource science is often practiced as if it is void of contextual knowledge characteristic of social science fields [28], leading to single-dimension management strategies that are unsuccessful.

The future of water resources, often termed Rio-to-reality [20] requires interdisciplinary approaches to education, approaches that remain uncommon [27]. Effective alternatives to the traditional siloed approach will be interdisciplinary and will educate for change [25], preparing professionals for an unknowable future. It is well understood that learning is more effective when we cross professional boundaries, ideologies, and disciplines [29]. In such an interdisciplinary approach, each person is bounded by life experiences, yet brings an individualized contribution to collective learning [30]. Experiences have shown that when water-resources students are engaged in

collaborative education, each bringing individual strengths, group learning is optimized [31]. A variety of water-resource graduate programs have emerged recently to advance this need. The DANCERS program along the Danube [32] and the Vienna Doctoral Programme on Water Systems (DK-WRS) are interdisciplinary and innovative examples of resident programs. The Online Watershed Learning System (OWLS) is an example of a graduate program that allows access to virtual watersheds for study [33]. The more innovative of such programs explicitly incorporate risk analysis [34] and simulation of alternative futures [26]. The DK-WRS has identified three principal challenges to be addressed by emerging interdisciplinary programs: Integrating several disciplines, maintaining depth, and teaching subjects remote from a student's home discipline [29].

Effective instruction occurs when student preconceptions are challenged to either grow or diminish in accordance with disciplinary knowledge [8,31]. However, traditional classroom environments often lack the reciprocal communication required to obtain and utilize student preconceptions [31], leaving conceptions unchanged [35]. Solutions can be found in constructivist approaches [36] in which students collectively engage in the formation of their knowledge, using the instructor as a resource. Constructivist learning approaches knowledge as a malleable concept formed by experience [31]. Although experiential learning in water-resource programs is widely accepted and practiced at the graduate level [37], curriculum designs that meet the interdisciplinary demands of natural-resource management have yet to take hold [27]. Institutions of higher education face growing responsibility to produce professionals capable of operating within dynamic social and environmental systems [25], helping emerging professionals develop the adaptive skills to manage for an unknown future [25]. Professionals who express knowledge, leadership, and understanding across disciplines promote group diversity, information sharing, and innovation [25]. These skills are vital for inclusive decision-making, participatory representation, and awareness of reflexivity [38] because they generate the adaptive capacity necessary under climatic and social uncertainty [25].

Yet, a need remains unfulfilled. Several innovative graduate curricula have emerged (e.g., Water in the West [39], DK-WRS [29], DANCERS [32,34]), but the literature does not offer a structure for a constructivist, interdisciplinary graduate class that can lead interested students into the discipline. We offer such a structure here. Further, integrated watershed management is complex and most often burdened by insufficient information for informed decision-making [40]. Climate change adaptation is inherently uncertain [41] and requires that uncertainties be estimated even if the bounds around uncertainty are large [42]. In such settings, expert opinion serves as a tool for identifying and considering the significance of possible futures [43].

2. Design

2.1. *The Adaptive Watershed (TAW): A Capacity Development Tool for Watershed Managers*

TAW (<https://www.iisd.org/project/adaptive-watershed-training-watershed-based-adaptation-and-management>) is a capacity development program developed by The International Institute for Sustainable Development (IISD). It serves as a tool to assist watershed stakeholders in construction and implementation of watershed plans [44]. Using the concepts of ecosystem management and adaptive management, TAW emphasizes action and inclusion to develop management plans that are holistic and dynamic. Ecosystem management ideas encourage users to bring social, economic, ecological, and physical systems as variables into a relationship that results in economic and environmental security for humans and other elements of the ecosystem. Adaptive management adjusts for changes in social, economic, ecological, and physical systems by helping participants prioritize goals and implement solutions [45].

TAW brings together both social and ecological management perspectives, organizing information by themes and modules, structured as a three-day workshop aimed at improving management effectiveness. TAW has three themes (Figure 1): (a) Understanding our watershed and our people, (b) making informed decisions, and (c) inclusive management: Committing to action and evaluation.

The themes are implemented through 14 modules designed to advance collaboration among stakeholders. Watershed management plans developed using TAW are inclusive and employ Integrated Water Resource Management (IWRM) principles to generate resilience to climate change scenarios by incorporating adaptability to changes in political, environmental, social, and/or economic landscapes.

