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Projecting the Provision and Value of Water from National Forests in Southern California under Ecological Change

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Section 1: Introduction

Access to water is essential to economic growth, human well-being, and healthy ecosystems. Growing populations, urban uses, demands for agricultural commodities and recreation uses, coupled with the projected effects of climate change will likely exacerbate water scarcity in the future, in particular in arid and semi-arid areas around the world (Gosling and Arnell 2016).

In California, the most recent drought from 2012-2017 remains in the public memory, with climate-related precipitation issues continuing to be an ongoing concern for policy makers. State and local initiatives sought to constrain demand during the drought by various means, and bond issues relating to water supply infrastructure were approved in 2014 ($7.5 billion, Jezdimirovic and Hanak, 2016) and are on the ballot for 2018 (approximately $10 billion, Hoilbert, 2018). Global climate models predict that most areas with Mediterranean-type climates will become drier (Polade et al., 2017). Correspondingly, climate change is expected to affect precipitation patterns in California (Cvijanovic et al., 2017), resulting in adverse effects for the supply of surface water in the state's major hydrological basins (Dettinger and Georgakakos, 2015; Vicuna et al., 2007).

National forests, managed by the U.S. Department of Agriculture (USDA) Forest Service, represent an important source of surface water for downstream communities in southern California. Lands managed by the USDA Forest Service supply about 47 percent of surface water supply in California (Brown et al., 2016; Brown et al., 2008). The four national forests in southern California – Angeles, Cleveland, Los Padres, and San Bernardino – contain the headwaters for much of the local surface water supply for the Los Angeles and San Diego metropolitan areas.[1] But limited information is currently available to public land managers to evaluate potential trade-offs when making resource management and planning decisions that account for changes in ecosystem service values in the face of climate change.

Basin-level assessments have shown that water supplies from hydrological basins that supply southern California are vulnerable to the effects of climate change (e.g. Foti et al., 2014; Pagán et al., 2016). Understanding the value of changes in water supply from

[1] This area includes counties such as Orange and Ventura County.

national forests in southern California can help communities plan adaptations and investments related to imported and local sources, and can help land managers assess the relative value of actions that may affect water supply for downstream communities.

The purpose of this paper is to investigate the value of water from public lands and how this value will change in the future as climate changes. The value of water is estimated by 1) projecting the volume of surface water runoff from four national forests in southern California under future climate scenarios at mid- and end-of-century, and 2) estimating the potential change in water prices necessary to equalize demand to the projected change in the supply of surface water in the future. We generate estimates by coupling projections of surface water runoff from a dynamic global vegetation model with a range of estimates of the price elasticity of demand for surface water from the literature.

Section 2: Importance of Ecosystem Service Valuation for Water in the National Forests

National forests were established primarily to provide water provisioning services to nearby residents. In fact, public concern about adequate supplies of clean water resulted in the establishment of federally protected forest reserves in 1891 (USDA Forest Service, 2000). The vast majority of freshwater in the United States originates from forests – about 80 percent – out of which about 14 percent originates from national forests (USDA Forest Service, 2000). About two-thirds of the country's runoff comes from national forests;[2] in the west, national forests provide about one third of freshwater runoff since they encompass the headwaters of major rivers and mountain ranges (USDA Forest Service, 2000).

National forests connect and encompass watersheds as well as terrestrial and coastal ecosystems, producing a variety of valuable environmental services, including the supply and purification of fresh water. There are 81 National Forests in the western U.S., collectively occupying 573 thousand km^2 (57,300,000 ha). These National Forests provide

[2] This figure excludes Alaska.

an annual average water yield of 230 billion m^3 (Brown et al., 2016), 49 percent of the mean annual water supply in the west.[3]

The four national forests in southern California – Los Padres, the Angeles, San Bernardino and Cleveland – cover an area of 14,335 km^2 and generate a mean annual water supply volume of 2.05 billion m^3 (Brown et al., 2016)– amidst a population of almost 23 million people (U.S. Census, 2010). These forests are largely semi-arid and Mediterranean ecosystems. Wildfires and increasing drought in the area are further stressors on the ability of the national forests to provide water to the counties and municipalities. The national forests being studied are naturally subject to cycles of wildfire, the frequency and magnitude of which are exacerbated by the historical planting of non-native species. Of the 20 largest fires recorded in California, 11 – or 55 percent – have occurred within the counties that house one of the four national forests (Calfire, 2015).

