Investigating the Influence of Ethical and Epistemic Values on Decisions in the Watershed Modeling Process

Autumn R. Deitrick, Sarah A. Torhan, and Caitlin A. Grady

1Department of Civil and Environmental Engineering, Penn State University, University Park, PA, USA, 2Rock Ethics Institute, Penn State University, University Park, PA, USA

Abstract Throughout the watershed modeling process, modelers, collaborators, and stakeholders make decisions about how to study various challenges that impact watersheds. To understand these decisions, we investigated values held by modelers who have worked or collaborated on projects within the Chesapeake Bay Watershed and their influence on decisions made during the modeling process. Using a mixed-methodological approach, we designed an online survey and semistructured interviews to evaluate these complexities. In total, we received 27 survey responses from Chesapeake Bay Watershed modelers and conducted four semistructured interviews. The results indicate that ethical and epistemic values impact every stage of the watershed modeling process. These values occur alongside decisions, motivations, outcomes, and objectives that often involve collaborators and stakeholders in addition to the modelers. Therefore, including these values in scientific discourse can increase transparency around watershed modeling that guides policy decision making processes. Our results articulate that a discussion of the ethical and epistemic values present throughout the watershed modeling process should be incorporated into model documentation to clearly explain assumptions and decisions.

Plain Language Summary Scientists use watershed models to determine how activities like farming and land development impact our waterways. Watershed models are computer-based tools that allow the user to input information, such as land use, fertilizer use, and types of agricultural operations, to predict how these factors might contribute to pollution in waterways. Modelers often work alongside other people to determine what information should and should not be included in a model. During this process, modelers must make various decisions that can impact how the model predicts pollution levels, which has implications for policies established by decision makers. Like all people, modelers have their own values that can influence their decision making. Our work seeks to understand if and how values influence modelers' decisions in their modeling process. To understand this, we surveyed and interviewed researchers in the Chesapeake Bay Watershed. Our results demonstrated that values indeed impact every stage of the watershed modeling process. Because values have an impact, we suggest that modelers should describe how these values influence decisions in watershed modeling reports.

1. Introduction

Watershed models can help stakeholders better understand complex environmental processes, address various sources of water pollution, and make policy and management decisions involving land use and agricultural practices (Caminiti, 2004; Korfmacher, 2001; Webler et al., 2011). Because watershed policy decisions directly impact environmental health and citizens' livelihoods, they are of critical importance (Webler et al., 2011). Citizens are often engaged stakeholders in watershed policy decisions since decision making occurs at the local community level (Korfmacher, 2001). To explore the consequences of various policies, decision makers use watershed models to examine the impacts of different watershed management scenarios proposed by stakeholders (Melsen et al., 2018). Decision makers have used watershed models in this way to manage the Chesapeake Bay Watershed (Chanat & Yang, 2018; Linker et al., 2000; Shenk & Linker, 2013). This paper uses the words watershed models, watershed modeling process, and modelers in broad contexts. When discussing watershed models, we refer to a wide array of models, such as the Soil & Water Assessment Tool (SWAT), SPAtially Referenced Regressions on Watershed attributes (SPARROW), and Chesapeake Assessment Scenario Tool (CAST), to simulate environmental processes in watersheds. Driven by the question of whether modelers’ values influence the watershed modeling process, this paper investigates ethical and epistemic choices in the watershed modeling process by surveying and interviewing modelers working in the Chesapeake Bay Watershed.
Just as decision makers oversee policy decisions that impact citizens' lives, modelers also make decisions in their work that can impact results. While various forms of watershed modeling exist, this study focuses on watershed modeling used to model the impact of human activity on hydrological processes, making modeling both a social and technical process (Korfmacher, 2001). Social interaction within the watershed modeling process can come from input that arises from collaboration and stakeholder engagement, introducing subjectivity and uncertainty into the modeling process (Melsen et al., 2018). At the same time, the technical processes encompass tasks such as parameterization, calibration, and validation of the model with associated uncertainty, all of which include implicit and explicit choices that watershed modelers make. These choices have the potential to influence model outcomes. The combination of these social and technical processes relates to the field of sociohydrology, which is the study of the interaction between human and water systems (Sivapalan et al., 2012).

Developing watershed models requires collaboration among modelers, managers, decision makers, and other stakeholders (Bremer et al., 2020; Cortner, 2000; Refsgaard et al., 2007). As a result, modelers generate varying model outputs based on stakeholders' preferences, and the differences among the outputs can illustrate the effect of these preferences on water quality outcomes (Melsen et al., 2018). Furthermore, modelers must decide what assumptions they should make in response to uncertainty as well as justifying these decisions to the public (Clark et al., 2011; Hämäläinen & Lahtinen, 2016; Liu et al., 2008). Consequently, the decisions that modelers make can significantly impact model outcomes, and these outcomes have the potential to influence policies (Melsen et al., 2019).

Although several authors have acknowledged the social and subjective tendencies of modeling (Argent et al., 2016), many members of the scientific community still believe that modeling is an objective task and free of values (Huesemann, 2002). Mayer et al. (2017) counters this belief by demonstrating that values, such as fairness and simplicity can influence decisions like defining model objectives. Involving collaborators and stakeholders in the watershed modeling process can potentially introduce additional perspectives, beliefs, and values held by these various individuals into the model beyond those introduced by the modelers themselves (Bessette et al., 2017; Dietz, 2013; Mayer et al., 2017).

Modelers, like all humans, make decisions guided by values. These values can then lead to the development of certain preferences that impact modeling decisions (Dietz, 2013; Mayer et al., 2017). When making decisions, modelers must consider social, environmental, and economic challenges (Glynn, 2017; Hämäläinen, 2015; Kelly et al., 2013). Many authors have pleaded for modelers to be more transparent about their decisions, assumptions, and values (Jarman et al., 2006; Korfmacher, 2001; Srinivasan et al., 2018). Some decisions that modelers make are explicit, and they include these decisions in model documentation (Mayer et al., 2017). On the other hand, implicit decisions guided by these values are typically ignored in documentation (French & Geldermann, 2005; Mayer et al., 2017). However, it is not to say that modelers are at fault; some of their decisions are made unconsciously (Melsen et al., 2018). If traditionally implicit decisions can become more explicit in model documentation, then models can better serve as policy decision making tools (Mayer et al., 2017; Voinov & Gaddis, 2008).