Figure 1. Logical flow of The Adaptive Watershed's (TAW's) approach to capacity development.

2.2. The Watershed Health Assessment Framework (WHAF)

The WHAF is a GIS-based visualization and data analysis tool developed by the Minnesota Department of Natural Resources [46]. The WHAF perspective recognizes intricacies between natural and human systems and identifies patterns across these interactions, compiling information into component scores (Figure 2). Components are scored using a three-tier system, with each tier ranging from 0 (unhealthy) to 100 (healthy). The lower end of the scale represents increased impairment and increased risk; the higher end represents lack of impairment and low risk. The first, and largest, component is termed watershed health. Health scores are watershed wide, and are developed from the average of five second-tier component scores. The five sub-components are: Biology, connectivity, geomorphology, hydrology, and water quality. Each of these sub-component scores is derived from the average of third-tier index scores. Index scores are the average of a range of GIS-based variables collected by a range of public agencies. Scores for indices, sub-components, and components allow the user to explore watersheds, identify stressors, and assess conditions and management practices that represent watershed health [46]. The WHAF also allows individuals to create and share map layouts, providing opportunity for wider communication and collaboration among stakeholders and watershed managers. The WHAF is a valuable watershed management tool because it compiles large data sets from many publicly available sources to highlight areas of concern over a wide range of spatial scales. Areas of impairment or concern represent water quality management opportunities. Beyond water quality itself, the WHAF is a GIS tool that facilitates spatial analysis of watersheds. The spatial decision-making the WHAF allows could be adapted in any catchment or watershed and could address any suite of societal needs such as dam replacement, land use change, or infrastructure.

Figure 2. Examples of Watershed Health Assessment Framework (WHAF) health scores from the Pine River Watershed, Minnesota (MDNR WHAF, 2018).

Used together, the WHAF and TAW encourage users to employ holistic tools and perspectives to generate depth and breadth, creating inclusive, adaptive, robust, pro-active watershed management plans. If watershed management is viewed as an equation, TAW provides the philosophical approach with an emphasis on human dimensions and the WHAF offers the variables and visualization tools needed for effective management. The combination is a suite of publicly available management and learning tools for inclusive watershed management under climate change scenarios.

2.3. The Pedagogical Design

This is a pedagogical design for a graduate level class intended to lead students into the discipline and demonstrate interdisciplinary thinking. It combines TAW and WHAF in a class that would support development in water resources, watershed management, sustainability, or environmental management. The approach includes a discussion of peer-reviewed papers that complement TAW modules and a writing experience to combine the elements of TAW and WHAF. The TAW is the core philosophical approach, the WHAF offers real data for analysis, and the refereed literature provides theoretical grounding. The innovation offered in this paper is the linkage among the three and the constructivist approach as students and instructor develop new learning through discussion and writing.

Discussion leadership alternates among participants. Each week one student identifies and distributes a relevant journal article for other students to study. Papers are selected to complement that week's TAW module. To open the discussion, the leader discusses the keywords that were used to locate the journal article and opens a discussion on the goals and contributions of the module.

Students are offered the following as guidance for reading and leading discussion of individual papers:

- Imagine that you have been invited to lead a workshop in a relatively small (e.g., 10,000 km²) watershed in any country you choose.
 - How will you introduce the module and get people interested?
 - What is the content and the flow of the module; what do you see as its contribution?
- Think about the paper you chose as a complement.
 - Does it have clear questions? Are those presented and framed well in the context of recent and relevant literature?
 - Are the methods clearly presented? Do you feel they are appropriate for the questions the paper is trying to address?
 - Are the data presented in clear and meaningful ways? Are the figures necessary and sufficient?

- Do you understand the data analyses? Are those analyses appropriate for the data and the questions posed? Were they performed correctly? Do you feel the assumptions of the statistical techniques have been met?
- Are the interpretations clear and logical based on the data and analyses? Has the literature been used correctly to synthesize and interpret the results?
- Do you feel that the questions and/or hypotheses posed have been addressed adequately?
- Based on what you understand of the module and the paper, where will you lead us? What do you hope we see and understand at the end of the discussion?

