Where Will We Get the Water?
Assessing Southern California's Future Water Strategies

Los Angeles County Economic Development Corporation

PRELIMINARY FINDINGS

DRAFT

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Assessing Southern California Water Strategies

Strategy	2025 Regional Potential (TAF*)	Typical Project Characteristics: Timeframe (years)	Drought-Proof (Reliability)	Risk (Project Aborted)	Enviro Opinion	GHG	Initial Cap. Cost ($millions)	Annual Oper. Cost ($millions)	30-yr cost Treated ($/AF)
Strategies to Replace or Augment Imported Water									
Urban Water Conservation	1,100+	0-2	🟢	🟢	🟢	🟢	$5	$0.5	$280
Local Stormwater Capture	150+	3-5	🔴	🟢	🟢	🟢	$40-$63	$1-$3.5	$350+
Recycling	450+	6-10	🟢	🟡	🟢	🟡	$480	$30	$1,000
Ocean Desalination	150+	6-10	🟢	🟡	🔴	🔴	$300	$37	$1,100+
Groundwater Desalination	TBD	6-10	🟢	🟡	🟡	🟡	$24	$0.7	$1,200
Strategies to Increase Imported Water									
Transfers-Ag to Urban	200+	4-10	🟡	🔴	🟡	🟢	n/a	n/a	$700+
Strategies to Increase Reliability									
Inter-agency Cooperation	**	0-5	🟢	🟡	🟢	🟢	low	low	n/a
Groundwater Storage	1,500+	3-5	🟡	🟡	🟢	🟡	$68-$135	$13	$580
Surface Storage	0	10+	🔴	🔴	🔴	🟡	$2,500+	$7.5-$15.5	$760-$1,400

*TAF-Thousand Acre-Feet
** Improves reliability and efficiency of existing supplies
Source: LAEDC

🟢 **Favorable** 🟡 **Neutral** 🔴 **Unfavorable**

I. INTRODUCTION

California is in a water crisis. The spring of 2008 was the driest in 88 years, and rivers across the state are running dangerously low. Furthermore, mountain snowpack has been subject to increased evaporation, a condition likely to be exacerbated in future years by climate change. The disaster in New Orleans has also brought attention to the aging dams and levees in the Sacramento-San Joaquin Delta system. An earthquake or levee breach could disrupt the intricate flow of water into and out of the Bay Area; such an event would create a water disaster in all parts of the state from the East Bay to the Mexican border.

In the face of this emergency, Governor Schwarzenegger has declared a statewide drought. His declaration has brought water to the forefront of California politics, news and public opinion. It is crucial to address California's long-deferred water issues now, while the entire state is focused on the threat to water viability. The Governor and Senator Feinstein have collaborated to produce the Safe, Clean, Reliable, Drinking Water Supply Act of 2008. This act proposes spending over $9 billion on various strategies to increase water supply, decrease the variability of supply, restore ecosystems and promote conservation and efficient water use. Speaker Pro-Tem Perata has introduced legislation that would appropriate over $600 million in previously authorized bond funds to restore the Delta and improve water infrastructure.

In November, Californians will face one or more ballot initiatives that would authorize funds to solve the water crisis. Approving the funds, however, is merely the starting point. The state's water needs are vast (and expensive). Yet, the budget crisis and the demands for other infrastructure improvements, education and health services, and other spending priorities mean the state will always have fewer resources to address water issues than there are worthy projects. In this context, California voters, elected officials and water policy makers must carefully select the strategies to which they will commit scarce resources. To this end, the LAEDC has produced for the Southern California Leadership Council (SCLC) a report evaluating strategies for improving Southern California's water supply based on cost-effectiveness, environmental impact and overall efficacy.

This preliminary report is a work in progress and will be updated frequently. Please check for the latest version at www.laedc.org/sclc/studies.html. The LAEDC is constantly seeking new input from water agencies and experts regarding existing and proposed water sources. To contribute information on water strategies, please contact Greg Freeman, Vice President of Economic Policy and Consulting, at greg.freeman@laedc.org, or call (213) 236-4846.

We evaluate nine water strategies. Urban water conservation, stormwater capture, recycling, ocean desalination, and groundwater desalination are viable strategies to replace or augment imported water. Transfers from agricultural users to urban users increase the volume of imported water. And inter-agency cooperation, groundwater storage, and surface storage are strategies that increase overall water system reliability, particularly during dry years.

BACKGROUND

Southern California, comprised of Los Angeles, Orange, San Bernardino, San Diego, Riverside and Ventura counties, is the 10th largest economy in the world and home to almost 22 million people. The semi-arid region's development was underpinned by imported water, which accounts for 60% of supplies overall and up to 90% in areas with limited local sources. Driven by natural increase – people already here having children – population growth is expected to add 6 million more residents, 2007 to 2030. Securing reliable water supplies for the next generation (and its successors) looms as a significant challenge.

Most of Southern California's water is imported from three sources: the Colorado River, the San Francisco Bay-Delta, and, for the City of Los Angeles, the Owens River Valley. All three sources are under pressure. The Colorado River Basin has endured eight years of drought, with no end in sight. Water levels at the two main storage facilities on the river (Lake Mead behind the Hoover Dam and Lake Powell behind the Glen Canyon Dam) have been reduced to less than half of their capacity. Supplies from the Bay-Delta and Owens River have already been reduced to return water formerly available for export to Southern California for local protection of endangered species and habitat restoration. Until the Delta is restored and a long-term solution for water exports is implemented, further cuts appear unavoidable. Exports from the Delta could also be cut off completely for a year or more if a temblor or flood were to destroy critical earthen levees. Continued population growth in California and throughout the Southwestern U.S. will place greater demands on these sources just as climate change threatens to reduce their productivity and reliability.

Water shortages or disruptions would have far-reaching and, if prolonged, dire consequences for Southern California. The region needs to undertake an urgent program to secure sufficient, reliable water supplies for the coming decades. The solution will have to incorporate a portfolio of water strategies, since no single strategy will provide a "silver bullet" solution to the region's water needs. The price of water security will not be cheap. The rate charged by MWD for Tier II treated water (currently $695 per acre-foot) represents the baseline cost of incremental water supplies in Southern California. Many of the water strategies evaluated in this report exceed the cost of the MWD-supplied water by hundreds of dollars per acre-foot. Since the MWD rate is expected to continue to rise substantially over the coming decade, many of the more expensive strategies will look more reasonable in the future.

METHODOLOGY

The LAEDC has evaluated nine water strategies based on their *potential* (the total average annual volume of water the strategy could add to the region's water supply available to urban water users). For each strategy, representative projects were selected and evaluated based on eight criteria: *reliability* (the ability to deliver water during dry years); *timeliness* (the number of years from project conception to the start of operations); *risk* (the probability that projects undertaken as part of a strategy will ultimately be completed and deliver or store water); *environmental friendliness* (the likely reception projects can expect based on their environmental impacts); *greenhouse gases* (the impact of the project's operations and water deliveries on the state's carbon footprint); *capital cost* (the initial cost of the strategy); *operating cost* (the ongoing annual cost of the strategy); and *30-year cost* (the all-in cost per acre-foot for water sourced from the project, including initial capital costs plus operating costs, interest payments, and, where applicable, the cost of transporting the water to Southern California).

In selecting representative water projects for each strategy, we gave preference to those that are large, already in operation, or likely to come to fruition. Some projects have little in common. Our objective has been to create an apples-to-apples comparison, particularly for the cost of the projects typical of each strategy, which we have estimated on a per acre-foot basis. Our data and calculations are based on the best available public information. Some data were unavailable and have been estimated by extrapolation. Throughout the process, we always erred on the side of understating a project's yield (amount of water supplied), therefore overstating the unit cost of its water, but we also used low estimates of the project's costs, therefore potentially understating the price of its water. These effects should be roughly offsetting in the final price of water per acre-foot.

