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Research Paper

Economic and policy drivers of agricultural water desalination in California's central valley

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ABSTRACT

Water desalination is a proposed solution for mitigating the effects of drought, soil salinization, and the ecological impacts of agricultural drainage. In this study, we assess the public and private costs and benefits of distributed desalination in the Central Valley (CV) of California. We employ environmental and economic modeling to estimate the value of reducing the salinity of irrigation water; the value of augmenting water supply under present and future climate scenarios; and the human health, environmental, and climate change damages associated with generating power to desalinate water. We find that water desalination is only likely to be profitable in 4% of the CV during periods of severe drought, and that current costs would need to decrease by 70–90% for adoption to occur on the median acre. Fossil-fuel powered desalination technologies also generate air emissions that impose significant public costs in the form of human health and climate change damages, although these damages vary greatly depending on technology. The ecosystem service benefits of reduced agricultural drainage would need to be valued between $800 and $1200 per acre-foot, or nearly the full capital and operational costs of water desalination, for the net benefits of water desalination to be positive from a societal perspective.

1. Introduction

The twin stressors of water scarcity and soil salinization diminish agricultural yields and grower profitability in arid regions (Welle and Mauter, 2017). Climate models project expansion of arid regions and increased probability of drought in both the western United States and the majority of agricultural regions worldwide (Cook et al., 2015; Huang et al., 2016; Wang, 2005). In these water stressed regions, growers often augment water supply with alternative sources including brackish groundwater and agricultural drainage water. The application of these lower quality water sources can lead to the accumulation of salts and, in areas with insufficiently permeable soil, to the development of shallow saline water tables (Ghassemi et al., 1995). Recent studies estimate the cost of soil salinization in California at $1.7 to $7 billion dollars per year (Howitt et al., 2009; Welle and Mauter, 2017). As a result, improving the sustainability of food production systems in arid, drought prone, and salinizing regions is a high environmental and policy priority (Sabo et al., 2010).

Traditional responses to the diminished yields associated with soil salinization increase agricultural land area, intensify agricultural water consumption, and impose downstream environmental impacts. Local land fallowing reduces agricultural production and drives land-use change, which is often associated with increased greenhouse gas emissions (Tilman et al., 2011). The second response, salinity leaching from salt-impaired fields via the excess application of irrigation water, consumes scarce water resources, raises elevated groundwater tables, and often leads to the discharge of saline tile drainage to sensitive environmental ecosystems (Wichelns and Oster, 2006). While alternative drainage management schemes include re-application of tile drainage to salinity tolerant crops or storage in evaporation ponds, most tile drainage is discharged to the environment (Schwabe et al., 2006; Wichelns and Oster, 2006). Specific contaminants found in this agricultural drainage, notably selenium and boron, impair reproduction, inhibit growth, suppress the immune system, and cause mutagenesis in fish and birds (Chang and Brawer Silva, 2014; Ohlendorf, 1989). Thus, conventional salinity management practices force trade-offs in agricultural productivity and environmental sustainability (Schoups et al., 2005).

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Nomenclature

List of Symbols

R	Revenues
S^S	Soil salinity
b	Crop salt tolerance slope parameter
p	Prices
Y_M	Theoretical maximum yield
L	Leaching fraction
S_W	Water salinity
W^T	Water treated
Π	Profits
W	Applied water
υ	Prices
Y	Production
δ	Exponential response function intercept
γ	Exponential response function elasticity
X	Resources use
ω	Resource cost
τ	Factor productivity
β	Resource coefficient
ρ	CES elasticity parameter

Subscripts

g	Region
i	SWAP crop group
j	Resource
ws	Water source (project water, surface diversion or groundwater)
land	Land resource

Water treatment technologies offer a potential remedy to this impasse by allowing farmers to treat existing irrigation waters or access new impaired water sources, including saline groundwater or agricultural tile drainage. Drainage water leached from agricultural soils and discharged through tile drains can be deionized and beneficially reused as a source of irrigation water, while the residual brine concentrate may be disposed of through subsurface injection or crystallized and disposed of as solid waste. Desalination of tile drain discharge would simultaneously minimize ecosystem damages, limit soil salinization, reduce agricultural water intensity (acre-feet/acre-year), and offer a new source of irrigation supply.

