Teaching and Educational Methods

Teaching Water Resource Economics for Policy Analysis

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Abstract
Water resource economics (WRE) course design merits fresh attention, given global water crises and innovations in effective water management and governance. WRE courses need to provide tools for analyzing a new generation of water policy tools and to present a well-rounded perspective on the role of benefit-cost analyses (BCAs) in the policy process. Updated WRE courses can emphasize water's role in energy, food and development economics, social justice and cross-cultural considerations, up-to-date understanding of neurobehavior in economic decision making, and the importance of nonmarket valuation and regional economic methods. Use of geospatial data in WRE econometric analyses deserves attention, as well as more sophisticated treatment of risks related to extreme events so that policy processes can consider these more fully. The article provides a number of other practical recommendations for designing upper-level undergraduate and graduate WRE courses, and includes a list of key topics and sources for class readings.

1 Introduction and Background

As this special issue emphasizes, teaching water resource economics (WRE) merits new attention in this time of global water crises. Innovations in effective water governance and management are arising to address an increasingly unpredictable future. In this article, I focus on themes I find important in teaching WRE as applied to analyzing public policies. The themes are selected based on my WRE research, teaching, and outreach experience over several decades.

I began teaching WRE in the 1980s, within the broader context of graduate and upper-level undergraduate classes in environmental and resource economics (ERE). In the early 1990s, I founded a new WRE class at the University of Arizona. The southwestern United States has a rich history in WRE research, dating back many decades and providing abundant regionally relevant material for teaching (Anderson 1961; Kelso, Martin, and Mack 1973; Howe 1978; Colby 1985; Brown and Ingram 1987; Ward 1987). The WRE course arose based on requests from water research colleagues in a wide range of disciplines to provide WRE training for upper-level undergraduate and graduate students.

Experience with the WRE class I have taught for more than 30 years forms the basis of this article. The class is oriented toward agricultural and resource economics, hydrology, public policy, engineering, law, Native American studies, and environmental science students. The course is available to upper-level undergraduates and to graduate students. The course requires proficiency in differential calculus and undergraduate microeconomics. Class size is capped at 40 students, and the course is offered once each school year. A few years ago, the course title and description were revised to reflect current social issues associated with water: "Economic Analysis of Water, Food, and Environmental Policies" (a list of key topics is provided as an Appendix to this article). Another course I teach at the graduate level, "Incentive-Based Policies and Environmental Markets," also has a significant WRE component, and many graduate students take both courses.

My courses have primarily been taught in person, in the classroom. However, the WRE courses also worked well as synchronous online classes during the COVID-19 pandemic. The interactive exercises translated well to online formats and were perhaps even more appreciated during that time of isolation for many students.

Teaching ERE and WRE to experienced natural resource professionals outside of academic settings has profoundly shaped my university course offerings. I taught for several years in the Kennedy School of Government Environmental Economics Executive Training Program. Participants in that program have extensive professional experience in resource management and seek to deepen their ability to apply economics to natural resource challenges. I have taught for many years in an annual month-long foundation-funded program for environmental professionals from all over the world, Kinship Conservation Professionals. I teach short courses in continuing education programs for judges and water masters in U.S. state and federal courts, for attorneys, and for engineers. These courses provide an opportunity to convey fundamental WRE principles for those who make key decisions on water litigation and water management.

Experience teaching ERE and WRE to working professionals motivated me to create negotiating and bargaining exercises to make WRE concepts and methods less abstract. Teaching working professionals also has shaped my university WRE courses by including material on neurobehavior and cross-cultural conflict resolution, and an overall focus on how economics is useful in design, implementation, and evaluation of public policies (Colby and D'Estree, 2000).

In the following section, I explore several key themes related to teaching policy-relevant WRE. That is followed by a section with brief specific recommendations for designing WRE courses, a summary, and an appendix providing specific course topics and sources for course readings.