Three numbers go into the calculation of each project's overall cost per acre-foot of treated water ready for delivery in Southern California: capital cost, operating cost, and yield. The capital cost is the initial cost of building or implementing a project. The operating cost is the yearly cost of keeping the project running. We assume the project's capital cost is funded by issuing debt, which is amortized over a 30-year period at a rate of 5.00%. The annual debt payments are added to the operating cost to determine the total cost per year. This number is then divided by the project's yield per year to determine the cost per acre-foot of water over the next 30 years. Many of the projects will have useful lives that exceed 30 years, which at first glance implies a lower cost per acre-foot once the debt has been repaid. However, most projects likely will experience rising maintenance costs after 30 years, as old capital facilities need to be repaired or replaced. To be conservative, therefore, we assume projects will face constant costs over their lifespan, and thus they will provide water at a constant price.

Two additional costs may also be included in the final price of water. Where applicable, the cost of transporting the water to Southern California has been included. We have also included treatment costs to make for a fair comparison with desalination projects, which produce treated, ready-to-drink water. We used the $155 difference between the cost MWD charges for treated and untreated water.

II. STRATEGIES TO REPLACE OR AUGMENT IMPORTED WATER

Southern California's traditional sources of imported water are under increasing pressure. Recognition of the environmental consequences of diverting water has led to court-ordered curtailment of water exports from the Bay-Delta and the Owens River. An ongoing eight-year drought in the Colorado River Basin has depleted stored supplies. Moreover, water agencies throughout the Southwest have belatedly realized the Colorado River is oversubscribed due to annual allocations that were based on the average flows during an exceptionally wet period. Continued population growth will increase the potential demand on the sources of Southern California's imported supplies. Simultaneously, climate change, and in particular the likely decrease in the winter snowpack in the Sierra Nevada Mountains that acts as a giant natural reservoir, threatens the reliability of supplies imported from Northern California. Finally, the fragility, vulnerability and unsustainability of the Delta as a transfer point for water exported to Southern California also results in reduced reliability of water necessary to sustain our economy and our lifestyle.

Faced with these challenges and constraints on imported supplies, Southern California must embark on a concerted self-help program that replaces or augments imported water with locally sourced supplies. In this section, we examine five strategies that could supplement or even offset current imports: urban water conservation, stormwater capture, recycling, ocean desalination, and groundwater desalination.

URBAN WATER CONSERVATION

Southern California needs to increase its water supplies to meet the needs of a growing population and to protect against inevitable interruptions to imported sources. Such interruptions may occur due to environmental mitigation; drought; natural disaster; and climate change. Using water more efficiently reduces demand, which has the same effect as adding water to the system. Conservation is a simple, reliable and environmentally friendly strategy that has already paid dividends within the region.

Conservation has helped hold water consumption at roughly the same level in the City of Los Angeles over the past 10 years, despite a growing population. These efficiency gains are the product of initiatives to curb indoor water use undertaken as much as 20 years ago. These initiatives include building code requirements for low-flow toilets and showers in new homes and rebates for water-efficient appliances, in particular dishwashers and washing machines.

For example, the City of Santa Monica, considered a regional leader in water conservation, has enacted a water conservation effort as part of its Sustainable City Plan. The plan aims to reduce water consumption by 20% of 2001 levels by the year 2010. (As of 2008, citywide water use has fallen by 6% while the number of residents and businesses has increased.) In general, water is too inexpensive for a price increase to motivate conservation. (Tiered pricing structures, in which the price of water increases steeply after predetermined usage thresholds, have shown some efficacy in curbing demand.) Santa Monica's conservation program instead seeks to convince residents and businesses to reduce water consumption as a civic responsibility. The "20-Gallon Challenge" campaign provides residents and businesses with a list of easy ways to save water. The city offers residents free education on sustainable landscaping. Businesses, plumbers and landscapers can obtain certifications to prove they use water-efficient practices.

The city also makes conservation appealing to the wallet. Santa Monica residents and businesses can obtain rebates on high-efficiency bathroom and kitchen fixtures, laundry machines, and irrigation controls. The city will also help fund synthetic turf installment and sustainable landscaping that involves climate-appropriate plants.

While water conservation measures are currently optional, Santa Monica has also taken legal steps to ensure these plans are eventually adopted by everyone. By city ordinance, all transferred or sold properties must be equipped with low-flow toilets, showers and faucets. Larger fixtures in new or remodeled buildings must meet Energy Star standards. Similarly, new and remodeled landscapes must have water-efficient irrigation. Another ordinance prohibits creating waste water runoff from excessive irrigation and hosing down hardscapes. The city employs officials to patrol the city and enforce these ordinances.

Conservation alone will not solve Southern California water needs, but it is a hugely important strategy – the cheapest, easiest and most environmentally-friendly means of improving reliability. In addition to expanding existing supplies, an aggressive regional conservation effort could make negotiations with the rest of the state on other water strategies less contentious. Building support for a solution in the Bay-Delta that combines environmental restoration and secure supplies for Southern California will be easier, for example, if Southern California is seen to be treating water as a precious resource by implementing aggressive conservation strategies.

Potential: Urban water conservation could have an impact equivalent to adding more than 1 million acre-feet of water to the regional supply (about 25% of current annual use). Southern California has already taken significant strides with indoor conservation measures. Outdoor conservation offers the opportunity for even greater savings. The amount of water conserved will depend on how many people participate, and how aggressively they conserve. Both factors will be heavily influenced by the nature and extent of water agency conservation programs. Even without the drastic measures taken in Southern Nevada – where new homes cannot install lawns in the front yard – there is enormous potential to decrease demand on the water supply in Southern California through greater water efficiency and conservation.

Individual water conservation and efficiency projects do not, by themselves, yield a lot of water (as shown below). Yet, the aggregate impact of hundreds of thousands of small projects and millions of people changing their behavior could be equivalent to adding a new source on par with (or greater than) MWD's share of water from the Colorado River.

- Running the dishwasher only when full (2.5 gallons per load)
- Washing only full loads of clothes (15-50 gallons per load)
- Replacing high-volume flushing toilets with low flow models (2-4 gallons per flush)
- Watering at night to reduce evaporation (20-25 gallons per day)
- Reducing each irrigation cycle by 1-3 minutes (20-25 gallons per day)
- Repairing leaks and broken sprinkler heads (20 gallons per day per leak)
- Replacing water-hungry lawns and gardens with climate-appropriate plants (55 gallons per square foot per year)

Reliability: In general, reducing demand through conservation is one of the most reliable sources of water, since the efficiency gains are not subject to interruption by drought or competing environmental restoration needs.

Timeliness: Conservation efforts can begin immediately (and are already underway throughout the region). Gains from demand reduction accumulate gradually, one water-efficient washing machine or reduced irrigation cycle at a time. In an emergency (such as complete loss of water from the Bay-Delta following an earthquake), conservation could yield overnight gains from extreme measures such as severely curtailing outdoor water use.

Risk: Water conservation carries almost no risk. To the extent that conserved water relies on changes in behavior, the strategy's continued success will depend on the persistence of residents in their conservation efforts. Many of the efficiency measures, such as low-flow toilets and drought-resistant landscapes, are likely to remain in place once installed.

Environmental Considerations: Conservation is perhaps the ultimate in environmentally friendly sources of water. The strategy does not require an environmental impact report; no habitat or wildlife are harmed by humans using less water. To the extent that conservation reduces the need for alternative sources of water (and the associated environmental impacts), it lessens the overall environmental cost of meeting the region's water needs. Also, some conservation strategies are nature-friendly: replacing lawns with native plants tends to support local wildlife. Furthermore, conservation efforts aimed at the general public may encourage Southern Californians to adopt more sustainable lifestyles in general and improve the region's image.

Greenhouse Gases: Transporting and purifying drinking water is energy-intensive, and sometimes requires fossil fuels. Conservation reduces the carbon footprint associated with the region's water supply to the extent that is displaces the need for electricity from fossil fuels to produce, transport and purify imported water.

