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Economic Benefits to the Central and West Coast Basins from the Program Elements Encompassed by the Judgment Amendments

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Executive Summary

The Central and West Coast groundwater basins ("basins" or "Central and West Coast Basins") are located in southern Los Angeles County. Groundwater produced from these basins provides approximately forty percent of the water supply for residents and businesses in all or parts of 43 cities. The 4 million residents in the area comprise more than ten percent of the total population of the State of California.

This report measures the economic costs and benefits of the various program elements encompassed by the proposed judgment amendments (Judgment Amendments) to pumpers extracting groundwater in the basins. Because those pumpers include water agencies, who collectively serve nearly 4 million customers the economic costs and benefits also extend to the region as a whole. The analysis calculates such costs and benefits by modeling basin storage, water supply augmentation, replenishment and water leasing activities, taking into account variations in the availability of imported water. The analysis is conducted at an aggregate level, which means the collection of all water agencies and entities in the Central and West Coast Basins. The analysis conservatively examines only the benefits that would accrue to the current holders of adjudicated groundwater rights in the Basins and does not attempt to quantify the direct or indirect benefits that may accrue to other entities (e.g., entities that may seek to access the "regional" storage space). Benefits are expressed in both annual and present value terms, with present values calculated in 2009 dollars. The potential benefits are calculated based on the use of the storage space by a groundwater right holder whether through a priority right granted under the Judgment Amendments or on a "space available, at risk of spill" basis. Finally, the time frame for the analysis is 2009-2030, the term of the Judgment Amendments.

Once adopted, the Judgment Amendments will provide significant economic benefits to the region that overlies the Central and West Coast groundwater basins and to the parties holding adjudicated groundwater rights in the basins. Those benefits are primarily attributable to lowering the average cost of water service and improving the reliability of water service, which, in turn, can be stated as an economic or dollar value. As will be seen, substantial economic benefit attaches to storage itself. Additionally, the value of groundwater pumping rights for each party will increase by virtue of the groundwater storage options provided by the Judgment Amendments, whether or not the party participates in storage, since the amendments would augment those parties' water rights, which can be exercised to lower their cost of water service and improve the reliability of their water supplies.

Summary of Total Expected Net Benefits, Years 2009-2030 (million $'s)

	Low	High
Central and West Coast Basins Total	$560	$944

Expected Increase in the Value of Water Rights in the CWCB over the Period 2009-2030 ($/AF)

	Low	High
Central Basin	$1,793	$3,318
West Coast Basin	$1,523	$3,449

It should be noted that the proposed Judgment Amendments can facilitate the approval of significant government funding for storage projects. The State Department of Water Resources (DWR) has stated that funding for groundwater storage has not been made available to the Central and West Coast Basins because of the lack of legal certainty associated with the use of storage. The Metropolitan Water District (MWD) has a policy that funding for local projects such as groundwater storage is conditioned upon the absence of legal challenge associated with a proposed project. The Judgment Amendments would provide the legal certainty required by the state and MWD as a condition of funding support. However, to be conservative, the value of such external funding support is not included in this analysis.

This study considers the optimal conjunctive use of groundwater and imported water in the basins under two sets of operational rules: (*i*) the rules encompassed by the existing Judgments governing groundwater rights in the Central and West Coast Basins (Judgments); and (*ii*) the rules encompassed by the proposed Judgment Amendments. These two situations are identical in the specification of each party's groundwater extraction right but differ according to the flexibility with which they would have a new opportunity to use storage capacity in the basins, based upon a standardized structure to be specified by the court. The availability of enhanced storage results in two broad types of economic benefits: lowering the average cost of water service (since replenishment water and other sources of stored water can be substituted for more expensive Tier 1 supplies), and improving the reliability of water service (since local groundwater is more dependable than water imported by the MWD.

The Judgment Amendments also enable pumpers to increase their annual pumping rights by engaging in water augmentation projects and developing recycled water sources that allow a higher level of pumping to be sustained over time. For instance, a proposed augmentation project at Montebello Forebay could increase the inflow into the Central and West Coast Basins by 16,465 AF per year through enhanced stormwater capture, a quantity that can be reliably extracted from the basins on a recurring basis thereafter. Similarly, advanced treated recycled water injected or otherwise delivered to the basins can provide a reliable flow of water that can be extracted in addition to annual pumping rights under the Judgment Amendments.

The report considers four scenarios regarding management of the basins under the Judgment Amendments, to determine whether there is a measurable benefit or detriment as parties react to the new opportunities. In Scenario 1, there is assumed to be 20,000 AF of recycled water development in West Coast Basin beyond current levels. This quantity is on the lower end of recycled water augmentation and in this respect the scenario is a conservative estimate of the net amount of increased recycled water to be made available through water rights augmentation projects to be permitted under the Judgment Amendments. The other three scenarios each differ from Scenario 1 in a single aspect. Scenario 2 is identical to Scenario 1 other than it assumes no recycled water development. Comparing outcomes for these two scenarios allows one to isolate the contribution of recycled water to the net benefits of the amendment package. Scenario 3 keeps the level of Tier 1 purchases fixed at existing or baseline levels (whereas they are optimized in Scenario 1). Scenario 4 examines the case where an additional 34,000 AF of recycled water is available in the Central Basin, in addition to the 20,000 AF assumed for the West Coast Basin in Scenario 1.

Over the period 2009 – 2030, the benefits of the Judgment Amendments to the region are $808 million under Scenario 1, with $222 million accruing to agencies in the West Coast Basin, and $586 million to agencies in the Central Basin. Increasing the quantity of recycled water by adding 34,000 AF per year in the Central Basin increases economic benefits to $944 million in Scenario 4.

Expected Net Benefits of the Judgment Amendments over the Period 2009-2030 (million $s)

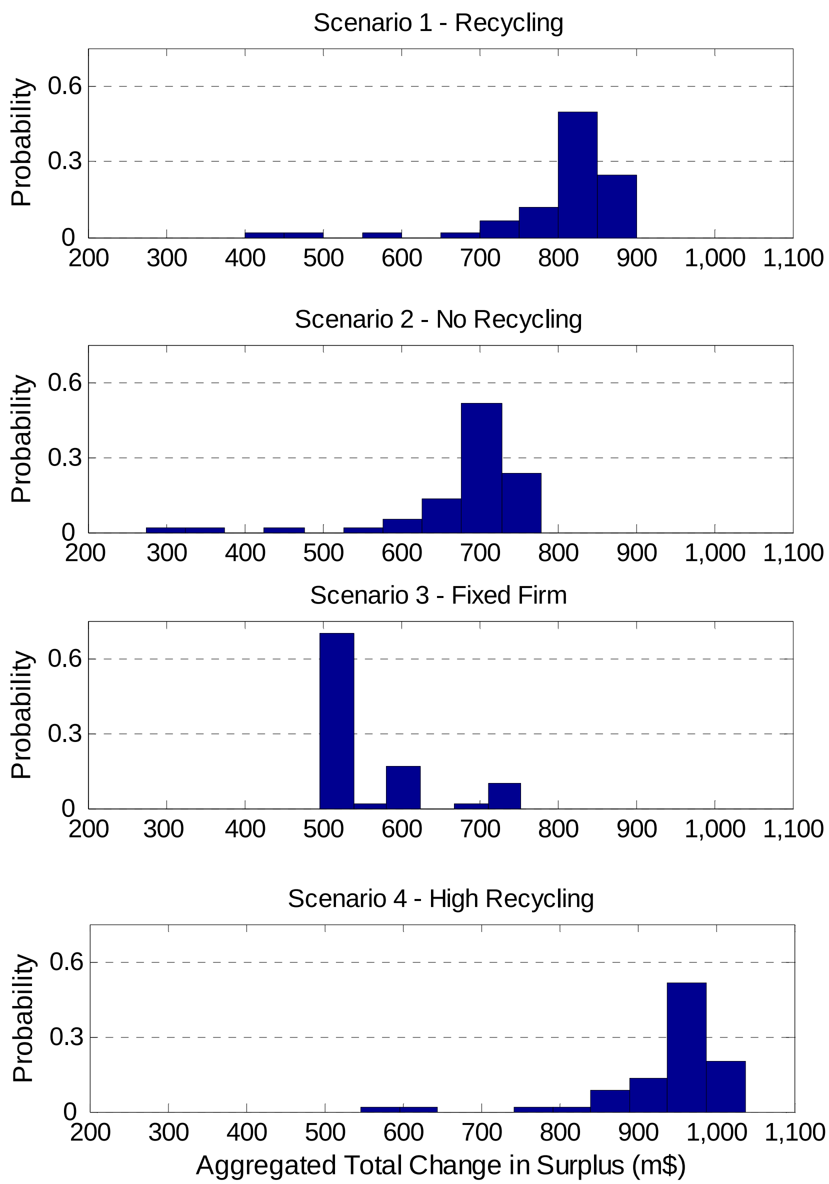
	West Coast Basin	Central Basin	CWCB Total
Scenario 1 (20,0000 AF recycling)	$222	$586	$808
Scenario 2 (No recycling)	$98	$586	$684
Scenario 3 ("Fixed Firm")	$171	$390	$560
Scenario 4 (54,000 AF recycling)	$223	$721	$944

Scenarios 2 and 3 are not optimal in important respects. Scenario 2 demonstrates that investment in additional recycled water in the West Coast Basin passes a benefit-cost test; keeping recycled water use in that basin at its current level lowers economic welfare by $124 million (from $808 million to $684 million) over the term of the amendments. Similarly, keeping Tier 1 purchases at baseline levels in the face of the Judgment Amendments lowers economic welfare by $228 million (from $808 million to $560 million).

Of course, the actual outcome under any scenario depends in large part on future precipitation and imported water deliveries into Southern California. Accordingly, this study and the modeling used calculate expected outcomes over a range of both hydrologic cycles and imported water supply conditions. To capture the variability of future imported water supplies, we rely on modeling commissioned by MWD after Judge Oliver Wanger of the U.S. District Court in Fresno imposed flow-related restrictions on Delta exports to protect the delta smelt.[1] The data

[1] United States District Court for the Eastern District of California, "Interim Remedial Order Following Summary Judgment and Evidentiary Hearing," filed December 14, 2007, accessed at: http://www.fws.gov/sacramento/es/delta_smelt.htm (commonly referred to as the "Wanger decision".)

provided by MWD indicate the availability of imported water supplies under the delta smelt restrictions. The modeling also uses the 82 years of historic rainfall from 1922 – 2003 and assumes that such hydrology will be repeated in the future. Because the term of the Judgment Amendments is shorter than the number of years for which we have hydrologic forecasts, the study took 22-year intervals of the forecast beginning at 60 different dates.[2] Looking across these 60 different forecast intervals captures the range of outcomes under each management scenario. Thus, the water supply forecasts used in this study show the availability of imported water under current environmental restrictions and demand levels assuming that the historic hydrology repeated itself. The results of this analysis are presented in the following figures:



[2] A twenty-two year cycle generally coincides with the initial term of the Judgment Amendments. Since the Judgment Amendments probably will not cease immediately at the end of the 20-year term provided in the operative court documents, an extra two years is assumed for a winding down of storage programs authorized under the Judgment Amendments.

The figure displays the probabilities (the percentages on the left axis on each of the above graphs) that any particular scenario results in a given amount of economic benefits. For example, there is a roughly 50 percentage probability that Scenario 1 will produce between $800 and $850 million in economic benefits to the region, as reflected on the top blue bar on the above graph. Note that the benefits listed in the table at page 5 above represent the *average* of all expected benefits across all hydrologic intervals for each of the four studied scenarios. Some particular hydrologic sequences can result in lower benefits than those average benefits, with some chance that benefits can be as low as $400 million. However, there is no hydrologic sequence for which the Judgment Amendments perform worse than the baseline under the existing Judgments.

Under all scenarios, the analysis concludes that the amended judgments will have little or no effect on the market for leased water rights. The analysis concludes that the marginal value of water is not affected significantly merely because parties may store water in addition to leasing unused rights to others. The free transferability of water held in storage permitted within the amended judgments means that available transferable supplies remain largely unchanged. Thus, transferable water will remain largely available at essentially stable lease rates. As more water is placed into storage, the available supply of transferable water is likely to increase, augmenting opportunities for lease or transfer, and probably reducing the cost of doing so.

Overall, the amended judgments will encourage the following:

- increased local supply through greater storage of groundwater;
- increased reliability of supply, especially in times of drought or imported supply restriction;
- increased use and development of recycled water;
- increased efficiencies in the capture of storm flow and other local supply; and
- increased use of now-underutilized groundwater pumping rights.

The analysis predicts an overall likely benefit to the region of between $560 million and $944 million over the period 2009-2030.

1. Introduction

Groundwater extracted from Central and West Coast Basins provides a reliable source of water for nearly 4 million people residing in 43 cities in Los Angeles County. Over the past ten years, FY1996-1997 to FY2006-2007, water users in the area overlying the Central and West Coast Basins extracted an average of 243,226 AF of groundwater to meet an average annual retail water demand of 665,661 AF.[3]

Groundwater extraction is adjudicated in both the Central and West Coast Basins. The judgment in the West Coast Basin, which was finalized in 1961, established an "Allowed Pumping Allocation (APA) of 64,468.25 acre-feet per year (AFY). The judgment in the Central Basin, finalized in 1965, established an "Adjudicated Right" of 217,367 AFY[4]. The combined adjudicated rights in both basins (281,835.25 AFY) exceeds the natural inflow into the basins through interior and mountain front recharge, local water conserved at the spreading grounds, and net underflow from adjacent basins, and the difference between actual pumping and the natural inflow (145,205 AFY) is reconciled by artificial recharge activities maintained by the Water Replenishment District of Southern California (WRD).[5]

This study considers the optimal conjunctive use of groundwater and imported water in the basins under two sets of operational rules: (*i*) the rules encompassed by the existing judgment; and (*ii*) the rules encompassed by the proposed Judgment Amendments. These rules are identical in the specification of each agent's right to groundwater, but differ according to the flexibility with which pumpers can use available storage capacity in the basins to provide reliable water delivery.

The economic analysis separates agencies' groundwater storage from recharge operations undertaken through spreading activities at Montebello Forebay by WRD and through barrier injection by the Los Angeles County Department of Public Works (LACDPW). Water placed into storage by an agency --whether through spreading, direct injection, or in-lieu storage -- is considered to be a storage operation and not a replenishment operation; that is, stored water is viewed as water banked for future extraction. Moreover, because the adjudicated rights of water pumpers is not altered by the Judgment Amendments, any change in the pattern of groundwater use that arises through puts and takes into individual and community storage accounts does not alter the average annual groundwater deficiency (long-term average of natural inflows less outflows) in the Central and West Coast Basins. As a consequence, recharge operations undertaken by WRD, which currently target the difference between annual average pumping levels and natural inflows, are not altered in the long-run by changes in the storage operations of the

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[3] Water Replenishment District of Southern California, *Engineering Survey and Report, 2008* (updated May 2, 2008): http://wrd.org/engineering/reports/Final_Report_May2_2008.pdf.
[4] The term "adjudicated rights" will be used to refer collectively to "Allowed Pumping Allocation" and "Adjudicated Rights" throughout this report.
[5] Water Replenishment District of Southern California, *Engineering Survey and Report, 2008*, Table 4 (updated May 2, 2008): http://wrd.org/engineering/reports/Final_Report_May2_2008.pdf.

individual water pumpers, and are assumed to continue in a similar manner to historic replenishment activities.

The Judgment Amendments also enable water pumpers to increase their annual pumping rights by engaging in augmentation projects and developing recycled water sources that allow a higher level of pumping to be sustained over time. For instance, a proposed augmentation project at Montebello Forebay is expected to increase the inflow into the Central and West Coast Basins by 16,465 AFY through enhanced stormwater capture, a quantity which can be reliably extracted from the basins on a recurring basis. Similarly, advanced treated recycled water injected or otherwise delivered to the basins can provide a reliable flow of water that can be extracted in addition to annual pumping rights under the amendments through the optimal quantity of storage in the Central and West Coast Basins.

The report is organized as follows. The next section frames the study by providing background information on basin operations and defining several potential sources of economic value encompassed by the Judgment Amendments. Section 3 presents a formal framework for assessing the value of the major program elements outlined in Section 2 and develops an algorithm to identify the optimal mix of Tier 1 and replenishment water imports for agencies confronted with various storage possibilities in the basins. Section 4 projects the annual availability of replenishment water and the profile of future rationing of non-interruptible water by the Metropolitan Water District of Southern California (MWD) in light of the recent Wanger decision and Biological Opinion concerning the Delta Smelt. Based on the hydrologic record over the period 1922-2003, a "post-Wanger distribution" of annual MWD water availability is projected for each year of the historical record. Section 5 applies the storage and extraction framework developed in Section 3 to the post-Wanger distribution of MWD water deliveries of imported water. The results of this analysis reveal the expected economic benefit to the region resulting from the Judgment Amendments, and also the range of possible outcomes.

2. Background

2.1 Water Demand and Supply

The value of groundwater storage in the Central and West Coast Basins is embodied in the efficiency in which agencies extracting water in the basins can meet their retail water demands. Retail water demand in the area overlying the basins is projected to be relatively stable over time due to offsetting trends of nominal population growth and increased conservation. Retail water demand is compiled from the Urban Water Management Plans of individual water agencies extracting groundwater from the basins and centered on the year 2015.[6] Projected retail water demand in the area overlying the basins is 714,188AF in the year 2015.[7]

Water demand in the area overlying the basins is predominantly met through a combination of groundwater pumping, direct use of recycled water for non-potable uses (e.g., for industrial uses and for irrigation of parks, golf courses, and street medians), and purchases of imported water from MWD. Table 1 reports retail water demand and the available local water supply in the area served by groundwater from the basins. Residual demand for imported water, which is the difference between total retail water demand among water pumpers relying on groundwater from the basins and local water supply, represents the demand for imported water from MWD. Residual demand for imported water represents the difference between retail demand among users of groundwater in each basin and the sum of: (i) the adjudicated rights of water pumpers; (ii) other available groundwater resources (projected groundwater extraction by Central Basin MWD from the Main San Gabriel Basin); (iii) recycled water for direct use (not including replenishment deliveries); (iv) and desalter water (projected by the City of Torrance).

The residual demand for imported water reported in Table 1 (313,003 AFY) is considerably lower than the level of MWD imports reported by WRD in FY2006-07 (387,525 AF). There are three reasons for this discrepancy. First, the actual level of groundwater pumping in FY2006-07 was 235,770 AF, which is lower than the adjudicated rights of 281,835 AF due to a combination of storage adjustments in individual carryover accounts and operational inefficiencies among pumping agents. Residual demand for imported water in the area served by Central and West Coast Basins groundwater represents the annual water shortage that cannot be met from local sources gross of any storage adjustments and assumes that operational inefficiencies that preclude the full extraction of each water pumpers adjudicated rights do not persist over time. Second, water imports reported by WRD for FY2006-07 include 11,451 AF of imported water purchased for injection at the West Coast Basin, Dominguez Gap, and Alamitos seawater barriers. Residual demand for imported water considers retail water demand to be met by water agencies in the Central and West Coast Basins, which segments consumer demand from barrier injections used for storage by individual water pumpers and from water used to meet replenishment obligations. Adjusting reported imported water use in FY2006-07 for these discrepancies, residual demand for imported water in FY2006-07 was 318,976 AF.

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[6] The year 2015 was chosen because it is a standard reference point for urban water planning in California, and also because it falls part way through the term of the Judgment Amendments.

[7] Retail Municipal and Industrial water demand in West Coast Basin is taken from the values reported in the 2005 Urban Water Management Plans for West Coast MWD (Table ES-1) and the City of Torrance (Table 2.2-1). Retail Municipal and Industrial water demand in Central Basin is taken from the values reported in the 2005 Urban Water Management Plans for Central Basin MWD (Table ES-1), City of Long Beach (Table 4), City of Compton (Table 3.2-1), and City of Los Angeles (Table 3.2). The City of Los Angeles water demand represents the water demand of users overlying Central and West Coast basins, which is taken to be 15 percent of total retail water demand in Los Angeles (105,750 AF).

Table 1. Residual Demand for Imported Water in the Year 2015

	West Coast Basin	Central Basin	CWCB Total
Retail Municipal & Industrial Demand	237,299	476,889	714,188
CWCB Groundwater	64,468	217,367	281,835
Other Groundwater	0	42,000	42,000
Recycled Water, Direct Use	47,800	27,150	74,950
Desalter Water	2,400	0	2,400
Residual Demand	124,135	188,868	313,003

Source: Data compiled from Urban Water Management Plans (2005).

Finally, the discrepancy exists because retail water demand in the year 2015 includes projections for a nominal rate of urban population growth and the development of direct uses for recycled water. Recycled water for direct use was reported to be 41,899 AF in FY2006-07, a value 33,051 AF less than the projected use of 74,950 AF in the year 2015. Development of recycled water use to meet non-potable water demands is expected to keep pace with the growth of consumer demand through the year 2015, resulting in residual demand for imported water of 313,003 AF.

Under projected demand and supply conditions in the year 2015, a substantial portion of retail demand in each basin is met with imported water (52.3 percent in West Coast Basin, 39.6 percent in Central Basin, and 43.8 percent combined across both basins). Imported water is available from MWD through long-term contracts for non-interruptible water ("Tier 1 water") and through purchases of replenishment water ("seasonal water" or "surplus water") when replenishment water is available. Additionally, water is available for exchange between water pumpers in the basins through lease markets operating within each basin.

Tier 1 water is significantly more expensive than replenishment water, but nonetheless represents the dominant share of imported water purchased for retail use from MWD. Water pumpers serving consumers in Central and West Basin pay a reliability premium for Tier 1 water through long-term contractual arrangements for Tier 1 water. These contracts provide greater reliability of future water availability, although delivery quantities are subject to rationing under MWD's Water Allocation Plan in the event of a severe drought. Replenishment water from MWD is a less reliable source of imported water because replenishment water is only available seasonally between the months of October through April in some years, but not at all in others. Moreover, long-term contracts for Tier 1 water limit the ability of water pumpers to use replenishment water to displace Tier 1 sources of imported water at times when replenishment water is available from MWD.

Tier 1 water is subject to rationing. Table 2 summarizes the implications of the MWD Water Allocation Plan for water pumpers in Central and West Coast Basins under three levels of drought condition rationing. Under a Level 2 (10 percent reduction) scenario by MWD, Tier 1 deliveries are reduced between 2.7 – 8.1 percent, resulting in Tier 1 deliveries between 91.2 – 97.3 percent of the long-term contracted levels. Under a Level 4 (20 percent reduction) scenario, Tier 1 deliveries by MWD range between 85.6 – 93.8

percent of the long-term contracted levels, and, under a Level 8 (40 percent reduction) scenario, Tier 1 deliveries by MWD range between 71.4 – 87.5 percent of the long-term contracted levels of each agency.

