Teaching and Educational Methods

Reconciling Theory and Practice in Higher Education Water Economics Courses

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Abstract
The water economics course offered at the University of Waterloo provides students from the Department of Economics and other schools and departments across campus the opportunity to learn more about the application of economic theory, concepts, models, and methods to global water challenges. Students are prepared for real-world challenges by linking theory to practical examples. They are brought "into the field" through visits to local wastewater treatment facilities and real-world practical assignments. Emerging trends and water policy challenges in need of reconciliation with economic theory and methods are addressed. The practical examples make abstract water management challenges in the water economics literature real for students. Collaboration with other disciplines and sectors, as increasingly required in the water domain, is emphasized to effectively inform economically efficient water management. The annual course evaluation shows that economics students value especially the applied and interdisciplinary nature of the course.

1 Introduction

The main objective of this paper is to discuss how the water economics course program in the Department of Economics at the University of Waterloo has been set up to accommodate increasing societal and policy demand for a more applied, real-world, collaborative economics profession in the water domain. Water economics is a rather neglected field in applied economics. Although the journal *Land Economics* published its first issue in 1948, and energy and marine resource economics were covered in their respective scientific journals since the 1980s, the first *Water Resources and Economics* journal only appeared in 2013. The number of academic institutes where water (resource) economics is taught as a separate subdiscipline is limited. This despite the fact that planetary freshwater resources have become increasingly scarce over the past decades, the meteorological and hydrological impacts of climate change drive some of the most costly natural catastrophic events in the world, and water is increasingly traded in economic markets. Water is typically introduced as one of the natural resource categories or environmental challenges in the broader environmental and resource economics course curriculum.

The European Water Framework Directive (WFD) adopted in 2000, that is, Directive 2000/60/EC of the European Parliament and Council establishing a framework for community action in the field of water policy, has given an important impetus to the demand for trained water economists. The WFD is one of the first coordinated legal efforts across Europe to address water quality and transboundary river basin management using economic principles (Polluter Pays Principle), economic methods (cost-effective programs of measures), and economic policy instruments (water pricing). The Directive requires that economists work closely with other disciplines and decision makers on water-related challenges and solutions, for example to reconcile hydrological, ecological, and economic scales underlying the identification of the least costly way to achieve good chemical and ecological status of transboundary water bodies shared by multiple water users. At the same time, it introduced a plethora of real-world challenges for economists related to the definition and measurement of water services, cost recovery, environmental and resource costs, and disproportionate costs (e.g., Brouwer 2008; Martin-Ortega et al. 2015).

Similar challenges exist globally. For instance, when implementing policies to achieve Sustainable Development Goal (SDG) 6, that is, "clean water and sanitation for all." One of the specific targets under SDG-6 is "universal and equitable access to safe and affordable drinking water for all" (emphasis in underlining added). The societal benefits of access to clean water and sanitation are evident, especially under the current pandemic, but affordability remains a major concern with no clear universal definition or guideline (United Nations 2022). Moreover, classical dilemmas related to the provision of public services remain, in particular the development of a sustainable business case to attract the necessary investments and sustain the operation and maintenance of built water infrastructure in low- and medium-income countries (Hutton and Varughese 2016).

The water economics course presented here is one of the many graduate-level water courses at the University of Waterloo linked to its Collaborative Water Program (CWP). The CWP gives students from different schools and departments across all six University of Waterloo faculties (Science, Engineering, Environment, Health, Mathematics, and Arts) the opportunity to further develop their skills in interdisciplinary collaboration in the water domain. As such, it is one of the few truly interdisciplinary graduate water programs in the world (e.g., Carr et al. 2017; McQuarrie and MacLennan 2021; Taka, Verbrugge, and Varis 2021). While many water-focused graduate programs exist, they are usually housed within traditional departmental structures and lack the breadth of teaching and diversity of students available in a collaborative program. The CWP combines specialist training with collaboration opportunities, between students from different disciplines and between students and local organizations and communities (e.g., conservation authorities, farmer organizations). The goal of the CWP is to provide students with a broad, interdisciplinary foundation in water science, engineering, governance, and economics, beyond the disciplinary specialist training they receive in their academic home unit. The program consists of classroom lectures and a field work component, which are delivered jointly by 11 departments and schools from across all six academic faculties, including the Department of Economics, allowing Economics MA and PhD students to graduate with a water specialization.

Students in the CWP get a flavor of water economics through an in-classroom lecture, addressing the question why water is of interest to economists and which role economics plays in solving water challenges based on important tools in the economist's toolbox such as cost-benefit analysis (CBA) or water pricing. When discussing the relationship between water and the economy, a key learning objective is to make students understand the distinction between finance or financial analysis and broader welfare economics. The CWP field work typically has relevant economics aspects, such as the identification of economic drivers underlying specific water challenges and solutions for more sustainable watershed management with significant cost and benefit implications. CWP students interested in learning more about water economics are referred to the water economics course taught every Fall term in the Department of Economics.