2 Themes in Teaching WRE

2.1 Water Policy Challenges and Policy Instruments Are Evolving

Water policy challenges grow evermore complex as climate patterns affect regional hydrology, agriculture, and communities of humans and habitat. Policy tools related to managing water allocation and water quality continue to evolve, relying more on economic incentives. Water policies in many nations now involve extensive stakeholder input intended to reflect diverse values, including environmental water needs, indigenous cultural uses, recreation, and non-use values. Modern water policy initiatives include myriad incentives to reduce water use in agriculture, improve water quality, settle indigenous water claims, trade water to share shortages, and provide water for disadvantaged communities. These trends suggest incentive-based policy tools as an important emphasis in teaching WRE.

A classic contrast in ERE and WRE centers on command and control (C&C) regulations vs. price signals to influence resource use patterns. Examples of C&C policies include fixed quantity limits on pollutant discharges and mandates to utilize specific pollution control technologies (Stavins 2003; Olmstead and Stavins 2009). I find it useful to discuss location-specific case examples of incentive-based water policy tools and C&C instruments, inviting students to identify differences in policy design and performance (Goetz and Xabadia 2015; Colby and Hansen 2022). Incentive-based tools influence water use and pollutant discharge indirectly through economic signals, while C&C policies set explicit directives. Incentive-based tools provide flexibility in adapting behavior and technologies, enabling lower cost achievement of policy objectives. Incentives for research, innovation, and adoption of new tools are stronger when water users can create and choose lower cost approaches (Stavins 2003; Olmstead and Stavins 2009; Colby and Hansen 2022). Students can discover these differences by reviewing and critiquing benefit-cost analyses (BCAs) and other evaluations of actual water policy instruments.

Water use patterns are shifting in interesting ways, providing a dynamic context in which to understand the influence of policy instruments. For example, western U.S. cities with notable population growth are exhibiting decreasing per capita use and, in some cases, reduced total use. The 2007–2009 U.S. recession created some of the observed decline in urban water use, but water usage has remained below pre-recession levels in the recovered economy (Yoo et al. 2014; Bennett and Kochhar 2019). The global pandemic also affected water use patterns. An interesting question to put before a WRE class: after reviewing econometric studies, how much of the decrease in per capita use can we attribute to changes in policy instruments (such as water pricing) and how much to broader factors such as recession, recovery, and pandemic? Water prices and rate structures are only one among many incentive-based policy tools that WRE students need proficiency in understanding and evaluating. Other examples include cost sharing; tax credits and rebate programs for investments in water conservation technologies; consumer labeling for water-conserving products; and cap-and-trade programs to limit groundwater overdraft and water pollution.

2.2 A Broader Role for BCAs

BCA traditionally has been presented as a neutral and objective tool for choosing among resource management alternatives, such as deciding whether society should invest in a proposed infrastructure project or mandate use of pollution control equipment. In WRE courses, I make a point of discussing BCA of water projects that were funded and constructed, despite poor BCA evaluations. Examples for the southwestern United States include the Central Arizona Project and the Yuma Desalting Plant (Kelso et al. 1973; Gillon 2006). This gives students an opportunity to note that political considerations can override economic evaluations, as well as to observe that economists working for stakeholders tend to come up with BCAs that support their clients' positions. I follow reviews of actual BCAs by providing criteria for objective BCAs, criteria which students then apply to critique a BCA study of their choosing.

BCA plays a valuable conflict resolution role beyond its structured examination of benefit and cost numbers. Conducting and reviewing BCAs brings divergent parties together—giving them information on which to base discussions of water management alternatives and proposed projects. The BCA gives participants something specific "to shoot at." Their efforts to repudiate BCA values and recommendations helps reveal their own values to themselves and to other stakeholders. The dialogue process stimulated by critiquing a BCA from multiple perspectives can provide valuable information to decision makers and stakeholders.

WRE courses should ensure that students are aware of alternatives to BCA, such as multicriteria analysis, and the value of considering these alternative frameworks.