Table 2. MWD Water Supply by Agent and by Basin under Proposed Formula, as a Share of Current Use

	Shortage scenario		
Agent	Level 2 10% reduction	Level 4 20% reduction	Level 8 40% reduction
Central Basin MWD	97.30%	93.80%	87.50%
West Basin MWD	91.90%	85.60%	71.40%
City of Long Beach	95.00%	89.30%	78.40%
City of Los Angeles	96.70%	92.50%	84.70%
City of Torrance	91.20%	85.60%	71.90%
City of Compton	96.70%	92.40%	84.70%
Allocation by Basin [1]			
West Coast Basin	91.79%	85.60%	71.48%
Central Basin	96.53%	92.23%	84.25%

Source: Metropolitan Water District of Southern California, Board of Directors Water Planning and Stewardship Committee, Board Meeting February 12, 2008 (Attachment 2).

[1] Allocation by Basin is calculated based on a level of imported water use given by the residual demand of each agent.

In all cases, water supply among water agencies in West Coast Basin is rationed to a greater degree relative to water supply among water agencies in Central Basin. Given the level of imported water deliveries predicted by residual demand for each agent, the combined water allocation among water agencies in West Coast Basin (Central Basin) involves an aggregate delivery of 91.79 percent (96.53 percent), 85.6 percent (92.23 percent), and 71.48 percent (84.25 percent) of Tier 1 deliveries under Level 2, 4, and 8 reduction scenarios, respectively.

2.2 Benefits of Conjunctive Use

Conjunctive use of groundwater and imported water allows water pumpers to convert MWD's seasonal replenishment water supplies to a reliable source of water through a sequence of puts and takes into storage. The ability to store replenishment water for intertemporal consumption creates substitution possibilities between reliable sources of imported water and less expensive sources of replenishment water since storage decouples the timing of extraction from the timing of deliveries. Thus, as the ability of water pumpers to store water in the basins expands, greater levels of water can be reliably delivered to the region over time through storage and extraction, and the optimal water portfolio is comprised of larger quantities of replenishment water and smaller quantities of Tier 1 water.

The proposed Judgment Amendments increase the net benefit of water pumpers extracting groundwater in the basins in five distinct ways. First, the amendments enhance the ability of individual water pumpers to make puts and takes from the available storage capacity in the Central and West Coast Basins. Under the existing judgment, individual water pumpers are allowed to hold 20 percent of their adjudicated rights in individual carryover accounts. Carryover accounts allow water pumpers to forgo pumping at times when replenishment water is available, placing the unused portion of their adjudicated rights in a carryover account to be extracted under relatively dry conditions when the water is more valuable. Individual water pumpers can also extract up to 20 percent beyond their adjudicated rights in a given year under existing overdraft provisions. Under the amended judgment, individual carryover accounts are raised to 100 percent of each agent's adjudicated rights and additional storage possibilities are created through the use of individual and community storage accounts. The ability to hold a greater amount of water in storage creates value by allowing individual water pumpers to convert unreliable replenishment water into reliable water by making a sequence of puts and takes to and from storage or carryover accounts.

Second, the amendments allow individual water pumpers to increase their average annual groundwater pumping levels by developing augmentation projects and injecting advanced treated recycled water into the basins. To the extent that advanced treated recycled water can be procured at a lower cost than Tier 1 sources of imported water, recycled water provides comparable reliability in deliveries. Annual flows of recycled water and augmentation water allow water pumpers with access to these sources to increase their annual pumping levels above their adjudicated rights provided that the optimum quantity of storage is available in the basins. For instance, an individual agent who arranges the delivery of 1,000 AFY of advanced treated recycled water to the spreading grounds can increase his pumping level by 1,000 AFY above his adjudicated rights by matching the put with a take from storage in each year. At current subsidy rates for recycled water of $250 per AF, the net cost of recycled water in West Coast Basin is below the Tier 1 price charged by MWD, which provides water pumpers with the incentive to displace Tier 1 imports with advanced treated recycled water.[8] Recycled water delivered to the spreading facilities each year consequently augments the annual pumping allotment of the agencies that develop these sources.

Third, recycled water and augmentation water provide additional stabilization value that Tier 1 water does not. Unlike Tier 1 water, which is subject to dry year rationing under MWD's Water Allocation Plan (see Table 2 above), recycled water and augmented water sources provide a stable delivery profile that is not subject to rationing during severe drought events. Relative to a long-term contract for Tier 1 water, a long-term contract for a proportional level of advanced treated recycled water provides a larger quantity of water in periods where the value of water is highest due to rationing.

Fourth, the development of recycled water and augmentation water enhances the ability of water pumpers to place water into storage. For instance, an augmentation project that

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[8] MWD's Local Resources Program provides funding for the development of water recycling and groundwater recovery supplies that replace an existing demand or prevent a new demand on Metropolitan's imported water supplies either through direct replacement of potable water, or increased regional groundwater production. Metropolitan seeks development of 174,000 AFY of yield to meet a regional goal of 779,000 AFY by year 2025.

provides an additional 10,000 AFY of stormwater in the basins increases by 10,000 AFY the rate at which investing agencies can place water into storage.

Finally, the Judgment Amendments allow inter-basin transfers of limited quantities of water that have been placed into storage in the West Coast Basin for extraction in the Central Basin. Subject to the need to actually place water into storage before transfer, allowing transfers of stored water carries benefits similar to those that would be expected if additional water rights were available for lease within the Central Basin. Under current rules, water leases are possible among water pumpers within West Coast Basin and within Central Basin, but not between water pumpers in across basins. Since water leases do not entail the physical movement of groundwater from one location to another, but only from one allowable pumping allotment to another, a common lease market leads to an expanded trade region that serves to equalize lease prices across the basins over time. Inter-basin transfers of stored water provides value by allowing the right to extract stored water to trade from lower- to higher-valued uses across basins among water pumpers that are currently not allowed to trade under the judgment. The amendments, by allowing the transfer of stored water from West Coast Basin to Central Basin, facilitate trades across basins that are valuable to both exchanging parties.

The net value of these five components is assessed in a dynamic optimization framework that selects a long-term Tier 1 supply contract with MWD and a series of puts and takes from groundwater storage using replenishment water and advanced treated recycled water to meet annual imported water needs in the Central and West Coast Basins. Under baseline conditions, an aggregated agent in each basin selects a Tier 1 allocation, taking into account the potential for MWD rationing under drought conditions as specified in the Water Allocation Plan, and then augments these Tier 1 water supplies over time by consuming replenishment water (when available) and making commensurate in lieu contributions to carryover accounts by pumping an amount less than the adjudicated rights. The performance of the aggregated agent in West Coast Basin and Central Basin under baseline conditions is analyzed by constructing a post-Wanger distribution of MWD water deliveries that matches replenishment water availability and annual rationing levels to the hydrologic record over the period 1922-2003. Given the post-Wanger distribution of MWD water deliveries, the mean annual surplus from water consumption is computed for each basin over an 82-year horizon that follows the historical rainfall pattern in California over the period 1922-2003 under post-Wanger rationing. This exercise results in an optimized baseline allocation; that is, it recovers the maximum level of economic surplus that each basin could attain under prevailing rules for extraction, carryover and trading allowed by the Judgment. The optimized baseline is then used to calculate the maximum level of economic surplus net benefits water pumpers in the Central and West Coast Basins could acquire over the period 2009-2030 under the existing rules encompassed by the Judgment.

The optimized baseline outcome for each basin is then compared to the optimized outcome under amended conditions for each basin. The optimized amended outcome encompasses the full set of changes to storage and trading conditions embodied by the Judgment Amendments. The economic surplus available to each basin over the 22-year period 2009-2030 is calculated in a comparable fashion as described above for the optimized baseline. This value is then compared with the surplus generated in the combined Central and West Coast Basins under an identical post-Wanger distribution of MWD water deliveries under existing rules. The change in surplus between the amended outcome and the baseline outcome over the period 2009-2030 provides a measure of the value of the Judgment Amendments among water pumpers in the basins.

3. Projected MWD Supply

On December 14, 2007, Judge Wanger of the United States District Court for the Eastern District of California issued an Interim Remedial Order Following Summary Judgment and Evidentiary Hearing (the "Interim Order" or the "Wanger Decision"). To protect the threatened Delta smelt, the Interim Order remanded the U.S. Fish and Wildlife Service's (FWS) 2005 Biological Opinion on the effects of the Central Valley Project (CVP) and State Water Project (SWP) on the Delta smelt. The Interim Order has set new targets on the Old and Middle Rivers (OMR) flow. These targets in the Interim Order will reduce the reliability of SWP water supplies. This section of the report describes the water supply changes resulting from the Court-imposed and regulatory restrictions on federal and state pumping from the Delta.

The results described here are based on CALSIM II modeling runs commissioned by MWD in late 2007 and performed by CH2MHill. The CALSIM II framework is the standard hydrologic model used in California water planning. The Common Assumptions Common Model Package version 9A of the CALSIM II was used in this study. The model evaluates changes to project operations over the historic record and uses those data to forecast changes in future deliveries. The model simulation period is 1922 to 2003.

In order to evaluate the impacts of the Interim Order on the SWP water supplies, CH2MHill carried out three alternative CALSIM II runs: 1) baseline conditions, 2) the Wanger high bookend scenario (high OMR flow targets), 3) the Wanger low bookend scenario (low OMR flow targets). Here, we used CH2MHill's baseline condition and the midpoint of the high- and low-OMR flow targets CALSIM II runs to estimate the impacts on the State Water Project Table A and Article 21 supplies.[9]

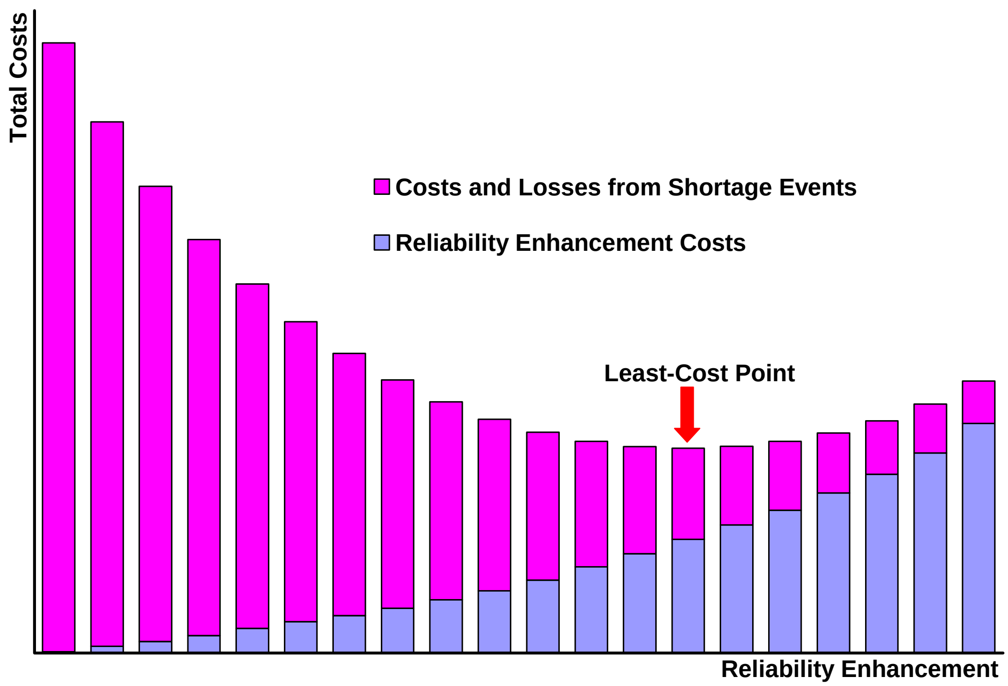
The Interim Order significantly reduces the reliability of Table A supplies. The mean annual reduction in Table A deliveries across all simulated years is 320,000 AF. Annual Table A deliveries are reduced in nearly all years, with an average reduction of 11%. The range of annual percentage changes varies from -29% to 5%. Article 21 deliveries are more impacted, with an average annual reduction of 96,000 AF, or 44%. Article 21 deliveries are totally eliminated in many years. The Interim Order will also affect surplus deliveries. Projected deliveries from the SWP are published each year and vary depending on the amount of water available and the predicted level of precipitation. SWP Table A deliveries in wet and average years (where deliveries are above 2,000,000 AF)

[9] Article 21 supplies are defined by the Monterey Amendment as water available to the SWP when excess water to the Delta exceeds the State Water Project's operational requirements.

will be expected to reduce more than deliveries in dry years (where deliveries are below 2,000,000 AF).

In order to project the impact of SWP delivery reduction on Metropolitan Water District water supply, Least-Cost Planning and Simulation Model (LCPSIM) was used. LCPSIM developed and maintained by DWR and CH2MHill. It is similar to load-planning models used in the electricity industry, and simulates a dynamically optimal water supply portfolio. It is a yearly time-step simulation model that was developed to estimate the economic benefits and costs of improving urban water service reliability at the regional level. The primary objective of the model is to develop an economically efficient regional water management plan by minimizing the total cost of reliability management (see Figure 1 below for illustration of LCPSIM's cost minimization objective). The total cost is the sum of two categories: the cost of reliability enhancement and the cost of unreliable service associated with water shortage events.

Figure 1. LCPSIM: The Effect of Increasing Reliability on Cost[10]



Water supply reliability can be achieved through demand reduction and through supply augmentation, including recycling, groundwater storage and recovery, and water transfers. The cost of reliability enhancement is comprised of three elements: the cost of reliability enhancements such as conservation and recycling, the cost of system operations, and the cost of buying and transferring water. The cost of unreliability is the welfare cost to consumers of a water shortage.[11] LCPSIM optimizes the degree of

[10] LCPSIM manual- http://www.economics.water.ca.gov/downloads/Models/LCPSIM_Draft_Doc.pdf.
[11] To access these parameters in LCPSIM: (1) cost of reliability enhancement options: from the *RUN/VIEW* menu, select *VIEW SUMMARY RESULTS* and then *FULL DISPLAY*; (2) system operation costs: from the *RUN/VIEW* menu, select *VIEW LC INCREMENT RESULTS*; (3) cost of buying and transferring water:

reliability over the entire simulation period by determining the portfolio of reliability-enhancing investments that minimizes the cost of these investments plus the cost of shortage in the event that demand cannot be satisfied.

LCPSIM allows for a number of conservation and recycling investments to be made to cope with water scarcity. These investments all require capital expenditures to complete, and will take a number of years to implement. The unit costs of these investments vary considerably, and are described in detail in the LCPSIM manual.[12]

Spot water transfers from the Central Valley are also available to address potential water shortages. For the South Coast region corresponding to the MWD service area, we set these transfers at a maximum of 600,000 AF per year in the baseline. The Wanger Interim Order impacts the potential size of the spot water market because of restrictions on through-Delta conveyance. Hence we decreased the maximum water transfers to 300,000 AF for the post-Interim Order scenario. While these transfer volumes are considerably higher than direct transfers to MWD member agencies in recent years, note that they are theoretical limits and LCPSIM endogenously determines how much water to transfer to minimize costs.

Direct impacts on M&I users are calculated under a long-run scenario. In this scenario, we allow for investment in the full range of conservation, recycling and groundwater storage options specified in the South Coast versions of LCPSIM. In addition, under the long-run scenario for the South Coast region, we double water transfer possibilities from Sacramento and San Joaquin Valley from 100,000 AF and 150,000 AF to 200,000 AF and 300,000 AF, respectively and consider an additional 150,000 AF of interim surplus and agricultural transfer opportunities from the Colorado River. The expected percent shortages (rationing) during the 82 years historical period for the long run scenario under post- Wanger restrictions are depicted in Figure 2.

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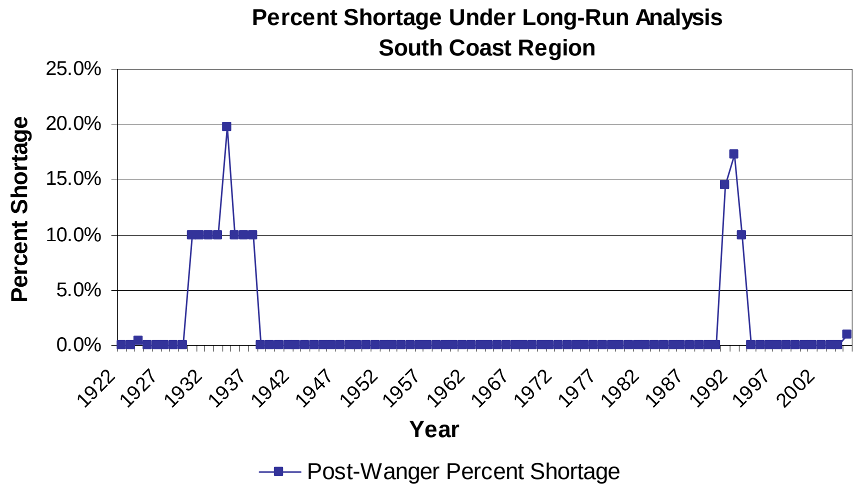
from the *RUN/VIEW* menu, select *VIEW OPERATION TRACE (Excel only)* and open the *LC Result Report* sheet; and (4) cost of a water shortage: from the *RUN/VIEW* menu, select *VIEW OPERATION TRACE (Excel only)* and open the *LC Result Report* sheet.

[12] LCPSIM manual- http://www.economics.water.ca.gov/downloads/Models/LCPSIM_Draft_Doc.pdf.

Figure 2. Annual Long-run Percent Shortage in the South Coast Region



4. Modeling Framework

The model of groundwater value used in this report builds on the standard dynamic framework employed in the academic literature.[13] The net benefits resulting from access to a groundwater resource are the gains from pumping (i.e., the demand for water) less the cost of extraction and conveyance, and a user cost component, which reflects the lost option value entailed by removing a unit of water from storage for immediate use. The stream of annual net benefits is discounted back to current dollars using a discount factor predicated on the rate of interest, which is taken to be 7.5 percent per year. The discount factor for a payment occurring in some future period *t* is then $(1.075)^{-t} \approx e^{-0.075t}$. Because water pumpers in the Central and West Coast Basins utilize groundwater storage over time, the use of a relatively high discount rate of 7.5% provides a conservative estimate of the value of the provisions in the Judgment Amendments.

With the exception of recycled water prices, all future prices are expressed in real terms under the expectation that nominal prices increase at the discount rate. Implicitly, this assumes that the long term trend in MWD prices, which is 7.5 percent per year,[14] is maintained over the period 2009-2030 considered in the study. In the event that water prices charged by MWD increase over the next 22-years at a faster pace than an annualized 7.5 percent rate of increase, the net benefit of the Judgment Amendments presented in Section 5 of this report understate the realized net benefit at higher water prices. If MWD prices increase at a faster pace than the discount rate of water pumpers in Central and West Coast Basins, the net benefit of augmented storage under the Judgment Amendments would be larger than calculated here for two reasons: (i) the amount of Tier 1 water used by water pumpers in the basins decreases from baseline

[13] Brozovic, N., D. Sunding and D. Zilberman, "Optimal Management of Groundwater over Space and Time." *Frontiers in Water Resource Economics*. D. Berga and R. Goetz, eds. New York: Springer-Verlag, 2005; Gisser, M. and D. Sanchez, "Competition versus Optimal Control in Groundwater Pumping," *Water Resources Research* (1980): 638-642; Brown, G. and R. Deacon, "Economic Optimization of a Single-Cell Aquifer," *Water Resources Research* (1975): 557-564.
[14] Based on historical MWD Tier 1 water prices over the period 1960-2010.

levels under the Judgment Amendments, and the value of the displaced water (i.e., the difference between the Tier 1 rate and the replenishment rate) would increase over time in real terms; and (ii) the timing of puts and takes into storage would create an additional source of value to water pumpers through lags introduced between purchased water placed into storage and groundwater pumped out of storage in subsequent periods. Assuming that MWD water prices rise over time at the discount rate of water pumpers (7.5 percent) implicitly suppresses capital gains generated from the lag structure of water placed in storage.

Recycled water prices increase over time at the escalation rate used in existing contracts. In making cost projections on recycled water development, WRD uses an escalation rate of 3.5 percent on O&M costs based on existing contract terms that specify inflation rates at a 0.2 percent premium over the consumer price index.[15] For the purpose of this study, a more conservative rate of 4.5 percent is employed as the inflation rate on recycled water prices. The difference between the inflation rate of recycled water and the inflation rate of imported water from MWD makes developing recycled water sources increasingly attractive over time.

The modeling framework makes clear separation between the net return to water pumpers pumping groundwater in the Central and West Coast Basins and the implication of the Judgment Amendments for basin management operations. To the extent that the Judgment Amendments reduce the annual cost of meeting replenishment obligations for the basins, this would represent an additional net return to water pumpers in the basins in the form of reduced assessments.

The next section describes the conceptual framework for calculating the net benefit of augmented groundwater storage to water pumpers in Central and West Coast Basins resulting from the Judgment Amendments. Section 3.2 provides details on the programming model that computes returns based on the conceptual framework and describes the parameters used to calibrate the programming model.

4.1 Conceptual Framework

The economic issue is to select a long-term level of Tier 1 water (Z) to maximize the expected net benefit of water delivered to retail users over the horizon, given an uncertain availability of replenishment water (R_t) and an unknown rationing level (α_t) imposed on Tier 1 deliveries in each future period t. The analysis acknowledges that water pumpers in each basin receive economic benefits from achieving a reasonably stable time profile of water deliveries to consumers, and the amount of water delivered at any time is the sum of Tier 1 deliveries, replenishment water deliveries (when available), and groundwater extraction (y_t).

