Using economic and other performance measures to evaluate a municipal drought plan

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Abstract

This paper explores the welfare costs associated with drought plan transactions between a municipal water agency, the El Dorado Irrigation District (EID) in California, USA and its customers. The EID imposes a tier pricing plan for municipal customers, which was formulated as a Discrete Continuous Choice (DCC) model within a climate driven Water Evaluation and Planning (WEAP) model of the EID water system. The DCC is subsequently inverted to estimate compensating variation (CV) or the loss of consumer welfare in the case where a customer does not receive water to match a preferred level of demand. In addition to monetized welfare loss, we look at other metrics of performance such as reservoir storage and hydropower generation. For the drought-of-record under full build-out, results show that the welfare loss to EID customers from the imposed drought plan is far less than if no drought plan were in place. This suggests

that current consumption is well beyond essential needs, and with no drought-plan, water shortages in the later period of the drought are pronounced corresponding to much greater welfare loss. Most of the cost associated with the drought plan is born by EID in the form of reduced revenues.

Introduction

Droughts cost money, estimated at $6-8 billion annually, in lost global economic output (Wilhite 2000). Regarded as the most costly natural disaster in U.S. history, the 1988 drought resulted in an estimated $40 billion in damages (Ross and Lott 2000). The managers of urban water systems must confront the challenge of anticipating when available water supplies may not be sufficient to meet typical water demands and how to implement policies to curtail these demands at the lowest loss of well-being. These policies have historically been 'command-and-control' (CAC) approaches such as rationing and use restrictions, which largely stem from the fact that municipal water prices are regulated, owing to the nature of the good and a limited competitive market. Yet a growing body of economic literature argues that this traditional CAC approach to municipal water conservation, through non-price policies such as conservation incentives, rationing, restrictions, prohibitions and enforcements on specific water uses is inefficient, as water is often priced well below its long-run marginal cost (Brennan et al. 2007; Olmstead and Stavins 2008; Mansur and Olmstead 2010).

Municipal water agencies have certainly recognized their conundrum. They are charged with providing a basic human necessity with substantial costs, but without any revenue guarantee let alone profit maximization objectives. One result has been a myriad of pricing schemes, with the dual aim of providing basic needs at a reasonable cost (equity) and the ability to recover costs and generate revenue from higher consuming customers (Agathey and Billings; 1987; Dahan and Nisan 2007; and Olmstead et al. 2007. The Increase Block Price (IBR) is perhaps the most well-known pricing mechanism, where customers pay a lower rate within an initial consumption block to meet necessity demand, while higher rates are charged for use beyond that block (Olmstead et al. 2007; Schoengold and Zilberman 2011).

This study explores the economic efficiency of a municipal drought plan for a water utility in California, the El Dorado Irrigation District (EID). The EID has a tier-priced water pricing policy in place, while simultaneously managing a CAC drought plan that includes a set of sophisticated drought indices, which are used to trigger drought stages and impose actions that are expected to decrease demand. The EID's drought plan goals include, *defining water demand curtailments that can reasonably be accomplished in drought conditions, are financially sustainable, administratively appropriate, user-friendly, and will perform well for all customers and stakeholders* (Brown and Caldwell 2008).

The expectation is that if customers are made aware of the level of demand curtailment required, and if the anticipated levels are achieved, no further service reductions will occur. The premise is that the use of the drought plan will improve the outcome because it will avoid the imposition of abrupt water supply shortages and other system failures. This research evaluates whether the overall level of social welfare in the transaction between EID and its customers is improved with their drought plan in place (White et al. 2001; Rossi et al. 2005; Rossi et al. 2007).

The paper opens with a review of typical elements of a municipal drought plan, including indices, triggers, and actions. It then describes the EID water system and a brief description of the EID drought plan (Brown and Caldwell 2008). Next, an EID water resources planning model is presented, along with a residential water demand and welfare model. Together, these are used to estimate the potential activation of the drought plan and the associated economic implications, respectively. The paper presents drought performance measures, including overall customer welfare associated with drought plan, reservoir storage, the quantity of hydropower produced, and a measure of environmental performance in terms of meeting in-stream flow requirement targets.

Elements of a Municipal Drought Plan: Indices, Triggers, and Actions

Drought planning literature has evolved and expanded over the past several decades, from early efforts that define droughts (Palmer 1965), to the development of indices of drought as it emerges and proceeds (Dracup et al. 1980; Garen 1993; Hiem 2000; and Strzepek 2010), up to current literature that combines indices and triggers to initiate a drought management response (Shepherd 1998; Steinemann and Cavalcanti 2006). Unfortunately, the literature becomes more sparse regarding actions to be taken once a drought response is initiated (Werick and Whipple 1994; White et al. 2001; Wilhite et al. 2000). Evidence derived from a review of actual water utility drought preparedness plans suggests that standard system level metrics of performance such as water supply reliability, water storage, regulatory compliance, etc., are commonly used to evaluate various options (Brown and Caldwell 2008; Corpus Christi 2009)

There are many drought indices, and we present two to suggest their nature and purpose for the less familiar reader (Heim 2002; Palmer et al. 2002). In the U.S., the Palmer Index or PDSI (Palmer 1965) and the Standardized Precipitation Index (McKee et al. 1993) are well known and widely used. The PDSI was developed to use temperature and precipitation information to provide a current assessment of conditions with respect to drought at local, regional, and continental scales. Though criticized for its complex, empirical derivation (Guttman et al. 1992, Alley 1984, Keyantash and Dracup 2002), PDSI is widely used. A useful synthesis of various indices was prepared by Heim (2002), while both Keyantash and Dracup (2004) and Dracup et al (1980) defined indices based on combinations of precipitation, evapotranspiration, streamflow, reservoir storage, soil moisture content and snow. The EID defined their own index, referred to as the Supply Remaining Index (SRI).

Indices can assist in ascertaining whether drought conditions are setting up or are in place, but are insufficient for specifying an appropriate response. Drought plans serve this purpose, defining triggers and actions to meet the goals of the plan. Much of the literature defining triggers build on previous discussion of indices as useful metrics for defining drought categories, or levels, typically using nomenclature such as “mild, moderate, severe, extreme drought,” or “level 1, level 2, level 3 drought.” (AWWA 1992; Steinemann and Cavalcanti 2006). Because drought has many definitions, multiple indicators and triggers can be useful for representing drought conditions. Combining indicators and triggers can assist in making drought management operational. For a drought plan based on multiple triggers, combinations of threshold values that lead to the declaration of a drought and/or a change in the drought level must be clearly defined (Steinemann 2003). However the indicator threshold combinations are defined, ideally definitions should, 1) provide advanced drought warning while minimizing false alarms; 2) provide stability and smooth transitions among drought levels during a drought; 3) provide assurance that drought conditions are receding when coming out of a drought.

Procedures for defining appropriate drought plan triggers are more developed than ideas on drought responses. Steinemann and Cavalcanti (2006) suggest both strategic longer-term actions, usually implemented before a drought, such as water pricing policies, and tactical shorter-term actions, usually implemented during a drought, such as water use restrictions. Werick and Whipple (1994) provide a much longer list of strategic and tactical drought responses, without specifying specific characteristics of potential actions. Because local context of both practical and political considerations is so important, it is not surprising that guidance on this step in drought planning is less detailed. There seems to be an overarching objective pursued by most water management entities: meeting the customers' expectations, even if these expectations are lowered during a drought (Bruvold 1979; Narayanan et al. 1985).