National forest management in southern California plays a key role in the provision of water as an ecosystem service. Forest plans explicitly state the need to balance the needs of downstream users and in-stream resource needs when engaging in land management activities. For example, the San Bernardino National Forest acquires water rights for riparian species management and recognizes the need to complete reauthorizations of stream diversions on the forest (USDA Forest Service, 2005b, 36-37). Forests also cooperate with other water agencies to engage in projects to maintain the provision of water to users and for resource needs (USDA Forest Service, 2005a, 23).

Forest plans and other guiding documents do not indicate how managers are to balance the effects of management actions on the provision of surface water, or what information is admissible in such considerations. Given the existing stressors to the supply of water in southern California and challenges associated with climate change, understanding the welfare impacts of changes in the supply of water for downstream users can help managers weigh actions that may affect water supply.

[3] The included states are: Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Utah, Washington and Wyoming.

Section 3: Methods

Economic values are estimated in a two stage process. The quantity of water from the national forests is estimated spatially via a dynamic vegetation model which is then coupled with economic water values. An advantage of coupling the biophysical model outputs with economic water values is that it can identify spatial heterogeneity in the provision and value of surface water as an ecosystem service. Model projections that vary across space, coupled with economic water value information, may allow policy makers to weigh trade-offs associated with site-specific forest management actions.

The volume of surface water runoff – average annual volume at baseline period (1970-1999), mid-century (2035-2064), and end-of-century (2070-2099) – is estimated using the MC2 dynamic global vegetation model (USFS, 2001) calibrated to southern California using multiple observation datasets. MC2 model simulates vegetation response to climate change over time, incorporating ecosystem carbon and water cycling, vegetation biogeography, and wildfire effects. Simulations are driven by downscaled climate projections based on three general circulation models (GCMs) simulating representative concentration pathway 8.5 (a “business as usual” emissions scenario; van Vuuren et al., 2011). The three GCMs span a range of future climate characteristics, from relatively hot and dry (MIROC5), intermediate (CCSM4), to relatively hot and moist (CNRM-CM5).

The marginal economic value of water is derived by using previously estimated price elasticities of demand for urban water in southern California (Baerenklau et al., 2014b; Lee and Tanverakul, 2015; Renwick and Archibald, 1998; Renwick and Green, 2000). The average price elasticity is calculated and then used to calculate the change in price that would equalize the change in quantity of water supplied to demand.

The average price elasticity of demand is multiplied by the forecasted change in volume of water for each national forest for each GCM to derive the forecasted change in value. The price elasticity of demand equation is given by:

$$\varepsilon_{x,y} = \frac{\delta V_x}{\delta P_y} \times \frac{P_y}{V_x} \qquad (1)$$

where ε is the price elasticity of demand, V is the volume of water from the national forest, and P is the relevant economic value of water, to be calculated at some point x and y. Re-arranging this equation gives:

$$\delta P_y = \delta V_x \times \frac{P_y}{V_x} \times \varepsilon_{x,y} \quad (2)$$

This change in price represents the change in the marginal value of water provisioning ecosystem service from the Angeles, Los Padres, Cleveland, and San Bernardino national forests. However, it is simply an artefactual experiment; no attempt is made to project or place assumptions on how water authorities may consider price changes in the future in the face of changes to water supply or to predict how households will adapt to future changes in the supply of water. Nevertheless, discussions with water agencies in Southern California suggest that if reductions in supply from national forests exceed 50% that alternative sources would be brought online (Griego, 2018; Mullen & Ramirez, 2018; Seinturier & Boushaki, 2018; Waner, 2018). Thus, the maximum decrease in supply considered for estimating price changes is 50%.

Section 4: Data

The annual volume of water supplied by the four national forests in southern California is provided in Table 1. The area of the national forest, the baseline (1979-1999) volume in thousands of hundred cubic feet (HCF), and the percentage change during the mid-century period and end of century are provided, broken down by national forest.

