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California Wildfires & Water Crisis: How Coastal Reservoirs Can Prevent the Next Disaster

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Abstract

California is not running out of water, but water is running to the sea (50%), while cities (10%) and farmers (40%) struggle with shortages, wildfires, and groundwater depletion. Traditional land-based water infrastructure—such as dams, aqueducts, and groundwater pumping—is no longer sufficient to meet the challenges posed by climate change, population growth, and ecological mandates. This article proposes a paradigm shift: a sea-based water solution built around coastal reservoirs (CRs) and seabed pipelines. These technologies capture excess floodwater near the coast before it mixes with saltwater and transfer it efficiently to high-demand urban areas using low-impact pipelines—similar in design to the Nord Stream system. Drawing lessons from successful implementations in Shanghai, Singapore, and Hong Kong SAR, we present a comparative evaluation showing that sea-based systems offer greater water yield, lower costs, and minimal environmental disruption compared to California's proposed $20 billion Delta tunnel. The paper outlines the scientific, economic, and environmental rationale for integrating coastal reservoirs into California's water strategy. With global precedents proving their feasibility, CRs represent a low-cost, high-resilience solution for securing California's water future.

Keywords

Coastal Reservoirs, Floodwater and Runoff, Environmental Impacts, Wildfire and Droughts, Desalination Plants

1. Introduction of Land-Based Water Solution and Its Limitations

California, the most populous U.S. state and the fifth-largest economy in the world, spans 423,970 km^2 along the Pacific Coast where the state's average precipitation is 582 mm/yr. It is home to over 40 million people as of 2025—comparable to the population of Canada—and is projected to grow to 50 million by 2050. Water is the foundation of California's growth, yet the state's diverse climate—from humid coastal zones to alpine peaks and arid deserts—makes managing water a persistent challenge. Approximately 75% of the state's water supply originates in the north, while 80% of the demand is concentrated in the south. The Greater Los Angeles and San Francisco Bay areas are the nation's second- and fifth-most populous urban regions, with 19 million and 10 million residents respectively, followed by San Diego (8th) and San Jose (13th) as shown in **Figure 1**.

Figure 1. California's rivers and lakes (source: GISGeography https://gisgeography.com/california-lakes-rivers-map/).

California's 20th-century development is closely tied to its engineering feats in water infrastructure. Major systems such as the State Water Project (SWP), Central Valley Project (CVP), Los Angeles Aqueduct, and Colorado River Aqueduct were built to transfer water across vast distances. Additional strategies like groundwater recharge, wastewater recycling, and conservation programs have been implemented to supplement supply. Collectively, these constitute the state's land-based water solutions.

However, these systems have reached their operational limits. Under the intensifying effects of climate change, California faces increasingly severe droughts, floods, and wildfires, which are exacerbated by outdated water allocation policies and infrastructure constraints. Table 1 lists the major climate-related disasters since 2000, underscoring a growing pattern of crises.

Table 1. California climate disasters since 2000.

Year(s)	Type	Major Event	Impacts	Estimated Loss ($)	Reference
2005	Flood	Los Angeles County Flood	Widespread infrastructure damage	Unknown	en.wikipedia.org/wiki/List_of_California_floods
2007-2009	Drought	Statewide drought	Emergency declarations, agricultural impact	Unknown	en.wikipedia.org/wiki/Droughts_in_California
2011-2017	Drought	Historic Drought	Severe water restrictions, ecosystem stress	$5.5 billion (2015 alone)	en.wikipedia.org/wiki/Droughts_in_California
2017	Flood	Statewide Floods	Levee breaches, evacuations	Hundreds of millions	en.wikipedia.org/wiki/List_of_California_floods
2018	Wildfire	Camp Fire	85 deaths, 18,800+ structures lost	$16.5 billion	en.wikipedia.org/wiki/Camp_Fire_(2018)
2020	Wildfire	August Complex Fire	Largest fire in state history (1 million acres)	$12.8 billion+	frontlinewildfire.com
2021	Wildfire	Dixie Fire	963,000 acres burned	$1.15 billion	en.wikipedia.org/wiki/Dixie_Fire
2020-2022	Drought	Severe Drought	Reservoir depletion, fallowed farmland	Over $3 billion (agriculture)	en.wikipedia.org/wiki/Droughts_in_California
2022-2023	Flood	Severe Winter Storms	Statewide flooding, evacuations	$1 billion+	en.wikipedia.org/wiki/List_of_California_floods
2024-2025	Drought	Continued Drought	Increased wildfire risk, water restrictions	Ongoing	en.wikipedia.org/wiki/Droughts_in_California
2025	Wildfire	Palisades & Eaton Fires	12,000+ structures lost, 27+ deaths	Likely $10 billion+	time.com/7207852

See attached data for full list of floods, droughts, wildfires, losses, and references.