Costs: Most conservation measures are relatively inexpensive, and many are free, at least to residents. Nominally 'free' programs, such as reduced watering, require education and outreach efforts that will likely be paid for by water users through their utility rates. Santa Monica's Sustainable City Plan spends $500,000 annually on education, outreach, rebates and incentives. The City expects to continue this expenditure indefinitely to ensure the conservation methods it advocates remain habitual. Compared to any other source of water, however, such efforts are inexpensive. In fact, conservation is the most cost-effective way to alleviate California's water problem. Table 1 shows the cost per acre-foot of Santa Monica's Sustainable City Plan.

Table 1
Urban Water Conservation

Initial Capital Cost	$5 million (over first 10 years)
Ongoing Operating Cost	$500,000
Production Capacity in Acre-Feet	2,900
Estimated Cost Per Acre-Foot	$280

Sources: LAEDC, City of Santa Monica

By the time the Sustainable City Plan meets its target, Santa Monica will have spent $5 million on various conservation programs. If the program saves 2,900 acre-feet per year (a 20% reduction in use), then the water 'produced' will cost $280 per acre-foot. Additional small increases in the amount of water saved would rapidly reduce the cost per acre-foot. Similar conservation efforts throughout Southern California would substantially reduce the demand for (and cost of) water.

Even the most expensive conservation efforts, such as paying homeowners to remove turf, are cost competitive. Drought-resistant native plants save an average of 55 gallons of water per square foot per year compared with lawn, for a savings of one acre-foot of water for each 6,000 square feet of lawn replaced, as shown in Table 2 on the next page.

Table 2 Paying for Turf Removal		
Subsidy per sq ft	$1.00	$1.50
Water Saved (gallons per year)	55	55
Square Feet Replaced to Save 1 Acre-Foot	5,925	5,925
Estimated Cost Per Acre-Foot	$385	$578

Sources: LAEDC; Southern Nevada Water Authority

Some homeowners can probably be encouraged to modify their yards without a subsidy. Yet, what would the cost be if Southern California agencies were to follow the lead of their counterparts in Southern Nevada and pay for turf removal? At a subsidy of $1 per square foot, it would cost almost $6,000 to save an acre-foot of water in a year. The cost rises to almost $9,000 per acre-foot of water in a year for a subsidy of $1.50 per square foot. Yet, the turf replacement program is a one-time cost. Over a 30-year period the cost per acre-foot amounts to $385-578, which is very reasonable when compared to other water strategies or MWD Tier II treated water, which is supplied to retail water agencies for $695 per acre-foot.

Note: turf buy-backs make inherently more economic and conservation sense in Southern Nevada compared to Southern California, because the latter's water supply is annually variable, while the former's is essentially fixed and fully allocated. There is a rational argument that outdoor irrigation provides Southern California with a drought buffer that Southern Nevada lacks. (With less 'slack' in the system, there is less scope for comparatively 'pain-free' cutbacks in Southern Nevada.)

STORMWATER CAPTURE

On the rare occasions when it does rain in Southern California, it tends to pour. A winter storm can dump an inch or more of water on the region in just hours. Most of the deluge is directed into storm drains, culverts, channels and concrete-lined rivers on its way to the ocean. The volume of water rushing through the storm channels can be remarkable, even terrifying, as anyone who has seen the heroics of the LA County Fire Department's swift water rescue team can attest. That storms should generate flash floods is hardly a surprise. Yet, the volume of water flowing directly to the ocean has increased substantially over the past 100 years as urban development has covered vast swathes of Southern California with impermeable surfaces. Roads, freeways, parking lots, and buildings prevent water from soaking into the ground and thereby naturally replenishing the underlying aquifers.

The amount of water percolating into the ground matters in Southern California. Roughly 40 percent of the region's water is sourced locally from groundwater. Growing urban development has diminished the natural rate of replenishment of the aquifers. While replenishment has been augmented from imported supplies for many years, the reduced availability of such imports suggests that we should find other ways to make up the losses to urbanization. One mitigation strategy is capturing stormwater and then allowing it to filter into the ground or injecting it directly into the aquifers. (This strategy is sometimes referred to as "water harvesting", reflecting the fact that the water is free for the taking.) Indeed, captured stormwater can replenish underground water supplies at a much higher rate than would occur naturally.

Stormwater refers to all runoff produced by rainfall events. Here we consider relatively clean runoff that can be captured and allowed to percolate into the groundwater or injected directly without the need for treatment. Unless the water is captured in one location and sent underground in another (which may incur transportation costs), the water is free. Some urban runoff is sufficiently contaminated that it would require treatment before being delivered underground. This water can be dealt with in two ways. A method called "first flush" involves diverting an initial portion of rainfall into normal runoff channels to the ocean; this first water carries off most of the contaminants from streets and other dirty surfaces. After these contaminants have been flushed away, subsequent runoff is diverted to ponds for percolation. Alternatively, all stormwater can be treated and stored, including the "first flush" water. Reducing the flow of contaminated runoff that reaches the ocean would have obvious environmental benefits. Treating the water puts the stormwater in the same category as wastewater. To keep our comparisons consistent, we consider treated stormwater under the strategy of water recycling.

Stormwater capture is an attractive water strategy for Southern California because every acre-foot of water sourced locally reduces the need to import water from outside the region.

Potential: Hundreds of thousands of acre-feet. Individual groundwater recharge projects are designed to capture up to 40,000 acre-feet of water per year. Sample projects include the Inland Empire Utility Agency's water recharge project that will capture 15,000 to 20,000 acre-feet per year and the Coachella Valley Water District's project in La Quinta that will capture 40,000 acre-feet per year via 39 recharge basins on 165 acres.

Reliability: Stormwater capture is only as reliable as the rains, which makes for considerable short-term variability. Climate change could increase the variability. As long as there is at least some rain, however, these projects should be successful. Stormwater capture should increase the overall reliability of the water system by adding another (local) source of supply, thereby lessening the region's reliance on imported supplies.

Timeliness: The key challenge for a regional stormwater capture project is finding a suitable site and conducting the environmental review. Some projects are already underway; new projects would probably require 3 to 5 years to implement.

Risk: There is minimal risk to completion for stormwater capture projects. Little infrastructure is required to send stormwater into the groundwater basins. However, there may be difficulties if diverting "in-stream" water requires diversion rights. Such rights for groundwater recharge are rare in California. (Typically, diversion rights are reserved for consumption and irrigation purposes.)

Environmental Considerations: Even an aggressive stormwater capture program would divert only a portion of the runoff to aquifers (at least some of the lost water would have ended up underground but for the hundreds of square miles of impermeable surfaces related to urban development). Current projects that capture runoff in the mountains and direct it to high-percolation areas have minimal adverse environmental impact. In fact, projects such as the spreading grounds preserved by the Pomona Valley Protective Association have operated successfully for almost a century. Going forward in urbanized areas, there is an opportunity to improve the environment by removing contaminants from urban stormwater runoff. Water flowing off city streets collects everything from trash to motor oil and metals (from the roads) to sewage spills. This water would have to be cleaned before being directed underground. Keeping contaminated water from flowing into the ocean should be a net positive for the environment.

Greenhouse Gases: Transporting and purifying drinking water is energy intensive, and sometimes requires fossil fuels. Capturing stormwater locally reduces the carbon footprint associated with the region's water supply to the extent that it displaces a portion of the need for electricity from fossil fuels to produce, transport and purify additional imported water.

Costs: A stormwater capture project incurs large initial costs. First, a suitable aquifer must be found. Then, its boundaries must be established to protect against contamination; exclusive rights to the groundwater must be obtained; and the pumps, pipes and other facilities necessary to efficiently use the water must be installed. After the facility is constructed, the operating costs are low because gravity feeds excess water into the ground until it is needed, whereupon it is simply pumped out again. The site requires little maintenance or supervision, and water does not evaporate while it is stored.