Table 1: Baseline Annual Water Volume from National Forests in Southern California and Projected Changes due to Climate Change Under Alternative GCMs

National Forest	Current Water Volume ($m^3 \times 10^{-6}$)	Baseline HCF ('000s)	Relative Change Mid-Century (%)	Relative Change End-of-Century (%)
Angeles	474.0	11,729		
CNRM-CM5 (hot-wet)			118	675
CCSM4 (intermediate)			-55	23
MIROC5 (hot-dry)			-57	-72

Cleveland	95.9	3,846		
CNRM-CM5 (hot-wet)			6	533
CCSM4 (intermediate)			-70	6
MIROC5 (hot-dry)			-89	-51
Los Padres	1,058.9	1,177,536		
CNRM-CM5 (hot-wet)			44	101
CCSM4 (intermediate)			-39	-6
MIROC5 (hot-dry)			-61	-81
San Bernardino	420.8	64,712		
CNRM-CM5 (hot-wet)			84	400
CCSM4 (intermediate)			-7	49
MIROC5 (hot-dry)			-40	-31
ACROSS ALL NFs	2,049.6	1,257,824		
AVERAGE CHANGE				
CNRM-CM5 (hot-wet)			63	427
CCSM4 (intermediate)			-43	18
MIROC5 (hot-dry)			-62	-59

Note: The HCF measure are from the MC2 model for the base period of 1970-1999 which differ from the Brown et al. (2016) measure from 2016.

The volumes in Table 1 are generated by MC2. The projected change in water provisioning is expected to increase relatively throughout the 21st century across all four national forests when driven with climate projections from CNRM-CM5 (hot and wet) GCM under RCP8.5 climate change scenario, from 6% (Cleveland National Forest, mid-century) to 675% (Angeles National Forest, end of century); on average, by mid-century water provisioning will increase by 47%, and by 123% by end-of-century under this GCM. In contrast, the projections from CCSM4 – the intermediate scenario – predicts decreases in water from all four national forests by mid-century relative to the base period; however, by the end of the 21st century, water provisioning is expected to increase across all four national forests on average by 18% under this GCM, with only a small decrease on Los Padres. When driven with climate projections from MIROC5 (hot and dry) GCM under RCP8.5, water provisioning services is expected to decline both by mid- and end-of-century across all national forests, ranging from 40% (San Bernardino National Forest) to 89% (Cleveland National Forest) by mid-century, and 31% (San Bernardino National Forest) to 81% (Los Padres National Forest) by end-of-century. San Bernardino appears to fare the best of the national forests in southern California, experiencing only a slight decrease by mid-century from CCSM4 projections (-7%), and the least amount of relative decline from MIROC5 (-40%). San Bernardino is likely the most resilient due to the snow packs in the higher elevations in this national forest.

With respect to prices, three types of pricing schemes for water to residential households are observed in California. First, non-tiered or uniform pricing where each household pays a fixed price per hundred cubic feet. Second, tiered pricing or block pricing is where the price per HCF for the household depends upon the amount of water consumed. In the case of increasing block rates, the first few HCFs are priced relatively low whereas subsequent HCFs are priced higher such that the per HCF price increases in conjunction with consumption. It is common for water agencies to allow the first 8 or 10 HCF consumed by households to be priced at the lowest tier.

The third type of pricing is allocation-based water pricing which is a type of block or tiered pricing structure where the price per HCF depends upon the household characteristics, such household size, lot size, any relevant medical conditions, as well as a “judgement” call by the water agency regarding what an “efficient” level of use is for households given their characteristics (Baerenklau et al., 2014a). The efficient level is called the household’s “water budget” and consumption beyond this level is deemed to be “inefficient.” With allocation-based pricing, the amount that households pay per HCF can vary across time and households.

Several recent studies have examined residential demand of urban waters in southern California. The price elasticity of demand for water by urban households is inelastic across all the studies. Renwick and Archibald (1998) analyze the extent to which price and alternative policy instruments reduce residential demand and their distributional implications in their assessment of demand side management policies to manage water resources. They estimated demand using household survey and concomitant utility use and price data of residents in Santa Barbara and Goleta, taking advantage of the state wide drought from 1985-1992. These two communities were selected for their exclusive reliance on local surface and groundwater supplies. Using both tiered and non-tiered price data, their water demand model provided an estimate of -0.58 for the price elasticity of demand across Santa Barbara and Goleta.

Analysing a larger cross-sectional monthly time series data for eight water agencies in California, Renwick and Green (2000) estimated a lower price elasticity of demand (-0.16). This study covers the effect of various demand side management residential initiatives implemented in California between 1989 and 1996, which also encompassed the drought between 1985 and 1992. The urban eight water agencies operate in a number of municipalities, including Los Angeles, San Diego, and San Francisco, collectively providing residential water to 24 percent of the state's population (over 7 million people). Both non-tiered and tiered prices were implemented by the water agencies during the study period and hence used in the demand model.

