Banff International Research Station

for Mathematical Innovation and Discovery

MATHEMATICAL MODELING OF WATER RESOURCE ALLOCATION STRATEGIES

SEPTEMBER 7- 9, 2007

WORKSHOP SUMMARY REPORT

Workshop Organizers

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I. LESSONS LEARNED

The workshop provided the participants with an opportunity to discuss a diverse range of issues in the area of water allocation models and to share experiences and perspectives from different jurisdictions. From the presentations and discussions some of the key lessons learned were:

1. That more research needs to be done in the area of water economics to provide answers to questions such as the optimal allocation patterns, the choice of irrigation technologies, the prospects of using water pricing and trading to address water scarcity, the role of uncertainty in water allocation decisions, and how to build intertemporal economic optimization models.
2. The type of model used depends on what kind of policy issue is being investigated. Several management questions can be addressed using a hydro-economic model like CALVIN or a modified WRMM. These include:
   a. Testing the welfare effects of changing water institutions (e.g. introducing water markets, water pricing, and water banks);
   b. Evaluating the social and private benefits of storage expansion/contraction and who should pay;
   c. Evaluating the benefits of conjunctive management.
   d. Evaluating the costs of instream flow objectives and constraints
3. That there is considerable scope for collaboration in research in which the different participants can make valuable contributions according to their unique strengths and comparative advantage. This however requires a shared solution-driven research focus.
4. The WRMM model developed by Alberta Environment is capable of being adapted to use an explicitly economic objective function with multi-period solution values, perhaps augmented by a nonlinear optimization algorithm. This model is already available in the public domain for use by diverse researchers, but since there is no firm budgetary commitment or timeline to install these enhancements, it is not clear how the potential power and functionality of this modeling platform can be fully realized in the near term.
5. That a system needs to be developed to assemble detailed data on various aspects of water use and management. The data needs to be collected and organized in a way that it can be shared. Similarly a mechanism needs to be developed for sharing modeling

approaches and to harness the complementarities between the models being developed by the various participants.

6. That links need to be established between researchers and policy makers to ensure that the research being carried out addresses important practical questions and contributes in concrete ways to an improvement in water management.

II. INTRODUCTION

The workshop *Mathematical Modeling of Water Resource Allocation Strategies* was held from September 7-9, 2007 at the Banff International Research Station for Mathematical Innovation and Discovery. The purpose of the workshop was to bring together a small group of researchers and government and industry participants who are active in the use or development of water policy models to understand the 'state of the art' methods in water policy modeling and to explore opportunities to advance water economics research in Alberta. The participants were drawn from both the United States and Canada. The specific objectives of the workshop were:

1. To identify the principal modeling groups and approaches currently active on Alberta water issues and to identify the potential for diverse types of collaboration among the researchers;
2. To understand the current "state of practice" and the current "state of the art" in quantitative water modeling including alternative applications, techniques and methodologies (e.g., scope and scale - farm-level to basin-scale, model structures, assumptions, calibration, data requirements, software), strengths and weaknesses, and to identify potential areas for improvement in future work;
3. To identify whether there are relevant approaches and lessons from other jurisdictions about processes for interdependent quantitative analyses, including collaboration in such areas as data collection and data sharing, model verification and validation;
4. To identify the areas of opportunity for broadening or coupling economist's models of water quantity and quality to other physical models of land use policy and land use change, for example, and /or for introducing or integrating economic analysis to existing physical models.

The workshop was organized into five sessions with each session involving a presentation or set of presentations followed by questions and discussions by participants. The first four sessions were held on Saturday and explored various dimensions of water policy modeling. The fifth session was held on Sunday and focused on a series of questions raised by the topics covered on Saturday. This was followed by a discussion of opportunities to advance water policy modeling in Alberta. The next section of this report summarizes each of the five sessions without attempting to record or to present fully the wide range of technical issues and discussion surrounding each session.

III. PRESENTATIONS

Session (A): State of the Art Approaches to Water Modeling

This session was led by Prof. Richard Howitt, Department of Agricultural and Resource Economics, University of California, Davis. The title of Richard's presentation was “State of Art Approaches to Water Modeling.” The presentation provided an extensive survey of computational techniques and approaches. Some important points in Richard’s presentation were:

- That both simulation and optimization water models have a role - often complementary. Simulation models help us understand the physical properties of the system while optimization models are necessary to evaluate the costs and benefits of policy options such as water pricing and trading, establishing instream flow objectives, investment in storage capacity, and conjunctive management. Where values, preferences, or the resource base is changing, optimization will have a greater role because of the need to evaluate the public and private values from new management approaches.
- That both spatial and intertemporal allocation problems are important, but usually have to be solved at different scales due to complexity.
- That inductive parameter estimation is theoretically preferable, but calibration methods may yield better disaggregated fits for a given data set.
- That large hydroeconomic models are generally easier to run and debug if they are constructed as modular, but formally linked, units rather than fully integrated models. There is greater flexibility in terms of questions that can be addressed, and it is easier to

manage model development. Someone needs to be responsible for integration – i.e., ensuring that data inputs and outputs are compatible.