The El Dorado Irrigation District and its Drought Plan

The El Dorado Irrigation District lies on the western slope of the Sierra Nevada Mountains (Figure 1) and is the current beneficiary and manager of water resources development efforts realized in the South Fork of the American River watershed beginning with the California Gold Rush of the 19th century. The EID provides water to a population of more than 100,000 people within its service area for municipal, industrial, and irrigation uses, as well as wastewater treatment and recycled water services, and as such, is one of the few California districts that provide a full complement of water-related services. While agricultural water customers still remain within the EID service area, single family residential (SFR) customers represent nearly 75% of the total revenue and 55% of the total volume from water sales by EID (Sharon Fraser, personal communication).

Total operating revenues for EID in 2010 was $46.3 million, with water related revenues of $37 million on 44 MM3 (36 TAF) or $0.85/m^3. Water, reclaimed water, and wastewater sales represented about 92% of revenues from 2001 through 2005, dropping to 86% from 2006 through 2010, while hydropower grew from 6% to 12% of revenue for the same period. Recreational revenues have remained at 2% of total revenue.

While hydropower revenue has grown as a percentage of the total, it has varied considerably from year-to-year based on both climate and electricity markets. EID has owned and operated the hydropower facility since 2005, generating a high of 111 GWH in the wet year of 2005 corresponding to $5.6 million in revenue and a low of 60 GWH in the dry year of 2008, yielding

$4.8 million in revenue. The highest and lowest revenue years were 2010 and 2009, when 79 and 73 GWH were generated corresponding to $7.8 million and $2.9 million in revenue, respectively.

EID's Water Supply and Demand

In terms of water supplies, the EID system is comprised of: (i) long-standing water rights on the South Fork of the American River watershed, including several small reservoirs (Project 184): (ii) an interbasin connection to the larger Jenkinson Lake that is adjacent to the Cosumnes River Watershed, and (iii) a series of contracts and agreements with the US Bureau of Reclamation and others that allow EID to withdraw water from Folsom Lake located downstream, at the western end of the system. These contracts allow the larger western zones, notably Zones 1 and 2, access to more reliable supplies but also require substantial pumping.

Different parts of the district have physical access to water from different sources (Figure 1). The level of storage in Jenkinson Lake dictates how certain demand zones are supplied with water, though some zones can receive water from only a single source. A main point of take for EID's project 184 water is the diversion at Kyburz from the South Fork of the American River. Instream flow requirements to satisfy fish flows below Kyburz, restrict when and how much water EID can take. Table 2 summarizes the current and future annual average available water supply by source and the zones they serve. In 2010, EID's previous 5-year, average raw water delivery was 33 million m^3 (MM3) or 41 Thousand Acre-feet (MAF). Current EID projections of future demand in 2030 are about 50 MM3 (62 TAF).

Table 1. Summary of EID current and future water supplies and the zones they serve.

Water Supply Sources	2010 MM3 (TAB)	2030 MM3 (TAB)	Zones Served
Jenkinson Lake	28 (23)	28 (23)	All
Project 184, El Dorado Forebay	19 (15.1)	19 (15.1)	All
[1]**Project 184, Permit 21112**	-	21 (17)	Z1 and Z2
[2]**Folsom USBR**	9.3 (7.6)	9.3 (7.6)	Z1 and Z2
[2]**Folsom, Fazio**	-	9.2 (7.5)	Z1 and Z2
[3]**SMUD, El Dorado**	-	49 (40)	Z1-Z7,Z18, Z28
Recycled Water	3.7 (3)	9.5 (7.7)	Z1-Z2
Total	**60 (49)**	**145 (118)**	

[1]The Permit 21112 water is part of Project 184, which is a senior water right acquired by EID from Pacific Gas and Electric; [2] The Folsom supplies are negotiated with the US Bureau of Reclamation, with the point-of-take limited to Folsom Reservoir; [3] The Sacramento Municipal Utility District (SMUD) is entering into an agreement with EID to provide a future supply from the Middle Fork of the American River, via Folsom. In drought conditions, SMUD allocation will be reduced to 50%, 30%, and 15% of total under one, two, and three year multi-year drought conditions.

A Summary of the EID Drought Plan

Motivated by the evidence that hydrologic conditions in the EID source water region were highly uncertain, EID developed a drought preparedness plan that would: (i) effectively anticipate the occurrence of all drought conditions and reduce impacts by activating conditions of the drought plan; and (ii) reliably satisfy the curtailed levels of customer demand during periods of drought plan activation (Brown and Caldwell 2008).

For EID, selecting robust indicators and setting a trigger value for each drought stage to minimize supply shortages required trial and error experimentation. This process was informed by an understanding of how the EID water supply system works and a mathematical analysis of potential water shortfalls. Various indicator values were tested for each stage, to “trigger” soon enough to warn and late enough to correspond with drought. Potential drought indicators and corresponding trigger levels were tested by comparing how accurately they predicted drought over the entire hydrological record (1922-2004). One trigger that performed well was the days-of-water-supply-remaining index (SRI), which ranges from a value of 1.0 for full supply to 0.0

for no supply. The SRI was defined as a function of system wide reservoir storage; worst case expected reservoir inflows based on the historical record; and normal (unconstrained) demand in the coming months. It was also determined that the presence of a positive ENSO signal could improve the ability of the proposed triggers to anticipate droughts in the historical record (Figure 2). The final triggers used to determine drought threshold and stage based on the SRI values are shown in Table 1.

The fact that SRI is based on storage within EID's own reservoirs is important. If EID were to terminate reservoir releases, the SRI would remain near 1.0; and strictly speaking, no drought stage would be called. This would of course mean no delivery of water either. At the other extreme, if EID did not constrain reservoir releases, then the SRI would hover near 0.0 and Stage 3 drought would artificially persist. Thus, we reiterate the goal of the drought preparedness plan, to find the ideal set of triggers and actions, that would *define water demand curtailments that can reasonably be accomplished in drought conditions, are financially sustainable, administratively appropriate, user-friendly, and will perform well for all customers and stakeholders* (Brown and Caldwell 2008).

Table 2. The Number of Days Supply Remaining Trigger Plan Summary

Month	**ENSO**	**SRI**	**Last month's stage**	**This month's stage**
May	Any	<0.60	0	1
			1,2,3	Last month's stage
June – Sept	Any	<0.35	2	3
	<0.35*	<0.4	0,1,2	2
	<0.35*	<0.4	3	3
Any	Any	>0.75	0,1,2,3	0

* the ENSO average of three previous months must be less than 0.35

Using the triggers summarized in Table 1, EID concluded that to successfully navigate a 3-year hypothetical drought, demand curtailments of 15% in Stage 1, 25% in Stage 2, and 50% in

Stage 3 would be needed. The hypothetical drought was derived from the actual drought-of-record, 1976 and 1977, with a third year of drought artificially imposed by assuming a repeat of the 1977 hydrology. To evaluate the plan's performance under these hydrologic conditions, it was assumed to occur under a 2030 estimated level of demand. In formulating the plan, EID concluded that this drought sequence and level-of-demand would lead to no unanticipated, reductions in the level of customer demand satisfaction.

