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Efficiency, equity, and sustainability in a water quantity–quality optimization model in the Rio Grande basin

Frank A. Ward[a,*], *Manuel Pulido-Velázquez*[b]

[a]*Department of Agricultural Economics and Agricultural Business Campus Box 30003, New Mexico State University, Las Cruces, NM 88003, United States*
[b]*Hydraulic and Environmental Engineering Department, Technical University of Valencia (Univ. Politecnica de Valencia) Cami de Vera, s/n. 46022, Valencia, Spain*

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ABSTRACT

Integrated hydrologic and economic optimization models at the basin scale provide a framework for policy design, implementation, and evaluation in water-stressed basins. Despite the considerable potential that basin scale analysis offers, few basin-wide studies have examined tradeoffs among efficiency, equity, and sustainability when analyzing the design of water resource programs. This paper develops a basin scale framework to identify hydrologic and economic impacts of alternative water pricing programs that comply with environmental regulations for protecting water quality. Key issues are examined that confront integrated hydroeconomic basin models: linking water and economics, spatial and temporal scale integration, and quantity–quality relationships. Economic efficiency is defined and measured for each of two urban water pricing arrangements that comply with urban water quality protection regulations. Alternative measures of equity are analyzed in both spatial and temporal dimensions. Sustainability is evaluated physically for protecting the water supply and financially for long-term revenue viability. The approach is illustrated from results of a dynamic nonlinear programming optimization model of water use in North America's Rio Grande basin. The model optimizes the net present value of the basin's total economic benefits subject to constraints on equity, sustainability, hydrology, and institutions. It is applied to assess impacts of a two-tiered pricing program that complies with recently implemented drinking water quality standards for the basin's two largest U.S. cities: Albuquerque, New Mexico, and El Paso, Texas. Results suggest that two-tiered pricing of urban water supply has considerable potential to perform well in meeting the aims of efficiency, equity, and sustainability. Findings provide a general framework for designing water pricing programs that comply with environmental regulations.

1. Background

The typical river basin contains several water-related human activities, including water storage, diversion, pumping, distribution, purification, and pollution. Basin scale analysis provides a comprehensive framework for informing the design of measures that produce efficient, equitable, and sustainable distribution of economic benefits and costs of water programs. Several basin scale analyses have been conducted since the mid 1990s. Allan et al. (1997) presented a comprehensive and detailed basin scale model for southeastern Michigan; Bockstael et al. (1995) integrated ecological and economic modeling for the Patuxent drainage in Maryland; Booker (1995) in a celebrated study, developed and

* Corresponding author.
E-mail addresses: fward@nmsu.edu (F.A. Ward), mapuve@hma.upv.es (M. Pulido-Velázquez).

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applied an integrated hydrologic-economic-institutions analysis of seven Colorado Basin states. Conway et al. (1996) developed a basin scale model of the Nile Basin in Egypt that operated at three scales: global (climate change), regional (land use patterns), and river basin (water management). de Wit (2001) used a basin scale model to conduct policy analysis for the Rhine and Elbe basins in Europe; Rosegrant et al. (2000) and Cai and Rosegrant (2004) introduced an integrated economic-hydrologic modeling framework of the Maipo river basin in Chile. Varela-Ortega et al. (1998) built a dynamic programming model to examine effects of various water conservation policies in selected Spanish watersheds.

Several papers containing water decision support models have been published: large-scale integrated river basin scale models applied to simulate the economic impacts of policies for managing droughts (e.g., Booker, 1995; Characklis et al., 1999; Booker et al., 2005; Ward et al., 2006); assessments of the economic value of streamflow by location in a basin (e.g., Pulido-Velazquez et al., 2006a,b; Jenkins et al., 2004); optimal system operation (e.g., Pulido-Velazquez et al., 2004); water allocation and policy options (e.g., Letcher et al., 2004); water transfers and water markets (e.g., Rosegrant et al., 2000; Draper et al., 2003; Knapp et al., 2003; Ward et al., 2006; Jenkins et al., 2004), analysis of tradeoffs among competing uses (Ward and Lynch, 1997; Burke et al., 2004; Watkins and Moser, 2006), and assessments of regional economic impacts of climate change adaptation (e.g., Tanaka et al., 2006).

