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Managing Water in the West

Scoping Methods for Evaluating and Computing Future Agricultural Water Needs

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Cover Photograph: Agriculture and irrigation near Ashton, Idaho. Minidoka Project, Idaho.
Photograph by Dave Walsh.

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14. ABSTRACT Reclamation is responsible for delivering water to irrigators in 17 western states. In order to meet its mission of delivering water in future years, Reclamation must plan for future conditions. One aspect of this planning is to understand how the demand for water will change in the future and determine ways to predict the potential changes in water demand. Previous studies have used varied methods for predicting future water demand, but all of them ignore the potential for crop distribution to be impacted by future conditions. This scoping level study investigated the possibility of using agent-based models to predict the changes in crop distribution and land use that will impact future agricultural water demand. Previous uses of agent based models indicate that the tools are appropriate for predicting land use change and could be extended to predict crop distribution. A fiscal year 2015 proposal was submitted to the Science and Technology Program to develop an agent based modeling tool to attempt to predict agricultural water demands under climate change projections, using the Boise Valley as a test case. Historical land use, economic, water delivery, and weather data is available to support the study.

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Executive Summary

Reclamation is responsible for delivering water to irrigators in 17 western states. In order to meet its mission of delivering water in future years, Reclamation must plan for future conditions. One aspect of this planning is to understand how the demand for water will change in the future and determine ways to predict the potential changes in water demand. Previous studies have used varied methods for predicting future water demand, but all of them ignore the potential for crop distribution to be impacted by future conditions.

This scoping level study investigated the possibility of using agent-based models to predict the changes in crop distribution and land use that will impact future agricultural water demand. Previous uses of agent based models indicate that the tools are appropriate for predicting land use change and could be extended to predict crop distribution.

As a follow-up to this study, a fiscal year 2015 proposal was submitted to the Science and Technology Program to develop an agent based modeling tool to attempt to predict agricultural water demands under climate change projections, using the Boise Valley as a test case. Historical land use, economic, water delivery, and weather data is available to support the study.

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Project Summary

Irrigated agriculture comprises the largest consumptive use of water in the Western United States. Thus, predicting how agricultural water demands will respond to climate change is an essential to understanding how western water resources can be sustainably managed in the future.

Goal of the Scoping Study

This scoping level study was designed to conduct preliminary research to determine if agent-based models can be used to better predict agricultural demands under climate change conditions.

Agricultural Demand Definition

Agricultural demand is a generic term used to describe the amount of water that is needed to irrigate crops for agricultural production. It can be interpreted conservatively to include only the quantity of water necessary for maximum growth potential of a particular crop (excluding conveyance losses), or interpreted to include the total amount of water diverted from a stream, or pumped from an aquifer, (including conveyance losses) and applied to a crop. This study is focused on the conservative interpretation; recognizing that application of these values in water management modeling exercises will require additional work to account for basin infrastructure characteristics.

Previous Quantification of Agricultural Demands

Agricultural demands have been considered to varying degrees in previous Reclamation studies that attempted to quantify the impacts of climate change on regulated river systems. Approaches have ranged from using demands that represent current conditions, to using estimates that account for the potential change in demands due to projected climatic changes. The following Reclamation studies illustrate the various methods that have been used to date:

- The River Management Joint Operating Committee (RMJOC) Climate Change study in the Pacific Northwest used a pattern of demands representative of wet, median, and dry conditions for the last ten years of record (Reclamation 2011a). Use of conditions-based demand patterns in modeling allows the time series of demand values to change automatically during model runtime in response to changing basin conditions (wet, median, or dry depending on projected inflows and in some cases carry-over storage).

This study essentially extrapolated this functionality, and used the conditions-based demand patterns to estimate the demands that may occur as a result of climate change. This study did not account for potential changes to land use or crop distribution that could occur due to climate change which may significantly alter demand patterns. Modeling the system in this fashion allowed for an estimate of diversion shortages based on current needs; i.e. diversion shortages were quantified given the assumption that demands remained similar to those of the last ten years, while inflows changed due to climatic shifts in temperature and precipitation. Because this study did not account for the changes to demands that are likely to result from climate change impacts on land use and crop distribution, it was therefore limited in its ability to estimate total water availability and delivery as a result of climate change.