2.3.1. Writing

A writing component is an essential part of the workshop, because graduate students receive great benefit from refining and practicing writing and editing skills. In this simulation, each student develops a paper written for a watershed manager or training leader. Writing that is targeted to an action-oriented audience (e.g., a watershed board) must be succinct. Therefore, students are asked to produce a focused, intensive document to challenge each person to think more deeply and write more concisely. This exercise helps each student hone skills he/she will need in graduate school and in a professional career. The paper is intended to tie together TAW and WHAF methodologies to produce a climate-sensitive action plan for the watershed. By using both the WHAF's ability to locate and analyze watershed data and TAW's ability to engage diverse stakeholders, students learn how to construct ecosystem-based, inclusive, adaptive watershed management plans. The paper is framed as actions the watershed board could take in the next 3–5 years to best prepare residents/citizens for the climate conditions predicted for 2050.

The paper proceeds through two phases:

- *Use the WHAF and any other available information to characterize the watershed.* This phase includes land use, water resources, and human dimensions (e.g., demographics, economics). The product is a 5-page analysis that demonstrates an understanding of land use and water resources in a watershed, ties together land use and water quality, and would serve as a background white paper for a watershed board in an actual professional experience.
- Each student is then offered a 2050 predicted climate scenario for each of two sub-basins and is asked to propose management strategies that will increase resilience and would be undertaken in the next 3–5 years. This product is a 5–7-page paper that would be offered to a watershed board for discussion and action. The paper details anticipated changes in water quality and other watershed variables based on predicted 2050 climates and suggests actions (e.g., BMPs to be considered) that would increase resilience. In this classroom setting, proposed changes are based on informed opinion. Clearly, such proposals would not be implemented on the ground without further development. We see two examples of such further development: In a more advanced class (e.g., impaired waters, land-use planning), teams of students might model variables such as land use, hydrology, economics, and water quality. In a watershed board setting, the board members would evaluate this first cut, and commission a more in-depth analysis of some alternatives.

Each person receives peer and instructor reviews of his/her paper after each phase. Students present their proposed strategies in an open forum at the end of the semester, using PowerPoint visuals. That final discussion is interactive, with each person receiving comments from others in the room. Finally, each person revises and submits a final document intended to represent a transmittal to the watershed board. Our assessment approach was similar to that used by [27]; skill development was assessed via reflective writing assignments and presentations that were graded by standard rubrics using Bloom's taxonomy of learning domains.

We tested the design with a 15-week class of Master's and Honors students. We asked for anonymous feedback on the design after weeks five and ten, as well as at the end of the semester. There was apparent growth in understanding and engagement as the semester progressed. We did not

have a final assessment (e.g., final exam to test objective knowledge). In general, student comments were very positive and each felt that understanding the linkage between TAW and the WHAF was a meaningful and useful investment of time. Exemplary comments from three evaluations included:

“Reading the TAW modules and journal articles individually helped to meld our perspectives and understanding during discussion. I felt that this added level of responsibility, paired with the element of choice, led to a more engaging, active learning experience. I think that applying TAW to selected peer-reviewed journals was especially relevant because it simulated the complexities watershed managers face. Understanding that watershed management is an extremely diverse and integrated vocation, I appreciated the opportunity to navigate each watershed’s uniqueness in terms of current and future environmental, social, political, and economic climates. This experience gave me a broader understanding of the range of tools available and appropriate given a range of conditions.”

“I found that this structure transferred well when characterizing our watersheds using the WHAF tool and added another layer of professional resemblance. Writing to a watershed board with suggested actions meant exploring the TAW and WHAF data to determine which information was pertinent to the development of a watershed management plan under future climate conditions. I felt that this structure gave context to our understanding of watershed management and allowed us to apply it in a more professional and interactive way.”

“Overall, what we learned was very buildable, each unit added another dimension of understanding regarding relationships between people and water quality. I believe that this experience increased my ability to think critically and with elasticity, skills that I now see as critical to the development of effective watershed management plans.”