Table 3 Stormwater Capture	
Initial Capital Cost	$40-63 million
Ongoing Operating Cost	$1-3.5 million
Production Capacity in Acre-Feet	17,500-40,000
Estimated Cost Per Acre-Foot	$350+

Sources: LAEDC; Inland Empire Utility Agencies; Coachella Valley Water District

We estimated the cost of stormwater in Table 3 based on projects planned and operated by the Inland Empire Utility Agencies (IEUA) and the Coachella Valley Water District. Stormwater typically costs from $300 to $400 per acre-foot, which includes $155 per acre-foot in treatment costs. The rest covers interest on capital costs plus the cost of the pumps that extract the water for use.

Stormwater sites in Southern California have been in operation for many decades (such as Grant Ponds in the Eastern Municipal Water District). In these cases capital costs are no longer an issue. We have selected stormwater capture projects that are large and new to illustrate the incremental cost of additional capacity. Smaller projects that can be incorporated into new developments may end up being more common. (For example, impermeable parking lots may be designed with plant beds instead of concrete dividers. The asphalt could be sloped to channel runoff into these islands, which would allow water to percolate locally. Stormwater retention basins could be incorporated into urban landscapes as is common in other arid states.)

RECYCLING

Southern California, an area with limited local water supplies to meet the needs of a growing population, consistently sends small rivers of comparatively fresh water into the ocean in the form of treated wastewater. The wastewater could be cleaned up to the same standards as drinking water and returned to the local water supply. Yet, many people are put off by a process that has been described by detractors as "toilet to tap". Thus, water recycling has been largely confined to reclamation for non-potable uses such as landscape irrigation. Attitudes are changing, however. Southern California water agencies have developed several recycling projects with the intent of tapping the large, reliable, local source offered by treated wastewater.

The "ick" factor is the biggest obstacle to greater investment in recycling wastewater. Many Southern Californians seem to imagine that their drinking water is transported directly from some pristine source (snow or rain, or perhaps an underground spring) to a water treatment facility and then on to their homes. This is true for some, but not all, of the region's water. The Colorado River is one of the main sources of water in Southern California, and it contains a lot of heavily treated wastewater from cities upstream. (In this context, what happens in Las Vegas doesn't stay in Las Vegas; water drawn from the Colorado River is used in Las Vegas, collected as wastewater, treated and then discharged into the Colorado River from which it is then re-diverted for reuse in California.)

The presence of treated wastewater in the water supply should not be cause for alarm. Recycled water is monitored at the recycling treatment plant, at the recharge basin, and in the groundwater before it is withdrawn for further treatment to ensure that it meets state and national standards for drinking water. The water is cleaned in four stages including microfiltration, reverse osmosis, ultraviolet light, and oxidation. The process is so effective that the West Basin Municipal Water District has been selling recycled water to customers who need ultra-pure water. Given the advanced treatment processes available, the shift to viewing wastewater as something too valuable to be thrown away is long overdue; the astronauts on the international space station have been drinking recycled water for years. In Southern California, there is more separation between the source and re-use; most recycling projects use the water to recharge underground storage, where it is filtered through sand, gravel and clay before returning to the regional supply. Some Southern California water agencies avoid the issue entirely by sending recycled water into a separate system for outdoor use, primarily for irrigation.

A key advantage of recycled water is its reliability; recycled water is drought-proof because the wastewater treatment facilities produce a steady supply of water even in dry years. In addition, the recycled water is a local source, which lessens reliance on imported water from the Colorado River and the Bay-Delta. One limitation is created by the dissolved salts in recycled water. To reduce the salt content, recycled water typically has to be used in conjunction with a desalting operation or blended with captured stormwater or imported water.

Potential: The *Southern California Comprehensive Water Reclamation and Reuse Study* identifies more than 30 recycling projects in Los Angeles, Orange County, San Diego and the Inland Empire with the potential of yielding more than 450,000 acre-feet of water within five years. There is a lot of variation in size among the projects.

Reliability: Recycled water is among the most reliable sources of water since the source (treated wastewater) flows consistently, even in dry years.

Timeliness: Allowing for planning and the environmental review, projects can be developed in 6 to 10 years.

Risk: The risk to recycling projects comes from public opposition. San Diego built a water recycling facility, but had to release the water into the ocean after local voters rejected "toilet to tap" following an ill-informed and irresponsible scare campaign in the local media.

Environmental Considerations: Water must be removed from the environment for human consumption. Any method of removing it involves at least the possibility of environmental damage through habitat destruction and fossil fuel combustion. Reusing water reduces the need to remove more water from the environment. While the recycling process requires some use of energy, its incremental impact is far less than that of most other strategies.

Greenhouse Gases: All water is treated before use and the treatment process requires power; any increase in water use will require more electricity. If the electricity is sourced from fossil fuels, the state's carbon footprint will be impacted. Transporting water also uses a lot of electricity, in particular for the pumps used to lift water over mountains. Locally sourced recycled water does not have to be transported as far as imported supplies. If recycled water is used, the carbon footprint of the region's water supply will be affected by treating recycled water, but by less than with avoided imports. The region's carbon footprint could conceivably fall if recycled water displaces some of the current imports.

Costs: Water recycling projects require a significant amount of initial capital because expensive treatment and distribution facilities must be constructed. The operating costs pay for the various stages of treating water as it passes through the facility. Orange County made headlines recently with its new water recycling plant, investing $480 million to produce 72,000 acre-feet of water per year.

Table 4
Water Recycling

Initial Capital Cost	$480 million
Ongoing Operating Cost	$30 million
Production Capacity in Acre-Feet	72,000
Estimated Cost Per Acre-Foot	$1,000

Sources: LAEDC; Orange County Water District

We estimate the all-in cost of water from the OCWD plant at $1,000 per acre-foot, including capital and operating costs (before recharging underground storage) and treatment (after the water is pumped back up to the surface). For comparison, the Eastern Municipal Water District has a smaller recycling operation that produces 13,700 acre-feet per year. The water is diverted to a separate system for outdoor use at a cost of about $350 per acre-foot. The cost is lower in part because it is not treated to drinking standards. The EMWD's recycled water is also cheaper because their facility only cost $49 million to build, a tenth of the OCWD's capital cost, while it produces a fifth of the water that the OCWD plant produces. Moreover, the EMWD's price per acre-foot does not reflect the fact that their recycled water would not be available without the concurrent operation of a groundwater desalter at considerable cost.

OCEAN DESALINATION

For decades, the desalination of ocean water has been the holy grail of water supply. So much water, so tantalizingly close! Desalination promises an extremely reliable (drought-proof) water supply that is limited only by the cost of removing the salt and the energy required to do so. The price of desalination has been falling with technological advances, particularly improvements to the semi-permeable membranes used in the reverse osmosis process. Nonetheless, the cost remains high at an estimated $1,000 per acre-foot, exclusive of any delivery charges.

Desalination plants require large amounts of electricity. This power is used to force seawater at high pressure through membranes to create fresh water. Desalination plants often co-locate with power plants along the coast for easy access to electricity and seawater. Clearly, desalination makes the most sense when power and seawater are plentiful and fresh water is scarce. For this reason, most existing desalination plants are in the Middle East, where fossil fuels are cheap. Nuclear aircraft carriers and submarines also utilize desalination technology because nuclear reactors produce abundant energy.

As energy costs rise, fresh water supplies fall, and desalination will become a more attractive option as technology improves. The major barrier remains price, since desalination is currently one of the most expensive strategies for augmenting the water supply.

Potential: MWD, which offers subsidies for water produced by desalination plants, estimates the regional potential for such facilities to be 150,000 acre-feet per year. The proposed Poseidon project in Carlsbad recently permitted by the state will deliver 56,000 acre-feet per year.

Reliability: Ocean desalination is the ultimate drought-proof source. At a sufficiently high price (and with an adequate source of power), desalination can provide almost limitless supplies of water, on demand.

Timeliness: 6-10 years, based on the experience of Poseidon with its proposed Carlsbad plant in San Diego County.

Risk: High, due to the difficultly of finding a suitable location for the plant, high energy demand, environmental opposition, potential problems with brine disposal, and the relatively high cost of the resulting water.