Let W_t denote the level of water consumption. Adding water deliveries across the available sources, the water portfolio can be written $W_t = \alpha_t Z + R_t + y_t$. The economic

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[15] Personal communication with Robb Whitaker, WRD (January 27, 2009).

trade-off facing water pumpers in selecting the components of this water portfolio is that Tier 1 water, Z, is the most expensive water source available in the water portfolio, but is more reliable than replenishment water, R_t. Therefore, to maintain a stable level of water deliveries that meet consumer demand in each period, water pumpers who wish to economize on water costs by selecting a smaller level of Z in the portfolio must seek to stabilize the sum of replenishment water consumption and groundwater consumption ($R_t + y_t$) through a dynamic pattern of puts and takes to and from basin storage. That is, under "wet" conditions in which $R_t > 0$, y_t must be reduced (creating in lieu storage) and a level of R_t in the water portfolio must be selected that can be matched by greater extractions of y_t under "dry" conditions in which $R_t = 0$. The larger the level of storage available for extraction in the basin, the larger the potential swings in y_t over time, and hence the greater the ability of water pumpers to meet a stable water delivery profile over time through combinations of replenishment water and groundwater deliveries. For this reason, a greater ability to store groundwater translates into a lower cost of service by allowing replenishment water to replace Tier 1 water in the water portfolio.

Let c denote the long-run average real cost of groundwater pumping, and P_Z and P_R denote the real prices of Tier 1 water and replenishment water, respectively. The optimal long-term contract level for Tier 1 water satisfies

$$\underset{Z}{Max}\, E_0 \left\{ \sum_{t=0}^{T} u(W_t) - \alpha_t P_Z Z - P_R R_t - c y_t \right\},$$

where E_0 is the expectations operator, $W_t = \alpha_t Z + R_t + y_t$, and $u(W_t)$ denotes the benefits from water use in period t. The optimal level of Tier 1 water to select, Z^*, depends on the expected availability of replenishment water (R_t) in each subsequent period (t=1, 2,…, T) and the associated pattern of extractions (y_t) that together provide water use level W_t.

The economic performance of the system is shaped by physical constraints such as the equation of motion $S_{t+1} = S_t + g - y_t$ (where S_t denotes the amount of water held in storage at time t and g denotes the inflow of groundwater into storage in the basins) and the available storage capacity in the basin.

Viewed this way, the conditions under the existing judgment and its amendments can be modeled as different evolutions of production, storage, and recharge in the basin. The net value of expanded storage possibilities under the Judgment Amendments relative to possibilities under the existing judgment is the difference in the present value of net benefits that arises under each set of rules.

To illustrate the various outcomes implied by the model, it is helpful to consider the case of an agent without the ability to store groundwater. In this case, conjunctive use is not possible. Without any ability to store water between periods, the economic optimum involves selecting a long-term contract that involves a higher level of Tier 1 water than the level that maximizes net benefits in periods without water rationing. The reason is that purchasing excess Tier 1 water in "wet" periods provides insurance against losses when MWD rationing occurs in "dry" periods. It would be optimal in this case to leave a portion of pumping rights unexercised (i.e., select y_t < adjudicated rights) in periods where MWD rationing does not occur (α_t =1) so that water needs could be met by increasing y_t to compensate for MWD rationing in periods where α_t <1.

Now suppose groundwater storage becomes available. In this case, the optimal level of Tier 1 water in the water portfolio decreases, allowing water pumpers to consume replenishment water in "wet" periods when replenishment water is available and to take the difference between desired water consumption and available pumping rights as in-lieu storage investments. The water placed in storage subsequently can be used to meet the difference between desired consumption levels and dry period rations when replenishment water is not available. As the ability to store water increases, Tier 1 sources of imported water are increasingly displaced through combinations of replenishment water and storage that can attain similar levels of water reliability over time.

4.2 Model Parameterization

The conceptual model is applied to the Central and West Coast Basin by setting the key parameters of the conjunctive use model described in the Section above to reflect demand and cost conditions in the study area. While the underlying price and availability of the various sources of water available to each basin are not altered by the amendments, the cost of the water supply portfolio constructed to meet demand in each period, as well as the pattern of water availability during dry periods differs substantially under the existing Judgment and the Judgment Amendments due to changes in storage and extraction possibilities. This subsection defines the storage capacity available to water pumpers under the existing Judgment and its amendments and describes the parameters used to apply the conjunctive use model to the Central and West Coast Basins.

The ability of water pumpers to shift water between time periods is limited by the sum of carryover accounts and storage accounts, both of which are modified by the Judgment Amendments. Table 3 presents the proposed storage allocation in the basins under the amended judgment. The total storage allocation provided to water pumpers under the Judgment Amendments, which is the sum of individual and community storage accounts, is 243,300 AF (61,300 AF in West Coast Basin and 182,000 AF in Central Basin), with the remaining balance of the storage allocated to regional storage and Basin Operating Reserve.

Table 3. Storage Allocation Under the Amended Judgment

	West Coast Basin	Central Basin	CWCB Total
Individual storage	25,800	87,000	112,800
Community storage	35,500	95,000	130,500
Total storage to agents	*61,300*	*182,000*	*243,300*
Regional storage	9,600	23,000	32,600
Basin operating reserve	49,100	125,000	174,100
Total	**120,000**	**330,000**	**450,000**

Source: Central Basin Third Amended Judgment and West Coast Basin Amended Judgment

The Judgment Amendments also provide for an increase in individual carryover accounts from 20 percent of adjudicated rights to 100 percent of adjudicated rights. Carryover accounts can be converted to storage accounts, with the level of conversion of carryover to individual storage limited to 40 percent of adjudicated rights. The remaining balance of an individual's carryover rights not converted to individual storage is retained by each agent as carryover rights, which implies that individual water pumpers retain the ability to store 100 percent of their adjudicated rights in the basin as credit for future extraction, either holding this water in a carryover account or in physical storage. Physical storage is economically more valuable than carryover storage in the sense that storage allows new water sources to be claimed as annual pumping rights, for instance recycled water and augmentation water delivered to the basins physically develop stored water that otherwise would not exist in the basin, providing for concomitantly greater extraction levels over time. However, physical storage that is not coupled with the development of new water sources provides similar economic returns as carryover storage since such storage allows the intertemporal pattern of conjunctive use of surface and groundwater supplies without increasing average extraction levels. The sum of carryover accounts, emergency overdraft, individual storage, and community storage is referred to hereafter as the storage capacity of the Central and West Coast Basins.

The storage capacity under the Judgment Amendments depends on the sequence of conversions of carryover rights to storage. The reason is that, unlike the conversion of carryover rights to individual storage, which converts carryover units to storage units on a one-to-one basis, individual water pumpers can acquire community storage to increase their individual storage capacity to 200 percent of their adjudicated rights without reducing the storage capacity of other water pumpers below 100 percent of their adjudicated rights.

Table 4 summarizes the pumping rights and storage capacity in the Central and West Coast Basins under baseline conditions represented by the Judgment and under the Judgment Amendments. In the baseline, annual pumping rights in each basin are given by the adjudicated rights of basin members, while the storage capacity is the sum of carryover (the potential to run a temporary surplus of 20 percent of adjudicated rights) and emergency overdraft provisions (the potential to run a temporary deficit of 20 percent of adjudicated rights).

Table 4. Pumping Rights and Storage Capacity in the CWCB

	West Coast Basin	Central Basin	CWCB Total
Baseline Conditions			
APA	64,468	217,367	281,835
Annual Pumping Rights	***64,468***	***217,367***	***281,835***
Carryover (20%)	12,894	43,473	56,367
Emergency Overdraft (20%)	12,894	43,473	56,367
Storage Capacity	***25,787***	***86,947***	***112,734***
Amended Conditions			
APA	64,468	217,367	281,835
Augmentation Project		16,465	16,465
Recycled Water	20,000		20,000
Annual Pumping Rights	***84,468***	***233,832***	***318,300***
Group size (APA of members)	22,188	59,375	81,563
Within Group: Individual Storage	8,875	23,750	32,625
Within Group: Community Storage	35,500	95,000	130,500
Total Group Storage (200%)	*44,375*	*118,750*	*163,125*
Remaining carryover plus storage	42,280	157,992	200,272
Emergency Overdraft (20%)	12,894	43,473	56,367
Storage Capacity	***99,549***	***320,215***	***419,765***

Under the Judgment Amendments, the annual pumping rights of water pumpers increases in each basin by the amount of new water sources delivered. The projected new sources of water developed over the period 2009-2030 include an augmentation project in Central Basin that is anticipated to yield an additional 16,465 AFY of stormwater capture, and the development of 20,000 AFY of recycled water in the West Coast Basin.[16] The amount of recycled water that can be developed in the basins is limited under the amendments to 20,000 AF to reflect the level of development that is available using excess capacity at the existing injection wells located at the West Coast and Dominguez Gap barriers. If additional injection wells were developed, the potential capacity of additional recycled water use would increase.

In the combined Central and West Coast Basins, annual pumping is anticipated to rise from an average of 281,835 AF of exercisable rights under the Judgment to an average of 318,300 AF (= 281,835 + 16,465 + 20,000) of exercisable rights under the Judgment Amendments. This represents a conservative estimate of the development of physical storage from new water sources over the 2009-2030 period, as the potential exists to considerably develop recycled water sources. A variation from the benchmark parameter values provided in Table 4 considers an additional 34,000 AFY of recycled water development in Central Basin, and this project, which involves a considerably greater infrastructure investment to deliver recycled water to the Central Basin spreading grounds than the more immediate opportunity to utilize excess capacity at the existing injection wells in West Coast Basin, also appears to be economically viable.

[16] Personal communication with Robb Whitaker, WRD (January 28, 2009).

To calculate the net increase in storage capacity shown in Table 4, we compare baseline storage capacity to the amount available after the Judgment Amendment. Baseline storage is the total of what could be legally extracted over and above existing declared extraction rights in a given year. That amount is composed of 20% carryover (assuming it was not extracted in the previous year) plus emergency overdraft (which requires a make up). The calculation assumes there is no "Declared Water Emergency" that would allow for even more extraction under certain circumstances.

Storage after the amendment is, first, made up of the first group of pumpers to achieve 200% of pumping rights in storage, filling up their individual storage allocation and all of the community pool. At that point they can store no more. Even though that has happened, however, there are still water pumpers (outside the 200% allocation group) who can store their 40% of pumping rights in their individual storage allocation. Even though they have done that, they have more of their 100% carryover left, because they were prevented from storing more because the space is occupied (thus additional storage did not reduce their carryover).

Table 5 summarizes the range of parameters selected to characterize conditions in the Central and West Coast Basins for use in the programming model. All values in the table are common to all scenarios considered, and thus are not the basis for differences in value between scenarios.

Table 5. Summary of Parameters in the Programming Model

		Baseline		Amendments	
	Parameter	West Coast Basin	Central Basin	West Coast Basin	Central Basin
Demand intercept	a	28,262	28,440	28,262	28,440
Demand slope	b	0.1131	0.0566	0.1131	0.0566
Desired water use level	W*	237,299	476,889	237,299	476,889
10% (Level 2) Water ration	α_1	91.79%	96.53%	91.79%	96.53%
20% (Level 4) Water ration	α_2	85.60%	92.23%	85.60%	92.23%
40% (Level 8) Water ration	α_3	71.48%	84.25%	71.48%	84.25%
Groundwater allocation	G	64,468	217,367	64,468	217,367
Other Water Available	X	50,200	69,150	50,200	69,150
Storage Capacity	S^C	25,787	86,947	99,549	320,215
Recycled water storage	T	0	0	20,000	0
Augmentation water	A	0	0	0	16,465
Augmentation project pumping	N	0	0	0	23,100
Replenishment price, treated	P_R	$477	$480	$477	$480
Pumping cost	c	$80	$80	$80	$80
Addional pumping cost of N	d				$25
Tier 1 price	P_Z	$689	$635	$689	$635
Recycled water price	P_T			$600	
Discount rate	r	7.5%	7.5%	7.5%	7.5%
Escalation rate, recycled water	i			4.5%	
Constraint on storage rate	β	0.50	0.50	0.50	0.50
Constraint on extraction rate	δ	1/3	1/3	1/3	1/3

The benefit of water use in period t, $u(W_t)$, is approximated by the quadratic function $a(W_t) - b(W_t)^2/2$, which results in a linear demand function for water with intercept a and slope of $-b$. The parameters supporting the demand function in each basin are recovered by using the residential water demand elasticity reported by Renwick and Green (ε = -0.16) to linearly approximate water demand in each basin based on retail prices and quantities of water transacted.[17] The demand parameters in each basin, as well as the desired level of water use (W^*), is common to both the baseline and amended conditions.

The desired water use level (W^*) in each basin is taken to be total retail demand in the year 2015 (see Table 1). This level of water use is the calibration point for fitting the retail demand function to each basin under initial conditions with available replenishment water supplies, which implies that W^* maximizes the temporal net benefit of water consumption in periods where replenishment water is available. Under periods where replenishment water is not available, for instance during periods of rationing ($\alpha < 1$), the desired water use level cannot be maintained without augmenting Tier 1 supplies and groundwater consumption with takes from groundwater storage. The model considers three levels of water rationing (α_1, α_2, α_3) as indicated by the MWD Water Supply Allocation Plan (see Table 2).

The groundwater allocation (G) and other water available (X) represents the adjudicated rights and the sum of all other water supplies available to meet retail water demand in each basin, respectively. The difference between the desired water use level (W^*) in each basin and the sum of local supply (G+X) gives residual demand for imported water in each basin (see Table 1). Residual demand for imported water in each basin is met through some combination of replenishment water imports (R_t) and Tier 1 imports ($\alpha_t Z^*$), with retail water consumption "smoothed" towards W^* as best as possible in each period from a random and uncontrollable availability schedule of wholesale imports by making dynamic adjustments in the quantity of water held in storage.

Basin storage capacity (S^C) reflects the ability of water pumpers to shift pumping rights from wet periods to dry periods by making puts and takes into storage. Under baseline conditions, the storage capacity in each basin is taken to be 40 percent of the adjudicated rights in the basin (i.e., 40 percent of G). This reflects the fact that individual water pumpers can hold carryover accounts of 20 percent of their adjudicated rights and are allowed to cumulatively over-extract their pumping allocation by 20 percent of their adjudicated rights. Under the amended judgment, the storage capacity (physical storage plus carryover) provided to water pumpers in the combined basins increases to 100 percent of adjudicated rights with the additional possibility of creating 81,563 AF of storage through the conversion of community storage accounts to individual storage accounts (see Table 4).

[17] Renwick, M.E. and R.D. Green, "Do Residential Water Demand Side Management Policies Measure Up? An Analysis of Eight California Water Agencies," *Journal of Environmental Economics and Management* 40 (2000), pp 37-55.

The storage limit $S_t \le S^C$ for each basin places an important constraint on the potential net benefit available to each basin. This constraint is relaxed in each basin under the Judgment Amendments through an approximately fourfold increase in storage capacity (from 25,787 to 99,549 AF in West Coast Basin and from 86,947 to 320,215 AF in Central Basin). The increased storage capacity under the amended Judgment leads to a dynamic change in the use of groundwater pumping rights (G). In periods where replenishment water is available, the expanded storage possibilities in the basins provide water pumpers with a larger incentive to reduce their pumping levels below their adjudicated rights to make in lieu contributions to storage by replacing extractions with replenishment water purchases.

The Judgment Amendments allow the development of water resources that can increase the quantity of reliable water available through optimum storage. Under the existing Judgment, the pumping levels of water pumpers can vary year over year through adjustments in carryover balances, but the average quantity of groundwater that can be extracted from the basins over time is constrained to be no more than the adjudicated rights of water pumpers. The Judgment Amendments relax this constraint by providing water pumpers the ability to make optimum quantity contributions to storage.

There are two types of water resources that increase the ability of water pumpers to increase their average extraction levels: augmentation water (*A*) and recycled water (*T*). Storage created through development of these resources creates value both by increasing annual average extraction levels among participating water pumpers and by providing a reliable source of basin recharge that allows water pumpers to make more rapid "puts" into storage accounts. Advanced treated recycled water and augmentation water deposited into storage every year allows a greater annual quantity of groundwater to be reliably placed into the basin each year, and this water –like other sources of groundwater storage—can be extracted from the Central and West Coast Basins at times when imported water is scarce.

The net benefit of the amended Judgment incorporates 20,000 AFY of advanced treated recycled water in West Coast Basin and 16,465 AFY of augmentation water acquired by facilitating greater stormwater recharge in Central Basin. The 20,000 AF of recycled water development in West Coast Basin represents the most economical source available since it makes use of the excess capacity at the existing injection wells located at the West Coast and Dominguez Gap barriers.

The ability of water pumpers to acquire stormwater for storage in Central Basin requires targeted groundwater extractions to be made through new wells developed in the Montebello Forebay. The WRD has successfully implemented similar projects to conserve stormwater by increasing Whittier Narrows Conservation Pool and adding two new rubber dams on San Gabriel River, and these basin improvements are anticipated to result in an average annual increase in stormwater capture of 6,600 AFY. The proposed augmentation project in Central Basin (*A*) requires water pumpers in Central Basin to develop new wells and pipelines to pump and convey groundwater, making use of their existing adjudicated rights, from Montebello Forebay to their service regions. The annual level of pumping required by water pumpers in Central Basin (*N*) is 23,100 AFY.[18] The cost of well field and pipeline construction associated with the augmentation project is estimated to be $60 million and the operating and maintenance costs associated with pipeline development (*d*) are anticipated to be $25/AF.[19]

The model assumes that the capital cost of the augmentation project is incurred immediately by the participating water pumpers in Central Basin. However, the use of both augmentation water and advanced treated recycled water is lagged for 5 years to reflect the time needed to bring these water sources online.

Water prices are taken from the adopted water rates and charges for Central Basin Municipal Water District (CBMWD) and West Basin Municipal Water District (WBMWD) in FY 2008-2009.[20] The initial price of Tier 1 water in Central Basin is $635, which is the year 2009 price of untreated Tier 1 water delivered by CBMWD. This price, which includes a MWD commodity rate of $579/AF, $12 MWD RTS expense, and $44/AF CBMWD surcharge, is slightly lower than the rate set in West Coast Basin ($689) due to differences in surcharge rates. The price of replenishment water is $477/AF in West Coast Basin and $480/AF in Central Basin, which are the year 2009 rates reported by CBWRD and WBMWD, respectively, for seasonal storage. These prices are inflated over time at the discount rate (r = 7.5 percent), which implies they remain constant in real terms.

Pumping cost for groundwater extraction (c) is taken to be $80/AF, which is slightly higher than the estimated average pumping cost used by WRD in setting in-lieu rates for groundwater replenishment, which is $65/AF.[21] The cost of a unit of groundwater extracted from storage, accordingly, is the sum of the treated replenishment rate on the unit of water deposited through in lieu storage and the pumping cost necessary to recover the unit from storage, or $557/AF in West Coast Basin and $560/AF in Central Basin.

In the amended Judgment, Scenario 1, which assumes 20,000 AFY of recycled water development, the cost of recycled water in West Coast Basin (P_T) is $600/AF.[22] This value assumes a cost of advanced treated recycled water of $550/AF and a cost of $50/AF for well development used to make the resulting extractions. Since State law currently requires advanced treated recycled water to be placed in the basin rather than consumed directly, the gross cost of advanced treated recycled water for consumption is taken to be the sum of the acquisition cost of recycled water for storage and the pumping cost necessary to extract the water from storage, or $680/AF. The amount of recycled water that can be developed at this price is limited to 20,000 AF to reflect the excess

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[18] Water Replenishment District of Southern California, *Engineering Survey and Report, 2008*, p. IV-6 (updated May 2, 2008): http://wrd.org/engineering/reports/Final_Report_May2_2008.pdf.
[19] Personal communication with Jason Weeks, WRD (February 4, 2009).
[20] Central Basin Municipal Water District, *Water Use Report: Fiscal Year 2007-2008*.
[21] Water Replenishment District of Southern California, *Engineering Survey and Report, 2008*, p. IV-6 (updated May 2, 2008): http://wrd.org/engineering/reports/Final_Report_May2_2008.pdf.
[22] Personal communication with Jason Weeks, WRD (February 4, 2009).

capacity at the existing injection wells located at the West Coast and Dominguez Gap barriers.

Recycled water prices increase over time at an escalation rate based on existing WRD contracts of 4.5 percent on O&M costs. Because the escalation rate differs from the discount rate used in the study, the price of recycled water begins at $600/AF at time t=0 and trends over time according to

$$P_{T,t} = P_T \left(\frac{1+i}{1+r} \right)^t .$$

In a variation from the benchmark Scenario 1, Scenario 4 assumes an additional 34,000 AFY of recycled water is considered in Central Basin. This level of development represents the opportunity to pipe advanced treated recycled water from the Long Beach and Los Coyotes Water Reclamation Plants to the San Gabriel River Spreading Grounds. The projected net capital cost required to develop the project, assuming 25 percent outside funding, is $197.235 million, and the total cost of spreading advanced treated recycled water into storage for water pumpers in Central Basin (with costs amortized over 30 years) is anticipated to be $772/AF.[23] The full cost of storage and extraction of advanced treated recycled water, which includes $80/AF pumping cost at the time of extraction, is $852/AF.

Recycled water prices in Central Basin increase over time at an escalation rate based on existing WRD contracts of 4.5 percent on O&M costs; however, since the capital cost is fixed, the escalation rate applies only to O&M costs. This implies that the initial price of advanced treated recycled water for storage in Central Basin begins at $772/AF at time t=0 and trends over time according to

$$P_{T,t} = \left(\frac{1}{1+r} \right)^t P_{T,1} + \left(\frac{1+i}{1+r} \right)^t P_{T,2} ,$$

where $P_{T,1}$ = $422 is the unit cost of capital and $P_{T,2}$ = $350 represents O&M costs of the reverse osmosis facility and pipeline net of the $250 MWD LRP rebate.

The conceptual model outlined above envisions water pumpers placing water into storage as quickly as possible. The reason is that groundwater storage converts unreliable replenishment water into reliable water that is valued at a considerably higher rate. Since instantaneous adjustment of the storage stock is not possible at times when replenishment water is available, the dynamic program described below imposes management constraints on the rates at which in lieu contributions can be made to storage. The maximum storage rate in any period (β) is taken to be one-half the allowable pumping allocation of water pumpers in the basin (G). Under baseline conditions of the existing Judgment, this constraint is never binding since the allowable storage capacity (the sum of carryover water and allowed over-extraction) is forty percent of each agents adjudicated rights. Under the augmented storage conditions of the Judgment

[23] Personal communication with Jason Weeks, WRD (January 27, 2009).

Amendments, the combined amount of water that agencies in the basins can place into storage through in-lieu contributions is a maximum annual contribution of 140,918 AF.[24] Additionally, development of recycled water and stormwater resources increase the rate of groundwater storage. Under the amended Judgment, the maximum rate of groundwater storage in any period is given by $S_{t+1} - S_t = \beta G + A + T$, or 177,383 AF. Storage contributions up to this level can be made in periods where replenishment water is available as long as vacancy exists under the storage capacity of the basin. In periods where replenishment water is not available, in-lieu contributions to groundwater storage cannot occur, and storage contributions are limited to the sum of augmentation water and recycled water deliveries under the Judgment Amendments, or to a combined level of storage of 36,465 AF among water pumpers.