- The WaterSMART Basin Studies are intended to evaluate and address the impacts of climate change at a basin scale. Under the Basin Studies, current and future projected supply and demand are evaluated. Various methods were used to quantify projected future agricultural demand in the five basin studies that have been published as of August 2014 (Colorado River, Lower Rio Grande, Milk-St. Mary's, Santa Ana Watershed, and Yakima); ranging from complex land use models to determine possible changes in irrigated acres, to simple estimates of possible percentage increase or decrease in water demands (CWCB 2011; DBSA 2005; DBSA 2008; DWR 2001; MRCOG 2001; Reclamation 2003-2009; Reclamation 2011b; Reclamation 2012a; Reclamation 2012b; Reclamation 2012c; Reclamation 2013a; Reclamation 2013b; RGRWPG 2010; SSPA 2000; TWDB 2012). Although the more complex methods accounted for irrigated lands going into or out of production, only one of the studies accounted for changing crop types due to a changing climate although the methods were not explicitly described (SWWRC 2001). In general, the estimates of future demands in these studies were limited by current estimates of crop distribution and land use, which are likely to adjust with climate change.

- The recently completed, but not published as of August 2014, Hood River Basin Study (Reclamation 2014a) estimated changes in demands by increasing the amount of demand by ten percent per one degree Celsius (°C) increase in temperature. This factor was derived from a study conducted at Oregon State University of Agricultural Sciences on the impacts of climate change on agriculture in Oregon (Coakley et al. 2010). This increase in demands was based only on projected temperature changes and did not account for changes in precipitation. The benefit of this method is that a possibly more accurate estimate of total water supply is attained through the modeling process because some accounting is made for additional water needs. The limitation of this method is that the change to precipitation is not considered in this estimate of demand change and similar to the method used in the RMJOC study, this method assumes that land use and crop distribution remains similar to current conditions.

- The Desert Research Institute and Reclamation developed future irrigation demand estimates for eight major river basins in the Western United States by quantifying the crop water requirement using an evapotranspiration (ET) calculator (Reclamation 2014b). The demand estimates were quantified at the hydrologic unit code eight (HUC 8) scale and assumed current land use and crop distribution. The methodology used in this study was developed to understand, at a very broad scale, the potential for change in demands under three climate projections. Use of a sophisticated ET model enabled this study to account for potential changes in both temperature and precipitation. The limitation of this method lies in its assumption of current land use and crop distribution. Under such an assumption it does not fully account for changes that will likely occur under climate change.

The Idaho Water Resources Board investigated future agricultural and domestic water needs for the Boise Valley in 2010 for the Comprehensive Aquifer Management Plan (CAMP) study (WRIME 2010). Agricultural demands were estimated using an estimate of projected land use and crop distribution in ten year increments through 2060. Crop distribution was projected by scaling current percent distribution of crop types to projected changes in irrigated acres, and then ET was estimated using historical climate data. Total demand was adjusted for estimated conveyance and on-farm losses. No attempt was made at adjusting crop distribution for potential changes in climate and ET was not calculated using projected climate data.

In general, the previous methods used to develop future agricultural demands focus on the physical need for water, but assume the current cropping patterns and water management systems will remain relatively unchanged. Many factors will likely influence demands for agricultural water including economics, legal constraints (water rights), increasing populations, and land use change. The outlook for future agricultural water demands could look drastically different than what currently exists, and yet, the current methods do not account for the factors that would indicate potentially large shifts in demand.

Previous Uses of Agent Based Models

The limitations of the previous methods used to quantify future agricultural demands indicate the need for a more complete method that can account for the various factors influencing irrigator's decisions that result in changes in demand. Agent-based models (ABM) are a type of modeling tool that allows for the quantification of complex interactions between individuals or groups. Unlike standard equation based computational models, they can be programmed with the ability to adapt to influences from changing environments while allowing the individual agents to react to each other, and changes in the physical environment. In that sense, they are seen as tools that can more accurately reflect human decision making processes under various conditions. In addition, they allow for exploration of potential interactions that result from feedback loops and the identification of possible emergent patterns that result from the interactions (Heckbert et al. 2010, Matthews et al. 2007).

Attempts have been made to begin to understand how human decision making processes are impacted by changing environmental factors and vice versa. The fields of land use management and economics have benefitted from the use of ABMs, or Individual-Based Models (IBMs) as they are sometimes called, because both are better understood when decision making processes are included in the analysis, rather than simply focusing on physical or mathematical processes.