2 Water Economics Course Curriculum

The water resource economics course is a so-called "topics course" open to students from the Department of Economics and other schools and departments on campus. It is taught at both the graduate and undergraduate level. The course was developed in 2016–2017, and is taught every year during the Fall term. Teaching occurred in-person the first three years (2017–2019) and online in 2020. Since 2021, it has been delivered in a hybrid format, that is, in-person for students on campus and online for students working remotely from home. It is expected to continue this way in the years to come, where in-person lectures are live-streamed to enable remote access. The course outline is presented in the Annex to this paper.

Over the past 5 years, the average annual number of participating University of Waterloo students was 15 (with a minimum of 11 and maximum of 21 students each year), of which on average 15 percent was enrolled in another university department or school (varying between 8 and 20 percent). In addition to these internal enrollment statistics, each year a number of students from outside the University of Waterloo are also allowed to participate, varying between 1 to 5. This includes professionals or practitioners who pay a tuition fee to participate. These participants audit the course and do not do the exams.

The course is advertised as consisting of "classes in which the economics of major global water management challenges are addressed, including droughts and floods, water quality, and the water-food-energy nexus. Particular attention is paid to water resources valuation and pricing." The course aims to increase students' knowledge and understanding of the application of economic theory, concepts, and methods to global water resources management challenges. It combines theory and practice and follows a research-based teaching philosophy, meaning that economic theory, concepts, and methods are illustrated using real-world research results, many of which from the author self. For the theory part, it mainly relies on Ronald Griffin's (2016) book *Water Resource Economics: The Analysis of Scarcity, Policies, and Projects* published by MIT Press (Chapters 2, 3, and 9). In the first 2 years, also Douglas Shaw's book *Water Resource Economics and Policy: An Introduction* published by Edward Elgar was used, but I found that most relevant components were also covered in Griffin's book. For an introduction to water valuation, students read chapters 2 and 4 in Robert Young's (2005) book *Determining the Economic Value of Water: Concepts and Methods* published by RFF Press.

The theory is supplemented with specific applied readings. This includes two papers by Sheila Olmstead on managing water scarcity and water quality published in *Review of Environmental Economics and Policy* (Olmstead 2010a, 2010b). Although published more than a decade ago, these two papers provide students with an excellent introductory overview of the relevant water management issues from an economics perspective. Additional materials focusing on specific case studies like climate change and flood control are taken from the book edited together with the late David Pearce *Cost-Benefit Analysis and Water Resources Management* published by Edward Elgar in 2005.

Students are asked, among others, to write a short discussion paper about a published paper of their own choosing from the journal *Water Resources and Economics*. In doing so, they screen and learn more about state-of-the-art theoretical and empirical literature in water economics and get familiar at the same time with scientific publication protocols and academic review procedures, which is considered especially useful for graduate students who aim to publish their own research. A description of the article assignment is presented in Box 1 below.

The practical part consists of four main components. The first component is the water game *Irrigania* developed by Seibert and Vis (2012), which is played in groups in class (although it can also be played online) and then followed by an intermediate test consisting of questions related to the economically efficient allocation of surface and groundwater associated with the payoff functions underlying the game.

The second component is a group assignment related to dam building in the Niger river basin in West Africa, based on the work of former RIZA and IVM colleagues (Zwarts et al. 2005).[1] Students are asked to form groups of no more than 4–5 persons. They are provided with a database containing the numerical monetary impacts of dam building on different sectors, from hydropower to crop production, livestock, transportation and commercial shipping, fisheries, nature, and wildlife. Based on the database,

[1] RIZA is the former Dutch Institute for Integrated Freshwater Management and Wastewater Treatment, which was part of the Ministry of Infrastructure and Water Management. IVM is the Institute for Environmental Studies, the oldest interdisciplinary environmental research institute in the Netherlands.

Box 1. Discussion Paper Assignment

The discussion paper is a review of an article of a student's own choice published in the journal *Water Resources & Economics*. The paper size is between 2,000 and 2,500 words. Students can work on this discussion paper from the beginning of the course. Once an article of interest has been identified, the student informs the instructor about the selected article, and when approved, the student can start writing the discussion paper (a specific article can only be reviewed by one student, students are asked to select another article if their article was already selected by someone else). The paper is due at the end of the course. Students hence have several weeks to write the paper, depending on how quickly they decide on a specific article. No standard format is provided for the discussion paper, students are asked to develop their own structure based on their own evaluation of the article they read.

The specific learning objectives associated with this assignment are to learn (1) more about a specific water economics topic or specific economic method/model/tool applied to a water challenge, and (2) to critically read and analyze a scientific paper. Students are asked to demonstrate that they have understood the study or topic presented in their paper, for example by describing and discussing the relevance of the problem addressed in the article, the appropriateness of the methods or models to address the problem, the significance of the results, or the logic underlying the article's structure. They can refer to other literature in the field if considered appropriate. They are asked to describe in their own words what the theoretical or empirical contribution of the paper is to the existing literature, what the real-world policy relevance of the paper is, and to what extent they agree (or not) with the conclusions and policy recommendations.