Baerenklau et al. (2014b) examine the effect of introducing fiscally neutral allocation-based water pricing on residential demand in the Eastern Municipal Water District. The data include over 13,000 single family households with continuous monthly water use records between January 2003 and September 2012. The authors estimate two separate demand functions, one using non-tiered rates and the second using the water budget data for allocation-based pricing. The estimate price elasticity of demand with non-tiered pricing is -0.76 and for water budgets data is -0.58.

The fourth and last source of demand elasticities is from Lee and Tanverakul (2015) who conducted a meta-analysis of about 1,000 households in East Los Angeles and South San Francisco. Using 10 years of monthly water consumption data (January 2002 – December 2011) from California Water Service – the largest regulated American water utility west of the Mississippi River and the third largest in the country – the authors assess the influence of price and price structures on residential water demand. These data were used to estimate and compare price elasticities for periods when non-tiered and tiered rates were charged. The estimated price elasticity for East Los Angeles was -0.39 and -0.44 for non-tiered rates and tiered rates, respectively.Table ***2*** below identifies the price elasticity of demand and their average that are used in this paper.

Table 2: Water Price Elasticity of Demand in Southern California

Author	Year of Study	Price Elasticity of Demand	Pricing Structure	Notes
Renwick and Archibald	1998	-0.58	tiered and non-tiered	Covers drought from 1985-1992
Renwick and Green	2000	-0.16	tiered and non-tiered (combined)	1989 – 1996; 24% of CA population
Baerenklau et al.	2014	-0.76 and -0.58	tiered and water budgets, respectively	2003-2014; Eastern Municipal Water District
Lee and Tanverakul	2015	-0.39 and -0.44	non-tiered and water budgets	2002-2011; East LA
Average For All Studies		**-0.47**		

For this study, the average water rate from four cities – Riverside, San Jacinto, Redlands, and Colton – is used as they do not normally import water, but rather get their supply from the San Bernardino National Forest, either as surface water or ground water, or both.[4] Riverside and San Jacinto are located in Riverside County, while Colton and Redlands are in San Bernardino County. Some rely on groundwater exclusively (e.g. Riverside and San Jacinto) while others use a combination of surface and ground water (e.g. Redlands). All of

[4] Details were gathered from publicly available documents and from personal communication with each relevant water agency (Griego, 2018; Mullen & Ramirez, 2018; Seinturier & Boushaki, 2018; Waner, 2018). Though these municipalities do not import water due to their water rights, some exceptions may be made occasionally. For example, Redlands, has imported a small percentage (4%) a few times in the past after significant rain events that caused the water to be too turbid for the water treatment plant. In such an instance, they have imported from the State Water Project.

the municipalities use a tiered water pricing scheme. The average water rate of the four municipalities is calculated by taking its residential per capita gallon consumption for 2017 and multiplying by the average number of people per household for the municipality as recorded by the most recent United States Census; this household consumption is converted to HCFs. This average household consumption is then multiplied by the relevant tiered rate(s) for a single family household to arrive at an average cost per HCF per household. The average water rate per HCF across these four municipalities is $22.93 per HCF. This average value is applied to the volume of water from all four national forests to monetize the water provisioning ecosystem services.

Section 5: Results

The monetized value of water provisioning ecosystem service from each of the four national forests in southern California for the baseline period as well as the projected change at mid-century and end-of-century are given in **Error! Reference source not found.**. All dollar values are in 2017 dollars.

Table 3: Baseline Water Value from National Forests in Southern California and Projected Changes due to Climate Change Under Alternative GCMs

National Forest	Baseline value per year ($ millions)	Relative Change Mid-Century (%)	Relative Change End-of-Century (%)
Angeles	267		
CNRM-CM5 (hot-wet)		-56	-317
CCSM4 (intermediate)		26*	-11
MIROC5 (hot-dry)		27*	34*
Cleveland	88		
CNRM-CM5 (hot-wet)		-3	-251
CCSM4 (intermediate)		33*	-3
MIROC5 (hot-dry)		42*	24*
Los Padres	27,001		
CNRM-CM5 (hot-wet)		-21	-48
CCSM4 (intermediate)		19	3
MIROC5 (hot-dry)		29*	38*
San Bernardino	1,484		

CNRM-CM5 (hot-wet)		-39	-188
CCSM4 (intermediate)		3	-23
MIROC5 (hot-dry)		19	15
All forests	28,842		
Average, all forests			
CNRM-CM5 (hot-wet)		-30	-201
CCSM4 (intermediate)		17	-8
MIROC5 (hot-dry)		22*	21*

Note: Minor discrepancies are due to rounding errors. * indicates price changes that reflect decreases in supply limited to a maximum decrease of 50% due to contingency plans by water agencies when calculating the anticipated change in value.