Environmental Considerations: Ocean desalination plants need to be located next to the ocean, which limits the potential sites due to NIMBY objections from coastal property owners. The byproduct of the desalination process is a much saltier brine which has to be returned to the ocean. Some environmental groups object that the impact of the brine is detrimental, or at the very least unknown. [Both considerations make co-location with an existing power plant an optimal choice. The desalination plant will probably have a lower profile than the power plant, and the brine can be diluted with (warmed) cooling water already discharged from the power plant.]

Greenhouse Gases: Desalination is an energy-intensive process. If the energy is supplied by a fossil-fuel powered source, then desalination could be a significant source of greenhouse gas emissions. Desalination plants located next to the ocean will produce purified water at sea-level. Most water distribution is based on gravity to move the water; extra power will have to be expended to deliver the water. Again, if the energy is derived from fossil fuels, it will increase greenhouse gas emissions.

Both concerns can be mitigated or avoided. A desalination plant in Western Australia, for example, draws most of its power from wind turbines. Water need not be pumped too far back uphill for distribution. Inland water agencies might procure water from a coastal facility, and then trade the treated water (already at the coast) with an agency closer to the desalination plant. In return, the inland agency might intercept imported water otherwise destined for the coastal agency.

Costs: Desalination facilities are expensive to build, and they must be located near a large source of salty water like the ocean. These locations are often at low altitude, which means the purified water must be pumped uphill to its destination, requiring a significant amount of energy. More energy is required in the reverse osmosis process to push salty water at high pressure through a membrane. Because of this, desalination plants will not be economically viable without subsidies unless the price of competing sources go up. However, if the price of alternative water sources rises sufficiently (or sufficient subsidies are available), then desalination offers an essentially limitless and extremely reliable supply of water.

Table 5
Ocean Desalination

Initial Capital Cost	$300 million
Ongoing Operating Cost	$37 million
Production Capacity in Acre-Feet	56,000
Estimated Cost Per Acre-Foot	$1,100

Sources: LAEDC; Poseidon

The data in Table 5 are from Poseidon Resources, a company recently permitted to construct and operate a desalination plant in Carlsbad. Poseidon plans to sell water to various agencies at a rate of $800 per acre-foot (after a $200 per acre-foot subsidy from MWD). We have added $100 per acre-foot as a baseline estimate of the cost of transporting the water from the facility to a distribution point on a retail delivery system. Water from a desalination plant has been purified, so unlike other water sources, no additional treatment (nor associated cost) is required.

One risk that could significantly increase the estimated cost per acre-foot is the amount of water actually delivered. Over half the revenue generated per acre-foot will be used to amortize the debt incurred in constructing the $300 million plant. If the plant operates significantly below capacity, the debt payments will be spread over fewer acre-feet, so the price per acre-foot will rise. This is a real concern—Poseidon developed a plant in Florida that has consistently produced less water than its forecast production capacity.

GROUNDWATER DESALINATION

Ocean desalination is not an option for inland water districts if water cannot be pumped from the coast. However, inland areas can also take advantage of desalination technology by tapping brackish groundwater. The only difference between seawater and brackish water is the concentration of salt in the water that is being purified. There is less salt to remove from brackish groundwater so it uses less energy in the microfiltration process. However, brackish bodies of water are relatively small compared to the endless supply of ocean water.

Potential: The regional potential is yet to be determined. Desalination can be used to tap otherwise unusable groundwater (as in San Diego County); it can be used to remove salts added from agricultural operations (as in the Inland Empire Utility Agency); and it can be used in conjunction with recycled water recharge of underground aquifers (as in IEUA and EMWD).

Reliability: High.

Timeliness: 6-10 years, to allow plenty of time for an environmental review.

Risk: Moderate, based solely on the high cost of building and operating these facilities.

Environmental Considerations: Groundwater desalination appears to be below the radar of most environmental organizations.

Greenhouse Gases: The desalination of brackish groundwater requires less energy than ocean desalination since the incoming water is not as salty. This type of process will therefore contribute less greenhouse gas emissions than an ocean desalination facility drawing power from the same source.

Costs: High. The costs in Table 6 are based on the existing Menifee Desalter in Riverside County.

Table 6
Groundwater Desalination

Initial Capital Cost	$24 million
Ongoing Operating Cost	$700,000
Production Capacity in Acre-Feet	2,500
Estimated Cost Per Acre-Foot	$1,200

Sources: LAEDC; Eastern Municipal Water District

The EMWD desalter represents the high end of costs for groundwater desalination. The facility itself operates at normal cost levels, but since it is located in the Inland Empire it must pump salty brine all the way to the ocean for disposal. First, EMWD sends the brine to Orange County via a 63-mile series of "brine line" pipes. Then the brine is 'treated' (diluted with treated wastewater) at the wastewater treatment plant and discharged to the ocean. The cost of brine line, when added to the initial capital costs of the desalter, adds considerably to the cost per acre-foot. Charges for the disposal of the brine accounted for $310,000 of the $693,000 in annual operating costs.

EMWD's desalter is also a high cost example because the water being desalted is very brackish. The Menifee plant reduces dissolved salts from 2,000 parts per million to 330 parts per million. (Other facilities in the region start with water that may have a concentration of salts of 800 to 900 parts per million or less. Saltier water can require different membranes and higher pressure, both of which add to the cost.)

Finally, the costs in Table 6 are based on actual production (which varies from roughly 1,500 acre-feet per year to 3,360 acre-feet per year), not theoretical capacity. We estimate the facility produces 2,500 acre-feet on average. If the facility operated closer to maximum capacity, the final cost per acre-foot would drop significantly.

The cost per acre-foot in Table 6 represents the final cost of water delivered to the distribution system. Water from the desalter comes out at drinking standards, so we have not added a treatment cost to the water.

III. Strategies to Increase Imported Water

To meet the needs of its growing population, Southern California will need more water. Since importing water worked so well in the past, it is natural to consider a similar approach to meet future demand. There are three possibilities for imports: develop new sources; draw more water from existing sources; and seek transfers from agricultural users in other regions. Only the last possibility is feasible.

Developing new sources of imported water is a non-starter.

- The first limitation is financial. The existing water infrastructure – the canals, aqueducts, pumps, dams, reservoirs and hydroelectric plants that make it possible to transport water hundreds of miles across the state – was enormously expensive, even before the hidden costs of environmental mitigation are taken into account. Building a new aqueduct to connect Southern California with a source over two hundred miles away would cost billions of dollars. (For comparison, the San Diego County Water Authority explored the possibility of building a new aqueduct to import water from the Imperial Irrigation District, but found the projected $2 billion cost prohibitive.)

- The second limitation on new sources is environmental. California's water infrastructure was designed and largely built in an era before environmental impact reports. The existing water export operations have been the subject of decades of litigation. Environmentalists have successfully persuaded the courts to curtail exports from the Owens River (for habitat restoration) and from the Bay-Delta (to protect endangered species). Any significant new water diversion or storage project would be subject to a vigorous CEQA challenge. Even if it were ultimately approved, which is far from certain, lawsuits would delay the project for years.

Drawing more water from existing sources is another non-starter.

- The Colorado River is in the midst of a multi-year drought, and the main reservoirs on the river are below 50% of capacity. Worse, the eventual end of the drought may not bring much relief. California's annual allotment of Colorado River water is 4.4 million acre-feet, all of which is already allocated. Indeed, California has had to cut back in recent years to remain within its allotment, which it had routinely exceeded. Because the historical division of water among the Colorado River Basin states was based on flows during an unusually wet period, the total allocation of water (plus treaty obligations to Mexico) appears to exceed the long-term average flow. Some states' annual allotments have gone unused, but no longer. For example, increased water demand based on population growth is driving Utah to spend $500 million for a 158-mile pipeline to claim its share of Colorado River water.