When introducing the assignment in class, students are furthermore informed about the scientific review process in general, from the moment an author submits an article for review to the journal until acceptance of the paper for publication, and I share guidance on possible peer review criteria, such as originality, innovation, and importance of the study; literature review consistency and relevancy; study design, methods, analysis and findings; study conclusions, limitations, and future research directions. The submitted discussion papers are read and evaluated by the instructor and a second reader from the Department of Economics.

they are asked to perform a CBA for different scenarios of dam building, paying special attention to the distribution of the costs and benefits across different stakeholder communities in the transboundary river basin. Using their CBA results, student working groups are asked to write a short report to the responsible water agency about the economic optimum level of dam building and present their recommendations in class to their fellow students. A description of the group assignment is provided in Box 2.

The third component relates to survey data collection and analysis. Students are taught how different market and nonmarket valuation methods work in practice. This includes the design and implementation of household surveys. Students are shown online surveys and are taught how to apply statistical methods to the collected survey data. In the case of revealed and stated preference methods, large data sets are used by students in class to estimate hedonic price models, travel cost models, and choice models. Interested students are referred to the publications associated with the data they are given.

For example, the hedonic pricing database refers to house prices across the Netherlands between 1995 and 2005 and contains more than one hundred thousand observations. The database was collected as part of a study for the Dutch Government in which the benefits of water quality improvements were estimated (Brouwer et al. 2021). Besides financial transaction data, information was collected about

Box 2: Dam Building CBA Assignment

The CBA assignment is a group assessment of dam building in the transboundary Niger river basin. The paper size is between 3,500 and 4,000 words. Students start working on this paper after Cost-Benefit Analysis (CBA) is discussed in class in week 5. In class, students learn the theory underlying CBA, the historical background of CBA implementation in different countries around the world, including by the World Bank, and the different steps in CBA. These steps are exemplified using a real-world example of flood control comparing conventional engineering and nature-based solutions such as floodplain restoration in the Netherlands (Brouwer and Van Ek 2004; Brouwer and Kind 2005). Special attention is paid to the selection of the baseline scenario (the "without" situation in CBA), the inclusion of nonmonetary impacts and their valuation, the importance of distributional impacts across stakeholders in time and space, the choice of the discount rate, uncertainty, and sensitivity analysis. Students learn the technical background of CBA using the pre-coded Excel spreadsheet and examples provided in Brouwer (2022). This spreadsheet teaches students how to calculate net present values, internal rates of return, and benefit-cost ratios. The role of CBA in decision-making processes is discussed, as well as its relationship with environmental and social impact assessment procedures.

The assignment relates to a real-world water management challenge, that is, water, energy, and food security in the context of climate change, for which data are made available to conduct CBA. The case study is accompanied by a film produced by IVM under the Ministry of Foreign Affairs funded program Poverty Reduction and Environmental Management. The assignment paper is presented by each group of students in class, followed by questions from the instructor, students from other groups, and invited guests who present themselves as members of the Niger river basin committee interested in the students' findings and recommendations.

Students are asked to evaluate the incremental costs and benefits of four dam building scenarios to meet demand for energy and food in the river basin:

- Scenario 0: no dam building;
- Scenario 1: Markala dam built for irrigation (operational since 1947);
- Scenario 2: Markala and Sélingué dam built for electricity production (operational since 1982); and
- Scenario 3: Markala and Sélingué dams and the planned Fomi dam for electricity production.

Based on a real-world database provided to students containing sectoral impact data for the four scenarios over a time period of 50 years, they are asked to write up the results of the CBA, advising the relevant water agencies in the Niger river basin ex post about the economic efficiency of the two existing dams and ex ante about the desirability to build a third dam.

The learning objective associated with this assignment is for students to understand how to apply the different steps in CBA to a real-world example and justify decisions related to specific choices in each step such as the baseline scenario, the discount rate, and the CBA decision criteria, including follow-up questions such as how communities negatively impacted by the dam building can be compensated. The assignment aims at the same time to strengthen students' ability to work in groups and their communication skills. Both the written report and group presentation are evaluated. The instructor's evaluation is supported by the invited guests from the Niger river basin commission who have also read the written report and participated in the group presentations and discussions.

house characteristics, neighborhood characteristics, and environmental characteristics, including distances to different types of water bodies (rivers, lakes, canals) and associated water quality variables (including Secci depth, chlorophyl-A, nutrients, and heavy metals). Students are asked to regress house prices on these different groups of characteristics and identify their relative contribution to explaining the variation in house prices. The purpose of the assignment is to improve student understanding of the importance of having access to all relevant characteristics to avoid omitted variable bias, and the need to collaborate with spatial analysts to create the relevant spatial variables and water scientists to integrate water quality monitoring data into the database.