3 Water's Role in Energy, Food, and Development Economics

The water energy nexus has received considerable attention over the past two decades, as well as federal research funding in the United States. Energy resources are consumed in diverting/pumping and conveying water, pretreating it for its intended use, removing post-use pollutants, and recycling water for reuse. Significant amounts of water are used to generate electricity and cool power plants. Recent water-energy economic studies provide good choices for class readings, quantifying the economic interdependence of water and energy in various regions (Peterson 2017; Morales-García and Rubio 2023).

Emphasizing the roles of water in food production, processing, and transport links WRE to food-related topics that deservedly capture student interest. Food and development economics now accounts for a large share of undergraduate and graduate students enrolling in applied economics departments. WRE courses that include the role of water availability and water quality in developing economies provide these students with an entrée into resource economics concepts and tools they might not otherwise be exposed to.

4 Neurobehavior in Economic Negotiations

Water resource economists often advise (and study) negotiation and collaborative problem-solving processes, such as regional dialogues on water trading or on infrastructure cost sharing. The importance of interactive engagement in WRE leads me to focus on neurobehavior in several lectures of my semester-long WRE course. Having developed a background in neurobehavior helps me more usefully analyze the many longstanding rural-urban, environmental-agricultural water conflicts that create headlines. A cohesive neuroscience explanation of why people "go ballistic" about water is a valuable supplement to economic explanations.

New understanding of economic decision making provides nuanced alternatives to neoclassical assumptions about rational decision makers (Bossaerts and Murawski 2015). A decision maker's nervous-system state strongly influences the behavioral response to opportunities and threats, as water stakeholders weigh tradeoffs involving identity, culture, financial well-being, and exposure to risk. In interactions that entail perceived challenges to oneself, and one's water values and group, protection of self and group becomes a priority—quelling rational cognitive processes (Bader 2016).

Neuroception (continuous noncognitive monitoring by autonomic nervous system (ANS) to identify opportunity and danger), operating in primitive parts of the brain outside of awareness, connects perception of risk with behavioral responses in economic interactions (Porges 2011; Payne 2015; Singletary 2014). A key finding from clinical research is the central influence of perceived physical and psychological safety on decision making (Porges 2011; Bader 2016). Considering economic negotiations from a neurobiology perspective, negotiating processes can stimulate fight-flight-freeze reactions, especially when involving perceived threats to oneself or to one's group. The fight-flight-freeze ANS states significantly impair parts of the brain that weigh cause and effect and engage in problem solving. Research indicates that people in fight-flight-freeze states respond psychologically and behaviorally to perceived threats as though bodily safety is imminently threatened. This sheds light on the volatile nature of many water negotiations and policy-making processes.

The following example illustrates how pervasively trade-offs involving threat, safety, and neurobehavior arise in WRE. In addressing California Bay Delta policy dilemmas, California faces the daunting obstacle of hundreds of relevant jurisdictions, from the federal government down. Water experts offered this grim descriptor: "… a game of 'chicken,' where the management of a declining resource becomes deadlocked" (Hanak et al. 2011; Owen 2022). Michael George, the California Delta Watermaster (oversees administration of water rights), finds that his principal function as watermaster is as a mediator and facilitator. He observes, "The biggest shortage in the water system in California is trust" (Owen 2022). Not shortage of water, not shortage of funding—shortage of trust.

Classes in WRE can offer models of water negotiations structured to address neurobehavioral mechanisms. Respect fundamentally validates each party and addresses primal ANS issues stimulated by conflict—reinforcing validity and value of one's self and one's group (Geisler et al. 2013; Bader 2016). Water negotiations can be structured to provide respect, objectivity, and professional facilitation to improve outcomes (Levine 2010; Raio et al. 2013). There are important advantages to offering students a framework for the role of neurobehavior in WRE. Phenomena that previously seemed anecdotal and unrelated now can be understood as expressions of neurobehavior, and anticipated in structuring water negotiations and policy-making processes.