Analytical support of the EID Drought Plan via a Water Evaluation and Planning (WEAP) Model

The EID drought preparedness plan was developed based on a simplified systems model known as the Shared Vision Model (SVM) that assumed stationary hydrology based on historical observations and bulk, aggregated demand as a planning hypothesis (Brown and Caldwell 2008). This work built off the SVM by developing a Water Evaluation and Planning (WEAP) model of the EID system on a weekly timestep that incorporates: 1) spatially disaggregated and climate driven demand that evolves over time, with SFR demand modeled as a discrete and continuous decision developed from billing record data; 2) climate-driven hydrology that generates streamflow for input to reservoirs and diversions; and 3) the explicit consideration of the regulatory environment, including environmental flow standards (Yates et al. 2005; Yates et al. 2006). The model is referred to as WEAP-EID and Figure 2 demonstrates the graphical nature of the model, showing the western boundary of the service area new Folsom Reservoir, and the time varying demand through the year for Zone 2.

EID Demand and a Single Family Residential Discrete Choice Model

EID's water demand was explicitly represented in the WEAP model to characterize the diverse range of users and water supply services. Each of the 15 service zones was geographically located, disaggregated according to the 12 account types (single family, multi-family, municipal, domestic irrigation, etc), and configured to receive water from its physical connection to the water distribution system. Within each zone, the number of accounts and water use per-account-type were estimated from data provided by EID. The number of accounts was taken from 2007 data, while water use per-account was estimated as the average of all account types within a zone over the 4-year period, 2004 through 2007.

The exception was SFR demand. For this account type, a model was developed from a set of observed parameters to estimate the time series of actual demand and from which prediction of future water use under different parameters, most notably varying climate, could be made. The model's form was log-log after Hewitt and Hanemann (1993),

$$\ln w = Z\delta + \beta \ln \rho + \gamma \ln m + \omega + \varepsilon \qquad \textbf{Equ. 1}$$

where w is the observed level of consumption, Z is a vector of household and weather related characteristics that include household size, number of rooms, median age, home ownership, among others. The climate data include bi-monthly total precipitation and average temperature. The marginal price of water is ρ, m is the income of the individual, and δ, β and γ are parameters to be estimated. This is a two error structure model, where ω represents unobserved heterogeneity of preferences among consumers and ε represents unobservable error to the consumer as well as to the econometrician (Olmstead et al. 2007). We assume the two error terms are independent and normally distributed with mean zero and variance as σ_ω^2 and σ_ε^2.

The demand model is then formulated as Discrete Continuous Choice (DCC), as it considers the case where consumers face an increasing block rate price (see Olmstead et al. 2007 for details). The first decision is the block price decision, where customers choose the block in which they want to consume. Since there are a discrete number of blocks, this is a discrete decision. Second, customers decide how much to consume within that block or segment, which is a continuous decision. The model takes into account the probability that an individual chooses any of the blocks, and consumes a given quantity within that block. Additionally, it will consider the probability that an individual decides to consume at any of the thresholds defining the different blocks. Olmstead et al. (2007) show that the price elasticity of a DCC is a complex function of the parameters of the model, since the calculation has to consider a change in the whole price structure and includes a price effect and an income effect produced by a virtual subsidy implicit in the block rate structure.

Table 3 summarizes the parameters estimated for the DCC model derived from the eight-year billing record of EID's SFR accounts. These were bi-monthly bills that included more than a million records, where a demand model is estimated from each customer's record (e.g. 6 bills per-year for 8 years, totaling 48 records). The mean and standard error of the parameters for each explanatory variable are presented in

Table 3. The strong correlation with temperature is suggestive of the strong Mediterranean climate of California, characterized by warm, dry summers, with housing density the largest, negatively correlated value.

Table 3. Demand coefficient estimates for the Single Family Residential DCC model. Parameters include number of rooms (ROOMS); average family age (AGEFAMIL); number of people in household (HHSIZE); the year the house was built (YEARHOUS); relative population density in the district (DENSITY); home ownership state (OWNHOUSE); air temperature (TEMP); precipitation (PRECIP); marginal price of water (PRICE); income of household (INCOME). S_N and S_E are the variances of the two error terms. Column 4 presents the 't test' of statistical significance, showing that almost all coefficients are statistically significant CONSTANT is parameter associated with all factors that influence demand but are not modeled.

Parameters	Estimates	Std. Err	Est/s.e.
CONSTANT	-6.5	0.216	300.3
ROOMS	0.143	0.003	42.1
AGEFAMIL	0.034	0.002	14.7
HHSIZES	0.118	0.003	34.7
YEARHOUS	0.067	0.024	4.06
DENSITY	-0.213	0.014	-15.37
OWNHOUSE	0.183	0.009	19.61
TEMP	0.712	0.002	298.
PRECIP	-0.126	0.002	-60.9
PRICE	-0.174	0.008	-22.4
INCOME	0.138	0.101	13.6
S_N	0.007	0.007	1.15
S_E	-0.786	0.001	1004.

As the form of the selected model is in non-linear, the mean parameter values cannot be used in a single aggregate model run using mean values of the explanatory variables. Using a model for each consumer, however, it is possible to estimate the mean of the expected consumption and the elasticity. The mean value of simulated consumption was 129 m^3 (45.5 hundreds of cubic feet) while the mean of the observed consumption was 124 m^3 (43.9 ccf), resulting in an average bias of 3.6%. The mean price elasticity was estimated according to Olmstead et al. (2007) at -0.309, which is higher than the price coefficient of -0.174. As Olmstead et al. (2007) show, overall price elasticity of demand is a complex combination of both the price and income elasticities of demand associated with demand at each segment of the IBP. This overall price elasticity will be different from the simple price elasticity (the PRICE coefficient of the demand function given Table 3). In general, it is not possible to identify either the direction or the magnitude of the difference because several factors are involved in the formation of the overall elasticity.

Having developed a DCC for EID’s SFR customers, the model was implemented in WEAP to estimate water demand for the individual SFR accounts for which there was data. All input parameters were fixed in time, except for air temperature and precipitation. Individual demand estimates were aggregated to represent the total water demand within each of the 15 demand zones in the model. A scaling factor was used to estimate total SFR demand in each zone by relating the number of customers in that zone for which a demand model was successfully developed to its total number of customers. The WEAP allocation routine was then run in response to these simulated demands, witnh a full description of the Drought Plan imposed within the model. The models performance in simulating the EID’s water system for a historic period is described in the next section.

WEAP Calibration Results for the Historic Period

The WEAP model of the EID water system simulates streamflow; water demands, diversions, and deliveries; reservoir storage; instream flow rights; and hydropower generation on a weekly timestep for both historic periods and under future conditions. The historic period 1985 to 1995 was used for model calibration with corresponding demand estimates. These are water years, which begin in October and end in September of the following calendar year. This period was chosen because it encompasses an extended dry episode, and a complete climate record for the region was available (Maurer and Hidalgo 2008). The purpose of calibration is to ensure credibility and validity of the model in terms of 1) its ability to represent the actual EID water system; 2) properly depict the drought plans triggers and the corresponding stage and cut-back targets; and 3) simulate other important measures such as streamflow, reservoir storage, instream flow requirements, hydropower production, etc. Note that the current drought plan was not in place during this period.

In WEAP, water allocation among competing uses is achieved through a hierarchal ranking of priorities among those uses. The allocation priorities are integer values, with the lowest number corresponding to the highest priority. WEAP's demand priorities should not be confused with the priorities associated with legal water rights. In WEAP-EID, instream flow requirements were the assigned the highest priority value of 1, followed by EID demands, which were assigned a priority value 2. For the historic simulations used in model calibration, hydropower generation and Jenkinson Lake fill priorities were assigned priority values of 3 and 4, respectively, to reflect EID's historic policy of utilizing Jenkinson Lake to its full potential to meet water supplies (Table 4, Column 2).

