Water Research 141 (2018) 196–207

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/watres

Impacts of groundwater management on energy resources and greenhouse gas emissions in California

Thomas P. Hendrickson, Maya Bruguera*

ICF, 601 W 5th St., #900, Los Angeles, CA 90071, United States

ARTICLE INFO

Article history:
Received 14 November 2017
Received in revised form
8 May 2018
Accepted 9 May 2018
Available online 16 May 2018

Keywords:
Drought
Water resources
Energy efficiency
GHG emissions
Water-energy nexus
Sustainable groundwater management act (SGMA)

ABSTRACT

California faces significant energy and water infrastructure planning challenges in response to a changing climate. Immediately following the most severe recorded drought, the state experienced one of its wettest water years in recorded history. Despite the recent severe wet weather, much of the state's critical groundwater systems have not recovered from the drought. The recent Sustainable Groundwater Management Act (SGMA) aims to eliminate future depletion risks, but may force California basins to seek alternative water sources by limiting groundwater withdrawals during droughts. These alternative water resources, such as recycled water or desalination, can have significantly higher energy demands in treatment and supply than local groundwater or surface water resources.

This research developed potential scenarios of water supply sources for five overdrafted groundwater basins, and modeled the impacts of these scenarios on energy demands and greenhouse gas (GHG) emissions for water supply systems. Our results reveal that energy demands and GHG emissions in different water supply scenarios can vary substantially between basins, but could increase statewide energy consumption as much as 2% and GHG emissions by 0.5. These results highlight the need to integrate these energy and GHG impacts into water resource management. Better understanding these considerations enables water supply planners to avoid potential unintended consequences (i.e., increased energy demands and GHG emissions) of enhancing drought resilience.

1. Introduction

California recently endured a 5-year drought, registering the lowest statewide Palmer Drought Severity Index (PDSI) ever recorded in state history in July 2014 (NOAA, 2017). This drought exposed existing vulnerabilities, such as surface water shortages that nearly doubled the groundwater withdrawals, threatening resource availability for future droughts (Howitt et al., 2014). In response, Governor Jerry Brown enacted the first mandatory water conservation requirements (Executive Order B-29-15, 2015) and the legislature passed the Sustainable Groundwater Management Act (SGMA) creating the first statewide groundwater monitoring and limitations requirements.

This drought was followed by record high annual precipitation in the state, further exposing water infrastructure vulnerabilities (CA DWR, 2017d). Flooding occurred throughout California, and a spillway failure that evacuated several towns prompted an investigation into state dam resilience (Lund, 2017; Serna, 2017). Despite recent severe precipitation, many of California's groundwater systems remain severely depleted (Miller, 2017).

California will continue to experience extreme fluctuations in water availability and precipitation. Climate change is projected to increase the severity, duration, and frequency of droughts in California, and increase the frequency and intensity of extreme precipitation (Diffenbaugh et al., 2015; Cook et al., 2015; Walsh et al., 2014). California can address water infrastructure vulnerabilities by planning for weather extremes. In particular, expanding groundwater recharge efforts through natural and engineered systems can improve resilience to drought and extreme precipitation. Little state recharge infrastructure currently exists, however expanding these systems to capture excessive flows during wet periods enables communities to offset surface water shortages during drought (Kocis and Dahlke, 2017; Choy and McGhee, 2014).

Planning for climate impacts on water resources is inextricably intertwined with energy resources. The water-energy nexus has been well-documented, as water is required to produce energy, and energy is needed to supply water (US DOE, 2014; Kesicki and

* Corresponding author.
E-mail address: maya.bruguera@icf.com (M. Bruguera).

https://doi.org/10.1016/j.watres.2018.05.012
0043-1354/

Abbreviation definitions

SGMA	Sustainable Groundwater Management Act
GHG	Greenhouse Gas
PDSI	Palmer Drought Severity Index
UWMP	Urban Water Management Plan
DWR	Department of Water Resources
GSP	Groundwater Sustainability Plan
SWP	State Water Project
CPUC	California Public Utilities Commission
kWh	kilowatt hour
AF	acre-foot
CRA	Colorado River Aqueduct
CVP	Central Valley Project
CASGEM	California Statewide Groundwater Elevation Monitoring
CEC	California Energy Commission
RPS	Renewable Portfolio Standard
BAU	business as usual
SWRCB	State Water Resource Control Board

Walton, 2016). Fluctuations in climate can drastically influence California's energy requirements for water supply. Groundwater pumping in the state consumes an estimated 6000 gigaW h annually (Moran et al., 2014). Droughts increase these energy demands due to overdraft and lowered water tables. For areas susceptible to local water shortages, procuring alternative water resources, such as long-range transmission, desalination, or recycled water, can substantially increase energy intensity of water supply (Cohen et al., 2004; Stokes and Horvath, 2009).