Session (B): Modeling Agricultural Water Use

This session was led by Prof.Chokri Dridi, Department of Rural Economy, University of Alberta. The title of Chokri's presentation was "Water Modeling Challenges: Irrigation Technology Choice and Political Economy of Water Pricing." Chokri discussed modeling approaches that involve farm heterogeneity and technology choice. Many mathematical models used in water economics are principally planning models based on assumptions about profit maximizing behavior of representative agents. Another class of models considers the individual behavior of farmers, recognizing that farmers are heterogeneous and may use private information about their farm characteristics and practices to behave strategically. These models can be used to understand policy feedbacks including the heterogeneous response of producers to policy variables as well as behavior that influences the design of policy.

Some of the main points made in this session were:

- Pricing and trading influences the adoption of better irrigation methods and the retirement of less efficient lands for water conservation.
- That the political economy dimension of water pricing is an important factor in the success of water pricing reforms. In particular, volumetric water rates may be subject to manipulation by producers who determine whether or not the members of the Water Users Association are re-elected. The final water pricing structure depends on farm characteristics.
- Modeling these types of problems for a basin requires disaggregated approaches that consider individual water consumers and their interactions (for example agent-based approaches). These types of modeling approaches are complementary to the hydro-economic approaches discussed above. Outcomes from the agent based models can be fed into hydro-economic models to better understand policy outcomes.

Session (C): Empirical Issues in Water Value Estimation and/or Model Calibration

This session was led by two presenters, Professors Diane Dupont and Steven Renzetti, both of the Department of Economics, Brock University. Their presentation was titled, “Canadian Water Valuation and Demand Modelling: State of the Art and Future Directions.” Diane's presentation focused on valuation and its role in water management. She noted that historically there have been high rates of water consumption in Canada due to low prices and lack of metering, and that valuation is important if efficient water use decisions are to be made. Some of the other points that she made were:

- That the valuation of water is problematic because many goods/services provided by water were not bought or sold in markets. The total economic value approach could however be employed to derive estimates of the value of water. This entails aggregating the use, non-use/passive and existence values. The various values can be captured. Non market valuation techniques can be used to capture these values.
- That since consumers typically combine water with other market goods to provide useful services, use values can be revealed indirectly by observing consumers' choices of market goods and water.
- That to capture non use/passive use and existence values an artificial market can be constructed that describes change in water services/attributes. By directly asking respondents to state their preference for change or status quo, values can be inferred through stated preferences.
- Indirect and direct methods can be used to value water services. Indirect services include the travel cost method, hedonic price method and the defensive expenditure approach.
- That the direct methods that can be used to value water services are referendum style CVM, and attribute-based stated choice methods (ABSCM) or choice experiments (CE).
- That there are very few current Canadian studies that have employed modern nonmarket valuation techniques to estimate the value of water services.
- That context is very important in carrying out nonmarket valuation studies.
- That there are big knowledge gaps in areas such as passive use values, the values of ecosystem services and how values are affected by user characteristics. Although benefit transfer has been widely used to estimate the values of ecosystem services, considerable care needs to be exercised in its use since values are to a large extent context dependent.

Discussion after Diane's presentation highlighted the importance of getting some of these parameters into hydro-economic models being used to evaluate policy.

Prof. Steven Renzetti continued the presentation by discussing water demand modeling. He pointed out that there are few studies of Canadian residential water demands due to limited data and the government's low demand for specific parameter estimates as part of their own policy analyses. The few available studies were based on single equation models, many of which do not adequately address price endogeneity and are now out of date. However, based on US studies it could be inferred that water demands were generally inelastic but more elastic for outdoor use. With regard to industrial demand, microdata from the Industrial Water Use survey are available to support studies that use the KLEMW cost functions model. Studies on industrial water demand show that the price and output elasticities were higher in the manufacturing sectors than in the industrial or agricultural sectors.