5 Social Justice and Cross-Cultural Considerations

This facet of WRE and water policy deservedly has been receiving more attention in the United States as social justice and cross-cultural issues become more recognized. My classes typically include students from groups underrepresented in U.S. water policy making. These groups (Native Americans, blacks, Hispanics, and others) have not shared proportionally in the largesse of water infrastructure development and federal water and energy subsidies. They have been disproportionately affected by water pollution, drought, floods, and lack of safe drinking water. Many water conflicts have key components involving equitable access to water and its economic benefits (Colby and d'Estrée 2004; Banzhaf, Ma, and Timmins 2019). In my course, I include a segment on indigenous water issues in the western United States and econometric studies using spatial data to examine differential water quality impacts in minority communities (Shapiro and Walker 2021). The social justice and equity theme can encompass different topics that vary by location, tailored to the mix of students in WRE courses.

Drought in the southwestern United States and negotiations over how to address severe and growing shortages in Colorado River water-sharing arrangements have brought to the fore an array of social justice issues. Disproportionate effects of drought on water access for communities of color is becoming increasingly apparent (London 2018; Fernandez-Bou et al. 2023). Another social justice issue involves the roles of Native American nations in providing resilience for regional water supplies. Southwestern U.S. tribal nations, in some cases, have secured senior water entitlements through protracted litigation and negotiations (Thorson, Britton, and Colby 2006). New water-sharing arrangements based on these entitlements are now sought by cities and nontribal farms to alleviate shortages among more junior right holders. Tribes are participating in negotiations for agreements to make their more drought-secure water available. Social justice issues inevitably arise when a historically poor and disenfranchised group (tribal nation) negotiates with a more wealthy and politically connected entity, such as a major city.

6 Evolving Treatment of Risk and Uncertainty

As regional climate patterns shift, WRE needs to provide more sophisticated treatment of risk so that BCAs and other policy processes can consider these more fully. Extreme heat waves, drought, flooding, and other disasters are becoming more frequent and severe than the historical record indicates. Inclusion of economic approaches to climate risk and uncertainty that encompass extreme events will improve the relevance of WRE courses. For example, Dolan et al. (2021) finds that the projected range of changes in economic surplus exhibit far greater uncertainty than underlying climate-related hydrologic uncertainties in their models of major river basins. They identify widespread likelihood of "economic tipping points" that shift a region's capacity to adapt to and recover from water scarcity (Dolan et al. 2021). Niggli et al. (2022) analyzes recent extreme climate events in Europe, Australia, and Africa; they find economic losses related to direct and indirect consequences in various sectors are substantial in terms of portions of national GDP. Their models identified interactions among interconnected sectors that escalate loss and damage—particularly in health, energy, agriculture, and food supply (Niggli et al. 2022). Modeling approaches for economics of extreme events likely exceed mathematics and statistics capacities for most applied economics undergraduate students, so this theme may be best explored in depth in advanced WRE courses.

Neuroeconomics approaches are relevant to WRE risks and uncertainty challenges, providing improved understanding of neural mechanisms in decision making (Faralla et al. 2015; O'Doherty and Camerer 2015; Suzuki et al. 2016; Sherman, Steinberg, and Chein 2018; Korucuoglu et al. 2020; Krönke et al. 2020; Tisdall et al. 2020). Assessing risk and trade-offs in economic negotiations and policy processes is now understood as a complex, multifaceted neural process. Neural correlates of economic value may prove useful in overcoming uncertainties in contributing to water-related public goods (Krajbich et al. 2009; Krajbich and Dean, 2013). Experiments indicate that neuro-revealed values (using real-time functional magnetic resonance imaging) induce participants to truthfully reveal their own value in their bid to contribute to public goods (Smith et al. 2014; Grueschow et al. 2015). This could ease the process of funding public goods related to higher quality drinking water, infrastructure to alleviate water supply shortfalls, and water-dependent habitat for wildlife and recreation.

7 Use of Geospatial Data in WRE Econometric Analyses

WRE research has been revolutionized over the past decade by access to fine resolution (spatial and/or temporal resolution) data on land use, vegetation, crop mix, groundwater levels, water quality parameters, commercial fish catch, daily stream flows, and hourly electricity loads. Use of remote sensing data in econometric models is a worthy specialty in WRE courses, perhaps deserving its own course. A WRE course emphasizing use of spatial data needs strong prerequisites in statistics and econometrics, and could be structured to serve multiple advanced undergraduate and graduate majors. Applied economics journals (such as those listed in the appendix) provide a good selection of research papers that emphasize use of spatial data, providing a source of class readings. All WRE courses, even those at introductory undergraduate levels, can provide materials that illustrate the value of geospatial data in refining our understanding of water challenges and proposed solutions.