Values have the ability to drive decisions made throughout the watershed modeling process. Similar to how implicit decisions are often overlooked, ethical values are also typically ignored in scientific discourse (Tuana, 2017). Involving ethical values in scientific pursuits could aid researchers in making decisions to maximize benefits while minimizing harm (Tuana, 2017). Conversely, epistemic values, defined as “values that support or encourage responsible knowledge practices,” are more widely accepted as being present in scientific research than ethical values (Kuhn, 1977; Tuana, 2017). Although Tuana (2017) investigated values in scientific research broadly, the same ideas can be applied to modeling more directly. Being a responsible modeler requires an understanding of both the nature of the ethical and epistemic values involved in a decision as well as how to prioritize these values (Tuana, 2017). Moreover, acknowledging the presence of ethical and epistemic values in modeling could enable modelers to pursue knowledge and make decisions more responsibly.

One method to make internal value judgments more explicit is the use of mental models, which allows for the visualization of an individual's internal beliefs, observations, perceptions, and assumptions (Jones et al., 2011; Kempton et al., 1996). Mental models also help people visualize decision processes and the factors that influence decisions of interest (Morgan et al., 2002). Bessette et al. (2017) sought to improve mental models by developing values-informed mental models (ViMMs), including modelers' values in mental model visualizations. To date, two studies have investigated the use of ViMMs, and both have focused on climate risk management (Bessette et al., 2017; Dietz, 2013; Mayer et al., 2017).
et al., 2017; Mayer et al., 2017). Bessette et al. (2017) focused on expert and stakeholder ViMMs. They concluded that ViMMs could help build trust between analysts and the public while enhancing the representation of stakeholder values in climate risk management strategies. Mayer et al. (2017) focused on scientists' ViMMs and concluded that ViMMs could aid in making modelers' value judgments more explicit, which can help model users understand the values that may have influenced the development of a model.

Motivated by furthering our understanding of whether modelers' value judgments influence the watershed modeling process, this paper extends ViMM analyses to watershed modeling. Similar to climate risk management decisions, watershed management decisions impact the lives of many citizens. Every citizen lives in a watershed, and just as watersheds differ in size, location, and environmental conditions, so do the policies implemented to address various environmental threats. The values among the individuals involved in the watershed modeling process also vary. We seek to understand if implicit values influence multiple stages of the watershed modeling process and what those values may include.

We utilized ViMMs to study and articulate modelers' decisions throughout the watershed modeling process along with the values that coincide with these decisions. To accomplish this goal, we developed and deployed an online survey and semistructured interviews to assess values across modelers working in the Chesapeake Bay Watershed. This work reveals various ethical and epistemic values introduced consciously and subconsciously into the watershed modeling process. Highlighting the values of modelers can help improve collaboration among all individuals in the watershed modeling process and the transparency of decisions that impact society.

2. Methods

Building upon the framework created by Packett et al. (2020), we divided the watershed modeling process into three broad stages: (1) problem framing; (2) model set-up and testing (including data selection, calibration, and validation); (3) model interpretation and decision support. Modelers are the individuals who construct watershed models and make decisions throughout the watershed modeling process. For this study, modelers are denoted as collaborating when working with additional modelers and scientists. Additionally, modelers are denoted as engaging stakeholders when seeking input from nontechnical partners such as community members and farmers.

We utilized a mixed-methodological approach that was approved by Penn State IRB#: STUDY00015701. Our approach consisted of distributing an online survey and conducting semistructured interviews with modelers in the Chesapeake Bay Watershed. The survey provided us with an overview of modelers' preferences, experiences, and demographics, while the interviews provided depth and allowed us to examine the values present throughout the watershed modeling process. The survey was deployed in September 2020, and interviews took place between October and November 2020.

2.1. Site: Chesapeake Bay Watershed

The Chesapeake Bay is the largest estuary in the United States, and its watershed has been an important area of study for modelers for decades (Chesapeake Bay Program, 2021; US EPA, 2013). A major challenge that this watershed faces is pollution from natural, agricultural, industrial, and urban point and nonpoint sources (US EPA, 2013). Decades of intensive human-land use practices and pollution have led to the watershed's ecological and economic degradation (Ator & Denver, 2015). These complex watershed challenges have resulted in comprehensive computational modeling efforts (Paolisso et al., 2015) and active public participation (Bosch et al., 2012; Fraites & Flanigan, 1993). Additionally, researchers have acknowledged the presence of values in watershed modeling (Korfmacher, 2001) and cultural modeling (Paolisso & Maloney, 2000) in the Chesapeake Bay Watershed. This watershed's history is rife with political and social tensions due to conflicts between the regulatory agencies enforcing water quality standards and the individuals and organizations held responsible for the remediation of the watershed (Paolisso & Maloney, 2000). Therefore, this watershed is an ideal case study of active modelers and their values.
2.2. Survey Methods

2.2.1. Sampling Frame: Survey Respondents

We selected 70 potential survey respondents by utilizing web searches to identify modelers with experience on projects in the Chesapeake Bay Watershed. This preliminary set of participants created our initial sampling frame. Additionally, we allowed for snowball sampling by asking for additional names from survey respondents, which added two additional respondents to the sampling frame. The respondents worked in government, academia, or private organizations (Figure 1), and their professions included professors, graduate students, research scientists, and engineers. Out of the 72 respondents, 38 individuals opened the survey, but only 27 individuals responded to questions (Table S1 in Supporting Information S1).

We asked respondents to rank their expertise across a variety of areas on a scale from 1 (low expertise) to 5 (high expertise) (Table S2 in Supporting Information S1). The self-rating scores reflect that the respondents had the most experience in watershed modeling (Mean = 4.3) and the least experience in coupled ethical-epistemic analysis (Mean = 2.2). Every category except for coupled ethical-epistemic analysis had at least one survey respondent rate themselves as having high expertise. All in all, the respondents had diverse watershed modeling experiences (Figure 1).

2.2.2. Survey Instrument

Using Qualtrics, a survey creation software tool, we developed a 25-question online survey (Text S1 in Supporting Information S1) (Qualtrics, 2021). We sought participation via email solicitation and sent three rounds of reminder emails to increase the response rate. The survey consisted of four question sets: the first three sets were based on the three stages of the watershed modeling process, and the fourth set contained demographic questions. In the first three question sets, we asked respondents to identify individuals and sources of influence (e.g., additional modelers, guidance by literature, and policymakers) involved in the sets' corresponding stage of the watershed modeling process.

First, the Stage 1: problem framing question set tasked respondents to reflect on why they work on watershed modeling and the positive outcomes of watershed modeling in the Chesapeake Bay Watershed. The goal of this set of questions was to elicit values that motivate modelers' work.