- The Bay-Delta is in crisis. The area's current mix of urban development, agriculture, and water exports is not environmentally sustainable. Pumping water from the Delta has been curtailed to protect endangered species of fish, pending the development of a long-term habitat restoration strategy. There is no practical possibility of increased water deliveries from the Delta. Rather, Southern California's priority should be the implementation of a long-term fix that both protects the Delta as an ecosystem and tidal estuary and maintains exports as close to the pre-curtailment levels as is sustainable. [Quite apart from the environmental considerations, it is probably not in Southern California's interest to increase dependence on a water source that could be disrupted for a year or more if an earthquake or flood were to destroy levees in the Delta.]

- The City of Los Angeles imports water from the Owens River via two aqueducts. Because of necessary environmental mitigation, there is no possibility of increasing the amount of water imported from the Owens River. On the contrary, the LADWP has had to reduce its imports under a court order requiring that water be provided for environmental mitigation (around Mono Lake) and habitat restoration (restoring flows along part of the Owens River).

To increase water imports, therefore, Southern California will have to seek transfers via the existing infrastructure from other existing users outside of the region. In practice, this means negotiating with agricultural users, who account for 80% of the state's water use.

The subject of water transfers from agricultural users requires a light touch and considerable diplomacy. Signs in the San Joaquin Valley remind urbanites passing through on the freeway that "Food Grows Where Water Flows." Rhetorical flourishes aside, there is no danger that urban users will "steal" agricultural water. Many irrigation districts have senior water rights, including priority claims on Colorado River water as well as water delivered under long-term contracts through the federal Central Valley Project and/or the State Water Project. Their water rights are firmly backed by state and federal law. The underlying fear of a functioning water market is that farmers, who pay hundreds of dollars per acre-foot less than urban water agencies, will be outbid for the water, thus jeopardizing not only farm economics but the nation's supplies of food and fiber.

Agriculture is an important economic engine in California and water should not be transferred if it would imperil the industry or the nation's food security. On the margins, however, there is scope for beneficial water transfers, particularly when the agricultural water is being used for low-value, water-intensive crops such as hay and alfalfa. And just a few transfers could make an enormous difference for urban water supplies. Shifting just 5% of the state's water use from agricultural to urban users would increase the amount of urban water available by 25%—and would enhance agricultural area economies, if properly priced and managed.

TRANSFERS FROM AGRICULTURAL TO URBAN USERS

There are three strategies for freeing up water for transfer from agricultural to urban users: groundwater substitution; crop substitution (or, in rare instances, fallowing); and agricultural conservation.

In transfers based on groundwater substitution, an agricultural user sells his right to divert and use surface water to an urban user and makes up the difference by pumping more locally sourced groundwater. Farmers continue to use the same amount of water as before. Such transfers, based on the farmer's ability to temporarily switch to the use of groundwater, are very effective in meeting urban demand caused by drought or other short-term supply interruptions. Whether such transfers are sustainable depends on the local water basins in the agricultural area. If the substitution groundwater is extracted faster than it is replenished (a practice known as water mining), then it will eventually be depleted. In some cases, the aquifer can be used as a natural reservoir to be refilled by pumping additional water underground during wet years. The practice of using rights to surface water and extraction of local groundwater alternatively based on weather, hydrology and market forces is often called "conjunctive use".

In transfers based on crop shifting, agricultural users free up water by changing their crop mix to substitute low-water-use plants for more water-intensive crops. For example, a farmer might substitute winter wheat for rice in a particular year and transfer the difference in water use to an urban use. In some situations, farmers might even choose to take marginally productive land out of production in a year where the value of water were high enough to make that a prudent economic decision. Fallowing can hurt the local economy if it reduces demand for goods and services from the businesses that supply the farmers. This makes long-term transfers based on idling farmland particularly unpopular. MWD has pursued a strategy based on short-term fallowing as a form of drought protection. MWD makes annual payments to farmers along the Colorado River who continue to farm as usual. In exchange, the farmers agree to leave a specified portion of their fields fallow and transfer their right to divert and use Colorado River water to MWD during dry years. The combination of normal cropping patterns punctuated by reduced planting in dry years and predictable payments for the urban call on surface rights improves the position of both parties. Farmers are compensated for managing their water use on a variable basis, while urban users get augmented reliability of supply at a predictable price.

Transfers based on agricultural conservation also seem to offer advantages for both parties. Farmers can free up water by using water more efficiently, often through capital investment or improved agricultural practices. The disparity between urban and agricultural prices for water suggests it might be worthwhile for urban users to subsidize the cost of water-saving devices, like drip irrigation systems, that might not otherwise be a cost-effective choice for farmers.

Potential: Probably less than 500,000 acre-feet per year. Meeting even this modest target will require overcoming rural doubts about urban 'water grabs'. Climate change might make the certainty of payments for water transfers more attractive, or it might make rural areas more inclined to retain their water 'just in case'. Rapid urban development in the San Joaquin Valley could alter the water calculus, particularly if new residents decide they'd prefer to keep the water for regional development—as seems to be the case already among Sacramento Valley residents north of the Delta. Based on current transfer agreements, individual projects may supply 25,000-110,000 acre-feet per year.

Reliability: Moderate. The water is subject to the same risks as current imported supplies (such as climate change, drought and environmental considerations), but in most cases the irrigation districts have priority water rights, meaning that their senior rights to the water will be the last ones cut.

Timeliness: 4-10 years, mostly to allow for protracted negotiations, an environmental review and court challenges.

Risk: Moderate. The risk is less about completing the project than about securing a mutually beneficial agreement between a willing seller and a willing buyer.

Environmental Considerations: Water transfers from rural to urban areas can have unintended consequences for the environment. One of the key sticking points in the transfer agreement between the San Diego County Water Authority and the Imperial Irrigation District was the fate of the Salton Sea. This inland water body, which is sustained only by the runoff from farm irrigation, is an important habitat for migratory birds. Conserving water for transfer to San Diego would necessarily mean less water draining into the Salton Sea as tailwater from surrounding agricultural irrigation. Similarly, significant water transfers from the northern Sacramento Valley could mean reduced habitat for a variety of endangered species (not to mention the uncertainty of conveying the water through the Delta). Each transfer, therefore, requires a careful evaluation and mitigation of its environmental impacts.

Greenhouse Gases: Higher. Greenhouse gas emissions will be the same as those generated by the energy-intensive transport of current imports. All else equal, increasing imports will add to the state's carbon footprint. However, some transfers (those which result in reduced agricultural production) could produce some carbon offset on the farm.

Costs: IID agreed to sell SDCWA water for $300 per acre-foot.

Table 7
Water Transfers from Agriculture to Urban

Initial Capital Cost	n/a
Ongoing Operating Cost	n/a
Production Capacity in Acre-Feet	25,000-200,000
Estimated Cost Per Acre-Foot	$700+

Source: LAEDC; SDCWA

Water from the SDCWA-IID deal is transported to San Diego via existing MWD infrastructure. (MWD wheeling charges bring SDCWA's cost for the water up to $578 per acre-foot.) Since the water is paid for on an ongoing basis, there are no additional debt-service charges. Treatment costs add $155 per acre-foot.

Water treatment and transportation costs compose more than half of the final price per acre-foot, and the rest reflects the cost of convincing farmers to sell some of their water. Treatment and transportation costs are fixed, so the farmers' variable willingness to sell will determine the final price of transferred water. They may demand a high premium for their water rights; this is understandable, as their livelihoods depend on water.

IV. Strategies to Increase Water System Reliability

Southern California's water agencies have a long and distinguished history of consistently meeting the region's water needs. Delivering reliable water supplies in the future will be harder – and more expensive – than it has been in the past. The problem is not solely a lack of water, though the twin needs of habitat restoration and endangered species protection will constrain import volumes. Rather, population growth ensures demand will be steady or rising, even with conservation efforts, while the water supply is more consistently constrained and always variable. The amount of water available varies seasonally (wet winters followed by dry summers) and annually. Water system operators smooth out this variability by storing enough surplus water in the winter and wet years to last through the summer and periodic droughts. They rely on a portfolio approach to supplies (on the theory that sufficiently diverse sources are unlikely simultaneously to experience a shortfall) and abundant storage.