8 Nonmarket Valuation

Nonmarket valuation is highly relevant in WRE (e.g., instream flow values and ecosystem services provided by hydrologic functions within natural systems; compensating for and/or assessing losses due to water transfers, etc.) that can contribute to water policy and deserves emphasis in WRE courses (or perhaps its own specialty course). I provide several lectures on the important role of nonmarket valuation, including contingent valuation, travel cost, and hedonic methods (Young and Loomis 2014; Zuo et al. 2015). Using neuro-revealed values to obtain more accurate bids to contribute to public goods is a promising new pathway in nonmarket valuation (Smith et al. 2014; Grueschow et al. 2015). Students learn best practices for conducting these types of studies, and reviewing and critiquing valuation studies.

9 Regional Economic Analysis

Regional economic analysis contributes to improved understanding of many water challenges and potential solutions. Examples of methods to examine regional economies and changes over time include input-output modeling using software such as IMPLAN (Loomis 2002; Young and Loomis 2014; Yoo and Perrings 2017). Concerns over jobs and community economic vitality lie at the heart of many conflicts over sharing water during shortage and allowing water to be transferred into new uses. I would like to give more attention to the role of regional economic analysis and encourage those designing WRE courses to do so.

10 Course Design and Delivery Recommendations

10.1 Calculus, Microeconomics, and Statistics Prerequisites

Calculus is an important prerequisite for upper-division undergraduate and graduate WRE. Without the ability to review and decipher articles on constrained optimization, students lose access to much valuable WRE literature.

Requiring one prior undergraduate microeconomics class allows a WRE class to build on a working knowledge of supply, demand, market equilibrium, and elasticities. I provide refresher readings and exercises the first week of class. Students needing to rekindle their prior microeconomics exposure are motivated to work through these when faced with the first problem set.

A statistics prerequisite is also important and allows students to review and evaluate simple econometric models in WRE literature. While a semester of introductory econometrics would be ideal and would suit applied economics majors, this would be impracticable for students from other majors who take their own discipline’s variant of statistical modeling.

10.2 Design Class to Be Accessible to Multiple Majors

I design my WRE and ERE classes to be accessible to multiple majors. This creates a classroom environment that resembles water professionals' workplaces, composed of people of different expertise and different perspectives about water's value in differing uses. A multi-major class is more challenging to teach compared to only applied economics majors, but the quality of the classroom experience makes this uniquely valuable in the kinds of jobs students land after earning their degrees.

Even those economics students going into academia after earning a PhD will not be working solely with other economists. A distinctive trend over my years in WRE research, teaching, and outreach, is a shift in funding emphasis by U.S. federal agencies, international funders (World Bank and United Nations), and philanthropic foundations (such as Walton, Ford, and Rockefeller Foundations). It used to be common for funders to focus on economics separately from other water-related disciplines. However, the emphasis has shifted to calls for proposals that require multiple disciplines bringing their expertise to collaborative research on water issues.

WRE courses that include students from non-economics majors face the challenge of widely differing backgrounds in economics and calculus. This can be partially addressed by enforcing microeconomics and calculus prerequisites discussed earlier.

10.3 Consider Student's Career Aspirations

Water professionals are in high demand worldwide: water resource economists as well as hydrologists, engineers, fishery biologists, wetland ecologists, public health specialists, and conflict resolution experts (to list a few). Newton (2022) predicts a global shortage of millions of water professionals in the coming decade as an earlier generation of water professionals nears retirement. Water professionals need skills to participate in multidisciplinary teams to address complex water challenges. This reinforces my commitment to making WRE classes accessible to multiple majors.