As for agricultural demands: lack of data on water use and lack of volumetric pricing makes it difficult to understand producer behavior in response to increased water scarcity or water costs. Most studies on agricultural water demands in Canada have used the engineering/ agronomic approach where water demand is determined by crop type, precipitation, temperature, soil type and irrigation system efficiency. This is the approach currently used in the WRMM irrigation demand model. Some drawbacks of this approach are that output choices and investment are not modelled so it only captures changes in water use at the intensive margin, rather than considering how water use also changes at the extensive margin through changes in land use. A behavioral approach would examine the farmers' choice of inputs and outputs as a function of prices and preferences. A greater level of responsiveness would be captured since more substitution among inputs and land uses would be allowed. Finally, assumptions about profit maximizing behavior could be tested rather than assumed. The engineering and behavioral approaches should be treated as complements for each other since the weaknesses of one approach tend to be the strength of the other. Some future directions in water demand modeling that Steven identified were estimating residential demands using microdata and applying more advanced econometric techniques to estimate these demands. Discussion after Steven's presentation highlighted the need to collect better information about agricultural water use.

Session (D): Collaborative Modeling Exercises

This session was led by Prof. Jay Lund, Department of Civil and Environmental Engineering, University of California, Davis. Jay's presentation was titled "Insights from Optimization: In and Out of the Ivory Tower." Jay began his presentation by discussing why we do computer modeling. Modeling is used to:

- integrate empirical and deductive knowledge
- generate complex testable hypotheses;
- improve and test intuitive understanding
- identify gaps in our understanding
- explore and compare solutions to problems
- avoid costly trial and error associated with testing policy "in the field"; and
- reduce uncertainty and provide assurances.

In sum, the value of collaborative modeling efforts between economists and engineers is that they can help one structure complex problems, identify important gaps, explore novel solutions, demonstrate detailed thought, and provide and support insights that would be otherwise unavailable for complex systems. These models also allow us to explore complexities beyond our intuitive limits.

Professor Lund then discussed the CALVIN model which is an economically driven optimization model of California's water supply. He pointed out that the CALVIN model includes both surface and groundwater systems, urban and agricultural values of water, operating costs, and environmental flow constraints, and prescribes a monthly operation system over a 72-year representative hydrology. Important insights from CALVIN for Californian water policy include:

- water markets lead to large efficiency improvements.
- storage expansion in California was less valuable than conveyance expansion.
- groundwater and conjunctive use has large benefits
- Dismantling the O'Shaughnessy dam would not significantly change streamflows and result in environmental benefits because users would consume from substitute sources.

Session (E): Where to from here?

The session was introduced by reference to the following questions posed by the organizers and added to from the floor:

1. Would water policy research/researchers gain from having access to a common integrated modeling platform, such as augmented versions of *WRMM*, *WUAM*, or *CALVIN*? If so, which one, and why?
2. What about a common modeling platform at the farm-scale or cellular automata level?
3. What are researchers' data needs, data gaps, and data sharing possibilities?
4. What processes, funding, approaches and coordination could best make this happen?
5. What about the potential for greater interaction with scientists and researchers in other disciplines whose research methods, models and data may be relevant?
6. What are the three top policy questions regarding water use and management in Alberta that we need to be addressing in our modeling work?

After clarification of the questions, the discussion focused on Questions 1, 3, and 4.

Question 1 -

- Most of the discussion focused on question 1. Participants noted that lack of an optimization model for Alberta/Canada is a gap.
- Discussion focused on the Water Resource Management Model (WRMM) developed by Alberta Environment and whether or not it could be modified as an optimization model. It was pointed out that the WRMM was originally developed as a planning tool for surface water resources utilization, with the river basin being the unit of analysis. WRMM has the capability of computing a steady state water balance over a sequential period of user-defined time steps.
- Conclusion - WRMM is not an economic optimization model but could easily be modified since it currently assigns water based on priority when constraints are binding. Priorities are assigned using penalty functions which could be converted into water demand functions without changing underlying model structure. Water demands would come from other modules (similar to how the irrigation demand model and WRMM currently interact).

- The discussion of the WRMM was followed by a discussion of the Water Use Analysis Model (WUAM) developed by Environment Canada. The WUAM is an interactive computer simulation model designed primarily to provide projection of multisector water uses in a drainage basin context. Water use in the model is a function of price, so it is possible to test the effects of changes in price on water balance in the basin. However WUAM is not an optimization model. Therefore it is not possible to identify the costs and benefits of management options, nor could the model be modified to function as an optimization model.

Question 2

In the second half of this session the participants discussed the data problems that are commonly faced in modeling water allocation issues. Concern was expressed about data gaps, data reliability, and accessing the data that were available. The participants also noted the need for detailed documentation of data (metadata) so that the users of the data know the details about how the data were gathered and the manipulation carried out on the data.
Possible micro data sources for agriculture were noted, including data held by the irrigation districts. Various individuals agreed to follow up with David Hill on this.

Question 4.

Participants would like to collaborate but not formally. David Hill noted that stakeholders should be part of research design and that poor communication between science community and stakeholder groups is a problem.

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