Similarly, students are familiarized with the different types of travel cost models and are asked to estimate an individual travel cost model using survey data that include approximations of the opportunity costs of travel time to test the effect of visitors' travel time on the estimated consumer surplus. The travel cost database is based on the study presented in Mangan et al. (2013) in the *Journal of Sustainable Tourism*. The learning objective of using this study in class is to raise student awareness that the reliability of welfare estimation using travel cost studies also depends on the available survey data and often requires assumptions related to the estimation of travel costs.

For stated preferences methods, students go through the various Willingness to Pay (WTP) and Willingness to Accept (WTA) elicitation approaches and learn more about multiattribute utility theory, preference learning (or preference construction), preference stability, and possible sources of preference uncertainty in stated preferences research. The choice experiment data published in Brouwer et al. (2010) related to climate risks and water conservation in Australia is used to teach students how to estimate simple multinomial logistic choice models. As for the travel cost data, students learn how to derive WTP welfare estimates from the estimated choice models. For all data sets, students are provided with the relevant R codes to estimate the models.

Finally, the fourth practical component is a half-day visit to the local wastewater treatment facility in the Kitchener-Waterloo region, where students are given a tour of the facilities and a presentation by the regional manager about the investments in treatment technologies to keep up with a growing population and new environmental standards for emerging contaminants such as micropollutants or microplastics. Usually none of the economics students visited a wastewater treatment facility before, and their general knowledge of the connectivity between source water protection, drinking water supply, wastewater treatment, and stormwater management is very limited. Improving economics students' awareness and understanding of where drinking water comes from and where it goes after use is an important learning objective at the beginning of the course, as well as identifying where, when, and how economists collaborate with other experts and rely on noneconomic (scientific, engineering) data, for example in cost-effectiveness analysis and CBA (see Figure 1).

The "field trip" to the wastewater treatment plant is usually an eye opener for many to see where wastewater ends up, the investments needed to maintain and expand treatment capacity to serve growing urban populations, and the challenges of transferring these investment costs to the beneficiaries of the provided services. Contrary to students in science, environment, or engineering, this is often one of the very few field trips economics students undertake during their education. The visit gives the municipal managers of the treatment facilities the opportunity to raise student awareness of the operational size of the facilities and the societal and environmental benefits of collecting and treating wastewater. Students learn in class that the United Nations estimates that globally 80 percent of the wastewater flows back into the ecosystem without being treated or reused.[2] When visiting the treatment facility, they see and hear what it takes technically in engineering terms and economically in money terms to achieve SDG 6. More recently, wastewater monitoring also plays a key role in detecting COVID-19 community spread. Students are also made aware of this important function of wastewater plants in monitoring public health.[3]

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[2] https://www.unwater.org/water-facts/quality-and-wastewater/.

[3] In the Kitchener-Waterloo region, this is set up in direct collaboration with faculty members of the University of Waterloo's Water Institute (https://www.regionofwaterloo.ca/en/health-and-wellness/covid-19-wastewater-surveillance.aspx).