Table 4. The allocation priorities in WEAP for the calibration period and future analysis, where the smaller integer value represents the higher priority.

	1985-1995	**2028-2034**
Instream Flow Requirements	**1**	**1**
EID Water Deliveries	**2**	**2**
Jenkinson Lake Fill	**4**	Stage_0,1 **4** Stage_2,3 **3**
Project 184 Hydropower	**3**	Stage_0,1 **3** Stage_2,3 **4**

Figure 3 shows the simulated weekly streamflow below EID's main diversion on the South Fork of the American River. The simulated flows show good skill, with a Nash-Sutcliffe Efficiency (NSE) of 0.79 (McCuen et al. 2006). The model tended to under-represent the highest flows, most notably 1995.

The main storage reservoir for EID is Jenkinson Lake. Historically, EID has allowed the lake to be drawn down considerably during water-short conditions; but more recently they have realized risks with this policy, and in response developed the drought plan and revised their operating objectives to store more water in the lake. During this same period, EID acquired a 21 Megawatt, 530 meter fixed-head hydropower facility, with an annual generating capacity of about 110 Gigawatt-hours (GWH).

The WEAP-EID uses ranked priority among competing demands to allocate water under shortage conditions, where the demand(s) with the highest priority are assigned the lowest integer value of 1 (Yates et al. 2005 a., b). For the historic period, environmental flows were assigned the highest priority value 1; EID demands were assigned the next highest priority of 2, while the fill priority for Jenkinson Lake was set at 3. This emphasizes the lake as EID's primary water supply. Hydropower generation was considered a secondary benefit, and thus assigned a priority value of 4.

Releases from Jenkinson Lake were constrained to a maximum of 5% of available storage in any single week. Figure 4 shows the simulated and observed Jenkinson Lake storage under these fill and release criteria, with an NSE of 0.76, suggesting the model has good skill in simulating storage. Figure 4 includes the simulated total EID raw water delivery (bars) and observed total deliveries (marks) for all zones. Total deliveries were underestimated in 1985 and 1986, and overestimated in 1988. Interestingly, although no formal drought plan was in place, EID delivered nearly 25% less water in the 1988 drought year than for the previous 5-year average, suggesting substantial welfare loss from unmet demands. Note the limited recovery of Jenkinson Lake storage, as it still served as EID's primary water supply, despite its relatively low storage state (Fraser 2011, Personal Communication). Figure 4 also shows the drought stage, where there was persistent Stage 1 drought from mid-1987 through1989.

For the historic calibration period, hydropower generation ranged from a high of 120 GWh in the wettest year (1997) to a low of 63 GWh in the driest year (1992). The corresponding simulated drought stage is included in Figure 4, showing persistent Stage 1 drought conditions from 1987 through 1989, and periodic Stage 1 conditions in 1985, 1991 and 1992, and 1994.

With a water systems model capable of simulating both past and future EID conditions, we turn to evaluating the performance of the EID drought plan. Both monetary and non-monetary measures were used for the evaluation. Welfare loss from cutbacks and/or shortage was estimated as compensating variation (CV) for single family residential customers, with reservoir storage and hydropower generation as other valuation metrics. While the EID generates recreational revenue from Jenkinson Lake, recent historical data do not support deriving recreational revenue estimates from lake levels.

The WEAP model of the EID water system was configured to simulate the future period 2028 through 2034, using EID's recent estimate of future demand and a concurrent worst-case drought scenario. Before the assumptions and results of the future analysis are presented, the compensating variation model used to estimate SFR welfare loss is described.

Calculation of welfare loss due to rationing and/or shortage

An advantage of developing an econometric model of single family residential demand is that since price is included as one of the explanatory variables, it is possible to estimate the loss in consumer welfare in the case where a customer does not receive water to match a preferred level of demand as reflected by their historic pattern of use. This reduction can take place for two reasons. First, a drought plan calls for consumers to reduce consumption when the system reaches defined levels of water scarcity. This is rationing, and we will refer to this as *planned-shortage* in contrast to the second kind of reduction, where there may be insufficient water to meet demand, whether or not rationing has been imposed. We will refer to this to as *un-planned shortage*.

Using the demand models developed from the observation of consumer demand over the historic period, we estimated welfare loss, as measured by compensating variation (CV), associated with a reduction in the amount of water actually provided to each customer for a given WEAP model run. Compensating variation measures a consumer's willingness to pay to make up for their loss associated with a reduction in the quantity of a good (i.e. water) consumed.

Calculating a welfare change due to quantity restrictions has theoretical and practical challenges. First, from a theoretical perspective, a change in quantity involves solving a consumer maximization problem under an additional constraint (the quantity constraint) which means that the preference structure estimated with the original data, considering only a budget constraint, is not completely correct (Lankford, 1988). The challenge is to find the price (virtual price) that would lead a customer to consume exactly the restricted amount of water when this price is not observable. Furthermore, we need to find this price not in the demand function given in Equation 1, but in what economists call the Hicksian demand function, whose arguments are price and the level of satisfaction that a person achieves at the initial budget constrained situation.

Using the ordinary Marshallian demand function (equation 1) as a point of departure and integrability theory (See Mas-Colell et al. 1995), it is possible to recover the Hicksian demand function which is given by :

$$w = \frac{e^{Z\delta} p^{\beta}}{1-\lambda}\left((1-\lambda)\left[e^{Z\delta}\left(\frac{p^{\beta+1}}{\beta+1}\right) + u^{0} \right] \right)^{\frac{\lambda}{1-\lambda}} . \qquad \textbf{Equ. 2}$$

where u^o denotes the level of satisfaction or utility at the initial budget constrained situation, p is the price and the other parameters are the same parameters of the ordinary demand function given in Equation 1. Second, from a practical perspective the Hicksian demand function, needs to be inverted to find the virtual price π that satisfies

$$\bar{w} = \frac{e^{Z\delta}\pi^{\beta}}{1-\lambda}\left((1-\lambda)\left[e^{Z\delta}\left(\frac{\pi^{\beta+1}}{\beta+1}\right)+u^{0}\right]\right)^{\frac{\lambda}{1-\lambda}}. \qquad \textbf{Equ. 3}$$

in which $\bar{w}$ is the new (restricted) water consumption. For this particular functional form of the demand function u^o is given by

$$u^{0} = \frac{m_0^{1-\lambda}}{1-\lambda} - e^{\alpha}\left(\frac{p_0^{\beta+1}}{\beta+1}\right) \qquad \textbf{Equ. 4}$$

In other words, the initial level of utility is calculated using the initial consumption, initial price and income. Unfortunately given the functional form chosen for the demand function, it is not possible to explicitly solve the Hicksian demand for π, therefore a *bisection routine* was used to find π. The numerical nature of this routine prevented it from being recompiled into WEAP, so under a given set of climate inputs and system configurations including the drought plan, weekly values of the unconstrained demand and actual water deliveries were taken from WEAP-EID run and used as input for an *ex ante* evaluation of compensating variation.

After converging on the virtual price we calculate the compensating variation as the area below the Hicksian demand function between the initial and final price. For example, in the case depicted in Figure 5 for a 10% reduction in water consumption, we have the following information: the original price is p_0=0.69 and the virtual price is p_1=1.42, with the associated quantities given as w_0=40 and w_1=36, then the estimated compensating variation would be 4.22.