Next, questions from the Stage 2: model set-up and testing question set focused on the knowledge and experience that survey respondents had relevant to watershed modeling tools. Additionally, we were interested in understanding the factors that influenced a respondent's model selection (e.g., SWAT versus SPARROW). These factors

Figure 1. Survey respondents' work experience: (a) years of experience working with watershed models (n = 16), (b) respondents' places of work (n = 16), and (c) number of models that respondents have experience applying or working directly with (n = 22).
included user experience, data availability, consistency, model purpose, and popularity with peers. Respondents categorized these factors into bins labeled: “Yes, it is influential,” “No, it is not influential,” “It is influential in some cases,” and “I am unsure whether or not it is influential.”

In the third question set describing Stage 3: model interpretation and decision support, we sought to better understand how respondents disseminated their watershed modeling results. The final set of questions consisted of social identity questions that provided the option to disclose their gender identity, age, and experience. Here, we also asked the same question as Mayer et al. (2017), which sought to better understand the respondents’ level of expertise in several research areas (e.g., advanced computational methods, watershed modeling, and uncertainty quantification).

2.2.3. Survey Analysis

In total, a response rate of nearly 38% resulted in 27 surveys of varying completeness that were deemed comprehensive enough to include for analysis. Because we did not require respondents to answer every question, some questions have fewer than 27 responses. Given the sample size, we did not evaluate the statistical variation among the survey responses. However, this qualitative analysis is meaningful and illustrative since the respondents are part of a narrow pool of individuals with experience in watershed modeling projects in the Chesapeake Bay Watershed. While individuals have differing watershed modeling experiences, the survey sample population is relatively homogenous because of the respondents’ shared experience working on projects in the Chesapeake Bay Watershed. With these conditions, we have confidence in the representativeness of this sample regardless of its size since fewer cases are required when there is less variation among respondents (Schutt, 2014).

2.3. Interview Methods

2.3.1. Sampling Frame: Interview Respondents

At the end of the survey, respondents could indicate whether or not they wanted to be contacted for a follow-up interview. We conducted one-on-one interviews with four respondents via Zoom that lasted between 45 and 75 min, three of which were survey respondents who elected to participate and one volunteer from our initial survey sampling frame. Conducting interviews allowed us to deepen our exploration of the ethical and epistemic values present in the watershed modeling process and triangulate the results derived from the survey. During the interviews, we asked open-ended questions as well as follow-up questions. Interview respondents’ modeling experiences were varied and involved experience working on watershed and ecosystem modeling projects in both the Chesapeake Bay Watershed and other nearby watersheds. Their areas of expertise were also varied and were self-described with the following short phrases: soil biogeochemist and hydrologic modeler; computational ecohydrologist; ecosystem modeler and fisheries biologist; and hydrologist and biogeochemist. Additionally, all interview respondents have graduate degrees and are at different points in their careers.

2.3.2. Interview Instrument

To build upon information derived from the survey, we developed the interview questions after survey completion (Text S2 in Supporting Information S1). In doing so, we adapted questions from multiple scholars (Mayer et al., 2017; Tuana, 2017) with the goal of eliciting the values that drive decision making throughout the watershed modeling process. To align with this goal, the interview questions’ organization reflects the order of the three stages of the watershed modeling process. The interviews consisted of 12 questions, with the final three questions explicitly focused on ethical-epistemic values. To clarify the questions on ethical-epistemic values, each interview respondent received the following definitions that were defined based on Tuana (2017) and Kuhn (1977):

*Ethical Values* are values that individuals hold internally that guide their decision making process and can be thought of as their moral compass or what they consider right and wrong. Some examples of ethical values are fairness and welfare.

*Epistemic Values* are also values related to decision making, but here we are focused on things that help us in the pursuit of knowledge. Some examples of epistemic values are simplicity and reliability.

Our semistructured interview framework provided the opportunity to standardize questions across all interviews and have an element of flexibility that allowed interview respondents to respond to questions open-endedly. We
provided each respondent with the semistructured protocol before the interview, and then we audio-recorded and transcribed the interviews with the respondents' permission.

2.3.3. Interview Analysis

All interviews were assessed for their information power. Information power is defined as the richness of information obtained from respondents and follows the logic that fewer respondents are needed when there is sufficient, relevant information in the given sample (Malterud et al., 2015). After analyzing the interviews, we determined that all four interviews had satisfactory information power per the criteria set forth by Malterud et al. (2015): narrow study aim, dense sample specificity that related to our study aim, and strong quality of dialogue between researchers and respondents. Therefore, we found in our study that four respondents were a sufficient sample because of the information power demonstrated in the interviews.

Before the interviews, we assembled an a priori content analysis codebook containing seven code groups (Table 1). A priori codes are designated as the codes established prior to the interviews. Codes referring to motivations and outcomes, people involved in modeling, dissemination methods, and watershed modeling were developed based on the authors’ (ARD & CAG) collective experience from the extensive literature reviews and participation in watershed modeling. For topics on decisions, ethical values, and epistemic values, a priori codes were developed based on Mayer et al. (2017) and Bessette et al. (2017), additional scholarly literature, and the authors’ knowledge. Because it is impossible to anticipate all motivations, stakeholders, decisions, and values that interview respondents might discuss, a posteriori codes were added to the content analysis codebook after the interviews took place, and in vivo codes were derived directly from the interview transcripts. To code the interviews, the Zoom audio transcription feature was enabled. Author ARD manually identified transcription errors by listening to the interview audio and manually adjusting transcript text. In addition to the 86 a priori codes in the content analysis codebook, 24 in vivo codes arose from the interviews, and five a posteriori codes

| Table 1 | Code Groups and Examples of Codes Used for Interview Analysis |
|-----------------|---------------------------------------------------------------|
| Code groups     | Supporting information table number for complete code list | Example codes                      |
| Motivations, objectives, and outcomes | S3 | Water quality improvement |
| Groups, organizations, and people     | S4 | Food security |
| Dissemination tools and techniques    | S5 | Wildlife protection |
| Watershed model and system            | S6 | Additional modelers |
| Decisions                                 | S7 | Community members |
| Ethical values                           | S8 | Farmers |
| Epistemic values                         | S9 | Conference presentations |
|                                             |     | Public outreach |
|                                             |     | Share results with policy makers |
|                                             |     | Data availability |
|                                             |     | Funding |
|                                             |     | Model purpose |
|                                             |     | Stakeholder involvement |
|                                             |     | Collaboration |
|                                             |     | Watershed model selection |
|                                             |     | Fairness |
|                                             |     | Wealth/efficiency |
|                                             |     | Environmental justice |
|                                             |     | Simplicity |
|                                             |     | Robustness |
|                                             |     | Methodological soundness |
Figure 2. Modelers’ sources of motivation and valued outcomes: (a) why modelers are motivated to work on watershed modeling projects in the Chesapeake Bay Watershed \((n = 24)\) (b) Chesapeake Bay Watershed modeling outcomes that modelers value \((n = 22)\).
Bay Watershed, we might not have had many individuals with experiences working in different regions participate in our study. The lack of represented regions could have led to both the organizational access and popularity with peers factors to have less respondents rank them as influential.