The rate at which water is taken from storage (δ) is limited by the need to reserve stored water for extraction in subsequent dry periods. Drought conditions where MWD rationing of Tier 1 imports can occur tend to be grouped together in the hydrologic record, and the potential for sequential takes from storage to occur in consecutive periods limits the optimal take from storage in any period. To ensure that groundwater storage is never exhausted, aggregate takes from storage are limited to be no greater than 1/3 of the existing storage level in the basin (S_t).[25] The actual take from storage in period t is the amount of water need to make up the difference between desired water use level (W^*) and available water supplies net of extractions from storage ($W_t = G+X+\alpha_t Z^*$) up to the contemporaneous limit on storage "takes" of $S_t/3$.

4.3 Implications for the Replenishment Obligation of WRD

Artificial replenishment water in Central and West Coast Basins is provided by WRD. Natural inflow into the basins is 151,805 AFY, which reflects the 30-year balance of 145,205 AFY calculated by the USGS & WRD regional model and the 6,600 AFY of stormwater conservation projects introduced subsequent to the study, and the difference between annual groundwater extraction and natural inflow creates a replenishment obligation for WRD. Based on a 30-year average groundwater extraction level of 250,590 AFY in the basins and natural inflows provided by the USGS & WRD regional model, the quantity of water required for artificial replenishment is 105,385 AFY.[26] Of this amount, the predicted use of recycled water use for spreading operations and barrier injection in the year 2015 is 73,500 AFY.[27]

The need for artificial replenishment in the basins is projected to increase by the difference between annual groundwater pumping rights and the 30-year average

[24] This value is well within the historical range of imported replenishment water, for instance 208,000 AF or imported replenishment water was delivered to Montebello Forebay in 1961-62 (*WRD Engineering Survey and Report, 2008*, p. 52).
[25] This is the suggested extraction rate used by MWD.
[26] Water Replenishment District of Southern California, *Engineering Survey and Report, 2008*, Table 4 (updated May 2, 2008): http://wrd.org/engineering/reports/Final_Report_May2_2008.pdf.
[27] Recycled water projections in the year 2015 are compiled from the various Urban Water Management Plans.

groundwater extraction (31,205 AFY). This difference –"lost" water rights that are neither pumped nor placed into storage—does not arise at the economic optimum, as optimizing agents utilize their full extractable rights. Artificial replenishment is also projected to increase through the conversion of existing in-lieu replenishment contributions (e.g., 10,303 AF in FY2006-07) towards a higher-valued use of unused water rights as in-lieu storage. This projected increase in the annual replenishment obligation of WRD through the conversion of in-lieu replenishment to in-lieu storage and through an efficient utilization of existing pumping rights occurs at the economic optimum under baseline conditions of the existing Judgment.

Actual replenishment levels over the 22-year horizon are likely to differ from the levels predicted by the economic optimization model due to unforeseen operating inefficiencies, for instance due to pump malfunction, that periodically can result in lower pumping levels than the full groundwater allotment of each agent. In periods where agents are at their full storage capacity, such operating inefficiencies lead to "lost" water situations where unused pumping rights cannot be placed into storage. In FY2007-08, for example, water pumpers extracted 248,999 AF of groundwater out of an allowed extraction level of 315,267 AF (adjudicated rights plus carryover), and this resulted in 38,885 AF of "lost" water due to constraints on the ability of many water pumpers to carryover unused water under the judgment, an amount larger than the 27,383 AF that was carried over into FY2008-09.[28] This "lost" water results in a reduction in the artificial replenishment obligation of WRD, a feature that has displaced WRD demand for replenishment imports under the judgment on the order of 30,000 AFY.

Under the Judgment Amendments, the greater ability to place unused groundwater into storage accounts is likely to decrease the incidence of "lost" water events among pumping agents in the Central and West Coast Basins. The reason is that the storage capacity in the basins is full less often under the Judgment Amendments, so that periods in which operational inefficiencies arise are more likely to be matched to periods in which individual storage accounts have vacancy, leading to the conversion of "lost" water into storage claims. The greater conversion of "lost" water into storage claims under the Judgment Amendments raises the artificial replenishment obligation under the amendments relative to the baseline case in a way that is not predicted by the economic model (since operational inefficiencies are suppressed). However, suppressing operational inefficiencies in the economic model reduces the net benefit of the Judgment Amendments overall since the smaller annual replenishment obligation for WRD in the baseline case is coupled with a commensurate loss in groundwater extracted for consumption by water pumpers, which is a higher-valued use. When periodic operating inefficiencies exist, the resulting "lost" groundwater rights reduce economic surplus by the difference in the value of reliable water for consumptive use and the WRD replenishment rate. Suppressing the greater frequency of "lost" water events in the basins under the existing Judgment therefore understates the net benefit to water pumpers under the framework of the Judgment Amendments.

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[28] These data are complied from the Department of Water Resources *Watermaster Service Reports* for each basin (http://www.water.ca.gov/watermaster/).

4.4 Dynamic Program

The dynamic program used to value the change in net benefits is implemented as follows.[29] Based on the 82-year hydrologic record for the region over the period 1922-2003, an aggregated agent selects an optimal long-term contract for Tier 1 water (Z^*) to maximize the sum of net benefits in meeting basin water demand over the horizon subject to constraints on recharge rates, extraction rates, and on the available storage capacity in each basin. Using this Z^*, the net benefit of water use (the sum of groundwater extraction, Tier 1 water, and replenishment water when available) is recovered over a rolling horizon comprised of a sequence of 22-year periods beginning in the year 1922 and ending in the year 2003. This process results in sixty "draws" of hydrologic conditions over the period 2009-2030 comprised of overlapping segments of the 82-year hydrologic record (1922-1943, 1923-1944, through 1982-2003). Some of the periods are inordinately "wet", in which case the long-term contract specifies a greater quantity of Tier 1 water than is needed to augment groundwater supplies, and some of the periods are inordinately "dry", in which case the long-term contract does not specify a sufficient level of Tier 1 water to properly balance the reduced cost of water service with the cost of consumer rationing; however, in all cases, the level of Tier 1 water selected in the contract is determined prior to the realization of how dry or wet the ensuing 22-years will be. This process accords with the notion that the optimal choice of Z^* is based on post-Wanger rationing rules that make use of the entire hydrologic record over the period 1922-2003,[30] although returns from this choice of Z^* are projected into the 22-year period of study by assessing the change in performance across the full sample of 22-year draws. The net benefit of the Judgment Amendments over the period 2009-2030 is the average net benefit realized over these 60 draws.

The value of the Judgment Amendments over the period 2009-2030 is the sum of three components. First, under amended rules for storage in the Central and West Coast Basins, the cost of water service is lower over the period due to the substitution of replenishment water, recycled water, and augmentation water for Tier 1 water in the water portfolio. This value is realized as an annual flow of cost-savings over time, which can be discounted back to real terms (2009 $s) using standard present value calculations. Second, under both existing conditions and amended conditions, shortages occasionally occur under optimal basin management. Water shortages can differ in amplitude and duration under existing conditions and under conditions characterized by the amended Judgment, and the cumulative sum of penalty costs associated with consumer rationing – the reduction in benefits, $u(W_t)$, during times of consumer rationing—in principle can be greater or smaller under the Judgment Amendments. The penalty cost is realized as a periodic flow during periods of severe drought. Third, with a greater storage capacity available in the Central and West Coast Basins under the amendments, the ending stock of water held in storage at the end of the 22-year period is always greater under the

[29] Further details on the dynamic programming model are provided in Appendix B.

[30] Alternatively, it is possible to compute a Z^* for each 22-year sequence of the record and select the mean of the resulting Z^* distribution as the optimal Tier 1 contract level; however, this approach does not make full use of all the information in the hydrologic record in selecting Z^*. Moreover, the resulting values of Z^* that arise for each Basin using this approach are qualitatively similar to those presented here.

Judgment Amendments than under baseline conditions. While the actual increase in the net benefit of the Judgment Amendments is realized over long periods of time through a larger flow of net benefits, an artifact of truncating the analysis at a 22-year horizon is that it becomes necessary to reconcile the terminal stocks; that is, the final balance of groundwater held in storage in each case must be "cashed out" at the end of the final period to encapsulate values. The calculated net benefit of the Judgment Amendments for each draw of a 22-year period is therefore the sum of annual flow benefits (changes in the cost of water service and changes in penalty costs) and a terminal value placed on the change in the groundwater stock (amended Judgment stock less baseline stock) at the end of the horizon.

The net benefit of the increased storage provisions in the amended judgment is calculated by comparing the change in net benefit under the augmented storage and trading conditions allowed by the amendments with the net benefit under the existing judgment conditions in each 22-year interval. This process results in a distribution for the change in net benefit over a sequence of possible 22-year periods, each of which conforms to a different segment of the hydrologic record.

Under baseline conditions characterized by the existing judgment, each basin is assumed to be in a state of full use of storage potential authorized by the current Judgments (i.e., full use of the authorized 20% carryover) at the beginning of the program. This accurately reflects existing conditions in West Coast Basin, where the carryover level among water pumpers in the basin into 2008-09 was 11,359.5 AF out of 64,468.25 AF (17.6 percent) of adjudicated rights,[31] but over-allocates storage to Central Basin, where the carryover level among water pumpers in the basin recently declined from a carryover level of 21,140.66 AF out of 217,367 AF (9.7 percent) in 2007-08 to 11,350.89 AF out of 217,367 AF (5.2 percent) in 2008-09.[32] Adjusting the storage levels to full capacity at the beginning of the program inflates basin performance under baseline conditions in each 22-year period sampled from the hydrologic sequence and hence results in conservative measures of the change in net benefit relative to conditions under the amended judgment. The total net benefit of water use over each 22-year period is the sum of the net benefits in Central Basin and West Coast Basin.

Under the augmented storage and trading conditions characterized by the Judgment Amendments, the combined storage level in the basins at the beginning of the program is the sum of the baseline storage capacity in each basin. The storage level is then built towards the augmented storage capacity over time within the context of the dynamic series of puts and takes necessary to fulfill contemporaneous water demands. Since the rate at which water can be placed into storage in a given period is limited by physical constraints on basin recharge, this implies that much of each 22-year period encompasses an "accumulation phase" in which basin storage is developed towards the augmented capacity. During the accumulation phase, water pumpers in the basin are less able to

[31] Department of Water Resources, *Watermaster Service Report in the West Coast Basin,* Los Angeles County, July 1, 2007 - June 30, 2008 (http://www.water.ca.gov/watermaster/).
[32] Department of Water Resources, *Watermaster Service Report in the Central Basin,* Los Angeles County, July 1, 2007 - June 30, 2008 (http://www.water.ca.gov/watermaster/).

withstand dry condition water rationing by taking water from storage than would be the case for a basin beginning at a full storage capacity; hence the annual benefit at the end of the 22-year horizon is generally larger than the average annual benefit over the entire period, and annual net benefits are expected to be larger moving forward from the year 2030 after storage levels mature.

The dynamic program considers the net benefit of Judgment Amendments under a benchmark Scenario (Scenario 1) and three additional scenarios that consider various levels of recycled water development and Tier 1 water use. Each scenario variation represents a change in a single feature of the benchmark Scenario, which allows a value to be recovered for the particular feature being changed. The scenarios considered are:

(1) Scenario 1: 20,000 AFY of recycled water development in West Coast Basin;
(2) Scenario 2: No recycled water development;
(3) Scenario 3: Tier 1 water plus recycled water fixed at baseline level of Tier 1 purchases; and
(4) Scenario 4: 54,000 AFY of recycled water development (comprised of 20,000 AFY in West Coast Basin and 34,000 AFY in Central Basin).

Scenarios 2 and 4 reveal the incremental net benefit of various levels of recycled water development in the water portfolio of Central and West Coast Basins water pumpers. Scenario 3, which compares optimal management under baseline conditions to suboptimal management under the Judgment Amendments, isolates the role of reducing the average cost of water service by replacing Tier 1 water with replenishment water in the water portfolio. The net benefit of the Judgment Amendments in Scenario 3 ("fixed firm") by definition is smaller than the net benefit in the case of optimal portfolio adjustment; however, this case is useful in illustrating the risk-return trade-off associated with water management in the Central and West Coast Basins. With Tier 1 water use fixed at baseline levels, the return to augmented storage capacity in the basins is confined to arise only through stabilization of water deliveries rather than through the (optimal) combination of stabilization value and reduced cost of water service that characterizes the net benefit of the Judgment Amendment in the benchmark Scenario 1.

5. Results

This Section presents the assessment of the net benefit of the Judgment Amendments to the region over the 22-year horizon over the period January 2009 through December 2030. The net benefit of the Judgment Amendments to the region is the difference between the expected net benefit of water service obtained over the period under rules encompassed by the existing Judgment and the expected net benefit of water service obtained over the period under the expanded storage provisions encompassed by the Judgment Amendments.

Under conditions represented by the existing Judgment, the initial stock of water held in storage begins at the full potential storage capacity of the Central and West Coast Basins and the storage level varies over time from this level according to realized hydrologic conditions represented by each of the 60 draws of 22-year periods from the hydrologic record. Under conditions represented by the Judgment Amendments, the initial stock of water held in storage begins at the baseline capacity and ultimately must expand over time to reach the amended storage capacity level. The program under the amended Judgment therefore has two phases: (i) a transitional phase of stock accumulation in storage and carryover accounts; and (ii) a cyclical phase of stock depletion and recovery that adjusts and reverts back to the storage capacity according to realized hydrologic conditions. Depending on the sequence of wet and dry conditions that occurs over the 22-year horizon considered in the study, the length of time spent in either phase varies according to the timing of replenishment water availability used to make puts into in-lieu storage.

The net present value of the Judgment Amendments is the sum of three components: (i) the net present value of individual storage, community storage, and increased carryover potential for water pumpers; (ii) the net present value of inter-basin trading among water pumpers; and (iii) the net present value of regional storage. This report considers only the combined value of the first two components. The value of regional storage provisions, which in principle can involve sales of storage to outside parties that can eliminate the need for replenishment assessments, represents an additional net benefit of the Judgment Amendments not accounted for in this report.

The value of inter-basin trading is limited by provisions that prevent water leases from moving extractions from Central Basin to West Coast Basin. The program is therefore implemented independently for each basin to recover the economic incentives for water trading. Economic incentives for inter-basin transfers arise when the marginal value of water diverges across basins, and trading is allowed in such instances only from West Coast Basin to Central Basin (and then only up to 20,000 AF in any year). The dynamic program searches for differences in the marginal valuation of water across basins and reconciles these differences through trading under circumstances in which the economic incentive to trade implies a movement of water (up to the 20,000 AF limit) from West Coast Basin to Central Basin. The net benefit of the Judgment Amendments is then calculated after all allowable water transfers have transpired.

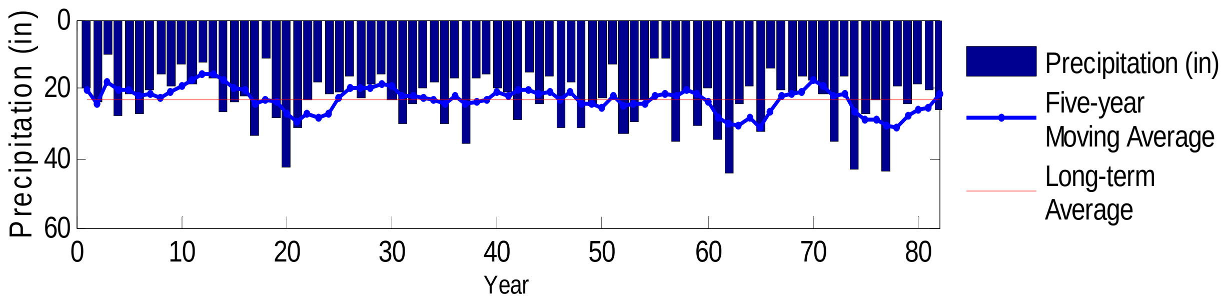
The economic model does not recover trading levels within each basin (*intra*-basin transfers). Such trades occur periodically under existing rules allowed by the Judgment and are anticipated to continue occurring. Moreover, the model considers only trades at the macro level driven by differences in economic value of water across basins under a coordinated optimal management regime in each basin. Water trades that occur for other reasons, for instance trades motivated to salvage a value for rights that would otherwise be lost due to unanticipated events such as a pump malfunction, are not predicted by the economic model. Such trades, which are likely to persist –and for similar reasons— under the Judgment Amendments, can be reconciled within each Basin and therefore would not be impacted by changes in inter-basin trading rules.

The framework described in Section 4 results in an optimal level of Tier 1 imports (Z^*) in each basin for each of four cases: (i) under baseline conditions that exist under the existing Judgment; (ii) under benchmark conditions of the amendments with 20,000 AFY of recycled water development in West Coast Basin; (iii) under amended conditions without recycled water development; and (iv) under amended conditions with 54,000 AFY of recycled water development. The value of the Judgment Amendments in each case is the difference between the net benefit over the 22-year horizon under baseline conditions and the net benefit under amended conditions (the sum of the net benefits in Central Basin and West Coast Basin). Additionally, a non-optimized scenario is considered that calculates the value of the Judgment Amendments in the case where water pumpers maintain a fixed level of Tier 1 water imports at the baseline optimal level.

The optimal level of Tier 1 imports (Z^*) is selected in each case by maximizing the objective function described in Section 4.1 subject to the various parameterizations of supply, demand and storage conditions described in Table 5. Z^* is calculated by sampling over the projected post-Wanger MWD water allocation developed over the 82-year hydrologic record in each of the four cases.[33]

Figure 3 depicts annual precipitation levels in Sacramento, California over the 82-year hydrologic record 1922-2003. Notice the particularly dry sequences involving consecutive years of low precipitation in periods 7-13, 23-29 and 65-70 of the sequence. These periods, which correspond to the calendar years 1928-1934, 1944-1951 and 1987-1992, provide the drought events that place the greatest strain on the ability of storage to smooth consumption. Other dry periods arise in the sample, but these periods are characterized by shorter periods of below-average rainfall punctuated by intervals with above-average rainfall that allow storage levels to recover.

Figure 3. Annual Precipitation over the 82-year Hydrologic Record, 1922-2003.



The five year moving average precipitation level clearly reveals the three major drought events as the points of greatest separation from the long-term average level of precipitation. The hydrologic record is characterized by below-average precipitation levels for much of the first 18 years, and considerable volatility exists in the annual precipitation levels over the horizon.

[33] It should be noted that, even in the 82-year horizon in which water pumpers in the basins spent a considerable length of time in the transitional phase of stock accumulation, beginning the water pumpers with an initial water stock at the full storage capacity under the Judgment amendments does not significantly alter the optimal choice of Z^* relative to the case in which storage must be built up from baseline levels.

Under post-Wanger water supply rules, periods of MWD water rationing and availability of replenishment water are lagged slightly behind the major drought events to reflect the development of system-wide storage stocks. The availability of replenishment water over the period is cyclical, with replenishment water made available to water pumpers in 26 out of 82 years in the sample period.

Table 6 presents the optimal long-run contract for non-interruptible (Tier 1) water under the post-Wanger distribution for each of the four cases based on the entire 82-year hydrologic record over the period 1922-2003. The demand for imported water in each basin (see Table 1) is 124,135 AFY in West Coast Basin and 188,868 AFY in Central Basin. The composition of the optimal water portfolio to meets water demand involves Tier 1 purchases that fall in the water portfolio as water pumpers are able to hold more groundwater in storage. Under baseline storage conditions allowed by the existing Judgment, the optimal contract specifies Z^*_{wcb} = 120,580 AFY for West Coast Basin and Z^*_{cb} = 180,730 AFY for Central Basin, implying that the water portfolios are comprised of roughly 97 percent Tier 1 water in West Coast Basin and 95 percent Tier 1 water in Central Basin. The difference between these values (3,555 AF in West Coast Basin and 8,138 AF in Central Basin) represents the annual shortfall in water deliveries that water pumpers seek to meet by selecting an intertemporal profile of imported replenishment water consumption, in lieu storage, and groundwater extraction. In periods where MWD rationing occurs, the margin between demand and Tier 1 supply rises (see Table 2) at the same time that replenishment water is unavailable, so that meeting the desired level of water consumption requires taking larger quantities of groundwater out of storage. For this reason, water pumpers in West Coast Basin, which, relative to their demand for imported water, have a smaller collective storage capacity than water pumpers in Central Basin (see Table 4), select an optimal level of Tier 1 imports closer in percentage terms to their desired imported water level.

Table 6. Projected Tier 1 Water Use

	West Coast Basin	Central Basin
Imported Water Demand	124,135	188,868
Tier 1 purchases:		
Baseline case	120,580	180,730
Scenario 1 (20,0000 AF recycling)	93,166	138,410
Scenario 2 (No recycling)	114,490	138,410
Scenario 3 ("Fixed Firm")	100,580	164,265
Scenario 4 (54,000 AF recycling)	93,166	104,320

Source: BEC calculations.

Under the benchmark scenario of the Judgment Amendments (Scenario 1), the optimal long-run contract for Tier 1 water over the 82-year hydrological record with post-Wanger distribution rules specifies $Z^*_{w,1}$ = 93,166 AFY of Tier 1 water for West Coast Basin and $Z^*_{c,1}$ = 138,410 for Central Basin.