In an early application of an ABM for land use change, Rajan and Shibaski (2001) developed a model to explore the rural to urban land use conversion by linking biophysical crop yield, rural income, and urban land use all while being influenced by market, physical, and social factors. Parker et al. (2003) shows that ABMs are appropriate tools to explore land use changes because they more accurately represent complex spatial interactions under heterogeneous conditions. In an applied example, Parker and Meretsky (2004) demonstrate the ability of an ABM platform to link landscape patterns to ecological and socioeconomic factors to explore the conversion of rural to urban lands.

Expansion on the land use conversion models has led to models that include more complex ideas of policy and ecosystem resilience. Over many years and iterations, Balmann (1997), Balmann (et al. 2002), Berger (2001), and Happe (2004), Happe(et al. 2006) developed an ABM platform called AgriPoliS that is used to explore farm policy decisions in Europe (Kellerman et al. 2008). AgriPoliS has been successfully calibrated at the individual farm and aggregate levels and simulated reasonable results to farm policy changes. It incorporated a spatial environment, political environment, behavior of agents, markets, and land markets. However, none of the applications of AgriPoliS appeared to be related to water, likely because all of the applications were in areas that are not water limited. The relationships that link the physical, political, economic, and social changes together in this tool have the potential to become a reasonable foundation for the work in the proposed study, but will require additional work to incorporate the relationship to water.

The ability of an ABM approach to successfully incorporate water-focused relationships was demonstrated in a 2007 study by Shluter and Pahl-Wostl. This study used an ABM approach to explore system resilience in a semi-arid river basin that uses water for aquatic species (fish) and irrigated agriculture. Agents, representing farmers, made decisions on the number of fields to irrigate using their knowledge of water availability and past experience. They supplement their farming income with fishing, which impacts the aquatic ecosystem. Policy decisions were tested in the model to determine the resilience of the ecosystem and the model performed as expected.

Models in general are simplified representations of very complex systems. ABMs attempt to address the complexities in more advanced ways than any other type of modeling tool. Because of this, they can be difficult to calibrate, validate, and verify. In each of the studies that have been included in this paper, there has been some discussion of an attempt at calibration, validation, or verification, but many acknowledge that it is not as straight forward as it might be in a physically based model. Polhill et al. (2008) suggests that in order to attain increased credibility in the field of modeling, agent-based modelers should follow standardized documentation protocols called Overview, Design concepts, and Design (ODD) to ensure that others can replicate their work and conduct their own validation, if necessary.

Agent Based Modeling Platforms

Another challenge with ABMs is that there are numerous platforms and there is not one accepted, standard method for developing simulation models. A Wikipedia page that compares agent based modeling software lists 84 different modeling platforms (Wikipedia 2014), and there are additional platforms not listed on this page. In an effort to narrow down the selection of modeling platforms for testing, a few high-level criteria were established and include the following: the platform should not have a license fee; it should be able to run in a Microsoft Windows environment; it should also have the ability to integrate with Geographical Information System (GIS) data; and it should be open source. Even after applying these filtering criteria, a large number of possible platforms still remained. A handful of promising platforms from this list were then selected and further evaluated to determine if they might have the capability to simulate the processes required for this project.

Based on these criteria and previous applications, three platforms were selected to carry forward for additional evaluation: Repast, Cormas, and Envision.

- Repast is a free, open-sourced, java based platform that has been used to investigate a wide range of problems including land use change. At first glance, it appears that this platform could have the flexibility to incorporate the methods that will be required in the proposed project. It also appears to have a substantial user community and online reference material that will be useful when developing a new model.

- Cormas is a free platform that uses the SmallTalk language. It has been used for many natural resource agent-based modeling projects in Europe and appears to be flexible for use with external models.

- Envision is a free, open sourced GIS based platform. It has been used for water resource related problems and is currently being explored for use in the Boise Basin.

Given that this is a relatively new method of modeling and there is not one accepted method or tool, these three models will be investigated for use in the proposed project, rather than focusing on one single platform. This will allow for flexibility should one of the platforms not be able to accommodate integration with a particular model or dataset.

Proposed Work

This literature summary showed that current methods for quantifying agricultural water demands ignore important aspects that may be key to determining the amount of water needed in the future: land use change and crop distribution. In an effort to determine how agricultural water demand may be impacted by climate change, a more complete method for determining agricultural water demand is necessary. The literature summary also suggests that agent-based modeling may be a promising tool for accounting for the multiple processes that may lead to an irrigator's decision to irrigate or not to irrigate, and what type of crop he might select for irrigation.