Uncertainty is another factor that we expected respondents to categorize as “Yes, it is influential” since uncertainty is often an essential element in peer-reviewed watershed modeling studies. In particular, we had hypothesized that treatment of uncertainty would be influential to most respondents because considering the sources of uncertainty, such as input, parameter, or structural uncertainty, in a particular model is a critical consideration (Liu et al., 2008). Additionally, handling uncertainty has ethical implications because modelers must make assumptions in response to uncertainty and then transparently communicate these assumptions to decision makers and stakeholders (Mayer et al., 2017). Most respondents did highlight treatment of uncertainty as important. However, one respondent indicated “No, it is not influential,” and six respondents indicated “It is influential in some cases.” It should be noted that some of the respondents might have been confused by the term “treatment of uncertainty.” When we listed “treatment of uncertainty” as a factor, we were thinking of it in terms of input, parameter, or structural uncertainty. However, some respondents might have interpreted “treatment of uncertainty” as uncertainty analysis, which is a process done by the modeler, and therefore is not really a criterion of model selection.

In addition to the various factors that influence watershed model selection, our survey results revealed that most respondents are subject to multiple sources of influence at each stage of the watershed modeling process (Figure 4). These sources of influence can introduce values in addition to modelers’ values. Additionally, survey respondents shared that the top three dissemination techniques they used during the model interpretation and decision support stage were publishing in peer-reviewed journals, presenting results at conferences, and sharing results with policy makers (Text S1 in Supporting Information S1: Q16). These dissemination techniques can also involve collaboration with other modelers as well as stakeholder involvement.

### 3.2. Interview Results

Our results showcase that the watershed modeling process is complex, complete with intertwining decisions, values, and individuals across all three stages (Figures 5, 6 and S1–S3 in Supporting Information S1). Just as a watershed modeling process can vary from project to project, it can also vary widely among individuals. This work showcases that modelers have differing motivations, objectives, and outcomes of interest in addition to different preferences as to which individuals to involve in the process. Some key decisions within the watershed modeling process that were reflected across all four ViMMs included which watershed model to use, collaborators to work alongside, and stakeholders to involve. However, a modeler does not have to take on these modeling
challenges alone: various groups, organizations, and people are involved at each stage (Figure 5). At each stage, collaborators, stakeholders, and modelers introduce various ethical and epistemic values into the watershed modeling process. The ViMM approach highlights several modelers’ ethical and epistemic values while illustrating their importance to decisions made throughout the watershed modeling process.

3.2.1. Motivations, Objectives, and Outcomes

We found that every interview respondent had more than one source of personal motivation to work on modeling projects that spanned 15 different motivations (Table 2). Respondents described or mentioned either five or six motivations each. The top motivations aligned with one of the primary goals of watershed modeling, which is to utilize environmental processes (chemical and physical) in water quality simulations (Johnson, 2008). Additionally, each interview respondent mentioned values alongside their motivations. While describing the need for “the science community to make their research relevant to decision making,” Respondent 3 mentioned the ethical value urgency as it applies to the threats of pollution, climate change, and food security. Respondent 1 articulated the ethical values, environmental protection and wealth/efficiency, as they shared that they want to dedicate their time to, “supporting farmer livelihoods, improving agricultural production, and making agricultural land use more efficient” to “reduce environmental impacts.”

Even though respondents seldom mentioned motivations while discussing the three stages of the watershed modeling process (Figures 6 and S3–S5 in Supporting Information S1), they shared their motivations for working on watershed modeling projects at the beginning of the interview (Text S2 in Supporting Information S1: Q1). Conversely, valued objectives and outcomes of interest appear on the ViMMs throughout the respondents’ discussions of the watershed modeling process. Each interview respondent described between seven to 10 objectives and outcomes that watershed modeling can positively impact. A total of 13 out of the 15 objectives and outcomes mentioned throughout the full interview appear in the ViMMs (Table 2). Again, values appear alongside these objectives and outcomes of interest. For example, credibility appears when Respondent 3 said, “if we have the goal of restoring the Chesapeake…it’s imperative that we support science-based management” and “provide credible information to managers who are making decisions about where to put practices on the landscape.”
3.2.2. Ethical and Epistemic Values

Ethical and epistemic values appeared during interview respondents’ responses to the first nine questions of the interview (Text S2 in Supporting Information S1), even though none of these questions specifically asked respondents to elicit value reflections. Before the final three questions, we read the definitions of ethical and epistemic values and asked respondents to reflect on values present in watershed modeling. After asking the respondents the question, “What values, ethical and/or epistemic, are relevant to how information from your modeling projects/research is interpreted and communicated?” (Text S2 in Supporting Information S1: Q10), they all struggled to provide an immediate answer. Unsurprisingly, three out of four respondents shared that values are not something that they typically reflect upon. Respondent 2 shared, “you try to evaluate the model objectively, not subjectively.” During this discussion, they also shared that integrity is part of this objective modeling.

Each interview respondent described multiple ethical and epistemic values reflected by their respective values-informed mental models (Figure 7). According to the respondents, these values drive modeling decisions. Furthermore, respondents indicated that these decisions influenced the objectives and outcomes of interest as well as other aspects of the watershed model and system. For example, across all four ViMMs, each respondent...
said that stakeholder involvement and collaboration occurred during the problem framing stage. Unsurprisingly, respondents discussed a more comprehensive range of epistemic values when describing the watershed modeling process than ethical values.

Interview respondents described all 12 a priori epistemic values when discussing the stages of the watershed modeling process (Figure 7b). We suspect this occurred because epistemic values are prevalent in scientific research and modeling (Tuana, 2017). In addition, the model set-up and testing stage included the highest average of epistemic values out of the three stages, which indicates the presence of epistemic values present during this decision rich stage.