2.3.2. Replicating the Experience

Our intent with this paper is to offer a future instructor a blueprint that would allow our experience to be replicated. The reason for doing so is to provide a single class an interdisciplinary graduate level experience in water resources, introducing students to integrated decisions and adaptive futures. The use of TAW and the WHAF make the approach generic; as a thought exercise, this is a decision simulation that is applicable in any landscape, addressing any suite of drivers governing landscape change. The process for doing so is to build a flow (expected 15 weeks) during which each TAW module will be discussed. Each week has a student leader assigned; that person locates and distributes a paper from the literature that complements the TAW module of the week. Each weekly discussion develops an understanding of the ways that TAW modules advance integrated watershed management. In parallel, each person is assigned a watershed from the WHAF. Through several weeks, he/she develops a characterization of the watershed as described above. That first paper receives peer and instructor reviews and each person receives climate scenarios for two sub-basins. Fine-scale climate predictions are readily available from any state or provincial climate office in the US or Europe and from many national climate offices in other countries. Because the intent is a thought exercise incorporating decision-making under uncertainty, it is not necessary to have precise future climate predictions. In this second phase, each person develops an understanding of anticipated land use and socioeconomic changes that might parallel each climate scenario. He/she then suggests a series of strategies a watershed board might consider as adaptive management. That second paper also receives instructor and peer reviews.

3. Discussion

Future watershed management will require watershed plans that are highly contextual both socially and environmentally [47]. This requires that watershed managers function in the complex science of the “total environment” [32], moving beyond traditional, myopic practices that focus solely on the biophysical properties of a watershed [48] and incorporating aspects such as traditional ecological knowledge [47], economic development, education, and community development [12]. In the same context, water resource education must advance development of managers who

can address a range of competing societal issues such as water scarcity, agricultural impacts, and climate change. Such practice requires managers to incorporate existing knowledge and policy networks, which requires cultural sensitivity and highly sophisticated management, communication, and negotiation skills [32]. Policy in the US (and elsewhere) currently assumes that watershed managers have the skills and knowledge to be able to facilitate these participatory approaches effectively [49,50], but that is not generally the case. To effectively facilitate collaboration and participation, watershed leaders must incorporate social science [51], a domain neglected in most natural resource academic programs [27].

Effective watershed management is an integrated and dynamic process. Participatory decision-making and effective participation are vital functions of watershed communities facing exceedingly complex and unpredictable climatic change [5]. Climate change is a multiplying influence (i.e., it exacerbates the negative impacts of other influences). Adapting to climatic change requires collaborative efforts among all stakeholders [12] to learn from and develop a long-term response to disturbances [15]. Further, a community's adaptive capacity is a result of combined social and institutional effectiveness [15]. Due to this, a community's ability to endure change and continue to function will be a requisite component of watershed governance [52].

The pedagogical design we offer here is constructivist, based in the logic and practice of collectively developing knowledge through interaction. When people effectively interact with others through a cooperative framework, interpersonal skills and problem-solving abilities are enhanced [53]. The ability of a group to think creatively is related to the ability of the members to collaborate, a skill that is essential in effective watershed management [25]. Providing students with a philosophical model of watershed management (i.e., TAW) and authentic data for informed decision-making (i.e., WHAF) galvanizes learning and motivates participants to apply their knowledge to develop adaptive alternatives [54]. The pedagogical model we offer here is grounded in publicly available tools but is applicable to any classroom and watershed setting. By engaging with this approach, future watershed or catchment managers develop hands-on experience in developing and evaluating alternative futures for water resources. The public nature of TAW and the WHAF give every person the opportunity to think through scenarios. Yet, the WHAF is used here only as a tool for visualization. An instructor will lead students through exemplary scenarios and adapt the discussions to catchment changes most relevant in the area of interest (e.g., water scarcity, dam removal, flooding).

4. Conclusions

Water quality management is most effectively accomplished when approached as managing ecosystems at the watershed or catchment scale. Ecosystems are subject to changing climatic as well as socioeconomic conditions. Future watershed managers must be sensitive to, and skilled at engaging with, a wide range of technical and human dimensions variables to guide sustainable, resilient management. We offer a pedagogical design for graduate students and professionals that uses publicly available tools and follows constructivist learning. The design is interactive and scaffolded, such that early learning leads to deeper thought. It empowers participants to consider climate-sensitive watershed management that explicitly encourages participation of vulnerable communities and advances an integrated approach to adaptive resilience. The design uses a free spatial visualization tool based in a US landscape and allows instructors to tailor the discussion to address the water-resource issues most relevant in the catchment(s) of interest. The result is a collaborative experience leading to more thoughtful, more integrative watershed professionals.

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