It is worth noting that the actual range of prices experienced by EID costumers over the 8-year period of observation is somewhat limited, although behavioral changes associated with one increase in the price levels when a three tier price structure was in place, was observed. In addition, water supply conditions during the period of observation were not extremely constrained, so the records do not capture actual customer behavior in times of extreme shortage (Figure 4). This limits the potential fidelity of the welfare calculations derived directly from the inverted demand functions and explains why the decision was made to extrapolate the estimation of compensating variation under extremely supply limited conditions from values calculated under more moderate supply shortages. This was accomplished by running a tobit regression of estimated compensating variation against the level of reductions. From this regression, the compensating variation was estimated for extreme cases, when the water reductions were above 70%, while using the direct estimation of compensating variation for less extreme levels of water supply reduction.

Evaluating the EID Drought Plan under future Conditions

The State of California's Urban Water Management Act requires urban water suppliers to submit a water management plan every five years to the California Department of Water Resources (DWR). EID's Urban Water Management Plan (UWMP) was submitted in 2010 and included projections of demand and supply to 2030 and the drought preparedness plan. These documents served as a basis for this analysis, where projections of future demand and supply were made for a period around 2030 (e.g. 2028 through 2034). Water use reduction set forth in the EID drought plan call for annual reductions goals of 15%, 30%, and 50% corresponding to Stage 1, Stage 2, and Stage 3 drought, respectively. Since reductions target outdoor use, it was assumed that in late spring, summer and early fall reductions dominate, and for each stage reductions are 20%, 35% and 60%, while for the other seasons, the reduction targets are 10%, 15%, and 40%, which together are meant to achieve the overall annual reduction goals.

Simulating Future Water Supply and Demand under Severe Drought Conditions

The UWMP reports 2010 water deliveries of about 48 MM3 (39 TAF), with a planned demand projection of nearly 75 MM3 (61 TAF) by 2030. The bulk of this increase occurs in the lower elevation, western zones (Z1 and Z2), where there is greater access to future supplies. Current, non-drought annual average water supplies are 60 MM3 (49 TAF), with plans to develop future water supplies through development and acquisition leading to about 145 MM3 (118 TAF) of annual capacity (Table 1).

Since EID's UWMP looked out to 2030, we chose to explore the ramifications of a severe drought during this period, given EID's projected levels of future demand and supply. This future simulation was made for a seven year period, 2028 through 2034, where the historic climate of 1974 through 1979 was assumed to repeat again for this future period. The historic period contains the two-year drought-of-record, 1976 and 1977, and a third, consecutive drought year was assumed to follow the second drought year by repeating the 1977 climate-year. Thus, the climate-years of the past were mapped to the future years as,

1974→2028; 1975→2029, ***1976→2030, 1977→2031, 1977→2032***, 1978→2033, 1979→2034

In addition to single family residential demand, Future water demands for the other water account types were estimated around 2030 based on projected population growth and estimated water use rates by account type for each zone. The sum of all demands under the assumption of no drought plan cutbacks is referred to as unconstrained demand, u_z. and is given for each zone and for each week as,

$$u_z = \sum_{a=1}^{A_z} \frac{P_f}{P_c} N_z^a \bar{R}_z^a \qquad \text{Equ. 5}$$

Where A_z is the total number accounts types in each zone, z; P_f and P_c are the current and future population projections, N_z^a is the number of accounts of type a in zone z in 2007; and $\bar{R}_z^a$ is the average use rate for all accounts for the period 2003 through 2007, in zone z.

Single family residential demand was estimated using the econometrics model for the representative customers within each zone (S_z), where all input parameters except for temperature and precipitation were held constant (see

Table 3). We have assumed that the representativeness of SFR customers within each zone does not change, and thus total SFR is scaled according to the population projection similar to the other accounts as shown in Equation 6. Finally, the total weekly unconstrained demand for each zone is simply, $U_z = u_z + S_z$, where total unconstrained demand, U_t is the sum of the zonal demand.

Defining Scenarios to Reflect Future Operating Policies

To assess the performance of the drought plan, two scenarios were created. The first is referred to as the *Full Plan* scenario, which assumes an active drought plan that fully meets the conservations objective. The second is referred to as the *No-Plan* scenario, which assumes a laissez-faire level of demand by EID customers or no conservation cutbacks. The results from two scenarios were analyzed for the future seven year period, 2028 through 2034, with particular emphasis on the three drought years, 2031, 2032, and 2033.

For both the future scenarios, the operating objectives of Jenkinson Lake and hydropower generation were modified to reflect the evolving EID operating policies. The Jenkinson Lake fill priority was increased during Stage 2 and Stage 3 drought conditions, while the Project 184 hydropower generating priority was decreased (Table 4, Column 3). Also, to meet the growing demands in the western zones served only by Jenkinson Lake and Project-184 Forebay water (see Table 1); the allowable maximum release from Jenkinson Lake in any given week was increased from 5% to 15% of available stored volume.

Results

With year one (i.e. 2028) used as model spin-up, conclusions are drawn from six of the seven years of simulation, which includes a wet year preceding (i.e. 2029) and two wet years following (i.e. 2033 and 2034) the 3-year drought (i.e. 2030, 2031, and 2032). A drought declaration is made in the mid-summer of the 2030 water-year, when Stage 1 drought is issued (Figure 6). "Official" drought conditions end in the late summer of 2033, with the drought having occurred through some portion of four summer seasons. Figure 6includes the storage in Jenkinson Lake and the drought stage for both the *Full-Plan* and *No-Plan* scenarios.

The triangles in the top of Figure 6indicate the total unconstrained demand, U_t for the simulation period, which ranges from 72 MM3 (59 MAF) in 2029 to 82 MM3 (67 MMAF) in 2034, consistent with EID UWMP 2030 projections. The bars in the top of Figure 6are the water delivered for the *Full-Plan* and *No-Plan* scenarios. Overall, the *No-Plan* scenario delivers more water, as there are no mandated cutbacks due to drought restrictions. However, in the third drought year, the *Full-Plan* deliveries 60.9 MM3 (49.4 TAF), which is slightly greater than the *No-Plan* delivery of 60.0 MM3 (48.7 TAF).

For the *Full-Plan* scenario, water conservation under Stage 1 and Stage 2 drought conditions yielded higher Jenkinson Lake storage when compared to the *No-Plan* scenario. Assuming conservation targets are met for the *Full-Plan* scenario, water conservation in the first and second years of drought help to avoid a Stage 3 drought declaration in the third year of drought, although just barely. At the end of September and while in Stage 2 drought conditions, the SRI nears but does not reach a value of 0.35 (Figure 7which is the established SRI cutoff value when Stage 3 drought would be declared (see Table 2, row 4).

For the *Full-Plan* scenario, the targeted reductions in water demand were assumed to be fully achieved in the first and second drought years, with no un-planned shortage and reductions in delivered water of 16% and 26% of U_t, respectively. Near the end of the third drought year, five of the western zones (Zones 9, 10, 11, 12 and 13) experience only a small amount of un-planned shortage of about 7% of each zone's total annual demand. These zones represent about 18% of

EID’s total delivery, so the total un-planned shortage is less than 1% of the total delivery over the 3-year drought. Recall that these zones are in EID’s western service area, and have fewer supply options and must rely primarily on Jenkinson Lake or Project 184 supplies.

For the *No-Plan* scenario, all shortages are considered un-planned and are relative to U_t,. The *No-Plan* scenario implies Stage 3 drought conditions near the end of the second drought year. While there is almost no un-planned shortage in years 1 and 2 of the drought, by year three, nearly all zones experience some un-planned shortage. The total delivered water for all zones is 27% less than U_t,, with un-planned shortages in the spring and summer months of the third drought year. However, for many of the zones, the water system has “failed”, delivering in some cases, only 10% of U_t. Only Zone 2, with full access to Folsom Water has no un-planned shortage.