### Table 2

| Motivations                                                                 | Number of respondents |
|-----------------------------------------------------------------------------|-----------------------|
| Scientific understanding of environmental processes                        | 4                     |
| Understanding how human activities affect environmental processes          | 3                     |
| Water quality improvement                                                  | 3                     |
| Agriculture and farming communities                                         | 2                     |
| Mitigation of climate change                                               | 2                     |
| Food security                                                               | 1                     |
| Model improvement                                                           | 1                     |
| Scientific understanding of how to combat pollution                        | 1                     |
| Simulating potential water quality improvement                             | 1                     |
| Soil health                                                                 | 1                     |
| Support management decisions                                                | 1                     |
| Support policy decisions                                                    | 1                     |
| Understanding where environmental pollution occurs                          | 1                     |
| Watershed restoration                                                       | 1                     |
| Wildlife protection                                                         | 1                     |
| My job requires me to do this                                               | 0                     |

| Valued objectives and outcomes of interest                                  | Number of respondents |
|-----------------------------------------------------------------------------|-----------------------|
| Understanding uncertainty                                                  | 4                     |
| Support management decisions                                                | 4                     |
| Agriculture and farming communities                                         | 3                     |
| Model improvement                                                           | 3                     |
| Simulating potential water quality improvement                             | 3                     |
| Support policy decisions                                                    | 3                     |
| Water quality improvement                                                  | 3                     |
| Scientific understanding of environmental processes                        | 2                     |
| Understanding where environmental pollution occurs                          | 2                     |
| Current population/general public                                          | 1                     |
| Food security                                                               | 1                     |
| Understanding how human activities impact                                  | 1                     |
| Understanding who may be responsible                                       | 1                     |
| Watershed restoration                                                       | 1                     |
| Wildlife protection                                                         | 1                     |


Respondents also mentioned nine different ethical values when they were discussing the stages of the watershed modeling process. When respondents mentioned or described other aspects of watershed modeling unrelated to the three stages, they discussed an additional 14 ethical values. The ethical values mentioned when discussing the three stages were primarily values focused on collaboration and stakeholder involvement. For example, engagement and democratic values illustrate the need to include individuals in the watershed modeling process. Additionally, fairness, food security, and common good are values that represent the importance of the impact that watershed modeling decisions have on management and policy outcomes.

Interview respondents reflected on epistemic and ethical value disagreements both within the scientific community and between the scientific community and the public relevant to watershed modeling in the Chesapeake Bay Watershed. When talking with Respondent 4, they shared their perspective of modeling being “overly simplistic,”
3.2.3. Collaboration and Stakeholder Involvement

The respondents indicated that collaboration and stakeholder involvement is critical in watershed modeling projects. These decisions appear on every ViMM during the problem framing stage and on three of the ViMMs in the other two stages (Figures 6 and S1–S3 in Supporting Information S1). In particular, the problem framing stage involved several individuals other than the modeler (Figure S4 in Supporting Information S1). Deciding the course of a watershed modeling project requires varying perspectives, beliefs, and values. In total, 12 different groups, organizations, and people appear across all four ViMMs. The final two stages of the watershed modeling process also require these varying viewpoints from individuals. As was evident on the ViMMs, each interview respondent described at least two other groups, organizations, or people other than themselves in the watershed modeling process. During the problem framing stage, Respondent 3 described collaboration and stakeholder involvement

“discounting the environment,” and how these actions have the potential to “mislead the public.” They described the epistemic values of reliability and simplicity during this discussion.
as including the modeling team, stakeholders, and decision makers. They further emphasized that “you want to think about providing information that is meaningful and credible to the decision makers.”

Respondent 4 shared that ecosystem modeling is an interdisciplinary process that involves many regional experts. Here, they also described the epistemic values of reliability and robustness. When interview respondents had to think about who could be harmed by and who could benefit from watershed modeling results influencing policy decisions, the answers varied.

Respondents 1 and 3 both identified agricultural and farming communities as potentially being harmed because of their history of being blamed for the nutrient pollution of waterways. Respondent 3 was also concerned about the scientific community being harmed because of the public's response to restoration progress.

4. Discussion

Overall, our research summarizes and analyzes responses from a subset of watershed modelers familiar with the Chesapeake Bay Watershed. We collected survey responses from 27 modelers and conducted in-depth semi-structured interviews with four modelers. This work provides rich information about motivations, objectives, outcomes, and values associated with the modeling process. Our work suggests that the modeling and scientific communities need to recognize that modeling is both a social and technical process, further affirming previous scholars' findings (Korfmacher, 2001; Mayer et al., 2017; Paolisso et al., 2015; Tuana, 2017). All interview respondents discussed ethical and epistemic values throughout the interview without realizing they were doing so, which illustrates how values unknowingly permeate the watershed modeling process. To make modelers more aware of implicit decisions and values, Tuana (2017) suggests that scientific integrity training should include coupled ethical-epistemic analysis training as part of its curriculum. Konar et al. (2019) also suggests that researchers should receive training in the social sciences and see this as an opportunity to advance the field of sociohydrology.

If modelers are to engage in responsible modeling, they must identify values and analyze their influence on decisions made throughout the modeling process (Tuana, 2017; Voinov et al., 2014). ViMMs can be a tool to assist modelers in examining their values, motivations, objectives, and outcomes of interest. Many values that interview respondents discussed throughout the interviews were also unique from one another, which supports previous scholars' assertions that each modeler brings different perspectives, beliefs, and values to a modeling team (Sanderson et al., 2017). Using ViMMs could help modelers become more self-aware of these influences and improve the watershed modeling process.

Srinivasan et al. (2018) argues that modelers should become more aware of biases in modeling, communicate assumptions made during modeling, and receive training in both natural and social sciences, all while cautioning modelers not to overexert themselves by taking on the laborious task of being both a modeler and social scientist. Tuana (2017) offers the solution of including individuals specifically trained in coupled ethical-epistemic analyses on teams to assist modelers in incorporating values into the modeling process. In addition, adding individuals trained to mediate the relationship between modelers and stakeholders can also alleviate the burden on modelers (Srinivasan et al., 2018; White et al., 2008).

Modelers should also recognize that their decisions can benefit some people while harming others (Dietz, 2013). For example, interview respondents pointed out that modeling decisions can unintentionally harm farmers, and that modelers should engage farmers in the watershed modeling process so that they can benefit from watershed policies. The scientific community can also face criticism and pressure from the public if the outcomes predicted by the watershed models are not achieved. If modelers can make their decisions and thought processes more transparent, then the public might feel included in the modeling process and understand when timelines and outcomes deviate from predictions (Voinov et al., 2016). In addition to examining their values, modelers should also consider the value disagreements within the modeling community and between the scientific community and the public (Dietz, 2013).

Identifying values present in the watershed modeling process is just one step in the pursuit to holistically incorporate modelers, stakeholders, and collaborators' values. In the future, modelers could document their implicit decisions, such as model choice and stakeholder involvement, in their model documentation and publications. This documentation would enhance reproducibility and discussions around implicit decision making in modeling,
furthering both social and physical sciences (Mayer et al., 2017). Jakeman et al. (2006) stresses that detailing the modeling process and documenting decisions could benefit both modelers and model users. Therefore, to achieve this increased transparency in model documentation, modelers should treat conversations with collaborators and stakeholders as a form of data collection the same way they would treat collecting data in the field. For example, Bessette et al. (2017) created stakeholder ViMMs for climate risk management to gain a better understanding of stakeholders’ values and preferences. Stakeholder ViMMs could also be created for watershed modeling projects.