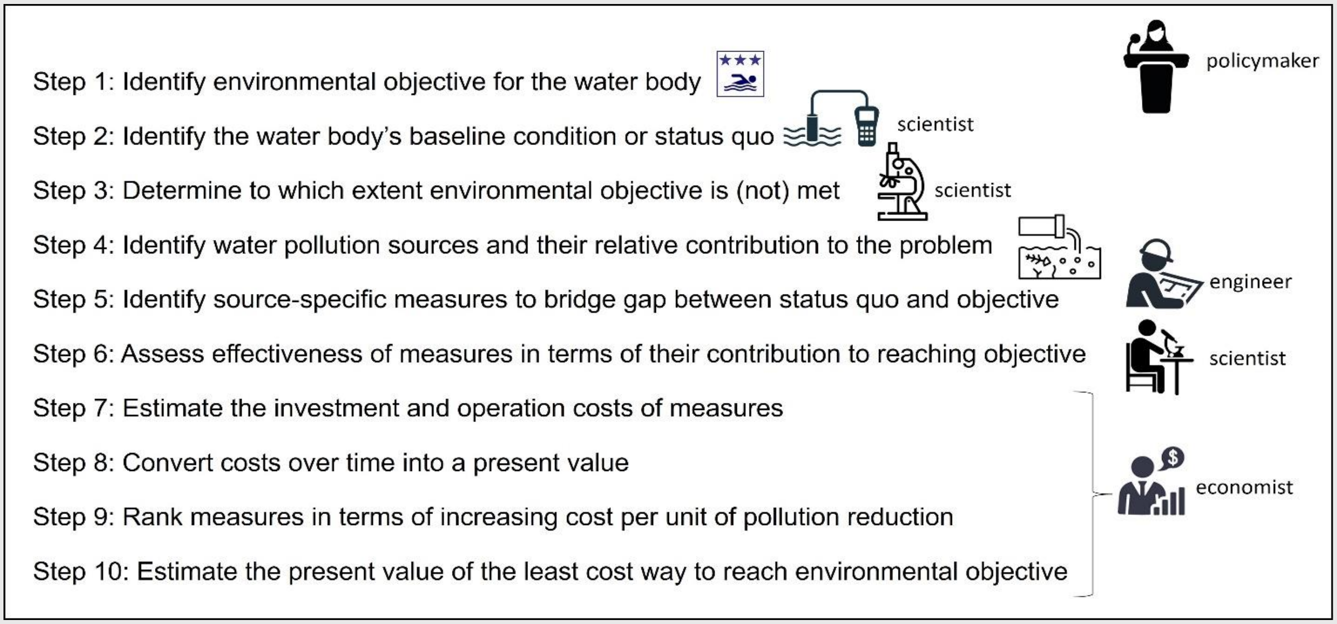

Figure 1: Illustration Used in Class of Collaboration Between Economists and Other Disciplines When Explaining the Methodological Steps Underlying Cost-Effectiveness Analysis

Source: Modified based on Brouwer and Deblois (2008)

The visit to the Kitchener wastewater treatment plant also shows the impact of climate change on the treatment facilities that were originally built in a floodplain to be as close as possible to the river. The floodplain overflows more often than when it was built in the early 1960s due to climate change. Drinking water and wastewater treatment plants are typically very vulnerable to flooding (e.g., Karamouz et al. 2016; Arrighi, Masi, and Iannelli 2018). Students are shown the new facilities that are built on top of the original infrastructure to anticipate future flood risk realities. Moreover, when discussing the pricing of water services to finance the necessary investments in aging water supply and stormwater infrastructure, students are made aware of the challenges cities like Kitchener face to introduce a stormwater user fee based on the amount of stormwater runoff a property's impervious surface creates. The city developed a stormwater credit policy that rewards residents and businesses for reducing the runoff flowing into local drainage systems, for example by installing rain barrels or cisterns and the creation of rain gardens on their property. Students are shown how an actual water bill looks like in class with a specification of a household's water use, its water and wastewater rate, and stormwater charge. Raising awareness is a key component to create public support for increasing the water bill. Concrete practical examples like these make abstract water management challenges in the water economics literature real for students.

3 Linking Theory to Practice

Water has a number of distinct features that sets it apart from other environmental assets. Some of those are accounted for in the theoretical expositions in Griffin's book, such as return flows and their implications for social welfare aggregation. Another example is dynamic efficiency in the context of groundwater depletion and the implication for the rate of groundwater extraction over time. Besides the economic implications of the distinction between stocks and flows, also the economic consequences of the relationship between water quantity and quality are addressed (e.g., Sinclair Knight Merz 2013). Water scarcity has important quality aspects, not least because the available amount of water has an impact on water quality as it dilutes concentration levels of specific water pollutants and in-stream flow affects the ecology of a water system. Differences in boundaries and scales between the economic and water system are pointed out, most importantly the fact that water, including unconfined groundwater, flows in watersheds and river basins, the hydrological boundaries of which usually do not coincide with administrative boundaries of counties, provinces, states or countries, and the boundaries of economic markets. Although market prices can change daily, key economic indicators like Gross Domestic Product (GDP) are typically presented on an annual basis for an entire country or state, while hydrological flow and chemical water quality are often monitored by the water sector at specific locations along water bodies at higher resolution time scales (e.g., hourly or even real-time). In the course, the consequences of these different spatial and temporal scales are discussed for integrated water and economic accounting (e.g., as foreseen in the United Nation's System of Environmental and Economic Accounting (SEEA) or the National Accounting Matrix including Water Accounts (NAMWA) developed by Statistics Netherlands) as a basis for hydroeconomic model development, calibration, and validation (Brouwer, Schenau, and van der Veeren 2005).

The various links made in the course between theory and practice are visualized in Figure 2. The square in the middle of Figure 2 represents a watershed in which various socioeconomic activities take place that make use of the available water resources, either as a source or a sink. Activities on the land (e.g., agriculture, industry, municipal wastewater treatment) influence water quality and aquatic ecology, requiring an integrated watershed management approach. This includes source water protection (e.g., from nitrate leaching or other land use disturbances), and building a resilient water sector with infrastructure that is able to anticipate the impacts of climate change (e.g., increasing stormwater runoff, wildfires disturbing source water intake, etc.) and future demand for treatment capacity due to population growth.

Incentives for watershed collaboration are theoretically explained using Coase theorem. A hypothetical example of upstream and downstream collaboration is presented, and students are shown under which circumstances collaboration benefits all stakeholders living in the watershed. They are also shown how depending on the distribution of property rights such as access to the available water or the right to pollute or the right to clean water, the welfare implications change across stakeholder groups. This provides the theoretical basis for the subsequent lectures on the design and evaluation of payments for watershed services (PWS) based on own work and that of others (e.g., Brouwer et al. 2011; Engel 2016; Wunder et al. 2018). Here, I also discuss the empirical evidence base related to the effectiveness of water pricing in different sectors (households, industry, and agriculture) based on price elasticities of water demand and PWS.