Table 5 summarizes drought plan performance measures, including compensating variation, average Jenkinson Lake Storage for the summer months, and total delivered water.

The CV estimate for the *Full-Plan* scenario and for all 3-years of drought is $1.01 million, with the majority of this welfare loss occurring in the third drought year (Table 5). Note that the objective and functional forms of water demand and compensating variation as a welfare measure both recognize water as an essential good, and as an essential good, the value of having no water is infinite. Thus, our problem moves from being continuous- having less water, to a discrete problem, where in some cases and places, there is no water provided at all. This fact becomes more apparent for the *No-Plan* scenario, where the CV estimate balloons to roughly $16 million (Table 5). The high CV is the result of zones moving from having to not-having water, as the data and economics theory reminding us of the essential nature of water. These results suggest that a successfully implemented Drought Plan would help EID avoid maneuvering in that decision space.

The results also suggest that the majority of cost associated with the Drought Plan would be borne by EID and not its customers. We estimated that a successfully implemented Drought Plan would deliver 18 MM3 (22 TAF) less water over three year drought (Table 5), which at $\$0.85/m^3$ would mean roughly $15.3 million of lost revenue in 2010 dollars. In addition, EID has possibly avoided a drought surcharge, with the current plan likely only enacting surcharge during Stage 3 drought (EID 2007).

Storage in Jenkinson Lake in the *No-Plan* scenario is lower relative to the *Full-Plan* scenario, with substantial differences in the summer months in the third drought year (i.e. the 2032 water year). The *Full-Plan* scenario leaves the reservoir at 26% of total storage, while the *No-Plan* scenario results in a nearly empty reservoir at 9% of total storage. Water conservation from drought plan restrictions has led to increased storage in Jenkinson Lake, achieved through conservation and diversions of EID’s Project 184 water.

Table 5. EID performance measures for the *Full-Plan* and *No-Plan* scenarios for the three drought years. Summer is defined as June 1 through August 31.

	Full-Plan			***No-Plan***		
	Yr 1	**Yr 2**	**Yr 3**	**Yr 1**	**Yr 2**	**Yr3**
Compensating Variation ('1000s)	$45	$66	$902	$0	$2200	$13,800
Average Summer Jenkinson Lake Storage (MM3)	22.2	18.1	13.0	20.4	12.9	5.5
Total Delivered Water, MM3 (% of *Ut*)	67 (88%)	67 (84%)	61 (74%)	75 (100%)	78 (98%)	60 (73%)

This storage implies maintained recreational benefits to the public and associated revenues to EID. The amount of hydropower generated for both the *Full-Plan* and *No-Plan* scenarios are nearly identical. Under drought conditions, hydropower generation is restricted primarily to the winter months, when there are few generating constraints, and very little summer generation due to the limited water supply and the higher priority to fill Jenkinson Lake. Total generation in 2029, a wet year, was 110 GWh, while generation for the three consecutive drought years was 80 GWh, 45 GWh, and 30 GWh.

Summary and Conclusions

The stated goal of the EID drought plan was to *define demand curtailments that can be reasonably accomplished and that perform well for all customers.* We have suggested that for EID, a key measure of their drought plan performance would be to achieve no 'un-planned' shortages. This paper has explored measures that can be used to evaluate the performance of EID's drought plan, allowing for a more rigorous and analytical analysis of the EID drought plan as opposed to being purely conjectural.

The result suggest that EID has formulated a very efficient drought plan to navigate a drought more severe than their drought-of-record. If EID were to experience a more severe drought than their drought-of-record and if they were to successfully implement their drought plan and achieve their stated reduction targets, then the plan could avoid EID having to impose the most severe drought restrictions- Stage 3, likely avoid un-planned shortages, and not need to impose a likely un-popular surcharge on its customers.

A shortcoming of this welfare estimation is the lack of low levels of consumption in the observed data, therefore the ability to estimate compensating variation at low levels of consumption is limited. The EID drought plan does not try to define the minimum level of essential consumption, but if the plan achieves its goals, EID would successfully keep this as a continuous problem (less significant) rather than a discrete, very significant problem. This result also shows that at higher levels of consumptions, “demands” are preferences and not “needs”, as people consume water for many uses beyond the basic levels.

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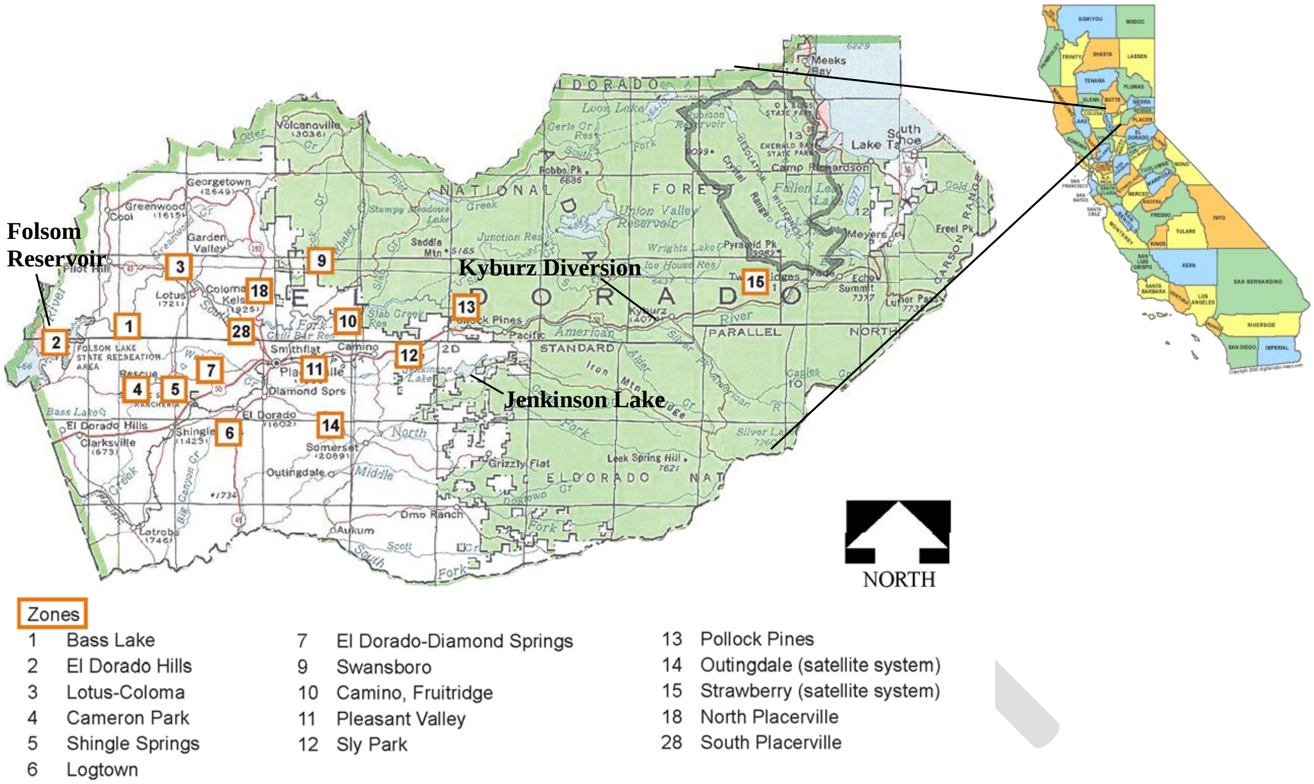

Figure 1. Position of El Dorado County in California and the physical location of the various water use zones within EID.