Engaging with the people who live in the watershed being studied is critical because the interactions between social and hydrological components of watersheds are complex and can change over time (Loucks, 2015; Yu et al., 2017). Modelers should be aware of these changes. Furthermore, sociohydrological models, like watershed models, need to account for complex cultural dynamics and the fact that humans can choose among different modes of thinking (Sanderson et al., 2017). Modelers can then incorporate this qualitative data along with the quantitative modeling data collected. Additionally, by considering the implicit decisions driven by values, modelers can become more aware of how their choices affect the sequence of steps taken in modeling projects and how these steps may affect outcomes (Lahtinen et al., 2017).

The most significant limitation of our work is the small sample size. However, as mentioned previously, this small sample is valuable given that the target population was specialized in occupation and study area. As seen in Figure 1, 53% of our survey respondents were from academia. This large academic representation is because the sampling frame was driven by publications, which are a function of the academic literature. Therefore, people not involved in these publications were not included. Another limitation is that we surveyed and interviewed modelers who had experience working on watershed modeling projects in the Chesapeake Bay Watershed. To expand this work in the future, exploring values and decisions associated with modelers in other watersheds worldwide would add depth and perspective to this area of scholarship.

Because our study only involved surveying and interviewing modelers, we urge other researchers to explore how values drive decisions on watershed modeling projects. This analysis is based on the verbal subjective commentary from respondents declaring their modeling process and values. Our work did not monitor what actually occurred during the modeling process. Further real-time investigation of how modelers handle their own values and other collaborators and stakeholders’ values throughout the watershed modeling process could provide invaluable insight into how values influence modelers’ decisions. Challenging modelers to acknowledge and record their implicit decisions and values during each watershed modeling stage would allow researchers to see how enhanced documentation benefits decision makers.

An additional noteworthy limitation is that we categorized values as either ethical values or epistemic values. There are no values that appear as both ethical and epistemic in our content analysis codebook. However, there exists ongoing debate about how to categorize certain values. For example, McMullin (2014) explains that the value of simplicity is context dependent and should be evaluated in a manner that takes this fact into consideration. The continued development of value frameworks in technical modeling processes is also an interesting pursuit for future scholarly work in sociohydrology.

5. Conclusions

This study presented the use of values-informed mental models (ViMMs) to both illustrate how modelers make decisions and highlight the values that drive implicit decisions made throughout the watershed modeling process. Our results suggest that ethical and epistemic values occur at all stages of the watershed modeling process, and collaboration and stakeholder involvement can influence these values. ViMMs can serve as a tool to make modelers more aware of how values can influence their decisions. Consequently, this increased awareness can improve the transparency of modelers’ decisions and thought processes by encouraging the inclusion of implicit decisions in model documentation. In turn, the inclusion of these implicit decisions driven by values can improve decision makers’ abilities to interpret and utilize watershed modeling results as a basis of their watershed management and policy decisions that ultimately impact society.
Data Availability Statement
As dictated by the Penn State IRB#: STUDY00015701 protocol, for the protection of human subjects our survey and interview data are unavailable for public release. However, all associated materials necessary to replicate this study, including the survey and interview protocol as well as the code list, are provided as supplemental information.

Acknowledgments
We would like to thank all of the survey and interview participants for their valuable perspectives and insights. Without them, this research would not have been possible. Funding for this research was provided by the Department of Civil and Environmental Engineering at Penn State as well as the Penn State Schreyer Honors College.