The baseline value of water varies across the four national forests, with the highest value from Los Padres ($27 billion), primarily because it is the largest national forest.

The projected change in marginal value (i.e., prices) is derived by applying the average price elasticity of demand from the California water demand studies listed in Table 2, which is -0.47; thus for every 10% increase in the price of water, the quantity demanded decreases by 4.7%. Reversing this relationship, the change in price is calculated when the projected quantity change occurs in response to climate change, as in Equation (2).

As noted in Table 1, the instances where MC2 forecasts a decrease in volume greater than 50%, in these situation the decrease is limited to 50%, due to expectations by water agencies that their supplies will not decline by more than 50%. This limit is implemented as the water authorities in the four municipalities contend that they will not experience declines greater than 50% by mid- or end-of-century due to demand management initiatives, improved water infrastructure, closing leaks, and finding substitute sources (Griego, 2018; Mullen & Ramirez, 2018; Seinturier & Boushaki, 2018; Waner, 2018).

Given the projected relative increase in water volume throughout the 21st century across all four national forests when driven with climate projections from CNRM-CM5 (hot and wet) GCM under RCP8.5 climate change scenario, the value of water from the national forests is expected to decrease on average by 30% by mid-century, and over 200% by end-of-century. The forecasted average decline in volume by mid-century from the CCSM4 (intermediate) GCM is coupled with a corresponding increase in value of 17% by mid-century; by the end-of-century, however, the value is expected to decrease by 8% on average across the four national forests.

This 50% volume floor results in an increase in the price; where the volume decrease is greater than 50%, the percentage price change is replaced with what the calculated price change at 50% (23.5%). For example, on the Angeles National Forest, by mid-century the projected decrease in volume from the MIROC5 GCM is 57%; using the average price elasticity of -0.47, the decrease in value should be 27%; however, in calculating the price change in this case, a decline in volume of 50% is assumed instead, resulting in a change in value of 23.5%. This volume floor has the greatest effect on the change in values from the MIROC5 GCM, with average increases of 22 and 21 percent through the 21st century.

Some of the projected declines in prices exceed 100% (e.g. an average of 201% with CNRM-CM5 by end-of-century), which would imply subsidies to households for every HCF that they consume. It is assumed that in reality, subsidies will not be provided, but rather water rates will likely be reduced to a minimal level to ensure operating costs to treat and deliver water are covered by the water agency.

Section 6: Summary

Using projected water volume from each of the four national forests to mid- and end-of-century under three different GCMs, projections of how the value will change is derived using price elasticity of demand estimates for treated water to urban households. Change is calculated against a 30 year baseline period of 1970-1999. By mid-century, the range of changes in water volume across the four national forests in southern California on average are expected to a decline by almost two-thirds (62%, driven by climate projections under MIROC5 GCM) or increase by almost two-thirds (63% with CNRM-CM5); by the end-of-century, average volumes are forecasted to vary by GCM, from a decline of 59% (MIROC5) to an increase of 427% (CNRM-CM5).

This change in volume is expected to result in changes in the marginal value (i.e., price) of water provisioning ecosystem service from these four national forests. Using price elasticity of demand to forecast behavioural changes in water consumption, prices are on average expected to decline by 30% (CNRM-CM5) to increase by 22% (MIROC5) by mid-century. By the end-of-century, large projected increases in water supply under the warm-wet model (CNRM-CM5) suggest a decline in prices by as much as 201%, while projected decreases in water supply under the hot-dry model (MIROC5) imply price increases of 21%. With the intermediate GCM, CCSM4, values range will increase by 17% by mid-century, and then decline by 8% by end-of-century.

Declines greater than 100% in absolute value imply subsidies to households per HCF of water they consume; as this is not practically possible, such declines can be interpreted to mean lowered water rates that will still be enough to ensure financial stability of the water agency; that is, water rates may be lowered but will still be high enough to ensure that the water agency's operating costs can be paid.

Caveats around the use of price elasticities for significantly larger changes in quantity, and assuming they do not change in the future. While demand for water will most likely remain inelastic into the future, the actual value could change over time as different pricing schemes and water costs are applied. A future area of research could explore how alternative pricing scenarios and assumptions about adaptations by water agencies and households would affect the range of estimated water values.

Water-related ecosystem services is among the tangible benefits supplied by national forests in southern California. Better understanding the economic value of water may help planners and policy makers by informing budgetary processes better reflect resource scarcity and public preferences.

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