Climate change may increase the seasonal and annual variability. And the region's growing population dilutes the protection offered by current storage facilities, because there will be less water available per capita (when the storage is full) to draw on during supply shocks. Moreover, the expected decline in snowfall in California mountain ranges, particularly the Sierra Nevadas, will reduce storage outside Southern California. Mountain snowpack acts as a vast reservoir that conveniently stores water in the winter, when it is abundant, and releases it in the summer, when it is needed most. If more precipitation falls as rain instead of snow, the storage capacity of this natural reservoir will be diminished.

To maintain water system reliability in the face of these challenges, therefore, water agencies will need to maximize their ability to store water when it is available. Three strategies for doing so are inter-agency cooperation (which has many of the same effects as increased storage), groundwater storage, and surface storage.

INTER-AGENCY COOPERATION

There are 26 member agencies of the Metropolitan Water District, each dedicated to providing secure, reliable water supplies within its service territory. Relying on these member agencies, roughly 300 retail water purveyors (water districts, investor-owned water utilities, and city water departments) actually serve water to homes and businesses throughout the region. These entities have undertaken a variety of projects that add water, such as desalination (primarily of brackish groundwater), recycling, stormwater capture, and urban water conservation. In principal, locally sourced water helps everyone in Southern California since it reduces the pressure to increase imports. In times of shortage, drought-proof local supplies provide more scope for sharing cuts in imported water across the region. Nonetheless, the principal strategies for augmenting or replacing imported water produce primarily local benefits. Need, storage and cost-effective opportunities do not always coincide within the territories of individual water entities. (One utility may have a prime location for stormwater capture, for example, but lack suitable storage capacity.) Absent cooperation among the various water utilities and their wholesalers and regulators, many promising opportunities may be missed. An integrated system where utilities routinely traded among themselves would not add volume to the system, but would improve reliability and efficiency by addressing short-term supply/demand/facility imbalances.

There are three paths to system integration: (1) through use of existing faculties (exchanges, wheeling, conveyance); (2) through the construction of integrating pipelines that interconnect Southern California's groundwater basins as storage reservoirs; and (3) off the shared MWD supply and distribution system. The first two paths are self-explanatory. The third is based on the concept of augmentation/conservation credits. Instead of physically moving water, water agencies could trade credits based on their MWD entitlements. This would open up the possibility of one water agency making an investment in retail and system conservation within another party's service area.

Potential: The strategy does not add new water to the system, but would allow the region to make better use of current supplies. There is considerable scope for improvements that could be realized for a relatively modest investment. A market in water credits, in particular, would allow (and incentivize) agencies to seek out the most cost-effective water projects across Southern California, not just within their own districts.

Reliability: A more efficient system would strengthen overall reliability and improve efficiency.

Timeliness: 0-5 years. In theory, interagency cooperation—which already occurs—could be enhanced immediately, but developing a predictable legal and accounting framework for routine trading would take several years so that experimentation and experience can be integrated into a trading regime with adequate protections and low transactional friction.

Risk: High initially, due to the uncertainty surrounding the outcome. Particularly with leadership and cooperation from MWD, such uncertainty could be reduced or significantly mitigated. (For example, the risk of trading water supplies over time could be ameliorated if the trade were "registered" or "administered" by MWD and back-stopped by a pledge of the water-debtor-entity's right to imported supplies.) Once a framework is in place, the risk of interagency cooperation falls substantially.

Environmental Considerations: Positive. Makes more efficient use of the water we already have; reduces the need for imports, reduces pressure on storage.

Greenhouse Gases: Neutral, because trading within the region does not augment supply and, just as with use of stored water, replacing the supply made available through storage will ultimately depend on importing, conserving, re-using or capturing other water.

Costs: TBD. The program itself should be relatively inexpensive to administer. Encouraging the development of the most cost-effective projects at the front end should restrain the overall cost of developing reliable frameworks for cooperation.

Table 8
Inter-agency Cooperation

Initial Capital Cost	Low
Ongoing Operating Cost	Low
Production Capacity in Acre-Feet	n/a
Estimated Cost Per Acre-Foot	n/a

Sources: LAEDC

There may be some relatively low investment and operational costs. For example, it may be necessary to add pipes to interconnect adjacent water agencies. Inter-agency cooperation is a strategy for improving the efficiency and reliability of existing supplies, not increasing supplies, so the production capacity and estimated cost per acre-foot estimates are not applicable.

GROUNDWATER STORAGE

Groundwater storage basins are an underdeveloped resource that could significantly improve the overall reliability of water supplies in Southern California. For Southern California, locally stored water is preferable to water reserves behind dams in Northern California. The ability to draw down reserves immediately when needed makes it easier to ride out dry periods and lessens the region's vulnerability to sudden disruptions of imported supplies.

Vast quantities of water can be stored cheaply underground. Statewide, the California Groundwater Coalition argues that there is room to store at least 9 million acre-feet underground. The Metropolitan Water District estimates there are 3.2 million acre-feet of unused storage capacity in Southern California alone. The cost of developing underground storage is attractive, since the construction of dams and other expensive infrastructure is not required.

While dams create recreational opportunities and offer the visual reassurance that the stored water is really there, reservoirs flood large areas and may negatively impact the local ecosystem. In contrast, the land directly above underground "lakes" can be developed like normal real estate. Furthermore, underground storage is perceived as an eco-friendly water management practice, in contrast with most other water strategies.

Currently, groundwater contributes 1.5 million acre-feet per year to the Southern California water supply, or 40% of overall supply. About half of this is replaced by artificially recharging underground aquifers, and most of the rest is refilled by natural sources. However, on average Southern California has tended to withdraw more water each year than gets replaced; this is unsustainable in the long-run. (However, it is precisely this "overdrafting" of the region's aquifers that has created the vacant storage capacity that this strategy seeks to exploit for regional benefit.) Surplus surface water supplies periodically exist, but they are not always efficiently conveyed to replenish groundwater storage.

Underground storage, also called water banking, does have its challenges. The most serious issue revolves around water rights in the aquifer or basin, since water utilities will not pump water into the ground without a secure right to pump it out again when it is needed. The water rights picture can get fuzzy if there is also surface water present, and potentially even more indecipherable when the groundwater and surface water interact such that drawing from one affects the other. The presence of multiple parties with claims to the underground water, or a shared aquifer that lies beneath multiple jurisdictions, can also delay or derail underground storage projects. As a consequence of the need for legal certainty when storing water underground, over 90% of the groundwater used in Southern California today is drawn from basins that are adjudicated or formally managed.

Issues may also arise regarding the physical characteristics of underground aquifers. Structure and capacity, flow (if any) of underground water, quality of the existing water, and any pollutants (including natural ones such as arsenic) that may be present will affect the development potential of a given groundwater basin.

Groundwater storage will not, by itself, produce incremental water supplies for Southern California. (All water that is currently in the ground has already been claimed, even if it cannot be accessed yet.) New groundwater storage will bank water produced by other strategies. Assessing groundwater strategies, therefore, involves analyzing the original source of stored water. Here, we consider three sources: stormwater runoff, recycled water, and imports.

Potential: 3,200,000 acre-feet of underground storage is available in Southern California. Individual project yields often start at about 1,500 acre-feet per year; many are significantly larger.

Reliability: Moderate. Groundwater storage is considered highly reliable once an aquifer has been charged with water. Pollution can be avoided through diligent management, but contaminants inevitably enter groundwater from time to time. Contaminated groundwater can be recovered by treating it before it is used. Groundwater reliability also depends on the source of the water; reliability will rise by diversifying replenishment water sources. Many existing and proposed projects use recycled water, one of the most reliable sources. Stormwater capture, on the other hand, is unpredictable and episodic; surplus imported water is only available in particularly wet years. Like any storage scheme, however, long-term reliability depends on periodic refills from water that is surplus to current demand. Thus, efficient use of groundwater storage goes hand-in-glove with water conservation, recycling, and import supply strategies.