Technologies potentially applicable to agricultural water desalination are distinct from conventional seawater desalination technologies for municipal water treatment in requiring higher water recovery, tolerance of highly variable feed streams, and cost-effectiveness at small to medium scales. The cost-effectiveness of these technologies will also be facilitated by limited requirements for pre-treatment, low operator oversight, and resiliency to intermittent or variable water quality. Several technologies for distributed agricultural water desalination have been piloted or installed commercially, including thermal desalination (e.g. multi-effect distillation), membrane-based desalination (e.g. reverse osmosis), and electrochemical desalination (e.g. electrodialysis)(Brame et al., 2011; McCool et al., 2010; Stuber, 2016). In each case, the technology is capable of reducing the total dissolved solids concentration of the product water to effectively zero.

Growing demand for drought mitigation and agricultural drainage treatment has motivated a number of studies assessing the technical feasibility and cost of specific agricultural water desalination technologies (Karagiannis and Soldatos, 2008; McCool et al., 2010; McCool et al., 2013; Rahardianto et al., 2008; Stuber, 2016; Yermiyahu et al., 2007). These studies have generated estimates of water treatment cost, but we are unaware of complementary work assessing the private benefits of technology adoption or the broader consequences of technology adoption for integrated food, energy, and water systems. There remains significant uncertainty about the implications of widespread water desalination for agricultural management practices such as soil leaching, the energy consumption of water desalination technologies and any associated air emission impacts, or the ecosystem services benefits of reduced discharge salinity. Explicitly quantifying these benefits and costs is critical for assessing the likelihood of technology diffusion and the role for policy interventions that maximize public benefits.

The present work quantifies the marginal public and private costs and benefits of agricultural water desalination under a range of future precipitation and climate scenarios in the Central Valley (CV) of California. We present the first assessments of the marginal private benefits of water desalination, realized as improved agricultural yields, using high-resolution multi-modal soil salinity and crop data. We then assess private adoption at the field-level by comparing private benefits to current desalination costs. Next, we contribute the first assessment of potential marginal public costs associated with adoption of agricultural water desalination. Public costs in the form of human health and climate damages are estimated for three different desalination technologies that use renewable, grid, and fossil energy sources. Finally, we back out the effective value of human health and environmental benefits in watersheds impaired by agricultural drainage that would be required for the technology to have net positive effects from a societal perspective.

2. Methods and data sources

We quantify the public and private costs and benefits associated with desalination systems in the CV, a region of high agricultural value, severe water scarcity, and impaired air and water quality. The most agriculturally productive region in the US, the CV includes about 9 million acres of cropped land producing the majority of California growers' $46 billion USD of revenue in 2013 (USDA, 2015). Water availability for irrigation is often scarce due to the aridity of the region, persistent drought conditions exacerbated by a warming climate (Cook et al., 2015), unsustainable groundwater withdraws (DWR, 2015; Medellin-Azuara et al., 2015), and suboptimal market mechanisms for water transfers (Draper et al., 2003). In addition to water scarcity, soil salinization has required widespread installation of tile drains that enable salinity leaching. Discharging this tile drainage into surrounding ecosystems has impaired surface water throughout the CV (Quinn et al., 2010).

A complete system analysis that incorporates the regulatory, legal, economic, and technical factors that impact water use and allocation is beyond the scope of the present work. Instead, this analysis is framed in marginal terms, and therefore limits the decision space by assuming that present-day regulatory environment, legal conditions, and management practices remain constant. Additionally, on the technological modeling side, we limit the analysis to that of a theoretical desalination system capable of reducing water salinity to 0 ppm TDS with 100% recovery for a cost of $1 per m^3 of feed, a middle value in the literature range of $0.78–$1.33 per m^3 of feed. This cost includes the financial costs of brine disposal, but assumes no environmental externalities associated with brine management. While no desalination system is capable of providing this exact service, it reduces the need to model all possible desalination system design choices. As a result of these assumptions, the analysis provides an upper bound estimate on the marginal benefits of actual desalination systems.