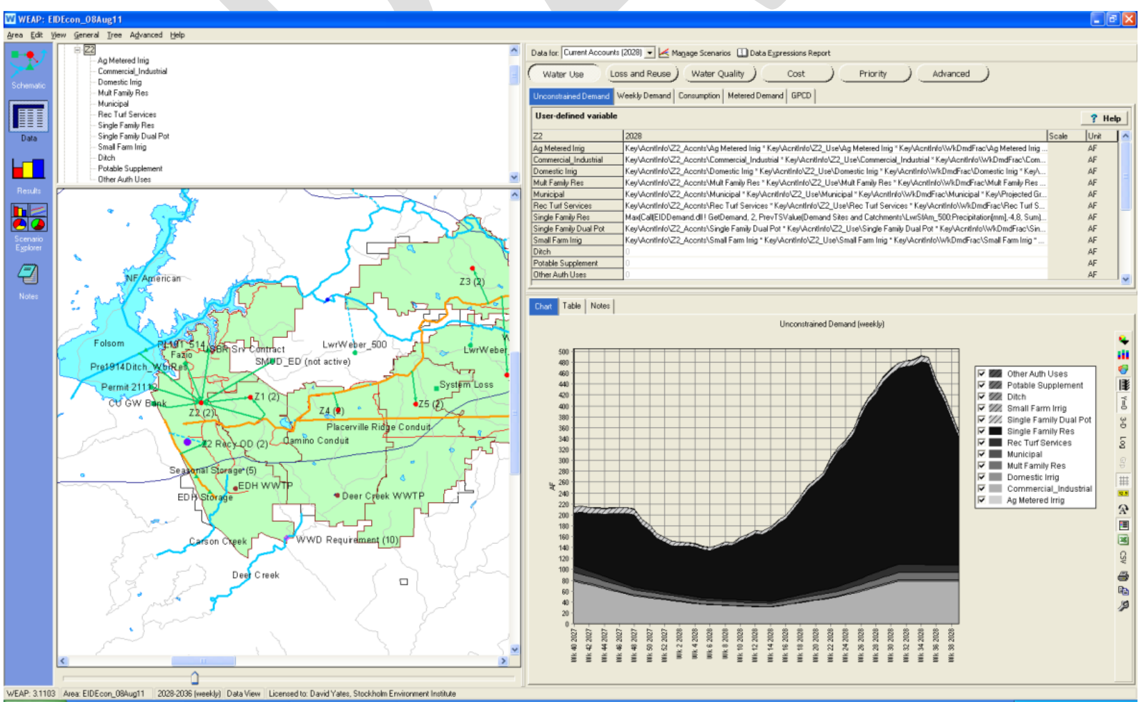

Figure 2. Screen shot of the WEAP EID model, depicting the western portion of the service area and Z2 demand for a single year. The darkest band is the SFR demand.

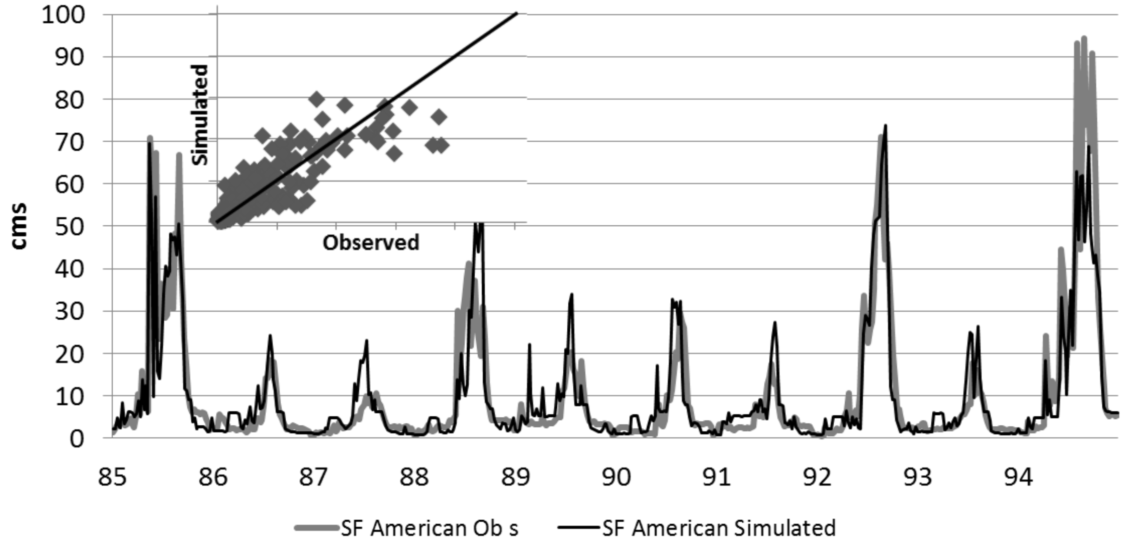

Figure 3. Simulated (dark line) and Observed (light line) South Fork of the American Streamflow below the Kyburz diversion, Calibration statistics include: a Nash-Sutcliffe = 0.79; RMSE = 6.6 cms; Total Observed Volume = 3.37 BCM; and Total Simulated Volume = 3.40 BCM. The inset shows these same data on an x-y plot.

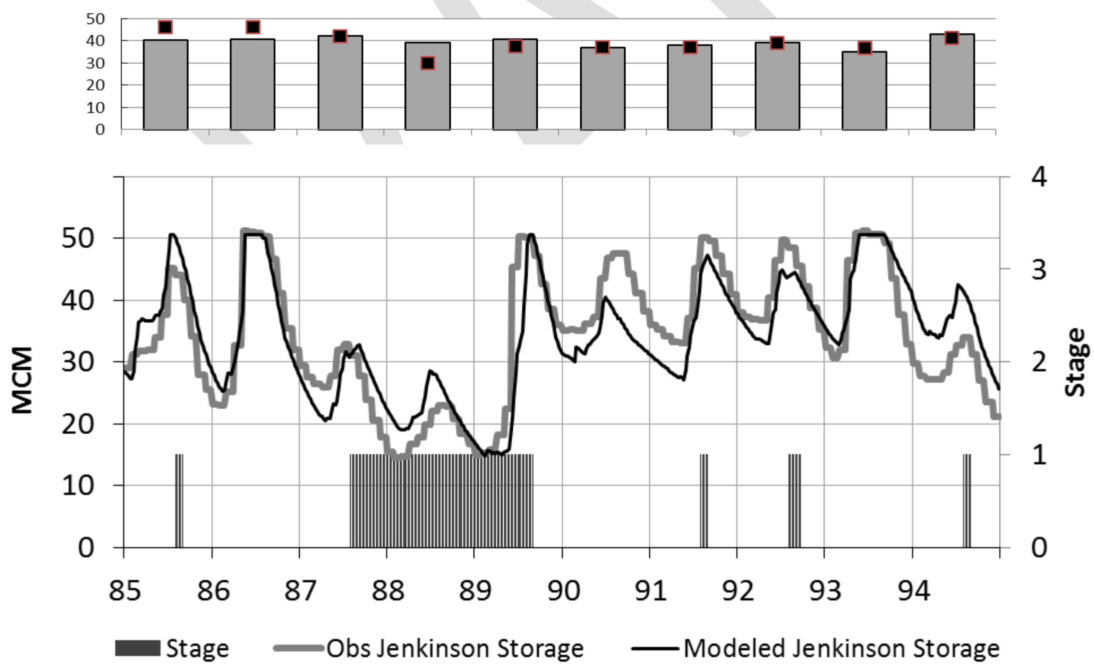

Figure 4. Simulated (dark line) and Observed (light line) Jenkinson Reservoir Storage (Nash-Sutcliffe = 0.76; RMSE = 5.6 MCM; Average Observed Volume = 36.5 MCM; and Average Simulated Volume = 33.8 MCM), and drought stage. Top Graph shows the simulated total EID demand for the same period in MCM during a period with no formal drought action plan.