References
Addor, N., & Melsen, L. A. (2019). Legacy, rather than adequacy, drives the selection of hydrological models. *Water Resources Research*, 55, 378–390. https://doi.org/10.1002/2018WR022958
Argent, R. M., Sojda, R. S., Giupponi, C., McIntosh, B., Voinov, A. A., & Maier, H. R. (2016). Best practices for conceptual modelling in environmental planning and management. *Environmental Modelling & Software*, 80, 113–121. https://doi.org/10.1016/j.envsoft.2016.02.023
ATLAS-t. (2021). ATLAS-t qualitative data analysis. Retrieved from https://atlasti.com/
Aitor, S. W., & Denret, J. M. (2015). Understanding nutrients in the Chesapeake Bay watershed and implications for management and restoration—The Eastern Shore. *US Geological Survey Circular*, 1406, 84. https://doi.org/10.3133/circ1406
Besse, D. L., Mayer, L. A., Cwik, B., Vezér, M., Keller, K., Lempert, R. J., & Tuana, N. (2017). Building a values-informed mental model for New Orleans climate risk management. *Risk Analysis*, 37(10), 1993–2004. https://doi.org/10.1111/risa.12743
Bird, A. (2018). Thomas Kuhn. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Winter 2018). Metaphysics Research Lab, Stanford University. Retrieved from https://plato.stanford.edu/archives/win2018/entries/thomas-kuhn/
Bosch, D., Pease, J., Wolfe, M. L., Zobel, C., Otero, J., Cobb, T. D., & Evanylo, G. (2012). Community DECISIONS: Stakeholder focused watershed planning. *Journal of Environmental Management*, 112, 226–232. https://doi.org/10.1016/j.jenvman.2012.07.031
Bremner, L. L., Hamel, P., Ponette-González, A. G., Pompeu, P. V., Saad, S. I., & Brauman, K. A. (2020). Who are we measuring and modeling for? Supporting multilevel decision-making in watershed management. *Water Resources Research*, 56, e2019WR026011. https://doi.org/10.1029/2019WR026011
Caminiti, J. E. (2004). Catchment modelling—A resource manager’s perspective. *Environmental Modelling & Software*, 19(11), 991–997. https://doi.org/10.1016/j.envsoft.2003.11.002
Chanat, J. G., & Yang, G. (2018). Exploring drivers of regional water-quality change using differential spatially referenced regression—A Pilot study in the Chesapeake Bay watershed. *Water Resources Research*, 54, 8120–8145. https://doi.org/10.1029/2017WR022403
Chesapeake Bay Program. (2021). Chesapeake Bay Program History. Retrieved from https://www.chesapeakebay.net/who/bay_program_history#:~:text=Chesapeake%202000%20established%2010%20goals,emphasis%20on%20ecosystem%20based%20fisheries%20management
Clark, M. P., Kavetski, D., & Fenicia, F. (2011). Pursuing the method of multiple working hypotheses for hydrological modeling. *Water Resources Research*, 47, W09301. https://doi.org/10.1029/2010WR009827
Cortner, H. J. (2000). Making science relevant to environmental policy. *Environmental Science & Policy*, 3(1), 21–30. https://doi.org/10.1016/S1462-9011(00)00042-8
Dietz, T. (2013). Bringing values and deliberation to science communication. *Proceedings of the National Academy of Sciences of the United States of America*, 110, 14081–14087. https://doi.org/10.1073/pnas.1212740110
Fraites, E. L., & Flanigan, F. H. (1993). Perspectives on the role of the citizen in Chesapeake Bay restoration. In M. Reuss (Ed.), *Water resources administration in the United States: Policy, practice, and emerging issues* (pp. 105–118). American Water Resources Association/Michigan State University Press.
French, S., & Geldermann, J. (2005). The varied contexts of environmental decision problems and their implications for decision support. *Environmental Science & Policy*, 8(4), 378–391. https://doi.org/10.1016/j.envsci.2005.04.008
Glynn, P. D. (2017). Integrated environmental modelling: Human decisions, human challenges. *The Geological Society of London, Special Publications*, 408(1), 161–182. https://doi.org/10.1144/SP408.9
Hämäläinen, R. P. (2015). Behavioural issues in environmental modelling—The missing perspective. *Environmental Modelling & Software*, 73, 244–253. https://doi.org/10.1016/j.envsoft.2015.08.019
Hämäläinen, R. P., & Lahtinen, T. J. (2016). Path dependence in Operational Research—How the modeling process can influence the results. *Operations Research Perspectives*, 3, 14–20. https://doi.org/10.1016/j.orp.2016.03.001
Huesemann, M. H. (2002). The inherent biases in environmental research and their effects on public policy. *Futures*, 34(7), 621–633. https://doi.org/10.1016/S0016-3278(02)00004-6
Jakeman, A. J., Letcher, R. A., & Norton, J. P. (2006). Ten iterative steps in development and evaluation of environmental models. *Environmental Modelling & Software*, 21(5), 602–614. https://doi.org/10.1016/j.envsoft.2006.01.004
Johnson, M. S. (2008). Public participation and perceptions of watershed modeling. *Society & Natural Resources*, 22(1), 79–87. https://doi.org/10.1080/08941920802220347
Jones, N., Ross, H., Lynam, T., Perez, P., & Leitch, A. (2011). Mental models: An interdisciplinary synthesis of theory and methods. *Ecology and Society*, 16, 46.1–46.13. https://doi.org/10.5751/ES-03802-160146
Kelly (Letcher), R. A., Jakeman, A. J., Barreteau, O., Borsuk, M. E., ElSawah, S., Hamilton, S. H., et al. (2013). Selecting among five common modelling approaches for integrated environmental assessment and management. *Environmental Modelling & Software*, 47, 159–181. https://doi.org/10.1016/j.envsoft.2013.05.005
Kempfert, W., Boster, J. S., & Hartley, I. A. (1996). *Environmental values in American culture*. MIT Press.
Konar, M., Garcia, M., Sanderson, M. R., Yu, D. J., & Sivapalan, M. (2019). Expanding the scope and foundation of sociohydrology as the science of coupled human-water systems. *Water Resources Research*, 55, 874–887. https://doi.org/10.1029/2018WR024088
Korfmarcher, K. S. (2001). The politics of participation in watershed modeling. *Environmental Management*, 27(2), 161–176. https://doi.org/10.1007/s002670010146
Kuhn, T. S. (1977). Objectivity, judgment and theory choice. In *The essential tension: Selected studies in the scientific tradition and change* (pp. 356–367). University of Chicago Press.
Lahtinen, T. J., Guillaume, J. H. A., & Hämäläinen, R. P. (2017). Why pay attention to paths in the practice of environmental modelling. *Environmental Modelling & Software*, 92, 74–82. https://doi.org/10.1016/j.envsoft.2017.02.019
Linker, L. C., Shenk, G. W., Dennis, R. L., & Sweeney, J. S. (2000). Cross-media models of the Chesapeake Bay watershed and Airshed. Water Quality and Ecosystems Modeling, 1(1), 91–122. https://doi.org/10.1023/A:1019394632305

Liu, Y., Gupta, H., Springe, E., & Wagener, T. (2008). Linking science with environmental decision making: Experiences from an integrated modeling approach to supporting sustainable water resources management. Environmental Modelling & Software, 23(7), 846–858. https://doi.org/10.1016/j.envsoft.2007.10.007

Louchis, D. F. (2015). Debates—perspectives on socio-hydrology: Simulating hydrologic-human interactions. Water Resources Research, 51, 4789–4794. https://doi.org/10.1002/2015WR017002

Ludic Software Inc. (2021). Lucidchart. Retrieved from https://www.lucidchart.com/pages/

Malterud, K., Siersma, V. D., & Guassora, A. D. (2015). Sample size in qualitative interview studies: Guided by information power. Qualitative Health Research, 26(13), 1753–1760. https://doi.org/10.1177/1049732315617444

Mayer, L. A., Lou, K., Cwik, B., Tuana, N., Keller, K., Gomnerman, C., et al. (2017). Understanding scientists’ computational modeling decisions about climate risk management strategies using values-informed mental models. Global Environmental Change, 42, 107–116. https://doi.org/10.1016/j.gloenvcha.2016.12.007

McMullen, E. (2014). The virtues of a good theory. In M. Curd, & S. Psillos (Eds.), The Routledge companion to philosophy of science (2nd ed., pp. 561–571). Routledge.

Melsen, L. A., Teuling, A. J., Torfs, P. J. F., Zappa, M., Mizukami, N., Mendoza, P. A., et al. (2019). Subjective modeling decisions can significantly impact the simulation of flood and drought events. Journal of Hydrology, 568, 1093–1104. https://doi.org/10.1016/j.jhydrol.2018.11.046

Melsen, L. A., Vos, J., & Boelens, R. (2018). What is the role of the model in socio-hydrology? Discussion of “prediction in a socio-hydrological world” by Levrat et al. Hydrological Sciences Journal, 63(9), 1435–1443. https://doi.org/10.1080/02626667.2018.1499025

Morgan, M. G., Fischhoff, B., Bostrom, A., & Atman, C. J. (2002). Risk communication: A mental models approach (pp. 351). Cambridge University Press.