The primary sector employing students from my WRE classes is academia, for those earning PhDs. For MS students, about half go on to PhD programs, and the other half go into careers working in applied economics in the private, public, and nonprofit sectors. Key employers for MS students and undergraduates in my courses are public agencies at the local, tribal, state, federal, and international level; nonprofit foundations and advocacy organizations; and consulting firms serving stakeholders involved in water resource conflicts. Proficiency in working across specialty fields is essential in all of these arenas of employment. Providing course material that addresses what is useful for each group's desired careers requires specialized forethought and design. For those aiming to be academics, an emphasis on econometric studies and optimization models is reported by past students to be particularly useful. For those working on water issues in the public, private, and nonprofit sectors, the bargaining and negotiations exercises are reported to be especially valuable.

10.4 Include Multiple Interactive Elements

Team assignments and interactive problem-solving exercises are essential for two reasons. They are widely recognized as key elements in adult learning (Hrach 2021), and they provide opportunity to develop interactive skills needed in WRE work settings. Exercises and assignments can be modeled on professional interactions among regional resource agencies and stakeholders. Interactive bargaining exercises keep students engaged and reinforce important concepts about allocating surplus and cost sharing. Online searches provide a wealth of fresh ideas related to design of economic-bargaining exercises (Docsity 2023; Harvard University 2023). (My classes use dark chocolate as the "currency" in these exercises, but instructors can develop their own favorite reward structures.)

10.5 Provide Diverse Examples of Leadership and Expertise
It is important to draw upon examples of economic problem solving and leadership in water challenges from diverse cultures and genders. A student who never sees someone "like them" (whether that is cultural background, skin color, or gender) playing a role in water economics has a much harder time believing they can successfully enter that field. Consider the cultural mix of your students, their genders, and nationalities to choose case studies and examples that help them see leaders and experts who share some of their characteristics. Our deliberate choosing of gender- and culture-inclusive language and examples will help diversify the WRE profession.

10.6 Promote Ongoing Networks after Graduation
Maintaining ongoing contact after graduation is rewarding in many respects. I genuinely enjoy seeing former students thrive in their careers and contribute in their spheres of influence. The data sharing, research collaborations, and professional connections are valuable in many different ways. Employment opportunities arise for newly graduating students with prior students now in a position to hire in their organizations or to serve as mentors to those just starting their careers. I cultivate post-graduation networking by connecting informally and by hosting a happy hour when I am visiting an area with several former students from different eras. An occasional e-newsletter with greetings to former students, that includes their news as well as your own, would be a more structured way to connect former students and keep up your own contacts with them.

10.7 Textbooks, Readings, and Other Teaching Material.
In my WRE courses, I use chapters from textbooks combined with applied economics journal articles. More details on course readings are provided in the appendix. I find it useful and enjoyable to link water economics to a broader cultural context reflected in world film and literature, exposing students to diverse voices and experiences. I provide a list of novels and films that include water economics as one of their themes, and ask students to identify concepts from class in a very brief written assignment on a novel or film they select from the list (see Appendix). I enjoy the insights and new angles on WRE that they glean from what they read and view.

10.8 Types of Assignments
I assign regular problem sets that require differential calculus, short presentations that link a class concept to a contemporary water challenge, team presentations analyzing specific economic components of case studies, and brief written exercises. The term project involves a brief paper and 15-minute presentation on a current water problem that is selected by the student and refined and approved in consultation with me as the instructor.

11 Summary
This article emphasizes specific aspects of WRE that the author has found to be most relevant and worthy of more emphasis among the WRE profession. This means that some standard WRE themes have received little attention here. Water law and regulations naturally are discussed in WRE readings and lectures, and some students may wish to take a water law or water policy class, in addition to WRE. Sustainability is an important contemporary theme, and its economic aspects should be integrated into WRE course materials. Macroeconomics provides useful frameworks for considering broader effects of water policy alternatives and can be brought into WRE course materials and discussions. No doubt readers will identify other themes not mentioned in this article that could form a valuable component in WRE classes.