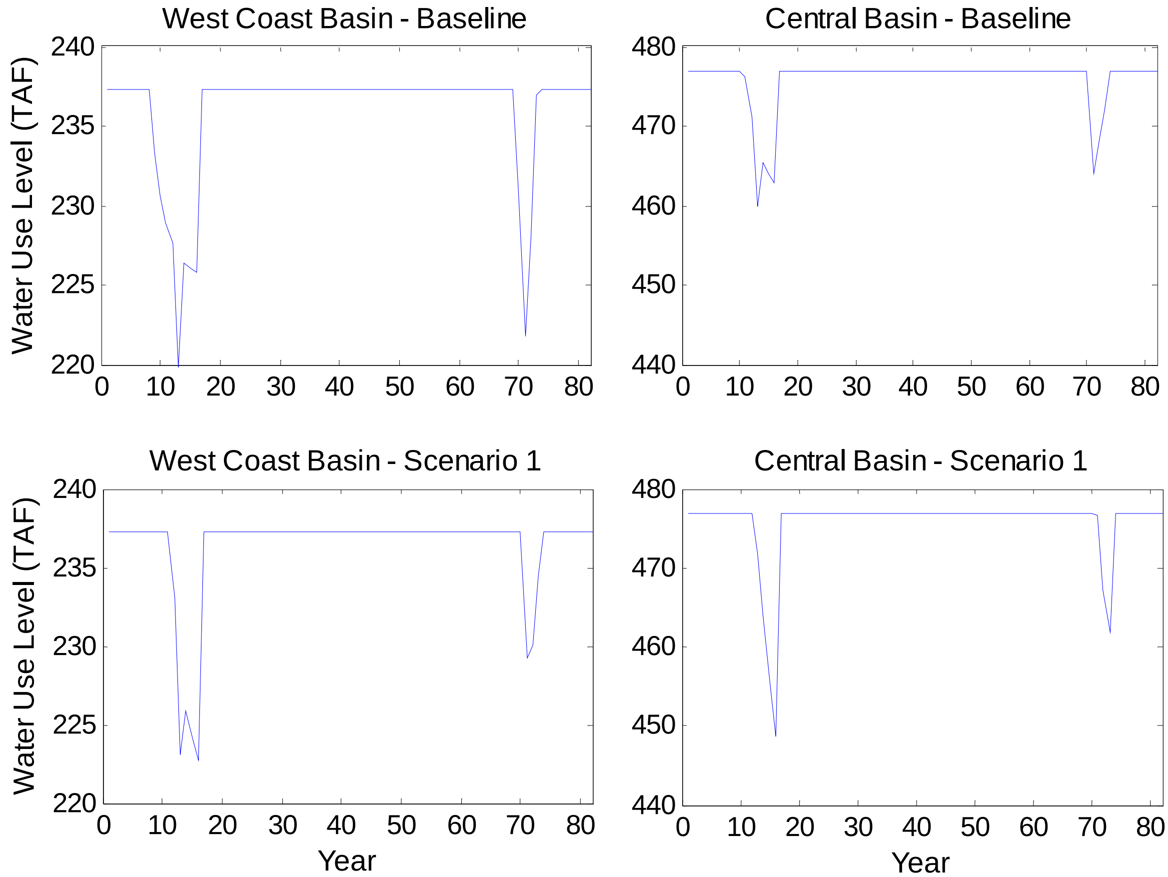
In Scenario 2, which assumes no recycled water development in West Coast Basin, the optimal level of Tier 1 water rises by more than 20,000 AFY to 114,490 AFY, while optimal Tier 1 imports remain constant in Central Basin. Each unit of recycled water displaces slightly more than a unit of Tier 1 water from the water portfolio since recycled water supplies, which are never subject to rationing under drought conditions, provide a superior source of non-interruptible deliveries than imported Tier 1 water. Similarly, in scenario 4, which includes an additional 34,000 AFY of recycled water development in Central Basin, the optimal level of Tier 1 water use in Central Basin decreases by slightly more than 34,000 AFY (from 138,410 AFY to 104,320 AFY).

Table 6 also presents the level of water use in the (non-optimized) selection of Tier 1 water in the "fixed firm" scenario. In this scenario, water pumpers in each basin respond to the additional storage possibilities under the amendments by maintaining the baseline level of Tier 1 water use, with the only displacement of Tier 1 water arising in this case as a result of the 16,465 AF of augmentation water in Central Basin and 20,000 AFY of recycled water development in West Coast Basin.

5.1 Benchmark Comparison

Figure 4 depicts the levels of water use that arises with optimal Tier 1 contract selection under the baseline case of the existing Judgment and under the benchmark scenario of the Judgment Amendments. The upper panels of the figure show the outcome under the existing storage rules of the Judgment, while the lower panels of the figure show the outcome for each basin under the Judgment Amendments. In each case, total retail water use is recovered for each year of the hydrologic record at projected year 2015 levels of retail demand and post-Wanger water supply conditions using the cost minimizing portfolio of Tier 1 water, replenishment water, recycled water, augmentation water, and groundwater extractions. In general, the figures reveal what would have happened under baseline conditions and under the benchmark conditions of the amended judgment if water pumpers encountered current water demand facing post-Wanger water supply allocations over a 82-year horizon that replicates the observed hydrologic conditions over the period 1922-2003.

Figure 4. Scenario 1 Water Use Levels under Baseline and Amended Conditions over the 82-year Hydrologic Record with Post-Wanger Supply Conditions.



Notice that water use in all cases indicates significant retail water rationing over years 10-16 and 70-73, time frames that accord with the hydrologic record over the periods 1931-1937 and 1991-1994. These periods align with the most significant drought events (and most severe post-Wanger MWD supply rationing) in the hydrologic record depicted in Figure 3, with the decline in water deliveries slightly lagging drought events due to the buffer stock of storage held be water pumpers in the basins.

In West Coast Basin, water deliveries fall to a similar level under pre-amendment and post-amendment conditions during the worst period of retail water shortage in year 10 (a decline of approximately 12,000 AF below the desired consumption level); however, retail water shortages are of shorter duration under the amendments. The same basic pattern emerges in Central Basin, although the water shortage in year 10 is more severe under conditions allowed by the Judgment Amendments than under conditions of the existing Judgment. The reason for this is that water pumpers in Central Basin have a larger storage capacity per unit of imported water demand than water pumpers in West Coast Basin, and, for this reason, select MWD contracts for Tier 1 water at a greatly reduced delivery level under the Judgment Amendments. Due to the relatively greater reduction in their optimal Tier 1 water contracts, water pumpers in Central Basin are exposed to more risk than agencies in West Coast Basin during drought events of long duration that deplete storage stocks, and this risk is particularly acute at the beginning of the time horizon during the transitional period of storage accumulation. After year 20, water supply conditions in Central Basin, like those in West Coast Basin, involve a similar but somewhat more stable delivery profile after implementation of the Judgment Amendments. Indeed, shortages in water deliveries in Central Basin under amended conditions are generally of smaller magnitude and shorter duration than under baseline conditions and the shortage event over periods 29-30 that occurs under baseline conditions is almost entirely averted under the amendments.

Figure 5. Scenario 1 Groundwater Storage Levels under Baseline and Amended Conditions over the 82-year Hydrologic Record with Post-Wanger Supply Conditions.

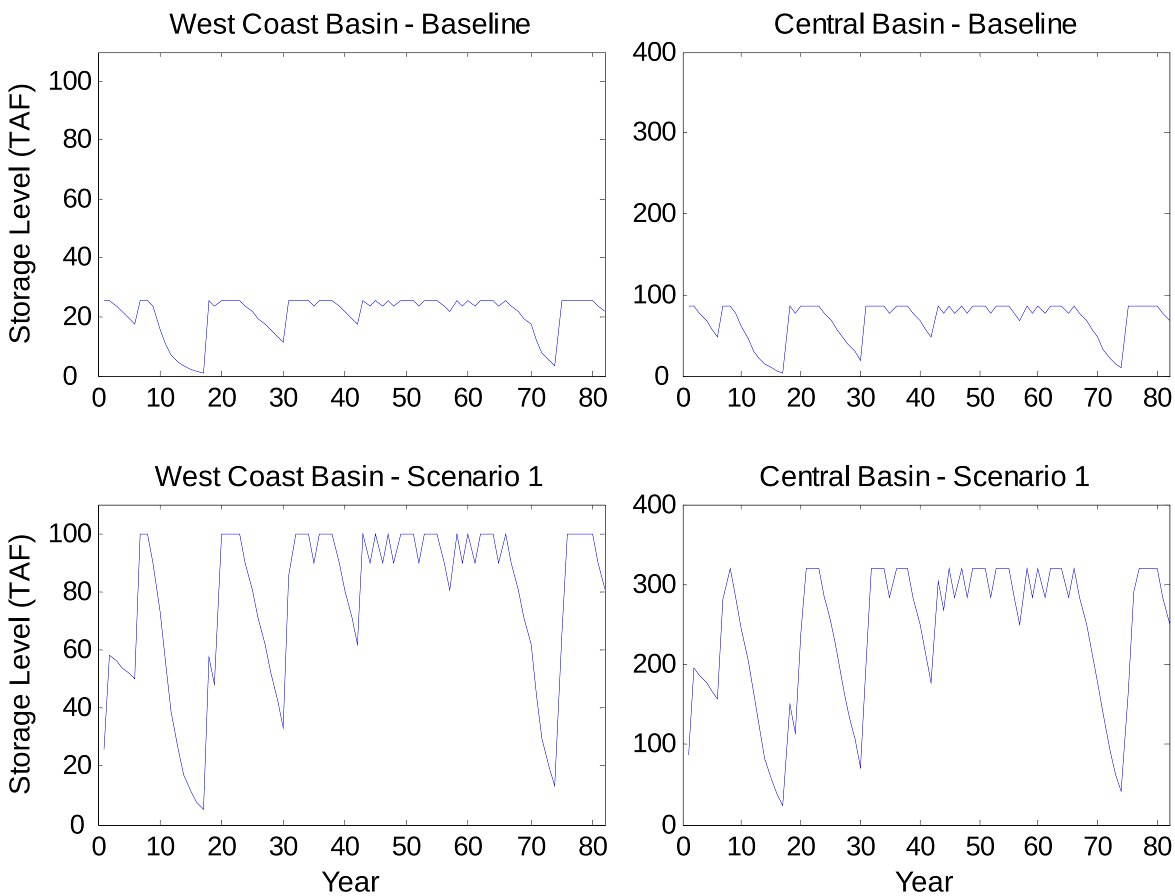


Figure 5 shows the commensurate sequence of storage adjustments that reconcile retail water deliveries and groundwater extractions. The upper panels of the figure show the annual storage level in each basin under the Judgment, while the lower panels of the figure show the annual storage level in each basin under the Judgment Amendments. Notice that the storage level over time is extremely volatile relative to water consumption in all cases. The reason is that frequent puts and takes from storage are required to stabilize retail water deliveries in a post-Wanger environment where imported water supplies are highly variable over time.

Under baseline conditions, each basin begins at a full storage allocation and the storage level decreases and recovers over time to match water deliveries to the desired level of retail water consumption according to the availability of replenishment water. Small declines in storage, which arise relatively frequently, occur to meet minor supply shortages when replenishment water is not available but MWD rationing does not occur. Water deliveries in these periods reflect the minor takes of groundwater stores necessary to fill the gap between imported water demand and Tier 1 supplies. Steeper declines in storage levels occur during successive periods in which replenishment water in unavailable from MWD, with the two sharpest drops occurring during periods of multi-year MWD supply rationing.

Relative to the baseline conditions, the dynamic profile of groundwater storage follows a similar pattern under the Judgment Amendments, with the exception that the storage level trends upward under the amendments in a transitional phase of stock accumulation. The overall pattern of storage adjustments is independent of the Judgment Amendments since the underlying hydrologic conditions that determine whether puts or takes are desired from storage are identical; however, the size of the desired storage adjustment in each period is considerably larger under the amendments to make use of the greater storage capacity.

Figure 6 plots the marginal value of water in each period. The upper panels of the figure show the marginal value of water in each basin under the Judgment, while the lower panels of the figure show the marginal value of water in each basin under the Judgment Amendments. The results show that in dry years it is not unusual for the value of water to consumers to exceed $2,000 per AF. These values, which help explain the large economic benefits of enhanced groundwater storage presented in this study, are consistent with estimates of the cost of dry year water conservation.[34]

Under all scenarios, our analysis concludes that the amended judgments will have little or no effect on the market for leased water rights.[35] The analysis concludes that the marginal value of water is not affected significantly merely because parties may store water in addition to leasing unused rights to others. The free transferability of water held in storage permitted within the amended judgments means that available transferable supplies remain largely unchanged. Thus, transferable water will remain largely available at essentially stable lease rates. As more water is placed into storage, the available supply of transferable water is likely to increase, augmenting opportunities for lease or transfer, and probably reducing the cost of doing so.

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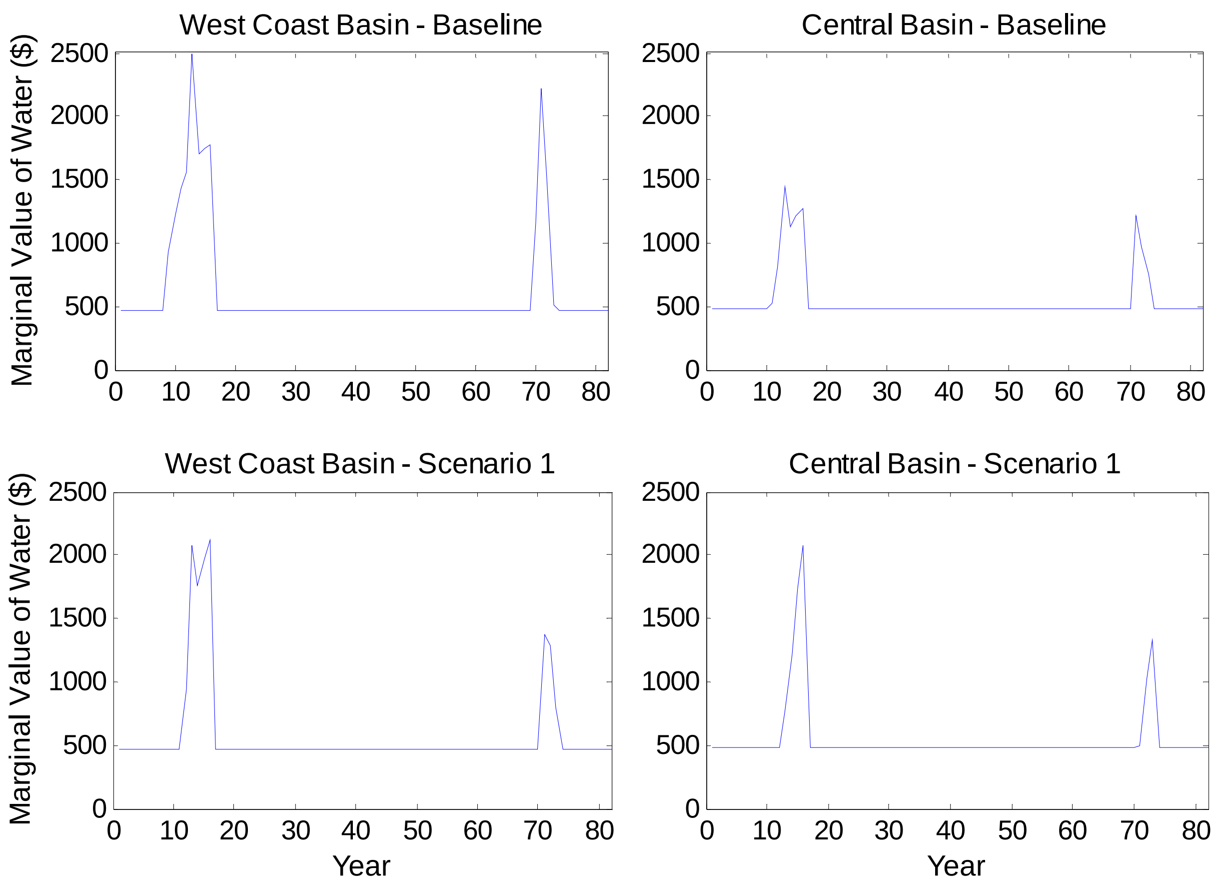
[34] LCPSIM manual- http://www.economics.water.ca.gov/downloads/Models/LCPSIM_Draft_Doc.pdf.
[35] Lease prices in Central and West Coast Basins have recently traded in the range of $100-200/AF. However, the significant quantity of "lost" water in each basin (e.g., 38,885 AF in FY2007-08) indicates the presence of operational inefficiencies that can drive trading prices down to salvage values. In all cases, the economic model suppresses operational inefficiencies and selects optimal contracts for Tier 1 deliveries, which lead to predicted lease prices that are aligned with the marginal value of water rather than with salvage values.

Figure 6. Scenario 1 Marginal Value of Water under Baseline and Amended Conditions over the 82-year Hydrologic Record with Post-Wanger Supply Conditions.



Under the Judgment Amendments, inter-basin transfers of stored water are permitted from West Coast Basin to Central Basin, although not from Central Basin to West Coast Basin at annual levels up to 20,000 AF. The augmented storage capacity available under the Judgment Amendments alters the economic incentive for inter-basin transfers somewhat. For example, an incentive is created to transfer stored water from West Coast Basin to Central Basin over periods 12-16 to bring into equilibrium the marginal value of water across both basins.

To calculate the expected net benefit of the Judgment Amendments over the period 2009-2030, we decomposed the 82-year hydrologic record into sixty segments of 22 years (1922-1943, 1923-1944, and so on through 1982-2003). The net benefit of the Judgment Amendments is recorded in each case as the change in economic value under baseline and amended conditions, and the expected increase in net benefit from the Judgment Amendments is the mean of the resulting distribution of net benefits. In each case, water pumpers in Central and West Coast Basins maintain the optimal level of Tier 1 imports for the entire 82-year series of water events, which makes use of the complete hydrologic record to reflect optimal water supply decisions over longer horizons than the 22-year period encompassed by the study. The long-run optimal value of Z^* over the 82-year hydrologic record with post-Wanger MWD water supply is fixed for all 22-year segments of the hydrologic record to account for the fact that the level of Tier 1 imports is selected *ex ante*, prior to the realization of actual hydrologic conditions over the ensuing 22 years.

At the beginning of each 22-year period, pumping agents in the economic model immediately reset their Tier 1 MWD water contracts to the optimal level under baseline conditions. Under amended conditions, the level of Tier 1 water use is maintained at the baseline level for the first five years, then reset to the optimal level under the Judgment Amendments at the end of year 5 to accord with the lag structure on the timing of recycled water and augmentation projects. The 5-year lag in the renegotiation of existing long-term contracts for Tier 1 water supplies accounts for the fact that the optimal level of Tier 1water use depends on the availability of water pumpers to replace imported water with augmentation water and advanced treated recycled water. This assumption provides a conservative measure of the value of the Judgment Amendments since the economic framework automatically implements the long-run optimal Z^* in year 5 without regard for information water pumpers may hold at that time on the prevailing hydrologic conditions. While this feature provides what is perhaps a realistic approximation of how water pumpers might renegotiate their long-term contractual relationships for Tier 1 water in advance, it also takes away the potential flexibility of water pumpers to control the timing of the reset date, for instance the program resets the long-term contract for Tier 1 water in one case during a period of 20 percent water rationing by MWD; something that would clearly be suboptimal if water pumpers can "pick" the date of contract adjustment according to prevailing hydrologic conditions. Implicitly, the model assumes water pumpers must adjust their long-term Tier 1 contracts in year 5 of the program prior to realizing any information on the hydrologic conditions that arise over the 22-year period and that these contracted levels cannot be renegotiated once the particular "hydrologic draw" is revealed. Ignoring the ability of water pumpers to align the date in which Z^* is reset to accord with a "wet" period in which replenishment water is available therefore leads to conservative estimates on the expected net benefit of the Judgment Amendments.

At the end of each 22-year period, the ending stock of groundwater held in storage often differs substantially between baseline conditions and amended conditions in each basin. The net present value of the Judgment Amendments is adjusted to value the difference in storage stocks in each case by valuing the terminal stock at the Tier 1 rate. Use of the Tier 1 rate to value the difference in storage stocks provides a conservative measure of value since groundwater held in storage is only extracted during periods where replenishment water is unavailable. The marginal value of water, on average, is higher when the average is conditioned over states of nature without replenishment water availability than when the average is calculated over the entire sample.

Figure 7. Expected Water Use Levels under Baseline and Amended Conditions, 2009-2030.

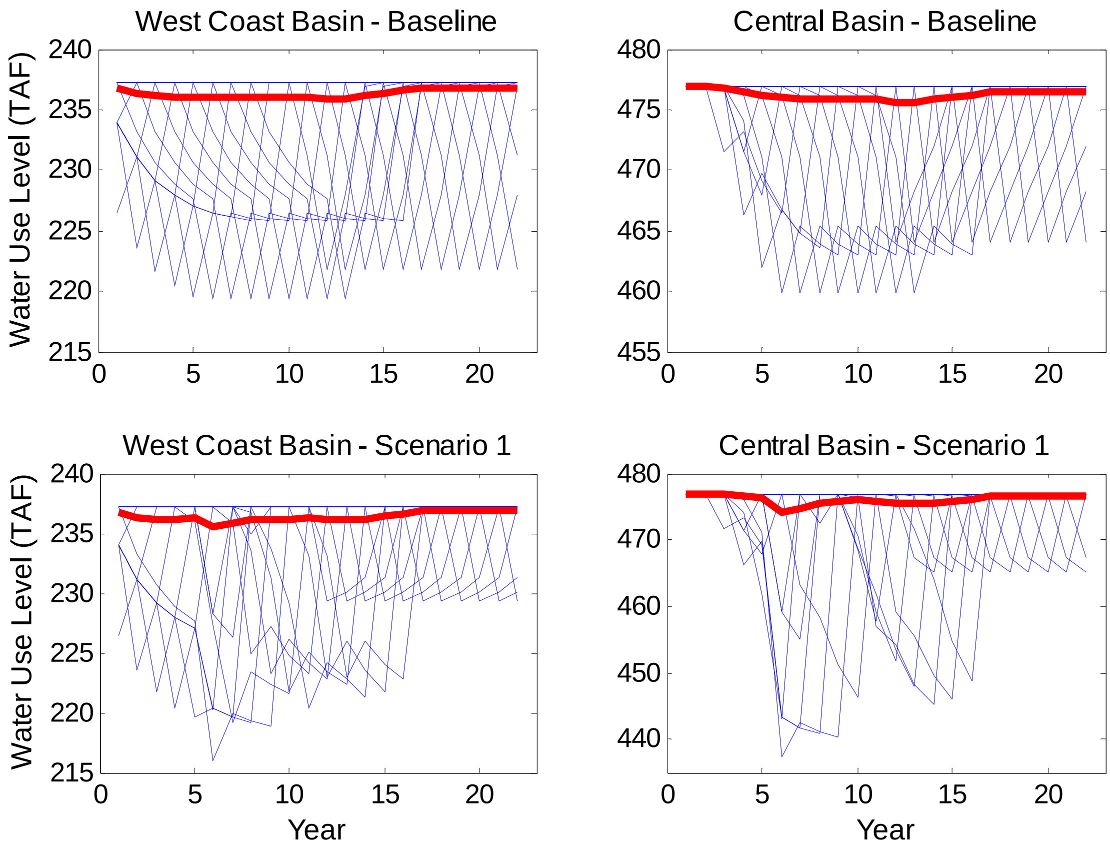


Figure 7 depicts the distribution of outcomes over the 60 draws of 22-year hydrologic conditions and the expected water use levels for each basin. The upper panels of the figure show the distribution of water use outcomes in each basin under the current Judgment in thousands of AF (TAF), while the lower panels of the figure show the distribution of water use outcomes under the Judgment Amendments. The bold red line represents the expected value of the distribution, which is the average level of water use in each year of the 22-year horizon, and the blue lines project the three major drought events in the 82-year sample through the rolling horizon of hydrologic draws. Each year is represented by 60 draws, and the expected water use level in each year averages a large number of draws in which water use remains at the desired level (W*) in each basin, and a small number of draws in which water shortages exist, with each of the three major drought events represented by a spike that rolls through the sequence of draws in the horizon.