When discussing the water sector, I dedicate a significant amount of time to the use of green infrastructure and nature-based solutions such as forested watersheds to find the most efficient combination of grey and green infrastructure (e.g., Pan and Brouwer 2021). This includes optimizing the connectivity of infrastructure for drinking water, grey (waste) water, and stormwater using hybrid centralized and decentralized water systems. In the classroom, New York City's water supply from the Catskill-Delaware watershed is used as a well-known example (e.g., National Academies of Sciences, Engineering, and Medicine 2018). Many, if not most, economics students do not know where their tap water comes from or where it goes. It often becomes clearer once they visit a municipal wastewater treatment facility, get a tour of the treatment facilities, and see how the treated wastewater is ultimately released again into the same water course from which the water is extracted for municipal drinking water supply. It helps them to better understand that water supply is part of a circular hydrological process and that cities are located in watersheds that supply these cities with water.

Special attention is paid to the economics of wastewater reuse and resource recovery based on the 2022 International Water Association (IWA) open access book *Resource Recovery from Water: Principles and Application*. The chapter on the economic analysis of resource recovery was used for the first time in the course in 2021 to see how useful students considered this new course material

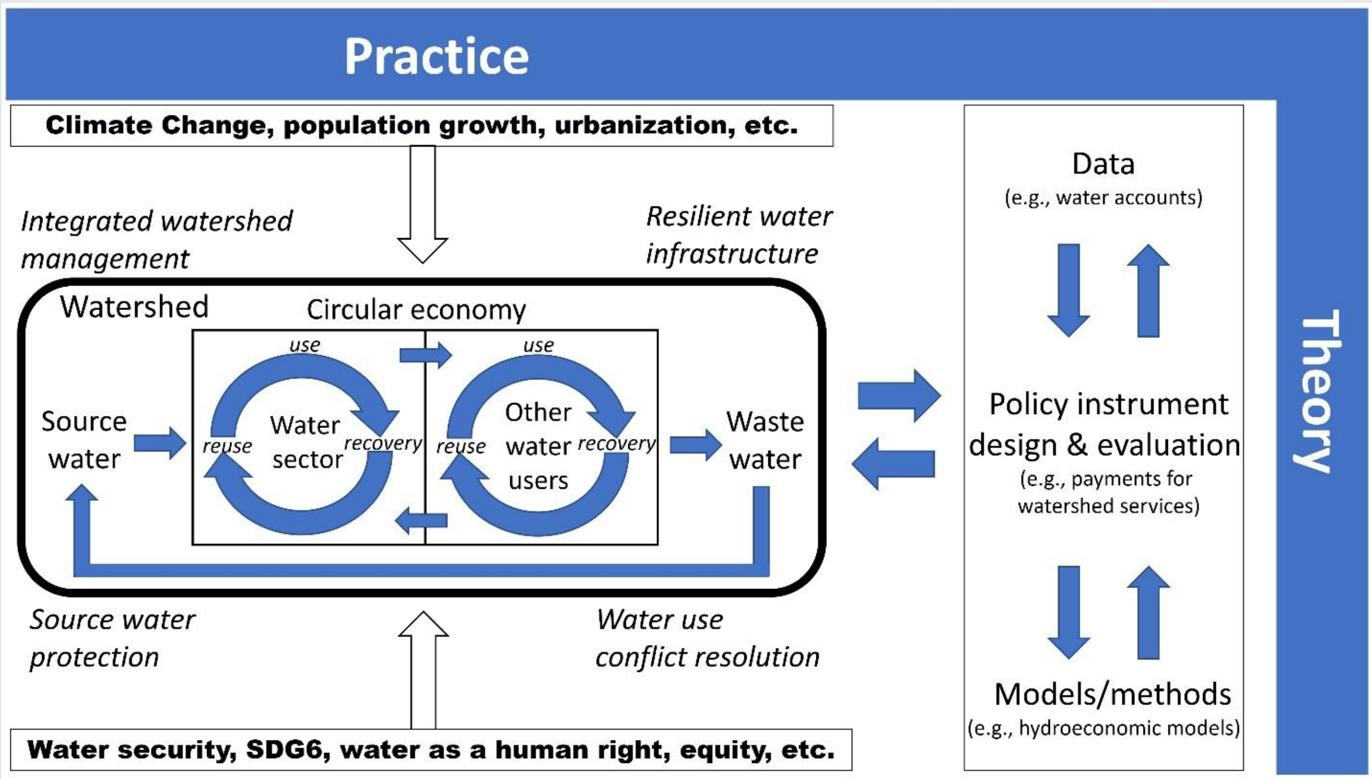

Figure 2: Linking Economic Theory to Real-World Water Management Challenges

compared to existing reading materials, in particular the new case studies making an economic case for resource recovery related to phosphorus recovery and wastewater re-use in agriculture. The practical examples appeared especially helpful to clarify and make students better understand the economic costs and benefits underlying the concept of a circular economy (Kirchherr, Reike, and Hekkert 2017).