To improve WRE offerings, systematic evaluation would be useful. Most universities conduct student evaluations of courses and sometimes (especially for junior faculty) peer reviews of course materials and lectures. In addition to these evaluation measures, WRE courses could benefit from a delayed retrospective assessment by students now working as water professionals and by students who have entered a graduate program. These individuals would be in a position to reflect upon the usefulness of WRE courses and ways to improve them. In addition, longtime water professionals could provide insights on what skills and topics are most relevant as they consider hiring students into a water resource career path.

This is an exciting era in which to be teaching WRE. Global water crises and changing patterns of water demand and supply imply that WRE courses need to provide tools for analyzing a new generation of water management strategies and policy tools. Presenting material on neurobehavior in economic decision making and a well-rounded perspective on the role of BCAs in the policy process is valuable in preparing new WRE professionals for their work. Emphasizing water's role in energy, food, and development economics and in social justice and cross-cultural considerations enhances the relevancy of WRE courses to broader groups of students. Nonmarket valuation, regional economic methods, and analytic methods for working with geospatial data also have an important place in WRE courses. Economic treatment of risks related to extreme events merits special attention. The topics addressed in this article could well form a two-semester sequence, as I find they cannot adequately be covered in a single semester. The Appendix provides a list of key topics and sources for class readings.

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Appendix: WRE Class Topics and Primary Reading Sources

Class Topics

I weave in an emphasis on current water policy challenges and innovative policy instruments throughout courses, as well as choosing cases that highlight social justice and cross-cultural considerations.

Some of the topics listed can only be treated briefly during a 14-week upper-level undergraduate and graduate course meeting 2.5 hours per week. The course material requires prior coursework in differential calculus and undergraduate microeconomics.

Review of Microeconomics, Consumer and Producer Theory, Applied to Water:

- Demand and supply, price signals, equilibrium, Consumer Surplus, Producer Surplus and elasticities
- Utility maximation and demand function
- Cost minimization, production function, and derived demand for inputs
- Pareto Optimality given specific assumptions (which do not hold in many water policy settings)
- Diamond Water Paradox
- LaGrangean constrained optimization and first order conditions

Neurobehavior in Economic Negotiations

- Polyvagal theory and autonomic nervous system (ANS) influences on economic interactions incorporated into WRE through readings, case studies, and bargaining exercises

Benefit-Cost Analysis (BCA)

- Guiding principles
- Review and critique of case studies in BCA and policy decisions

Cap and Trade in Theory and Practice

- Conditions for achieving efficiency
- Transferable permits to discharge pollutants and to use water
- Comparing cap and trade to other policy instruments
- End of pipe pollutants contrasted with ambient water quality programs

Risk and Uncertainty

- Expected value and expected utility
- Risk premium, certainty equivalent
- River basin studies addressing water trading and other risk management strategies

Valuing Water

- Why is it important in policy context?
- Use values—agricultural, urban, and industrial
- Nonmarket valuation: travel cost, contingent valuation, and hedonic valuation

Water Pricing

- Rate structures, tiered rates, and seasonal rates
- Marginal capacity cost
- Case studies: urban water utilities

Geospatial Data in WRE Econometric Analyses

- Review recent WRE econometric tudies

Suggested Sources for Course Readings

I update class readings each time a course is offered to replace older material. I add new journal articles and textbook chapters. I also add in-depth, updated journalism coverage of water issues making headlines through articles and videos.

The lists provided reflect my own geographic and topical interests. There are many other excellent books and journals that could be included.

Books

Burnett, K., R. Howitt, J.A. Roumasset, and C.A. Wada, eds. 2015. *Routledge Handbook of Water Economics and Institutions*. New York: Routledge.

Colby, B., and G. Frisvold. 2011. *Risk and Resilience: The Economics of Climate-Water-Energy, Challenges in the Arid Southwest.* Resources for the Future Press.

Dinar, A. 2022. *Advanced Introduction to Water Economics and Policy.* Cheltenham UK: Edward Elgar Publishers.

Dinar, A., and Y. Tsur. 2021. *The Economics of Water Resources: A Comprehensive Approach*. Cambridge UK: Cambridge University Press.