Under baseline storage rules of the Judgment, the water use level trends down initially in each basin from time 0 since the basins begin the program at the baseline storage capacity. The slight increase in water use towards the end of the horizon arises because the most significant drought event in the entire sample period, which coincides with years

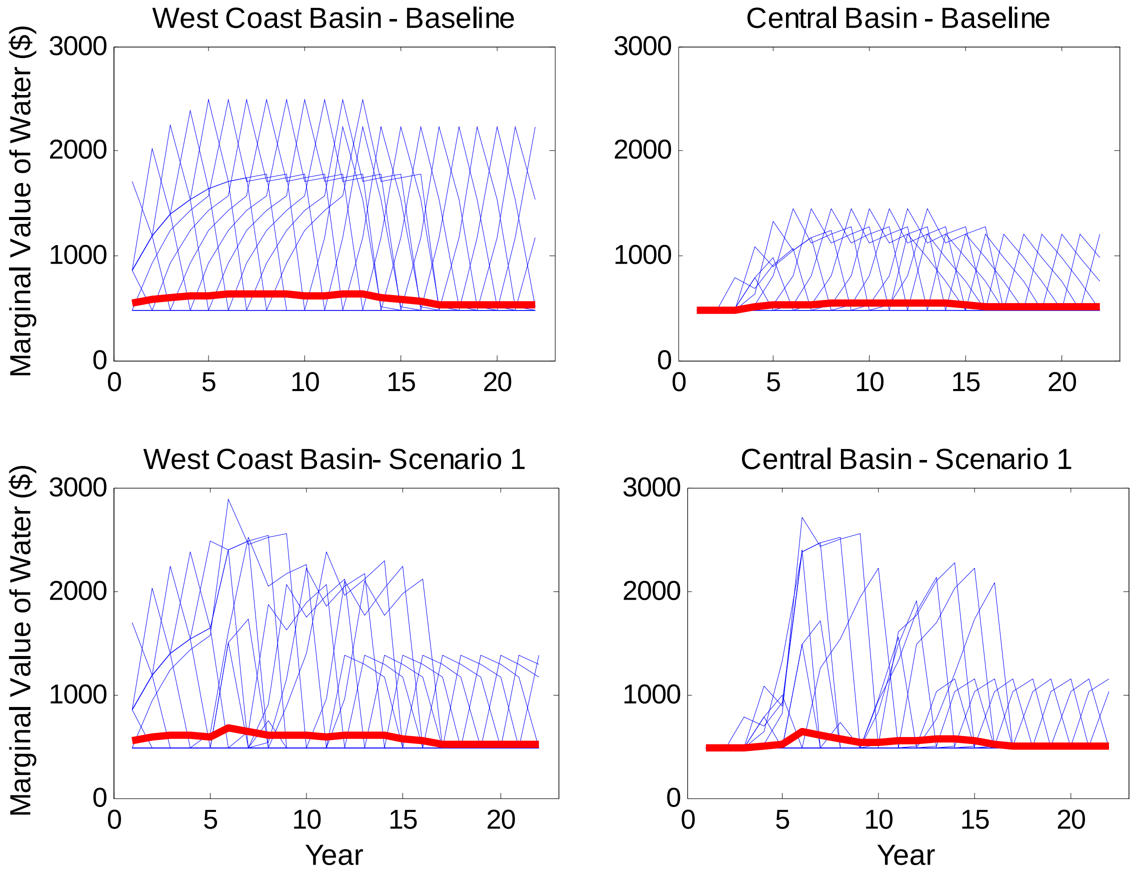
10-16 of the hydrologic record (calendar years 1931-1937), does not occur later than year 16 of any 22-year draw.

The lower panels of Figure 7 show the distribution of water use outcomes under the Judgment Amendments. Under the Judgment Amendments, the volatility in water use levels is initially larger than in the baseline case, but then drops sharply in year 16, after which time water supply stabilizes relative to the baseline outcomes. As in the baseline case, part of the reason for the decline in volatility (and rise in expected water use) over the last five years of the sample is an artifact of the inability to capture the most severe drought event in the hydrologic record in the last five years of any consecutive 22-year draw. The additional component of this trend, which explains the *relative* difference between the baseline case and the amended case, is the transitional phase of storage accumulation. Water supply is more volatile (and the average water use level is lower) during an initial period of storage accumulation in the basins, as water pumpers adjust their storage levels towards the amended capacity.

Figure 8 reveals the transition path of storage in each basin under the Judgment (upper panels) and Judgment Amendments (lower panels). Notice that the expected storage level trends down over time under baseline conditions from the beginning of the program at baseline storage capacity to a stable equilibrium of around 80 percent of capacity in each basin, while the expected storage level under the Judgment Amendments trends steeply upwards from the baseline storage capacity to an augmented level at a similar percentage of storage capacity. The upward trend six years from the end of the horizon occurs because the severe drought event that comprises periods 10-16 of the 82-year hydrologic record cannot sweep through the last 6 years of any of the various 22-year draws.

In all cases, notice that the volatility of annual storage levels about the mean is considerably greater than the commensurate volatility of retail water use presented in Figure 7. This outcome reflects a pattern of extractions from storage that is set to counterbalance periods of replenishment water availability through an optimal sequence of puts and takes to and from groundwater storage. At the economic optimum, water pumpers adjust groundwater stocks over time in a manner that provides a high degree of stabilization of water deliveries. The associated level of groundwater storage, which provides economic value only indirectly, is accordingly more volatile.

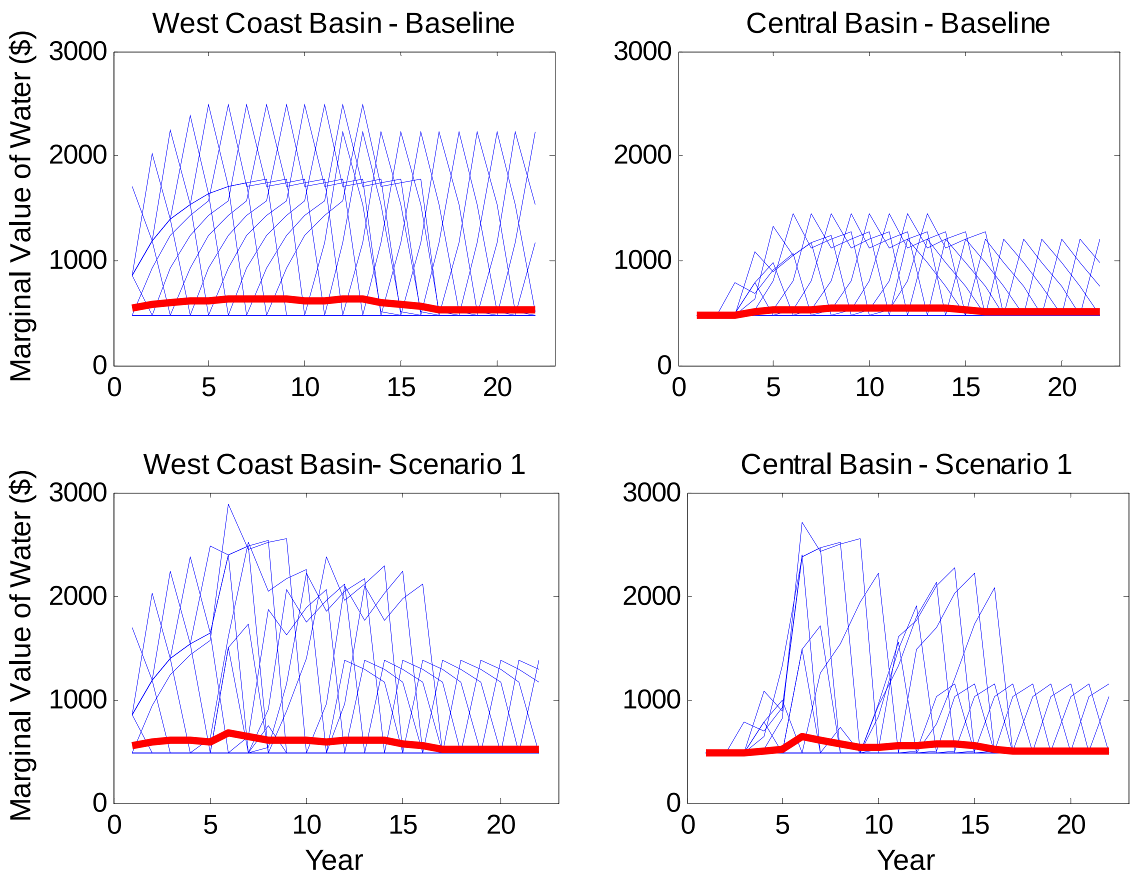
Figure 8. Expected Storage Levels under Baseline and Amended Conditions, 2009-2030.



The optimal use of storage in the Central and West Coast Basins involves a transitional phase of storage accumulation characterized by the most rapid approach path to the storage capacity permitted under the Judgment Amendments. Under the Judgment Amendments, the transitional phase of storage accumulation has an expected duration of between 6-8 years.

Figure 9 depicts the marginal value of water in each basin under the Judgment (top panels) and Judgment Amendments (bottom panels). The marginal value of water follows the opposite pattern as the water use level in each basin, rising above the replenishment rate during periods of water shortage. Because retail water demand is highly inelastic, a water shortage that is small in magnitude (in percentage terms) leads to a relatively large upward movement in the marginal value of water. Under baseline conditions, the marginal value of water expresses markedly greater volatility in West Coast Basin than in Central Basin, which reflects a greater propensity for shortages to occur in West Coast Basin.

Figure 9. The Expected Marginal Value of Water under Baseline and Amended Conditions, 2009-2030.



Under the Judgment Amendments, inter-basin water transfers are allowed to take place (at volumes up to 20,000 AFY) from West Coast Basin to Central Basin, but no trading is permitted from Central Basin to West Coast Basin. The model predicts periodic water transfers from water pumpers in West Coast Basin to water pumpers in Central Basin to resolve differences in the marginal value of water. The volume of trading is typically small and never exceeds 1,500 AF per year in any of the sixty draws. The reason is that economic forces tend to produce water scarcity in both Basins simultaneously, for instance during major drought events, and imported water supplies in West Coast Basin are rationed to a greater degree than imported water supplies in Central Basin (see Table 2). The marginal value of water tends to rise in both basins at once, and retail water demand conditions are sufficiently inelastic that small relative differences in the marginal value of water are resolved without the need to transfer large volumes of water between the basins.

The expected average net present value of the Judgment Amendments over the 2009-2030 period is $222 million to water pumpers in West Coast Basin, $586 million to water pumpers in Central Basin, and as a result, there is an $808 million benefit to the region overall. These values are comprised of an average annual net benefit flow of $8.4 million per year and a terminal value on the change in storage of $37.8 million in West Coast Basin and an average annual net benefit flow of $21.8 million per year and a terminal value of $105.7 million in Central Basin.

On a per unit basis of water rights, the net benefit to water pumpers in West Coast Basin over the period 2009-2030 is $3,449/AF and the net benefit to water pumpers in Central Basin over the period is $2,695/AF. An important reason why the amendment provisions provide greater value per AF of annual pumping rights to water pumpers in West Coast Basin than in Central Basin is that all recycled water development takes place in West Coast Basin in the benchmark scenario. The relatively greater potential to convert carryover rights to physical storage through recycled water development in West Coast Basin leads to higher average returns per acre foot of pumping rights in West Coast Basin than in Central Basin, an outcome that does not arise in the scenario variation without recycled water development.

5.2 Scenario Variations

This section presents the results of several variations from the benchmark scenario that allow for different levels of recycled water development. In each variation, the baseline outcome under the Judgment involves an identical economic optimum (as described above), and the optimal baseline allocation is then compared to the optimal outcome under the Judgment Amendments that arises for each level of recycled water development. Specifically, a Tier 1 water supply contract is selected for each basin based on the respective level of recycled water development, and the net benefit of the amendments in each case is compared to the baseline allocation. In addition, a "fixed firm" scenario is also considered for the baseline case of 20,000 AF of recycled water development in West Coast Basin that does not optimally adjust the Tier 1 water supply contract, but instead maintains the baseline level of reliable water deliveries (i.e., Tier 1 water less reliable water units acquired through augmentation projects and the physical storage of recycled water).

5.2.1 No Recycled Water Development

The benchmark comparison considered above exploits the most economical source of recycled water development available in the region by making use of excess capacity at existing barrier wells to inject 20,000 AFY of advanced treated recycled water into physical groundwater storage in West Coast Basin. To assess the value of the amendment provisions that allow physical storage to be created through recycled water development, it is helpful to consider the net benefit of the Judgment Amendments under circumstances in which recycled water resources are not exploited in the basins.

The distributions of water use levels, storage levels, and marginal values of water under the Judgment Amendments with and without recycled water development are qualitatively similar. These figures are provided in Appendix A of this report.

Access to recycled water has important implications for the performance of water pumpers in West Coast Basin since recycled water provides a reliable source of water that is not subject to rationing during extended periods of drought. The net present value of the Judgment Amendments in Central Basin remains relatively stable without the use of recycled water due to the ability of water pumpers in Central Basin to access reliable water for storage through stormwater augmentation.

Absent the physical storage of advanced treated recycled water in West Coast Basin, the expected net present value of the Judgment Amendments to the region over the 2009-2030 period is $684 million. Water pumpers in West Coast Basin receive an expected net benefit of $98 million and water pumpers in Central Basin receive an expected net benefit of $586 million. These values are comprised of an average annual net benefit flow of $2.7 million per year and a terminal value on the change in storage of $38.1 million in West Coast Basin and an average annual net benefit flow of $21.8 million per year and a terminal value of $105.7 million in Central Basin. Relative to the benchmark comparison with 20,000 AFY of recycled water storage in West Coast Basin, a similar stock of water is held at the end of the 22-year horizon, but the lack of advanced treated recycled water resources decreases the annual flow of net benefit to water pumpers in West Coast Basin by $5.7 million per year.

On a per unit basis of water rights, the net benefit to water pumpers in West Coast Basin over the period 2009-2030 without recycled water development is $1,523/AF and the net benefit to water pumpers in Central Basin over the period is $2,696/AF.[36]

In total, the incremental net benefit that results from the development of 20,000 AFY of advanced treated recycled water resources in West Coast Basin allowed under the physical storage provisions of the Judgment Amendments is $124 million (= $222 – $98). This implies that the incremental return to recycled water development above the $1,523/AF net benefit that accrues to pumping rights in West Coast Basin is a premium of $6,206/AF associated with each unit of recycled water developed in the Basin.

5.2.2 Fixed Firm

The net benefit of the Judgment amendments in the baseline comparison and the variations that consider different levels of recycled water development compare the difference in returns between optimal allocations of the water portfolio that arise from the change in storage rules. As discussed above, the optimization framework that determines the water portfolio has the desirable property that it leaves the expected marginal value of water across all periods unchanged. Although the dynamic profile of water scarcity can differ depending on the level of storage available to water pumpers in each basin, an

[36] The slight increase in the value of the Judgment amendments to water pumpers in Central Basin arises due to a slightly different pattern of water transfers that is generated through adjustments in the water portfolio of agencies in West Coast Basin. Water pumpers in West Coast Basin collectively raise their Tier 1 water consumption by more than 20,000 AFY, and the volume of water transfers to Central Basin is accordingly somewhat larger, leading to a slight rise in net benefit acquired by water pumpers in Central Basin.

equal expected marginal value of water over the horizon implies that the cumulative level of scarcity across all periods in the sample is not altered by amending the storage capacity available to water pumpers.

It is also possible to examine a scenario that uses the augmented storage capacity in the amended Judgment to mitigate the risk of water shortages among agencies in the Central and West Coast basins. The "fixed firm" scenario variation examines this possibility by (suboptimally) adjusting the level of Tier 1 purchases to leave the total amount of non-interruptible water in the water portfolio fixed. That is, from the (optimal) baseline allocation of 120,580 AF of Tier 1 imports in West Coast Basin and 180,730 AF of Tier 1 imports in Central Basin, the fixed firm scenario adjusts the Tier 1 contract downward to 100,580 AF in West Coast Basin (to account for the 20,000 AFY of recycled water) and adjusts the Tier 1 contract downward to 164,265 AF in Central Basin (to account for the 16,465 AFY of augmentation water). While such an adjustment does not make optimal use of the augmented storage capacity to generate economic benefits, it serves to illustrate the net benefit of the Judgment Amendments under circumstances that greatly mitigate the risk of water shortages. This analysis therefore provides a glimpse of the risk-return tradeoff available through alternative uses of storage in the basins.

Figure 10 depicts the distribution of outcomes for water use over the 60 draws of 22-year hydrologic conditions and the expected water use levels for each basin in the fixed firm comparison. The upper panels of the figure show the distribution of water use outcomes in each basin under the Judgment in thousands of AF (TAF), while the lower panels of the figure show the distribution of water use outcomes under the Judgment Amendments with the total level of non-interruptible water supply fixed at baseline levels. The bold red line represents the expected value of the distribution, and the blue lines project the three major drought events in the 82-year sample through the rolling horizon of hydrologic draws.

Notice that the variation in water use levels across the sixty draws of hydrologic conditions is similar to the baseline outcome during the transitional phase of storage development under the Judgment Amendments, but that the distribution of water use outcomes converges to the mean value of the distribution under the Judgment Amendments. Water deliveries in West Coast Basin are made without deviation from the desired consumption level after year 17 of the period and water deliveries in Central Basin are made without deviation from the desired consumption level after year 10 of the period. With the Judgment Amendments implemented by maintaining a fixed supply of non-interruptible water in each basin, water deliveries are made to retail water consumers at the end of the sample period without deviation from the desired consumption levels, irrespective of the prevailing draw of hydrologic conditions that characterize the availability of imported water supplies in the basins.

Figure 10. Expected Water Use Levels under Baseline and Amended Conditions with a Fixed Supply of Non-Interruptible Water, 2009-2030.

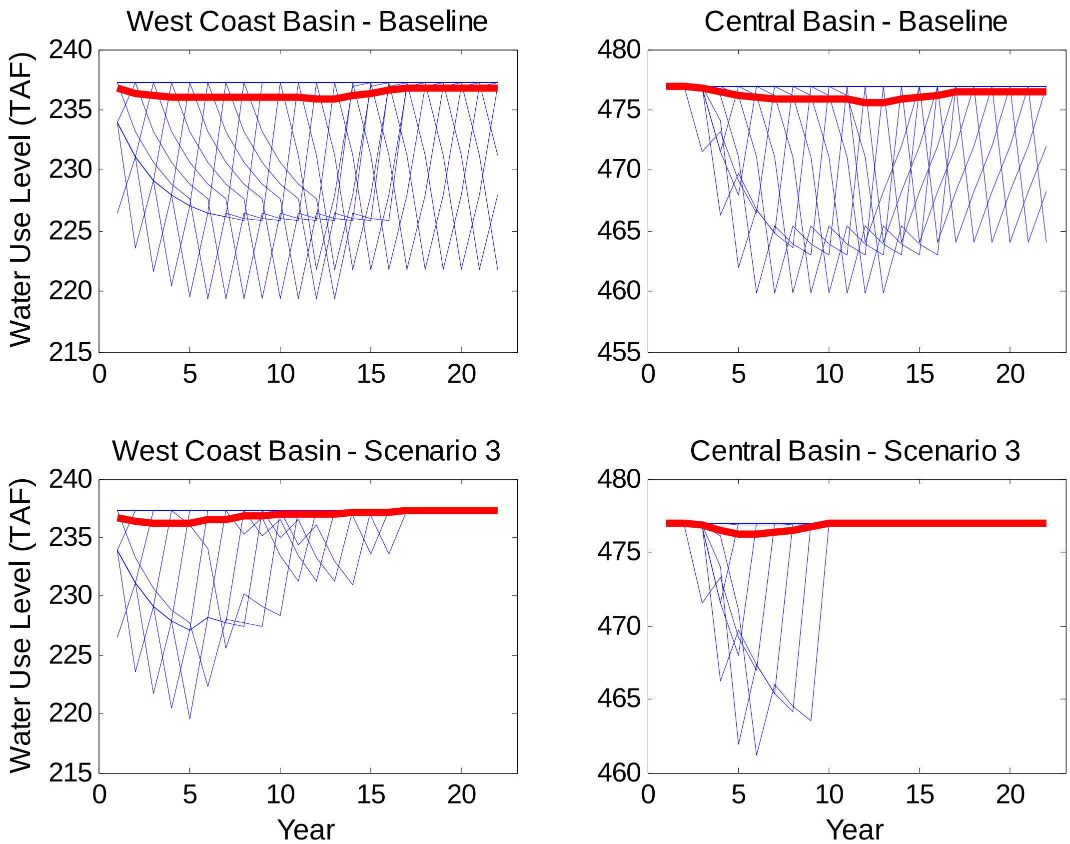
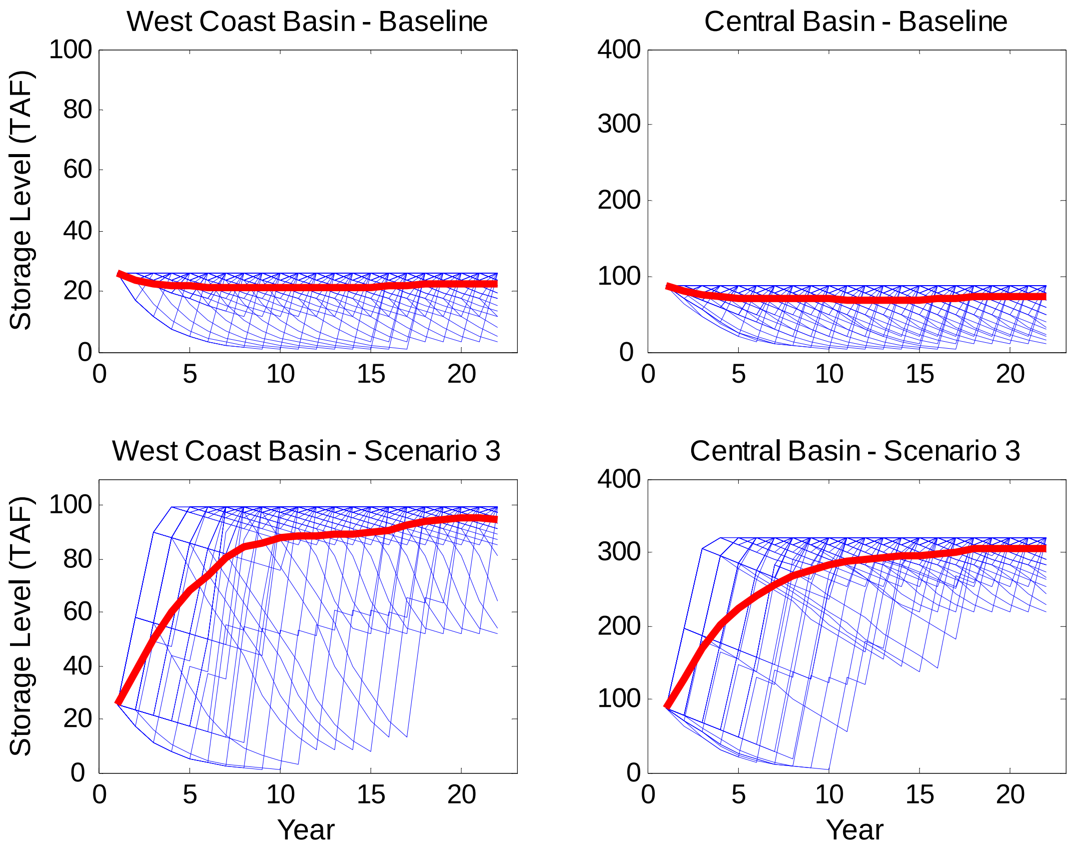


Figure 11 compares the expected path of groundwater storage in each basin over the period 2009-2030 under the Judgment (upper panels) and the fixed firm scenario of the Judgment Amendments (lower panels). Notice that the expected storage level under the Judgment Amendments trends steeply upwards from the baseline storage capacity to well over 80 percent of the augmented storage capacity, while the degree of variation in storage levels decreases, stepwise over time. This pattern of groundwater storage under the Judgment Amendments in the fixed firm scenario indicates the sub-optimal use of the augmented storage provisions in the basins.