These examples show considerable advances made in basin scale analysis in recent years. However, few of these studies have explicitly quantified tradeoffs among efficiency, equity, and sustainability in analyzing the design of water programs. The aim of this paper is to present a method for designing and implementing a water pricing program that addresses these three goals. To meet that aim, we present an analysis of water prices that send economically efficient and sustainable signals to water users while also addressing equity, in which subsistence needs for treated water are priced sufficiently low to be accessible to all. The paper describes a two-tiered (lifeline) water pricing system that prices basic subsistence needs cheaply, but charges a price equal to full marginal cost, including environmental cost for any uses in excess of subsistence. It meets that aim by describing a basin-wide optimization model that accounts for efficiency, equity, and financial and physical sustainability for the Rio Grande Basin of North America. The model examines impacts of a pricing program for implementing recently established environmental regulations that limit arsenic levels for drinking water for the basin's two largest U.S. cities, Albuquerque, New Mexico, and El Paso, Texas.

2. Study area and issue

2.1. *Rio Grande basin of North America*

The Rio Grande rises in the Weminuche Wilderness, San Juan County, Colorado, on the Continental Divide, as a snow-fed mountain stream at an elevation exceeding 14,000 feet above sea level. The river flows for 170 miles in southern Colorado through the San Luis Valley, then southward for 475 miles splitting New Mexico until it reaches the junction of Chihuahua, Mexico and Texas, USA. There, the Rio Grande becomes the international boundary between the United States and Mexico. Even under normal flow conditions, basin demands exceed supplies; emerging demands for environmental protection in the form of instream flows further increase competition for already scarce water. Overlaid on this is continued population growth, declining ground water levels, and deteriorating water quality. The upper Rio Grande basin (the Basin), is that part of the river that flows from its headwaters to about 70 miles south of the border cities of El Paso — Ciudad Juárez. Surface water from the river meets the primary water needs of three major cities of Albuquerque, New Mexico in addition to El Paso, and Ciudad Juárez. It also serves one million acres of irrigated land in the U.S. and Mexico.

In 1906, the U.S. — Mexico water treaty (the Treaty) provided that the United States deliver to Mexico 60,000 ac ft/year. In 1938, the Rio Grande Compact (the Compact) was approved by the US Congress, dividing annual waters flow among Colorado, New Mexico, and Texas. Environmental demands for and values of water continue to increase. The Rio Grande silvery minnow (the Minnow), was listed as an endangered species by the U.S. Fish and Wildlife Service in 1994.

2.2. *A water quality issue: arsenic treatment*

2.2.1. *Introduction*

Some of the Basin's soils contain high levels of arsenic, which can increase risks for some types of cancer caused by consuming water originating from its aquifers. While drinking water systems for the basin's two major urban areas, Albuquerque New Mexico and El Paso Texas did meet the previous US EPA's 50 ppb standard, some of their water sources fail to meet the 2001 10 ppb standard. Both Albuquerque and El Paso will need to secure revenues from its urban water customers to pay for the costs of complying with the new EPA arsenic standards.

2.2.2. *Drinking water: Albuquerque and El Paso*

Albuquerque is completing its surface water treatment plant now under construction. The arsenic treatment is estimated to raise the typical customer's annual existing bill of $621 by about $252, equal to 40% of its current level (Bitner, 2004). El Paso water customers have two main drinking water sources — surface water from the Rio Grande from mid-March through mid-October and groundwater from two aquifers: the Mesilla Bolson and the Hueco Bolson. About half of the water supply comes from the river in normal water years (Lockhart, 2005). Arsenic has been found in the water of 46 of the city's 175 wells. In 2005, El Paso built a 60-million-gallon-per-day (mgd) arsenic removal plant, the largest in the US. The complete cost of the package was $76 million, resulting in a 19% rate increase to its customers.

This paper compares two demand management instruments in each of two regulatory environments for urban arsenic treatment in the Rio Grande Basin: (1) marginal cost pricing without arsenic water treatment; (2) marginal cost pricing with urban arsenic water treatment; (3) two-tiered