Easter, W., ed. 2014. *Innovations in Water Markets*. Berlin: Springer.

Griffin, R. 2016. *Water Resource Economics*, 2nd ed. Cambridge MA: MIT Press.

Loomis, J. 2002*. Integrated Public Lands Management*. New York: Columbia University Press

Shaw, D. 2021. *Water Resource Economics and Policy*, 2nd ed. Cheltenham UK: Edward Elgar Publishing.

Roumasset, J., ed. 2015. *Handbook of Water Economics*. Berlin: Springer-Verlag Co.

Young, R., and J. Loomis. 2014. *Determining the Economic Value of Water*, 2nd ed. New York: Routledge.

Ziolkowska, J., and J. Peterson, eds. 2016. *Competition for Water Resources: Experiences and Management Approaches in the US and Europe*. Amsterdam: Elsevier.

Journals (with examples of recent relevant articles)

American Journal of Agricultural Economics

Li, M., W. Xu, and T. Zhu. 2019. "Agricultural Water Allocation under Uncertainty: Redistribution of Water Shortage Risk." *American Journal of Agricultural Economics* 101(1):134–153. https://doi.org/10.1093/ajae/aay058

Palm-Forster, L.H., J.F. Suter, and K.D. Messer. 2019. "Experimental Evidence on Policy Approaches That Link Agricultural Subsidies to Water Quality Outcomes." *American Journal of Agricultural Economics* 101(1):109–133. https://doi.org/10.1093/ajae/aay057

Paudel, J., and C.L. Crago. 2021. "Environmental Externalities from Agriculture: Evidence from Water Quality in the United States." *American Journal of Agricultural Economics* 103(1):185–210. https://doi.org/10.1111/ajae.12130

Ecological Economics

Gutiérrez-Martín, C., J.A. Gómez-Limón, and N.M. Montilla-López. 2020. "Self-Financed Water Bank for Resource Reallocation to the Environment and within the Agricultural Sector." *Ecological Economics* 169:106493. https://doi.org/10.1016/j.ecolecon.2019.106493.

Kreye, M.M., D.C. Adams, F.J. Escobedo, and J.R. Soto. 2016. "Does Policy Process Influence Public Values for Forest-Water Resource Protection in Florida?" *Ecological Economics* 129:122–131. https://doi.org/10.1016/j.ecolecon.2016.06.007.

International Journal of Water Resource Development

McIlwaine, S.J., and O.K.M. Ouda. 2020. "Drivers and Challenges to Water Tariff Reform in Saudi Arabia." *International Journal of Water Resources Development* 36(6):1014–1030. https://doi.org/10.1080/07900627.2020.1720621

Suresh, A., K.S. Aditya, J. Girish, and P. Suresh. 2019. "Micro-Irrigation Development in India: An Analysis of Distributional Pattern and Potential Correlates." *International Journal of Water Resources Development* 35(6):999–1014. https://doi.org/10.1080/07900627.2018.1504755

Journal of Agricultural and Resource Economics

Ifft, J., D.P. Bigelow, and J. Savage. 2018. "The Impact of Irrigation Restrictions on Cropland Values in Nebraska." *Journal of Agricultural and Resource Economics* 43(2):195–214. http://www.jstor.org/stable/44840983

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Journal of the American Water Resources Association

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Examples of WRE-Related Novels and Films I Recommend to Students:

Novels
The Man Who Killed The Deer, Frank Waters
Milagro Beanfield War, John Nichols
Ceremony, Leslie M. Silko
Mean Spirit, Linda Hogan
Woman at Otowi Crossing, Frank Waters
By The River's Edge, Elizabeth Cook Lynn
River Song and *Winterkill*, Craig Lesley
The Ancient Child, Scott Momaday
Angle of Repose, Wallace Stegner
Mara & Dann, Doris Lessing

Films
Thunderheart
Milagro Beanfield War
Chinatown
Jean de Florette (French, subtitles)
Pow Wow Highway
A Beautiful Mind (John Nash, game theory)
Erin Brockovich
A River Runs Through It

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