Timeliness: 3-5 years. Assuming water is available to be stored, installing pumps and preparing the site for water spreading (for infiltration) is a comparatively quick process. How long it takes to bring a project online will depend on the length of time required to study the local geology and hydrology, to evaluate and resolve any environmental impacts, and to resolve any legal issues over rights to pump water from the basin.

Risk: Moderate, depending primarily on legal issues and secondarily on physical operating arrangements.

Environmental Considerations: Positive. Groundwater storage is considered an environmentally friendly way to store water—particularly insofar as it eliminates or defers the need for new surface storage reservoirs and dams.

Greenhouse Gases: Minimal. The operation of underground storage facilities will require some electricity to pump water out of the ground. If the electricity is derived from fossil fuels, then the activity will generate greenhouse gases. The overall environmental footprint of the project also will depend on the source of the stored water: almost no extra emissions for stormwater capture, but some emissions for recycled water and imports.

Costs: Groundwater storage facilities require a varying range of initial capital costs depending on the location, hydrology and geology. At a given site, the boundaries of underground aquifers must be explored and any gaps must be identified. If the aquifer abuts a source of contamination, such as saltwater or leached pollutants, then care must be taken to buffer stored water from the potential contamination. It costs money to assess and monitor the conditions underground, so some groundwater storage locations will be more costly than others. Furthermore, if water sources that replenish the groundwater do not naturally flow near the site, then refill water must be pumped to the aquifer at additional cost.

Table 9 Groundwater Storage	
Initial Capital Cost	$68-135 million
Ongoing Operating Cost	$13 million
Production Capacity in Acre-Feet	150,000
Estimated Cost Per Acre-Foot	$580

Sources: LAEDC

Table 9 indicates the differences in costs faced by groundwater storage facilities. The Metropolitan Water District's facility in Hayfield would rely on water from the Colorado River, which would be inexpensive (for MWD) but may be available only episodically due to reduced flow and limited allocation. The San Gabriel/Montebello storage facility is typical in that it draws water from several sources, including recycled water, storm runoff and imported water. The recycled water must be treated and the imported water must be transported, so the water stored in this aquifer is more expensive. Native water captured and infiltrated in the spreading grounds operated by the Pomona Valley Protective Association provides the primary replenishment source for the adjudicated Six Basins underlying eastern Los Angeles and western San Bernardino counties.

Water from groundwater storage will vary widely in price due to numerous factors. We estimate the capital and operating costs of a large groundwater facility would typically amount to $131 per acre-foot. This includes pumping costs of $88 per acre-foot, based on the weighted average among existing groundwater basins in Southern California. This water would also need to be treated at a cost of $155 per acre-foot. This sums to a baseline price of $286 per acre-foot for water in groundwater storage. Water in storage has to come from somewhere, so there may also be an acquisition cost attached to the water. This can range from $0 for captured runoff water (as with PVPA) up to $1,000 for the most expensive recycled water (as with injection barriers to saltwater intrusion along the coast). As a result, we estimate the cost per acre-foot of groundwater will range from $286-1,286. The figures in Table 9 reflect an acquisition cost of $294 per acre-foot for surplus water from MWD. Choosing the MWD surplus water price makes groundwater storage easily comparable to surface storage, which we describe in the next section.

Surface Storage

Surface storage has played a vital role in helping Southern California cope with the court-ordered reduction in water exports from the Delta. The Diamond Valley Reservoir (DVR), built in Riverside County at great expense, has allowed MWD to draw down reserves and generally insulate the public from recent and on-going supply disruption, notwithstanding interruption and reductions in imports from both the Colorado River and from Northern California.

The utility of reservoirs is high, but their usefulness is matched by their cost. The capital costs are high because the projects tend to be enormous, capable of storing one million acre-feet or more. The marginal cost of water supplied from surface storage is driven up by the debt service or other capital costs required to finance the construction cost. Surface storage projects also face considerable opposition based on their environmental impacts (described below).

We do not expect any new major surface storage projects to be approved in Southern California. However, two projects have been proposed for Northern California: the Sites Reservoir and Temperance Flat Reservoir. These projects are described and evaluated below.

Potential: No new major surface storage projects are likely to be approved in Southern California, due to the high initial cost, the presence of more cost-effective alternatives, and probable environmental impacts. Outside the region, the Sites Reservoir will have a capacity of almost 2 million acre-feet and will yield 470,000 to 640,000 acre-feet of water annually, on average. The comparable figures for Temperance Flat are 1.2 million acre-feet and 183,000 to 208,000 acre-feet.

Reliability: Surface storage can be crucial for weathering extended dry spells. The long-term reliability of a reservoir depends on the source of the water used to fill it. On-stream projects that are also used for flood control face additional risks due to climate change. The reservoir must be left low during winter in order to maintain its capacity to capture (and thus moderate) the runoff from major storms. As the danger of flooding recedes late in the season, the reservoir can be refilled, storing water for use in the summer and fall. If climate change shifts the peak runoff to earlier in the year, it would pose a dilemma for dam operators: refill the reservoir too soon and risk a devastating flood; or keep the reservoir low too long and miss the opportunity to capture water.

From a Southern California perspective, dams in the northern part of the state have to be considered unreliable. To reach Southern California, water from Sites Reservoir would have to pass through the Delta. Temperance Flat water, although originating on the San Joaquin River south of the Delta, also faces a legally and environmentally tortuous path to Southern California. Pending a comprehensive solution in the Delta, water from these reservoirs will be subject to interruption.

Timeliness: 10 to 20 years. The permitting process may require several years to complete before the lengthy construction phase can get underway.

Risk: High. A proposed surface storage project may be abandoned or substantially modified before completion due to political pressure, funding constraints or environmental litigation.

Environmental Considerations: Environmental groups oppose surface storage projects because they inundate land (potential destroying the habitat of endangered species). On-stream projects draw particular ire because they impede fish migrating upstream to spawn.

Greenhouse Gases: The Sites Reservoir is off-stream and would require energy to pump water into the reservoir (more energy than is produced by its power plant). If the additional power is derived from fossil fuels, it will add to the state's carbon emissions. (This does not apply to Temperance Flat, which is on-stream). From a Southern California perspective, transporting the water from either of these projects (if feasible) would require additional energy, particularly for the pumps that would lift the water over the Tehachapi Mountains.

Cost: Constructing a surface storage reservoir is a massive undertaking. Land must be obtained, experts hired, a dam and power plant built, and water sources diverted. Projects this large cannot be completed without significant government intervention. Government subsidies and public debt issues pay for the initial capital, meaning the taxpayers eventually foot the bill. On the other hand, reservoirs have long useful lives, supplying reliable water and electricity at a relatively low price for decades.

Table 10
Surface Water Storage

Initial Capital Cost	$2.50-2.75 billion
Ongoing Operating Cost	$7.5-15.5 million
Production Capacity in Acre-Feet	200,000-500,000
Estimated Cost Per Acre-Foot	$760-1,400

Sources: LAEDC; Department of Water Resources

Table 10, based on the proposed Sites and Temperance Flat reservoirs, reveals the large initial outlay required to build surface storage. These costs would be paid off over decades by a combination of taxpayer dollars backing general obligation bonds issued by the state and consumer dollars backing project revenue bonds issued by water agencies. Combining debt repayments with the operating costs yields a total cost per acre-foot over the next 30 years of $389 (Sites) to $851 (Temperance Flat). This would be the price of the water at reservoir.

The California Department of Water Resources *Bulletin 132-05* (on the management of the State Water Project) reports that transporting water to Southern California from the Delta to Castaic Lake costs $212 per acre-foot. From the Delta to Lake Perris costs $391 per acre-foot. Treatment costs add a further $155 per acre-foot. Thus, water sourced from the proposed Northern California reservoirs would cost $760-1,400 per acre-foot, delivered to a retail agency in Southern California after treatment. If the reservoirs yield less water annually than projected, the costs would be higher still.