Rapidly urbanizing watersheds face a variety of external pressures and trends that have significant impacts on the watershed's water resources and their management.[4] Besides environmental pressures, for instance as a result of climate change, economic growth, and urbanization, societal trends have emerged that translate into principles of "equitable" or socially just water policy and decision-making, such as clean water and sanitation for all (SDG 6). In many cases, water affordability may be considered more important than economically efficient water use or water pricing based on full cost recovery. Often, water is in this case not so much considered an economic good as it is considered a human right. These societal trends shown at the bottom of Figure 2 are real-world trends that increasingly challenge water economists when examining and identifying economically efficient water demand management solutions.

There is undoubtedly competition over the limited available water resources that are increasingly under pressure due to climate change. The course is able to build on an extensive resource economics literature focusing on water allocation under scarcity, also addressed in the water game *Irrigania*. The distributional aspects of water allocation of, for example, dam building in a transboundary context are emphasized, and the concept of "benefits sharing" is introduced as an important additional criterion in project and policy appraisal (Qaddumi 2008). In this context, it is emphasized that

[4] To address these issues more systematically and holistically, I developed the interdisciplinary Water Institute summer school on *Climate Change and Water Security in Urbanized Watersheds: An Interdisciplinary Perspective* in 2019 together with faculty members of the Water Institute. The program of this summer school is delivered by around 20 professors from all six faculties on campus. Due to the pandemic, the summer school was delivered virtually over a period of 3 weeks in 2021 and 2022, with international participation tripling. Since 2021, the summer school is organized together with the Waterloo Climate Institute.

addressing global water management challenges requires not only collaboration between economists, natural scientists, and water resource engineers, but also between economists and other social scientists from environmental law, political science, business administration, sociology, or cultural anthropology. Institutions such as water agencies, transboundary river basin commissions, and water laws and regulations generally reflect more deeply grounded, often historic, underlying world views of how water management should be organized, to whom the water belongs, and how it should be allocated.[5] How existing transboundary agreements can change over time and exacerbate potential conflicts over water use is illustrated for the Nile using own work on the Grand Ethiopian Renaissance Dam (e.g., Kahsay et al. 2015; 2019).

The transboundary Great Lakes shared between Canada and the United States are used as another example to show that water security also has important quality aspects. Although the Great Lakes make up approximately 20 percent of the planet's freshwater resources, the annually recurring harmful algal blooms in some of these lakes due to excessive nutrient runoff (e.g., McKindles et al. 2020) constrain water availability for different water users around the lakes, resulting every year in significant economic damage costs (Smith et al. 2019). This is due to the fact that the Great Lakes' ecosystem is used both as a source and a sink.

The Great Lakes Water Quality Agreement overseen by the International Joint Committee, the oldest transboundary water management organization in the world created in 1909, has as its main goals to ensure the waters of the Great Lakes are drinkable, swimmable, and fishable. Drinkable means in this case that the waters are "a source of safe, high quality drinking water." However, no matter how clean source water is for drinking water purposes, there does not exist something like "drinkable" water quality. Water that is used for drinking water purposes always undergoes some degree of treatment to meet legal standards for clean and safe drinking water, and there are hence always costs associated with the treatment and distribution of water to residential homes. Even if households do not pay directly for their water supply, as was the case for centuries in Ireland until the government announced in 2011 that it would start metering residential water use, it is a general public misperception that water supply is "free of charge," and I use this as a starting point for a broader classroom discussion about water as an economic good (1992 Dublin Statement on Water and Sustainable Development), safe drinking water as a universal right (UN resolution 64/292, July 28, 2010), and financially sustainable business models for water infrastructure.[6]

4 Conclusion

In this article, the set up of the water economics course at the University of Waterloo is discussed, in particular how it tries to train and prepare economists with an interest in water management for a variety of real-world challenges. Both students from the Department of Economics and students studying water from other schools and departments on campus with an interest in economics enroll in the course. During the first month of the course, students with different disciplinary backgrounds are taught basic economic principles to ensure economics and noneconomics students continue the course with the same prior knowledge and understanding of why water use and management are fundamentally part of the economics discipline, which basic economic theory and concepts underly water resources management, and how economists aim to optimize water use based on economic

[5] Bakker (2014) presents an interesting critical review of trends in the water sector, focusing on the privatization of resource ownership and management, the commercialization of resource management organizations, the environmental valuation and pricing of resources, the marketization of trading and exchange mechanisms, and the liberalization of water governance.

[6] I show in my lectures that water consumption per capita was approximately 20 percent higher in Ireland than in the rest of the European Union where consumers pay for their water use before the introduction of water metering, suggesting metering and pricing have an effect on water consumption.

efficiency, as opposed to, for example, simulations of hydrological and biogeochemical processes in the natural sciences.