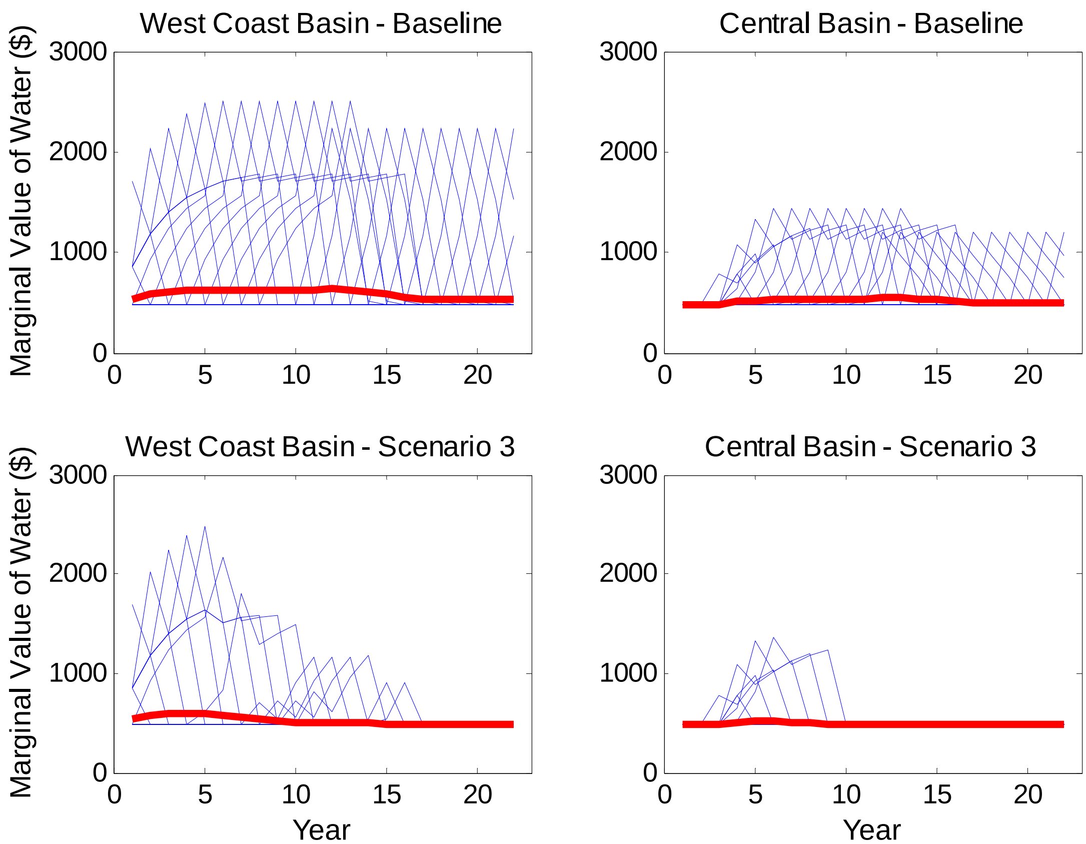
Figure 11. The Expected Storage Level under Baseline and Amended Conditions in the Fixed Firm Comparison, 2009-2030.



Under baseline conditions, in which the water portfolio is optimally adjusted in accord with the available level of storage in each basin, the available storage capacity in each period comes close to being entirely utilized. Across the 60 draws, the level of groundwater storage under baseline conditions ranges from full storage to a small fraction of capacity, with about 90 percent of the storage capacity being utilized in each year as draws from the hydrologic record project severe drought events through each year of the 22-year horizon. Under amended conditions with fixed non-interruptible supplies, in contrast, the storage capacity is not fully utilized after the basins complete the transitional phase of storage accumulation. This tend is most apparent in Central Basin, where the storage level towards the end of the horizon never falls by more than 30 percent from the maximum storage capacity in each year, even for draws from the hydrologic record that contain severe drought events.

Figure 12 depicts the marginal value of water in each basin under the Judgment (top panels) and Judgment Amendments (bottom panels) in the fixed firm comparison. The marginal value of water follows the opposite pattern as the water use level in each basin, rising above the replenishment rate during periods of water shortage to a level that reflects the underlying scarcity of water in consumption. Notice that the marginal value of water falls sharply under fixed firm management of the Judgment Amendments. This outcome reflects the fact that a water shortage never occurs towards the end of the 22-year horizon under the Judgment Amendments in the fixed firm scenario. Indeed, for all 60 draws from the hydrologic record, a retail water shortage never occurs at all in Central Basin during periods 10-22.

Figure 12. The Expected Marginal Value of Water under Baseline and Amended Conditions in the Fixed Firm Comparison, 2009-2030.



The suboptimal allocation of storage under the fixed firm scenario reduces the expected net present value of the Judgment Amendments to the region over the 2009-2030 period from $808 million to $560 million. Water pumpers in West Coast Basin receive an expected net benefit of $177 million and water pumpers in Central Basin receive an expected net benefit of $390 million. The value of the Judgment Amendments is comprised of an average annual net benefit flow of $5.7 million per year and a terminal value for the change in storage of $44.2 million in West Coast Basin and an average annual net benefit flow of $11.9 million per year and a terminal value of $129.0 million in Central Basin. Relative to the benchmark comparison that optimally adjusted the water portfolio under the amendments, the terminal levels of storage are larger and the annual benefit flow is smaller under the fixed firm portfolio adjustment.

The net benefit of the Judgment Amendments is the sum of the annual net benefit of reductions in the cost of water service and the cash value of the change in groundwater stock held in storage at the end of the 22-year horizon. In the fixed firm scenario, the change in the stock of groundwater held in storage at the end of the horizon under the amendments is considerably higher than in the benchmark comparison ($44.2 million in West Coast Basin relative to $37.8 million under the optimal water portfolio; $129.0 million in Central Basin relative to $106.9 million under the optimal water portfolio), which reflects an inefficient use of the groundwater storage over time. This inefficiency is reflected in a smaller annual flow of net benefits ($5.7 million per year in West Coast Basin relative to $8.4 million under optimal management; $11.9 million per year in Central Basin relative to $21.8 million under optimal management) and a commensurately lower overall net benefit from adopting the Judgment Amendments. The overall net benefit of the storage provisions encompassed by the Judgment Amendments nevertheless is $560 million in an environment characterized by greatly reduced risk of retail water rationing.

5.2.3 Recycled Water Development to 54,000 AF

In addition to the most economical source of recycled water development at existing barrier wells in West Coast Basin, it is possible to develop an additional 34,000 AFY of recycled water in Central Basin through the delivery of advanced treated recycled water from the Long Beach and Los Coyotes Water Reclamation Plants to the San Gabriel River Spreading Grounds. The projected total cost of spreading advanced treated recycled water into storage for water pumpers in Central Basin (with capital costs amortized over 30 years) is anticipated to be $772/AF, which represents a $177/AF premium over the cost of injecting advanced treated recycled water using existing barrier wells in West Coast Basin ($600/AF).

To assess the value of recycled water development in Central Basin under the Judgment Amendments, this section considers the net benefit of the Judgment Amendments under circumstances in which 34,000 AFY of recycled water resources are exploited in Central Basin. This development of recycled water occurs in addition to the 20,000 AFY of recycled water development in West Coast Basin.

The distributions of water use levels, storage levels, and marginal values of water under the Judgment Amendments in this scenario are qualitatively similar to the outcomes presented in the benchmark comparison. These figures are provided in Appendix A of this report.

The physical storage of advanced treated recycled water in Central Basin increases the expected net present value of the Judgment Amendments to the region over the 2009-2030 period from $808 million to $944 million. Water pumpers in West Coast Basin receive an expected net benefit of $223 million, roughly $1 million more over the period than in the case of no recycled water development in Central Basin, and water pumpers in Central Basin receive an expected net benefit of $721 million.[37] The value of the

[37] The slight increase in the value of the Judgment amendments to water pumpers in West Coast Basin as a result of recycled water development in Central Basin arises due to a slight increase in water transfers resulting from the portfolio adjustment of water pumpers in Central Basin. Water pumpers in Central Basin

Judgment Amendments is comprised of an average annual net benefit flow of $8.4 million per year and a terminal value for the change in storage of $37.8 million in West Coast Basin and an average annual net benefit flow of $27.9 million per year and a terminal value of $106.9 million in Central Basin. Relative to the benchmark comparison with 20,000 AFY of recycled water storage in West Coast Basin, similar stocks of water are held in storage at the end of the 22-year horizon, while the development of advanced treated recycled water resources in Central Basin increases the annual flow of net benefit to water pumpers in Central Basin by $6.1 million per year.

On a per unit basis of water rights, the net benefit to water pumpers in West Coast Basin over the period 2009-2030 is $3,454/AF and the net benefit to water pumpers in Central Basin over the period is $3,318/AF.

In total, the incremental net benefit that results from the development of 34,000 AFY of advanced treated recycled water resources in Central Basin under the physical storage provisions of the Judgment Amendments is $135 million (= $721 – $586). This implies that the incremental return to recycled water development above the $2,696/AF net benefit that accrues to pumping rights in Central Basin is a premium of $3,973/AF associated with each unit of recycled water developed in Central Basin. The premium acquired by water pumpers for recycled water development in Central Basin is roughly 35 percent smaller (on a per AF basis) than the premium acquired for recycled water development in West Coast Basin due to the relatively higher cost of developing these resources.

5.3 Discussion of Benefits Not Encompassed by the Study

The Judgment Amendments provide two notable benefits to Southern California's water supply network outside the economic framework considered here. First, the reduced Tier 1 contract levels in Central and West Coast Basins that result from the amendments (see Table 6) serve to reduce the demand on fixed resources in the MWD water supply system, leaving a greater allocation of non-interruptible water to other users in the MWD network. The optimal use of the increased storage capacity under the amendments dials down pressure on the water supply system in Southern California, which is expected at times to operate under conditions of extreme water scarcity, and making use of available storage to convert replenishment water into reliable water in regional water portfolio leaves a greater reliable water supply for agencies outside the scope of this study and therefore helps mitigate water scarcity for parties in Southern California. Second, the net benefit calculated in the present study does not encompass the regional storage component of the Judgment Amendments. The availability of regional storage also adds value to the water distribution network of Southern California, for instance units of storage provided by the amendments that are not allocated to specific use provide an

collectively reduce their Tier 1 water consumption by more than 34,000 AFY, and the volume of water transfers from West Coast Basin to Central Basin is accordingly larger (although still remaining below 5,000 AF per year in all cases). The economic value generated by additional water trading in response to the portfolio adjustment of agencies in Central Basin leads to a slight rise in net benefit for water pumpers in West Coast Basin.

option value component to agents. To the extent that the potential exists for use of the regional storage component in the future, the provision of regional storage has the potential to considerably increase the present value of net benefits to water pumpers that ultimately make use of this storage component.

6. Summary of Net Benefits

Over the period 2009 – 2030, the benefits of the Judgment Amendments to the region are $808 million under Scenario 1, with $222 million accruing to agencies in the West Coast Basin, and $586 million to agencies in the Central Basin. Increasing the quantity of recycled water by adding 34,000 AF per year in the Central Basin increases economic benefits to $944 million in Scenario 4.

Scenarios 2 and 3 are not optimal in important respects. Scenario 2 demonstrates that investment in additional recycled water in the West Coast Basin passes a benefit-cost test; keeping recycled water use in that basin at its current level lowers economic welfare by $124 million (from $808 million to $684 million) over the term of the amendments. Similarly, keeping Tier 1 purchases at baseline levels in the face of the Judgment Amendments lowers economic welfare by $228 million (from $808 million to $560 million).

Table 7. Summary of Expected Net Benefits, 2009-2030 (million $s)

	West Coast Basin	Central Basin	CWCB Total
Scenario 1 (20,0000 AF recycling)	$222	$586	$808
Scenario 2 (No recycling)	$98	$586	$684
Scenario 3 ("Fixed Firm")	$171	$390	$560
Scenario 4 (54,000 AF recycling)	$223	$721	$944

Source: BEC calculations.

Table 8 expresses the net benefit of the Judgment Amendments for all variations in terms of the expected increase in the value of a groundwater pumping right over the period 2009-2030. Depending on the level of recycled water development in each basin, the value of a pumping right in West Coast Basin increases by an amount between $1,523 and $3,454 per acre-foot and the value of a pumping right in Central Basin increases by an amount between $2,695 and $3,318 per acre-foot. In the fixed firm scenario the value of a pumping right rises by $2,646/AF in West Coast Basin and by $1,793/AF in Central Basin.

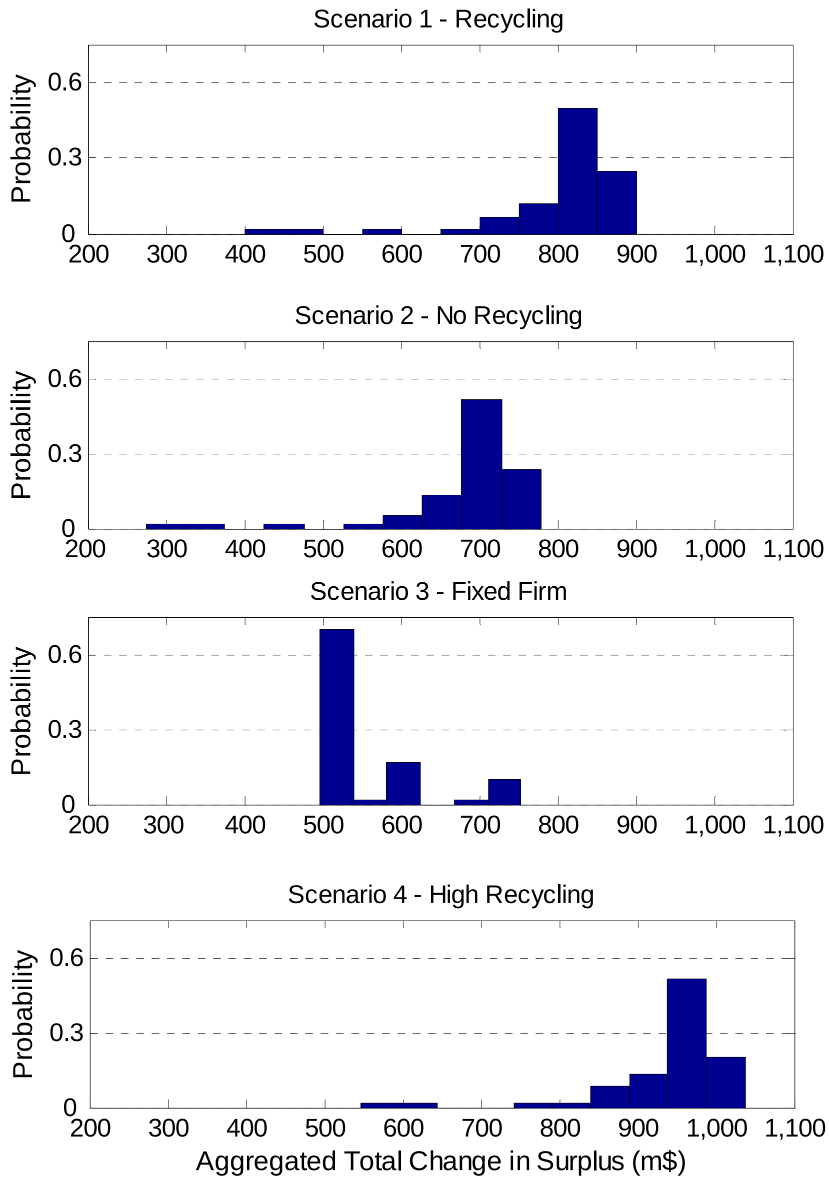
Table 8. Expected Increase in the Value of Water Rights in the CWCB over the Period 2009-2030 ($/AF)

	West Coast Basin	Central Basin	CWCB Average
Scenario 1 (20,0000 AF recycling)	$3,449	$2,695	$2,867
Scenario 2 (No recycling)	$1,523	$2,696	$2,428
Scenario 3 ("Fixed Firm")	$2,646	$1,793	$1,988
Scenario 4 (54,000 AF recycling)	$3,454	$3,318	$3,349

Source: BEC calculations.

Figure 13 shows the distribution of net benefits over the sequence of 22-year rolling horizons in the hydrologic record from 1922-2003. The figure displays the probabilities (the percentages on the left axis on each of the above graphs) that any particular scenario results in a given amount of economic benefits. For example, there is a roughly 50 percentage probability that Scenario 1 will produce between $800 and $850 million in economic benefits, as reflected on the top blue bar on the above graph. Note that the benefits listed in the table at page 5 above represent the *average* of all expected benefits across all hydrologic intervals for each of the four studied scenarios. Some particular hydrologic sequences can result in lower benefits than those average benefits, with some chance that benefits can be as low as $400 million. However, there is no hydrologic sequence for which the Judgment Amendments perform worse than the baseline under the existing Judgments.

Figure 13. The Distribution of Aggregated Net Benefit of the Judgment Amendments over Sequential 22-Year Rolling Horizons



Note that the mean and variance changes for different scenarios. Scenario 1, 2 and 4 have a very similar distribution, with a longer tail on the left and median located on the right side. However, there is a shift in mean of the net present value as more in situ water becomes available under the Judgment Amendment for the various scenarios which cuts their level of Tier 1 dependence. Scenario 4 with 54 TAF of recycled water is the most profitable scenario of all. The net present value of the Judgment Amendments aggregated over the two basins ranges between $400-$900 million for Scenario 1, $300-$780 for scenario 2, and between 600 million and $1 billion for scenario 4. Scenario 3, "Fixed Firm" leads to lowest aggregated net present value. Its median is located on the lower end of the distribution with $500 million value which is significantly lower than the median of the other three scenarios.