A proposal was submitted to the Science and Technology project for the Fiscal Year 2015 cycle to further investigate this topic. The major tasks include: (1) data collection, (2) conceptual model development, (3) ABM development, (4) scenario evaluation, and (5) documentation and outreach. The Boise Basin will serve as a test location in which to evaluate the developed methods. The Boise Basin was selected for two reasons: (1) it has a large amount of existing data and hydrologic modeling tools, and (2) it has relatively few existing water conflicts when compared with other basins in the west with similar data and modeling resources.

Available Data

A cursory investigation into available data was conducted during this scoping analysis. The list below describes the possible data types that will be needed for this study and the current available sources of this data.

- Historical Crop Distribution – Cropland Data Layers are spatially distributed crop types made available by the Natural Agricultural Statistics Service from 1997 through 2013 (USDA 2014b). Prior to 1997, statistics are available by county, though they are not spatially distributed. This data has been used by Reclamation to develop historical cropping patterns for all Reclamation Projects and the results of this work will be made available for this project (Patrick Wright, personal communication, June 2014).

- Water Right Data – Water right data are available from Idaho Department of Water Resources (IDWR) by place of use and place of diversion along with priority date and flow rate (IDWR 2014b). Historical data describing the quantity and timing of natural flow and stored water delivered is also available from 1986 through 2014 (IDWR 2014a).

- Weather Data – Historical weather (temperature and precipitation) data is available from the National Weather Service (NOAA 2014) and Reclamation's Agrimet Program (Reclamation 2014c).

- Crop Commodity Costs and Returns – Current, recent, and historical crop commodity costs and returns are available from the United States Department of Agriculture Economic Research Service at various spatial resolutions (USDA 2014a). Some of the data are only available at the national scale, but could be related to the types of crops grown in the Boise Basin.

- Climate Change Projections – The World Climate Research Programme's (WCRP) Working Group on Coupled Modeling (WGCM) publish downscaled Coupled Model Intercomparison Project (CMIP) CMIP3 and CMIP5 climate and hydrology projections through a website hosted by Lawrence Livermore. The climate and hydrology projection datasets are available from 1950 through 2099 (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections) (Reclamation 2013c).

- Demographic and Population Projections – The Community Planning Association of South Idaho has population estimates from 1980 through 2014 and has made land use and population projections through 2030.

- Estimates of Agricultural Water Demand – Historical and current estimates for agricultural water demand were developed for the Treasure Valley Hydrologic Project (Petrich 2004), the Distributed Parameter Water Budget for the Lower Boise Valley (Reclamation 2008), and for the CAMP study in 2010 (WRIME 2010). Estimates of future demand were also estimated for the CAMP study.

Given that the proposed project aims to better understand the decision making process that irrigators/farmers use to determine crop distribution and land use, it might be worth pointing out that, at this point in time, there is no intention to collect sociological data related to behavior directly. Instead, the goal is to evaluate and learn from historical patterns and attempt to determine if behavioral decisions can be derived from non-sociological data. The results will be verified by comparing them to data and by discussing the results with irrigators/farmers.

Most of the data is available for the past 20 to 30 years, which over time the Boise Basin has experienced considerable population growth and land use change. Although extreme drought/flood conditions have not occurred during that time period, there was variability in the water supply from year to year that may have impacted cropping and land use decisions. Given the changes over the last couple decades and water supply variability, the on-farm decision making processes should become apparent when the data are examined.

Possible Uncertainties

Uncertainty exists in any modeling exercise since models are simplified representations of the real world that can never fully represent the complexity that truly exists. Limitations exist in the mathematical representations of physical processes and the data that is available for the simulations. Although agent-based models attempt to more fully represent the complexity of reality through their incorporation of behavior based data, they can be difficult to calibrate, verify, and validate particularly when they are used in predictive mode.

In an effort to limit and better understand the modeling uncertainty associated with the agent-based approach, the developed model will be compared to historical data to ensure it is accurately replicating the historical decision making processes and a sensitivity analysis will be conducted to test the reasonableness of the model boundaries.

Conclusions

The scoping project that was conducted in 2014 was successful in determining that there is a need for a more complete method for evaluating future agricultural water demands. The current methods lack the ability to predict future land use and crop distribution that may result from climate change and that may significantly impact future agricultural water demands.

This project also showed that agent-based modeling could be a viable method for more completely evaluating future agricultural water demands. There is data available in the Boise Basin to begin identifying relationships that might exist between land use, crop distribution, water availability, water rights, commodity prices, and weather.

A proposal was submitted for the FY 2015 proposal cycle to continue this work.

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