Packett, E., Grigg, N. J., Wu, J., Cuddy, S. M., Wallbrink, P. J., & Jakeman, A. J. (2020). Mainstreaming gender into water management modelling processes. Environmental Modelling & Software, 127, 104683. https://doi.org/10.1016/j.envsoft.2020.104683

Paolisso, M., & Maloney, R. (2000). Recognizing farmer environmentalism: Nutrient runoff and toxic dinoflagellate blooms in the Chesapeake Bay region. Human Organization, 59(2), 209–221. https://doi.org/10.1177/001872590005900209

Paolisso, M., Trombley, J., Hood, R., & Sellner, K. G. (2015). Environmental models and public stakeholders in the Chesapeake Bay watershed. Estuaries and Coasts, 38(1), 97–113. https://doi.org/10.1007/s12237-013-9650-z

Qualtrics. (2021). Qualtrics XM. Retrieved from https://www.qualtrics.com/

Refsgaard, J. C., van der Sluijs, J. P., Hofberg, A. L., & Vanrolleghem, P. A. (2007). Uncertainty in the environmental modelling process—A framework and guidance. Environmental Modelling & Software, 22(11), 1543–1556. https://doi.org/10.1016/j.envsoft.2007.02.004

Sanderson, M. R., Bergtold, J. S., Stamm, J. L. H., Caldas, M. M., & Ramsey, S. M. (2017). Bringing the “social” into sociohydrology: Conservation policy support in the Central Great Plains of Kansas, USA. Water Resources Research, 53, 6725–6743. https://doi.org/10.1002/2017WR020659

Schutt, R. K. (2014). Investigating the social world (8th ed.). Sage Publications.

Shenk, G. W., & Linker, L. C. (2013). Development and application of the 2010 Chesapeake Bay watershed total maximum daily load model. JAWRA Journal of the American Water Resources Association, 49(5), 1042–1056. https://doi.org/10.1111/jaww.12109

Sivapalan, M., Savenije, H. H. G., & Blöschl, G. (2012). Socio-hydrology: A new science of people and water. Hydrological Processes, 26(8), 1270–1276. https://doi.org/10.1002/hyp.8426

Srinivasan, V., Sanderson, M., Garcia, M., Konar, M., Blöschl, G., & Sivapalan, M. (2018). Moving socio-hydrologic modelling forward: Unpacking hidden assumptions, values and model structure by engaging with stakeholders: Reply to “what is the role of the model in socio-hydrology?” Hydrological Sciences Journal, 63(9), 1444–1446. https://doi.org/10.1080/02626667.2018.1499026

Tuana, N. (2017). Understanding coupled ethical-epistemic issues relevant to climate modeling and decision support science. In Scientific integrity and ethics in the geosciences (pp. 155–173). American Geophysical Union (AGU). https://doi.org/10.1002/9781119096725.ch10

US EPA. (2015). Addressing nutrient pollution in the Chesapeake Bay. Retrieved from https://www.epa.gov/nutrient-policy-data/addressing-nutrient-pollution-chesapeake-bay

Voinov, A., & Gaddis, E. J. B. (2008). Lessons for successful participatory watershed modeling: A perspective from modeling practitioners. Ecological Modelling, 216(2), 197–207. https://doi.org/10.1016/j.ecolmodel.2008.03.010

Voinov, A., Kolagani, N., McCall, M. K., Glynn, P. D., Kragt, M. E., Ostermann, F. O., et al. (2016). Modelling with stakeholders – next generation. Environmental Modelling & Software, 77, 196–220. https://doi.org/10.1016/j.envsoft.2015.11.016

Voinov, A., Seppelt, R., Reis, S., Nabel, J. E. M. S., & Shokravi, S. (2014). Values in socio-environmental modelling: Persuasion for action or excuse for inaction. Environmental Modelling & Software, 59, 207–212. https://doi.org/10.1016/j.envsoft.2013.12.005

Weber, T., Tuler, S., & Dietz, T. (2011). Modellers’ ‘outreach professionals’ views on the role of models in watershed management. Environmental Policy and Governance, 21(6), 472–486. https://doi.org/10.1002/ep2.587

White, D. D., Corley, E. A., & White, M. S. (2008). Water managers’ perceptions of the science-policy interface in Phoenix, Arizona: Implications for an emerging boundary organization. Society & Natural Resources, 21(3), 230–243. https://doi.org/10.1080/08941920701239678

Yu, D. J., Sangwan, N., Sung, K., Chen, X., & Merwade, V. (2017). Incorporating institutions and collective action into a sociohydrological model of flood resilience. Water Resources Research, 53, 1336–1353. https://doi.org/10.1002/2016WR019746

References From the Supporting Information

Bird, A. (2018). Thomas Kuhn. In E. N. Zalta (Ed.), The Stanford Encyclopedia of Philosophy (Winter 2018). Metaphysics Research Lab, Stanford University. Retrieved from https://plato.stanford.edu/archives/win2018/entries/thomas-kuhn/

Bocking, S. (2004). Nature’s experts: Science, politics and the environment. New Brunswick, NJ: Rutgers University Press.

Cox, D., La Caze, M., & Levine, M. (2017). Integrity. In E. N. Zalta (Ed.), The Stanford Encyclopedia of Philosophy (Spring 2017). Metaphysics Research Lab, Stanford University. Retrieved from https://plato.stanford.edu/archives/spr2017/entries/integrity/

Hamilton, C., & Macintosh, A. (2008). Environmental protection and ecology. In S. E. Jorgensen, & B. D. Fath (Eds.), Encyclopedia of ecology (pp. 1342–1350). Academic Press. https://doi.org/10.1016/B978-008045405-4.00624-8

Hussain, W. (2018). The common good. In E. N. Zalta (Ed.), The Stanford Encyclopedia of Philosophy (Spring 2018). Metaphysics Research Lab, Stanford University. Retrieved from https://plato.stanford.edu/archives/spr2018/entries/common-good/

International Food Policy Research Institute. (2021). Food security. Retrieved from https://www.ifpri.org/topic/food-security

Jordan, A. (2001). Environmental policy: Protection and regulation (pp. 4644–4651). International Encyclopedia of the Social & Behavioral Sciences. https://doi.org/10.1016/B0-08-043070-7/04176-0
Merriam-Webster (2021). Dictionary. Retrieved from https://www.merriam-webster.com/
Perkins, N. H., & Brown, R. D. (1999). Environmental aesthetics. In Environmental geology (pp. 194–195). Springer. https://doi.org/10.1007/1-4020-4494-1_110
Psychology Today. (2021). Identity. Retrieved from https://www.psychologytoday.com/intl/basics/identity
Reiss, J., & Sprenger, J. (2020). Scientific objectivity. In E. N. Zalta (Ed.), The Stanford Encyclopedia of Philosophy (Winter 2020). Metaphysics Research Lab, Stanford University. Retrieved from https://plato.stanford.edu/archives/win2020/entries/scientific-objectivity/
Taebi, B. (2011). Ethics of nuclear power: How to understand sustainability in the nuclear debate. In Nuclear power—Deployment, operation and Sustainability. IntechOpen. https://doi.org/10.5772/17331
US EPA. (2015). Learn about environmental justice. Retrieved from https://www.epa.gov/environmentaljustice/learn-about-environmental-justice