SGMA requires planners to project water usage and resources while accounting for changes in climate, population, and behavior. The intended result is a "water balance" that allows basins to reach sustainable groundwater levels by 2040 (Sustainable Groundwater Management Act, 2016). Basins with overdraft may need to curb their groundwater use which, depending on the success of water conservation measures, may require expanding or beginning use of local alternative water resources (i.e., desalination, recycled water) with potentially greater energy demands. Although SGMA planning decisions will determine the energy intensity of water supply, energy demands and any associated energy environmental impacts are not a required consideration in SGMA.

Recent research in climate change mitigation and adaptation has increased focus on energy demands and the associated GHG emissions of water supply systems. Tidwell et al. (2014) mapped the electricity demands of water supply in Western U.S. states and counties, including agricultural irrigation, long-range conveyance, and drinking water and wastewater electricity consumption. The authors found that some states used over 30% of total electricity consumption for water and wastewater services. A utility-level assessment in California's Bay Area determined the energy intensity of drinking water in each pressure zone (i.e., a utility-defined area where water pressure is regulated), and found that energy demands can vary significantly within a water utility depending on the topography (i.e., pumping water over steep hills is energy intensive) (Spang and Loge, 2015). A recent California assessment used 2010 Urban Water Management Plans (UWMP) to create a tool for estimating the energy intensity of water supply in urban areas, projecting that energy intensities will rise for areas relying more on alternative water resources in the future (Stokes-Draut et al., 2017). This finding is similar to a recent case study of Saudi Arabia's groundwater management planning. Researchers found that replacing groundwater use with alternative water resources could increase the country's total electricity demand by 40% in 2050 relative to 2010 (Parkinson et al., 2016). Mo et al. (2014) compared the use of historical resources, non-potable reclaimed water, and desalinated water in San Diego, CA and Tampa Bay, FL, finding that maximizing reclaimed water use offered energy, GHG emission, and financial advantages over maximizing historical and desalinated water resources.

Multiple studies have analyzed the energy resource benefits of water conservation. One study used cost-abatement curve methods, where products are analyzed to visually communicate both the economic costs and environmental impact mitigation potential, to compare the relative costs of energy saved from water efficient products (i.e., WaterSense labeled fixtures that use less water relative to more common fixtures) and energy efficient products (i.e., ENERGY STAR labeled products). The authors found that for an annual analysis water efficient products were more cost-effective options for energy savings than energy efficient products, but saved less energy overall for over 20 appliances (Chini et al., 2016). Another conservation study found that water conservation efforts in Arizona could have significant electricity savings with no net cost (Bartos and Chester, 2014). A California study also used cost-abatement curve methods through the application of existing methods to estimate costs and GHG emission reduction potential in different California regions, finding that controlling pressure and water losses in water distribution systems in regions that rely on long-range transmission of water are more cost-effective GHG emission abatement options than regional investment in energy-efficient lighting or fuel-efficient vehicles (Stokes et al., 2014).

This research assesses the connections between SGMA planning and the related energy consumption and GHG emission implications. We used state and basin data to develop scenarios for future water supply resource mixes for five overdrafted California basins. Using these scenarios, we projected the associated energy and GHG emission intensity of water supply.

2. Materials and methods

Projecting electricity or energy resource mixes is often performed to estimate associated GHG emissions or other environmental impacts (U.S. EIA, 2017; IEA, 2016). We applied these same techniques to water supply systems to generate the associated energy demands and GHG emissions for projected estimates of water resource mixes for five California groundwater basins under different scenarios. Fig. 1 outlines our methodology. We detail and discuss any data gaps or limitations in Section 4.1.

2.1. Selecting groundwater subbasins and accessing resource data

Water resource mixes can vary substantially by region within California. To show these variations, we selected groundwater subbasins in five different state hydrologic regions. Each of these subbasins have been identified by the California Department of Water Resources (DWR) as "medium" (Niles Cone) or "high" priority (Modesto, Soquel Valley, Bunker Hill, Kaweah) (CA DWR, 2017c). Through SGMA, each of these subbasins is required to develop a Groundwater Sustainability Plan (GSP) for achieving sustainable groundwater elevations by 2040. DWR elected not to provide specific limitations on groundwater use in SGMA regulations. As a result, GSPs and any local groundwater withdrawal limits will be driven by subbasin representatives and based on local climates, water resources, and stakeholder dynamics (CA DWR, 2016b). Table 1 summarizes the subbasins included in this assessment. Figure A6 in Appendix A provides more context for these