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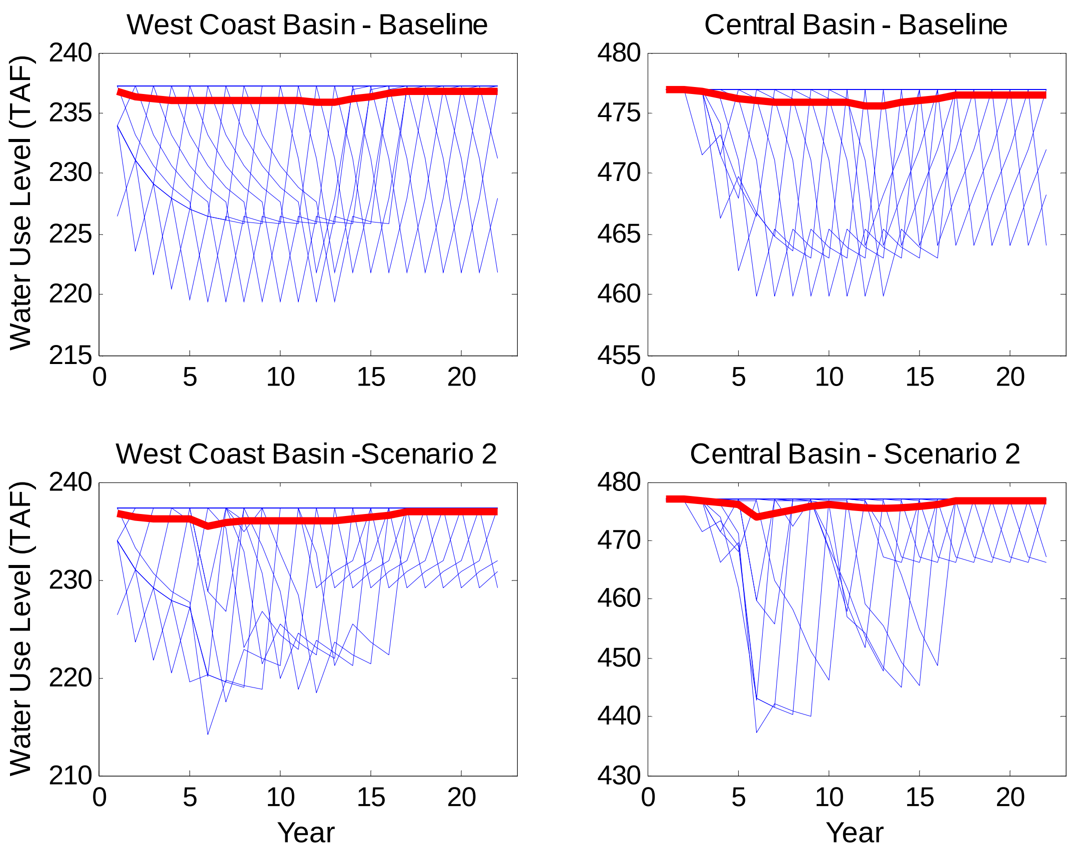
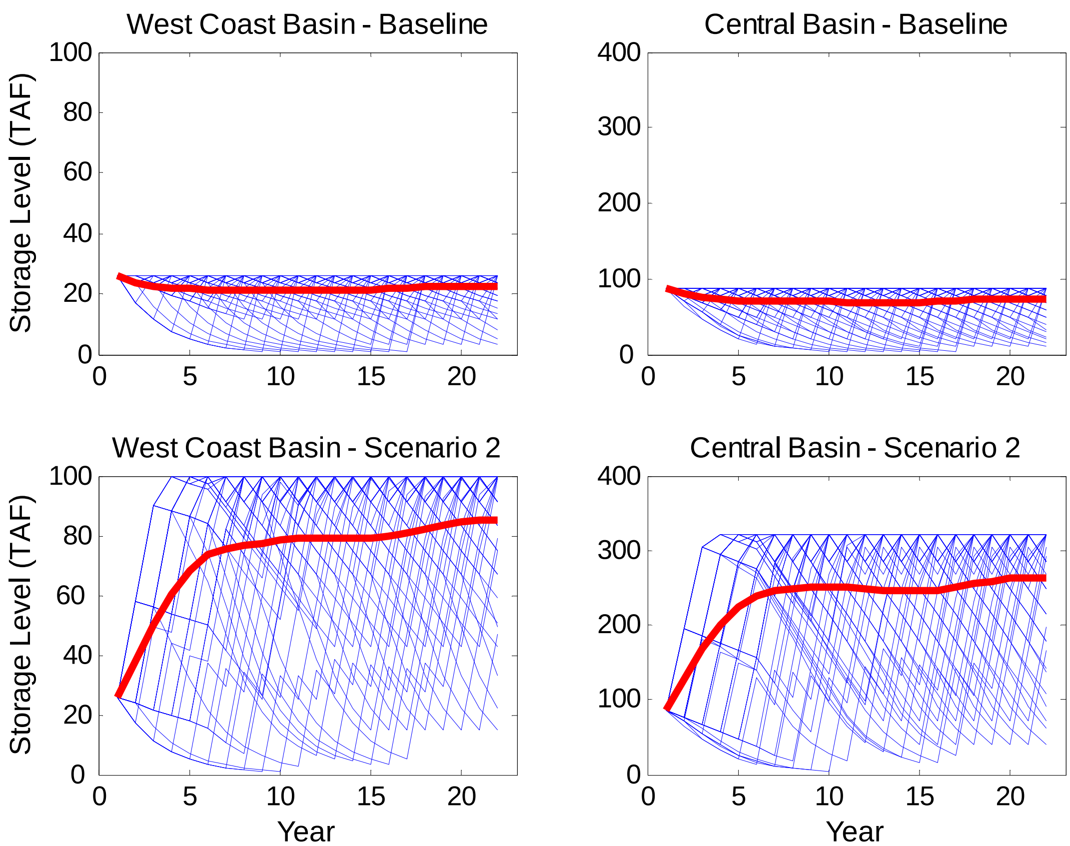
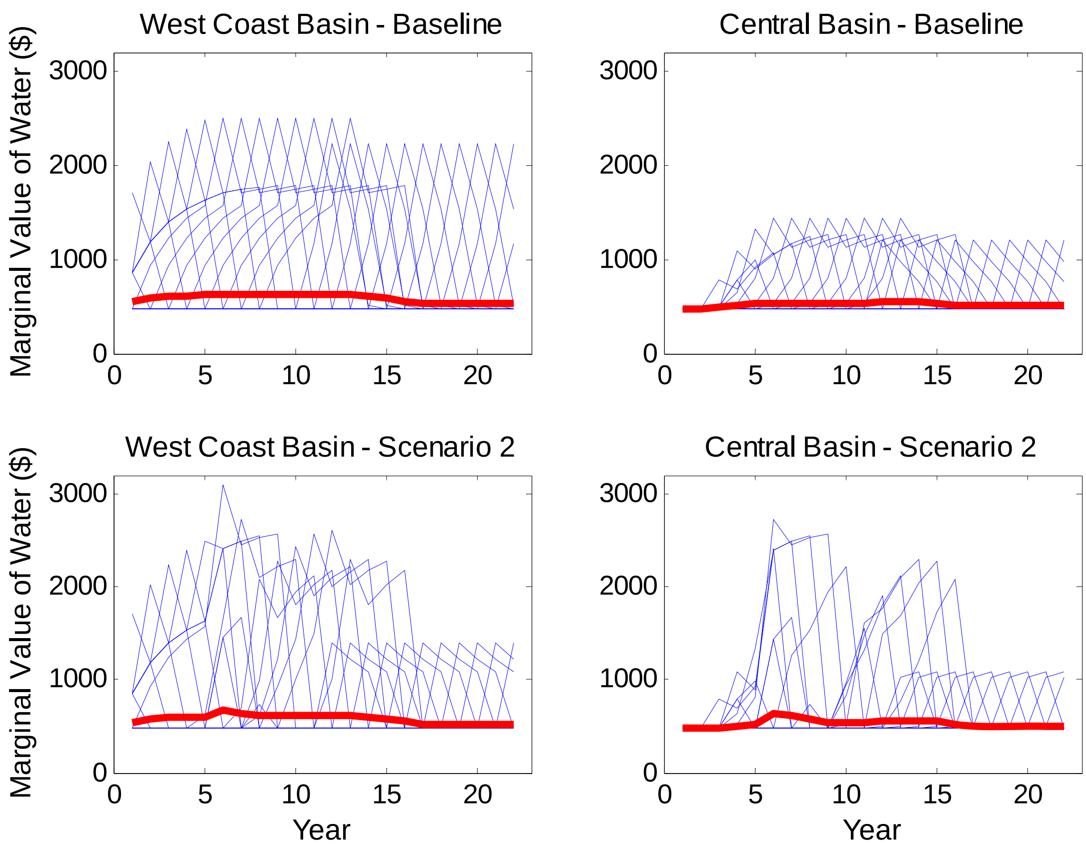
Appendix A: Outcomes of Scenario Variations 2 and 4

Scenario 2: No Recycled Water Development




West Coast Basin - Baseline
Central Basin - Baseline
West Coast Basin - Scenario 2
Central Basin - Scenario 2
Storage Level (TAF)
Year
0
5
10
15
20
100
80
60
40
400
300
200



Scenario 2 Summary:

<u>a. West Coast Basin</u>

Mean (Total Change in Surplus - 60 representations) = 9.8216e+007
Minimum (Total Change in Surplus - 60 representations) = -2.0872e+007
Maximum (Total Change in Surplus- 60 representations) = 6.5284e+008

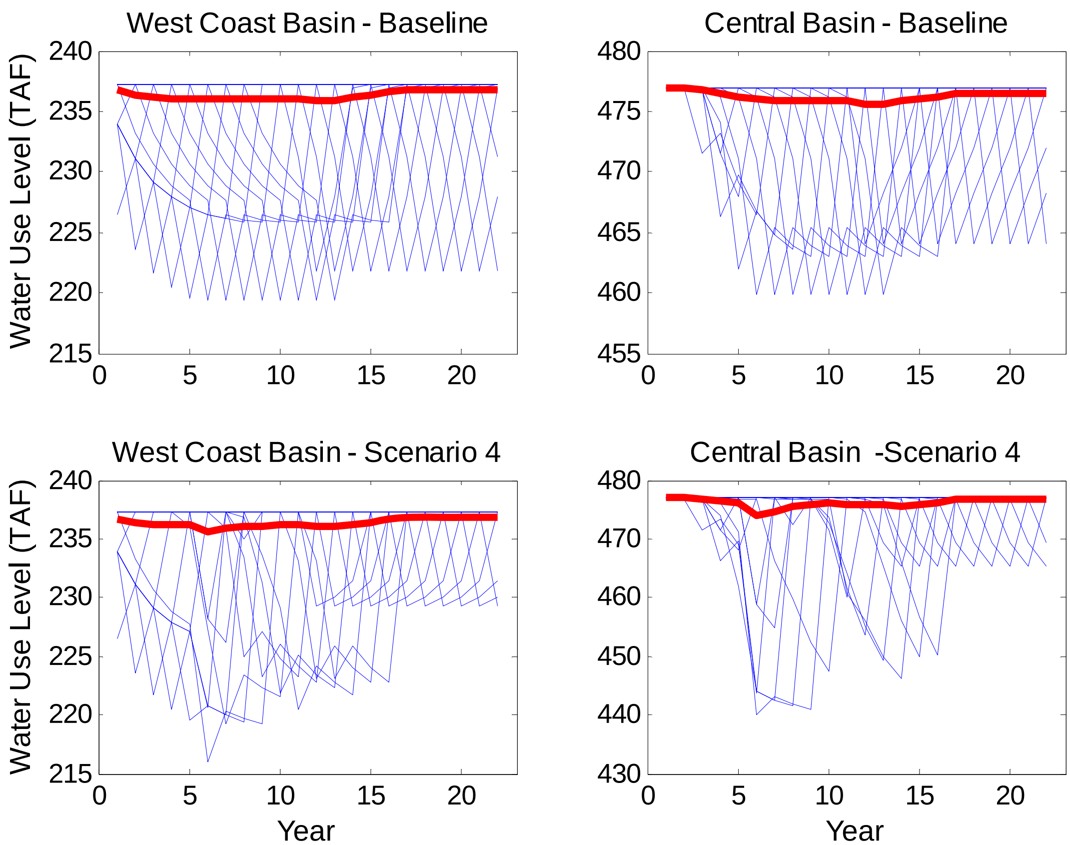
Mean value of the terminal storage stock – 60 representation = 3.8139e+007

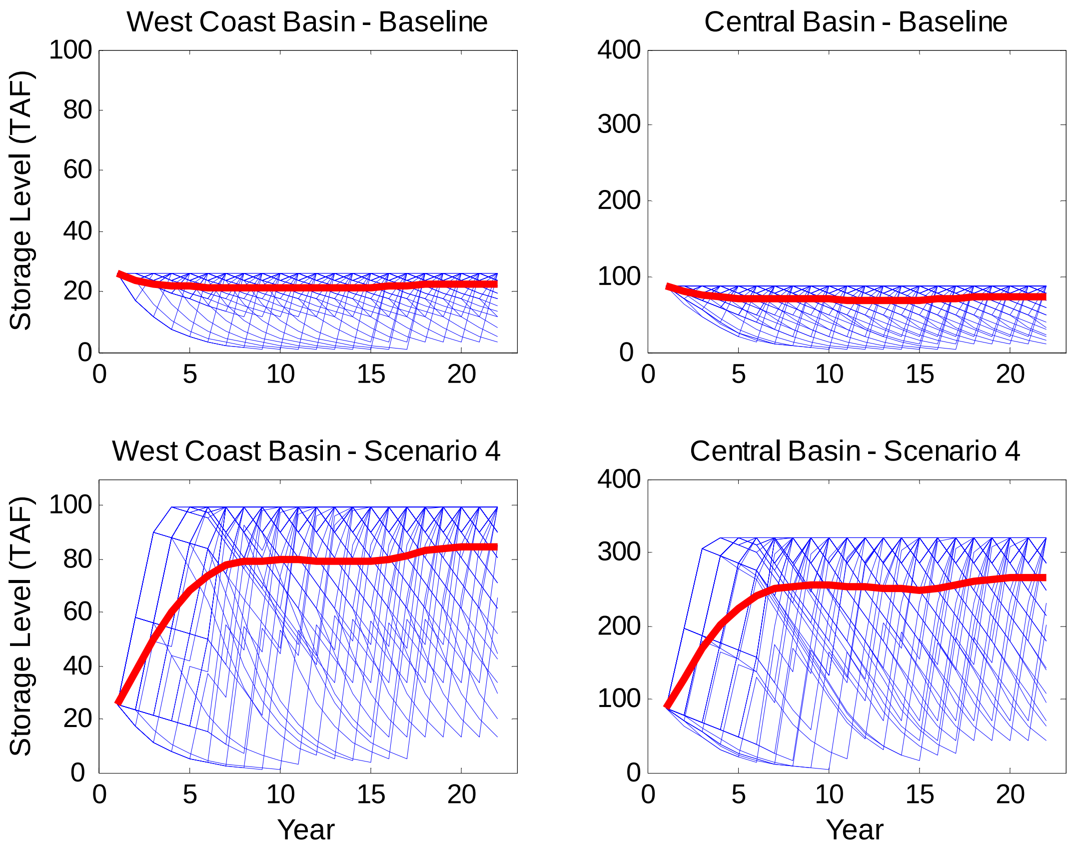
<u>b. Central Basin</u>

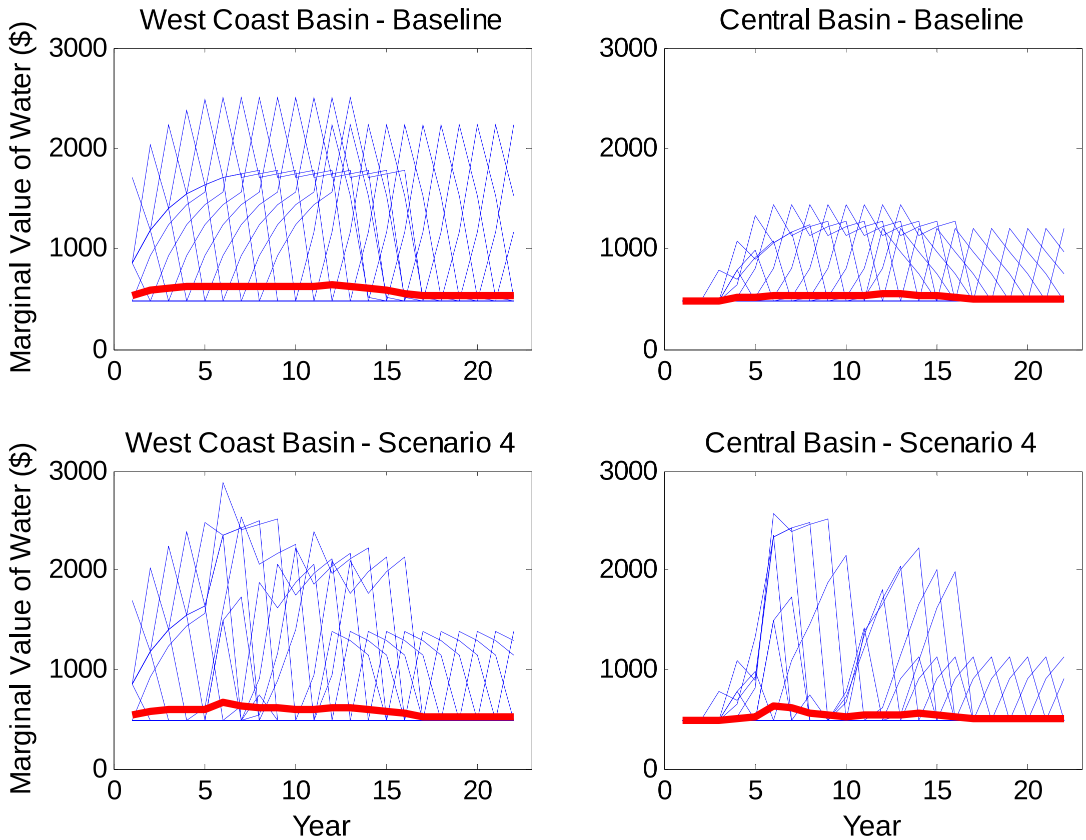
Mean (Total Change in Surplus - 60 representations) = 5.8608e+008
Minimum (Total Change in Surplus - 60 representations) = 2.9550e+008
Maximum (Total Change in Surplus- 60 representations) = 6.5284e+008

Mean value of the terminal storage stock – 60 representations = 1.0568e+008

Scenario 4: 54,000 AFY of Recycled Water (20,000 AF in WCB; 34,000 AF in CB)




West Coast Basin - Baseline
Central Basin - Baseline
West Coast Basin - Scenario 4
Central Basin - Scenario 4
Storage Level (TAF)
Year
0
5
10
15
20
100
80
60
40
300
200
400



Scenario 4 Summary:

<u>a. West Coast Basin</u>

Mean (Total Change in Surplus - 60 representations) = 2.2268e+008
Minimum (Total Change in Surplus - 60 representations) = 1.0728e+008
Maximum (Total Change in Surplus- 60 representations) = 2.5129e+008

Mean value of the terminal storage stock – 60 representation = 3.7725e+007

<u>b. Central Basin</u>

Mean (Total Change in Surplus - 60 representations) = 7.2116e+008
Minimum (Total Change in Surplus - 60 representations) = 4.3944e+008
Maximum (Total Change in Surplus- 60 representations) = 7.8864e+008

Mean value of the terminal storage stock – 60 representations = 1.0692e+008

Appendix B: Programming Model

Let:

α_t ≡ share of imported water available at time t
G ≡ groundwater –adjudicated rights
X ≡ other water available (direct use recycled + groundwater rights outside basin)
A ≡ Augmentation project water (0 in baseline; 17,000 AFY under amendments)
N ≡ Required pumping to attain augmentation project water
Z ≡ Imported Tier 1 water level
R_t ≡ Replenishment water at time t
R_{1t} ≡ Replenishment water for consumption at time t
R_{2t} ≡ Replenishment water taken for in lieu storage contribution at time t
S^c ≡ Basin storage capacity
S_t ≡ storage level at time t
y_t ≡ "take" from storage at time t
W_t ≡ Water consumption at time t
W^* ≡ Ideal water consumption in each period ("bliss point")
P_z ≡ Price of importer Tier 1 water
P_R ≡ Price of replenishment water
$P_{T,t}$ ≡ (Real) Price of recycled water at time t
c ≡ Price of groundwater (pumping and treatment cost)
d ≡ Additional O&M cost per AF of required augmentation project pumping
r ≡ Discount rate
i ≡ Escalation rate of recycled water price

Objective (Q*): Select Z to maximize

$$Q^* = \sum_{t=0}^{T} aW_t - 0.5bW_t^2 - \alpha_t P_Z Z - P_R R_t - P_{T,t} T - c(G - R_{2t}) - cX - cy_t - dN$$

Subject to:

(1) $W_t = A + G + X + T + \alpha_t Z + R_{1t} + y_t$
(2) $S_{t+1} = S_t + R_{2t} - y_t$
(3) $R_t = R_{1t} + R_{2t}$
(4) $P_{T,t} = \left(\frac{1+i}{1+r}\right)^t P_T$
(5) $0 \le S_t \le S^C$
(6) $0 \le y_t \le \delta S_t$
(7) $0 \le R_{1t}$
(8) $0 \le R_{2t} \le \beta G + A + T$
(9) A,T become available in year 5 (i.e., A=T=0 for t=0,1,2,3,4)

R_t: Replenishment water is available in a "wet" year but not a "dry" year:

1) replenishment water can be "consumed" directly (R_{1t});
2) replenishment water can be used to recharge storage (R_{2t}) when $S_t < S^c$
   a) recharge potential limited by the constraint ($R_{2t} \leq \beta G + A + T$)

W_t: Water use at time t depends on whether replenishment water (R_t) is available and whether rationing occurs ($\alpha_t < 1$) in the MWD supply allocation (NOTE: It is possible that replenishment water is not available even when rationing does not occur.)

Operating conditions in "wet" years:

(1) $\alpha_t = 1$ (no rationing)
(2) $y_t = 0$ (no extractions from storage)
(3) $R_{2t} = Min.\{\beta G, S^c - S_t\}$
(4) $R_{1t} = W^* - A - G - X - T - Z$

In "dry" years there are three levels of MWD rationing: $\alpha_t = \{\alpha_1$ (10%), α_2 (20%), or α_3 (40%)$\}$

Operating conditions in dry years:

(1) $\alpha_t = \{1, \alpha_1, \alpha_2, \alpha_3\}$ according to hydrologic record
(2) $R_{1t} = R_{2t} = 0$
(3) $y_t = Min.\{W^* - A - G - X - T - \alpha_t Z, \delta S_t\}$

Table 5 presents starting values for the benchmark situation (scenario 1) in each basin (West Coast Basin and Central Basin):

In addition, trading is only possible from WCB to CB. To consider one-way trading, the program needs to recover W_t in each basin for all t. Let $W_{c,t}^+$ and $W_{w,t}^+$ denote the ultimate (post-trading) water use in CB and WCB respectively at time t.

Additional programming conditions:

Step 1: Recover Z_w^* and Z_c^* for each basin without trading (as above)
Step 2: Recover the marginal value of water in each basin (e.g., $\lambda_{c,t}^* = a - bW_{c,t}$)
Step 3: Compare $\lambda_{c,t}^*$ and $\lambda_{w,t}^*$ in each period t
Step 4: Adjust $W_{c,t}$ and $W_{w,t}$ through water trading as follows
If $\lambda_{c,t}^* \leq \lambda_{w,t}^*$ then no trading occurs ($W_{c,t} = W_{c,t}^+$ and $W_{w,t} = W_{w,t}^+$)
If $\lambda_{c,t}^* > \lambda_{w,t}^*$ then trading arises and:

$$W_{c,t}^+ = \frac{a_c - a_w + b_w(W_{c,t} + W_{w,t})}{b_c + b_w}$$

$$W_{w,t}^+ = \frac{a_w - a_c + b_c(W_{c,t} + W_{w,t})}{b_c + b_w}$$

<u>Scenario Variations:</u>

Scenario 2: No recycling (T=0)

Scenario 3: Fixed Firm (leave z* fixed at baseline levels for each basin)
Scenario 4: 34,000 AF of recycled water developed in Central Basin

(a) Add this quantity into Q* as a separate cost from WCB recycled water

(b) Decompose the price of CB recycled water into two terms:

At time t=0: P_{T1} = \$422 and P_{T2} = \$350

(c) Escalate the price over time for CB recycled water as follows:

$$P_{T,t} = \left(\frac{1}{1+r}\right)^t P_{T,1} + \left(\frac{1+i}{1+r}\right)^t P_{T,2}$$