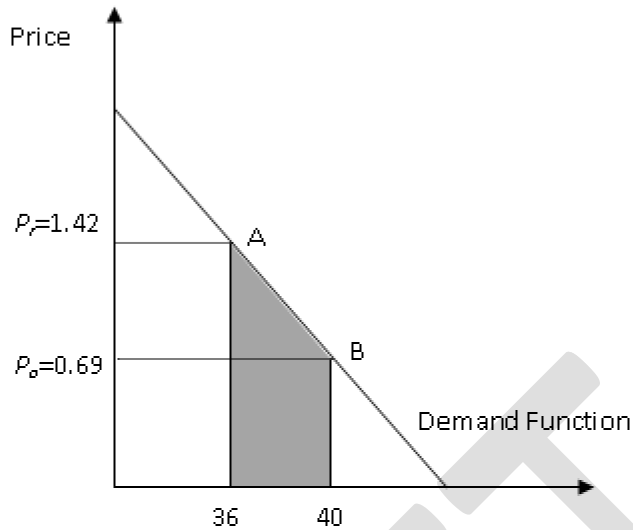

Figure 5. Graphical representation of compensating variation estimation

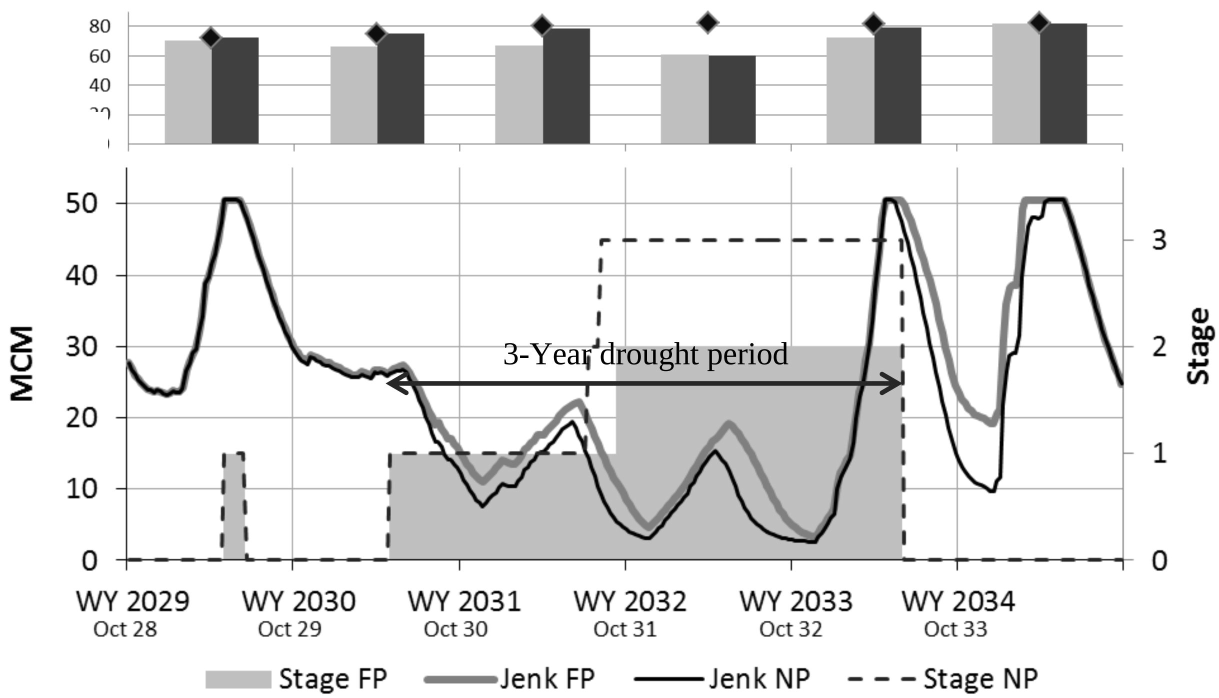

Figure 6. Jenkinson Lake storage and drought stage for the *Full Plan* scenario (Jenk FP and Stage FP) and the *No Plan* scenario (Jenk NP and Stage NP). Top graph shows the total unconstrained demand (triangles) and the simulated EID water deliveries for the *Full Plan* (light) and *No Plan* (dark) scenarios in MM3.

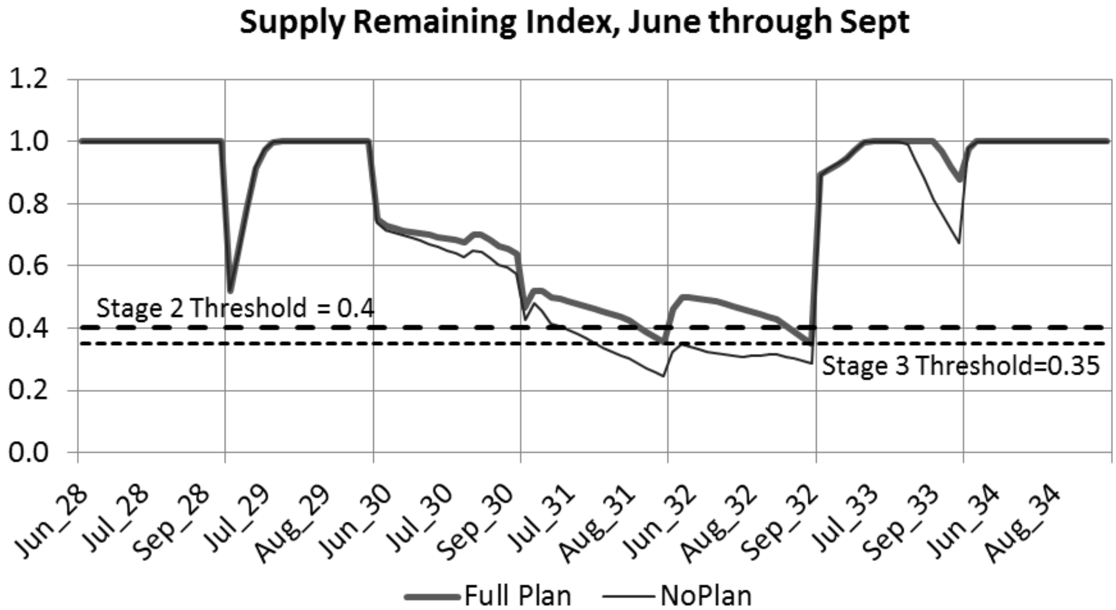

Figure 7. Supply Remaining Index for late spring, summer, and early fall period for both the Full Plan and No Plan Scenarios. The horizontal lines at 0.4 and 0.35 indicate the thresholds at which Stage 2 and Stage 3 drought are declared.