Special attention is paid in the course to the concept of "value" and value theory in economics (using Adam Smith's "diamond and water paradox"), compared to other social sciences, and the difference between price and value. The use and usefulness of nonmarket valuation methods are discussed across a wide variety of public water services. It is in this part of the course where students discuss how to reconcile principles such as water as an economic good and water as a universal right in practice. This is every year an interesting discussion, not only between economics and noneconomics students, but also between students with different sociocultural backgrounds. Approximately 40 percent of the students at the University of Waterloo are international students from more than 80 countries around the world with very different water experiences.

The results from the annual student evaluation surveys, completed after the course, show that what students appreciate most in the course is its applied and interdisciplinary nature, where economic theories, concepts, and methods are explained and exemplified based on practical water management challenges from around the world. Having students work together on practical examples and address emerging global challenges in integrated water management from different disciplinary perspectives is in line with global trends in impactful interdisciplinary scientific research (e.g., US Committee on Science, Engineering and Public Policy 2005), applied research programming, and practical water policy and legislation. The collaborative aspects of experiential learning advocated in the course are in the spirit of the call for action from America's 2020 Water Sector Workforce Initiative and the guidelines written by the European Water Economics (WatEco) working group, published in 2003 to support the various economic implementation aspects of the WFD (European Communities 2003). The same applies to the call for a two-way conversation between academic researchers and practitioners by the World Bank Director of Water Global Practice, Junaid Ahmad, during the first meeting of the International Water Resource Economics Consortium (IWREC) organized at the World Bank in 2014, so that "the richness of the [academic] research informs the daily operations of the World Bank and the questions that are asked by [the World Bank] clients are taken up by academia."[7]

In conclusion, water merits a specialist course in applied economics instead of being part of a broader environmental and resource economics program. The sheer size of the economic costs of global water stress and mismanagement as estimated for example by the Economist Intelligence Unit (2021) shows the urgency of the global water crisis. However, a legitimate question is which additional skill sets to those already taught in environmental and resource economics do students need to address the economics of water resources? The answer to this question is found in the fact that water security challenges have become so widespread (including places where there did not use to be water security challenges due to mismanagement and global climate change), so complex (e.g., not enough water, too much water, poor quality water, and combinations thereof), and so intertwined with other environmental pressures (e.g., climate and land use change) that standard environmental-economics textbooks on resource scarcity and pollution control have started to fall behind. Being able to understand the economic aspects of wicked, multidimensional water problems requires that economics students have a thorough understanding of the complexities involved without having to become a scientist or engineer themselves. This is achieved by connecting them with water graduate students in other disciplines (e.g., science, engineering, public health) with an interest in economics. Asking them to collaborate on joint assignments and pointing out where in the economic analysis such collaboration is essential to get both the environmental and economic "facts" right, including the identification of the risks and uncertainties involved, is crucial to doing sound (i.e., valid and reliable) economic analysis and

[7] https://www.worldbank.org/en/news/feature/2014/09/23/the-role-for-water-economists-in-shaping-policy-and-implementation.

creating credible and applicable economic narratives to support policy and decision making toward water security.

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Appendix

Table 1: Course Outline

Week	Course Description	Materials Used in Class	Reading Materials
1	Course introduction: the relationship between water and the economy	±75 slides based on own materials: -What makes water special? -Water as a source and sink -Relationship water and economy -Water as an economic good -Value and price of water -Why price water?	Olmstead (2010a, 2010b)
2	Supply and demand of water and optimal water allocation	Slides based on Griffin, chapter 2*	Griffin, chapter 2
3	Empirical estimation of supply and demand curves	Slides based on Griffin, chapter 3*	Griffin, chapter 3
4	Cost-effectiveness analysis and cost-benefit analysis	±60 slides based on own materials	Brouwer (2022)
5	Water pricing	Slides based on Griffin, chapter 9 and ±20 slides based on own materials	Griffin, chapter 9
6	Water game and intermediate test	Online water game*	Seibert and Vis (2012)
7	Watershed cooperation and payments for watershed services	±45 slides based on own materials	Brouwer (2018)
8	Economic valuation of water services	±40 slides based on own materials	Young, chapter 2
9	Presentation CBA assignment and field trip to wastewater treatment plant	-	-
10	Nonmarket valuation methods: revealed preference methods	±35 slides based on own materials	Young, chapter 4
11	Nonmarket valuation methods: stated preference methods	±50 slides based on own materials	Johnston et al. (2017)
12	Recap—what have we learned? Submission discussion paper	±50 slides based on own materials	-

* This includes own slides that further explain some of the figures and results presented in the reading materials.

The final grade of the course consists of the following four elements:

- Intermediate test following the water game (week 6)
- Group assignment CBA dam building (week 9)
- Discussion paper (week 12)
- Final exam based on all teaching materials at the end of the course

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