The fundamental water allocation formula—approximately 50% for the environment, 40% for agriculture, and 10% for urban use—has become a source of unresolvable conflict. Increasing water supply for cities directly threatens environmental flows or agricultural livelihoods. This tension came to a head in 2025, when devastating wildfires swept across Southern California, claiming 29 lives, displacing 200,000 residents, and destroying over 18,000 structures across 230 km^2 (Figure 2). In response, President Donald Trump issued his first executive order titled “Putting People Over Fish”, demanding reallocation of water from environmental to human uses—a move that ignited fierce political and legal debate.

These events make one fact clear: California’s land-based water strategy is no longer sufficient. As climate-driven extremes increase, and population continues to grow, a paradigm shift is needed. Rather than framing water use as a zero-sum battle between people and ecosystems, this paper proposes a sea-based water solution—namely, coastal reservoirs (CRs). By capturing a small percentage of excess floodwater before it reaches the ocean, CRs can augment California's water supply without undermining environmental flow requirements. Drawing on successful implementations in Shanghai (Qingcaosha) and Singapore (Marina Barrage), this paper explores how California can benefit from coastal storage infrastructure that simultaneously supports human development and ecological resilience.

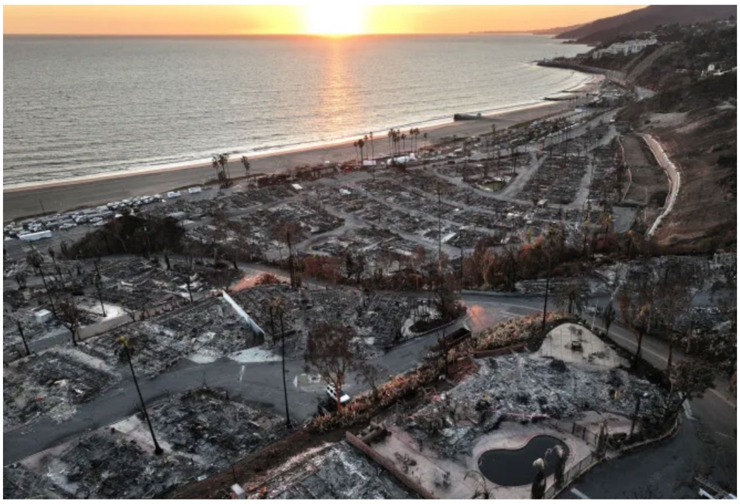

Figure 2. Southern California wildfires scorched large parts of the greater Los Angeles area in 2025.

2. Sea-Based Water Solutions: Concept and Global Case Studies

Traditional water management, particularly in regions like California, has relied almost exclusively on land-based infrastructure—including dams, aqueducts, and groundwater extraction—to meet growing urban and agricultural demands. However, in recent years, the global water community has begun shifting toward an innovative sea-based water solution. This transition was catalyzed by the formation of the International Association for Coastal Reservoir Research (IACRR), which has since evolved into the Specialist Group on Sustainable Coastal and Estuarine Development (SCED) under the International Water Association (IWA).

Global water leaders are now collectively advancing the concept of a sea-based water solution, which is built on two key components:

1) Coastal Reservoirs (CRs): Engineered near the river mouth or coastline to capture and store excess freshwater runoff before it mixes with seawater.

2) Interconnected Seabed Pipelines: Submerged, energy-efficient pipelines that transfer stored freshwater to inland or distant regions, overcoming geographic and hydrological barriers.

This integrated system offers a sustainable pathway to water security—avoiding the competition for land and ecological resources typical of land-based systems—while addressing both the spatial and temporal mismatches between water supply and demand.

California is not the first region to confront the paradox of water scarcity amid abundance—where, on one hand, people lack sufficient drinking water, and on the other, vast volumes of floodwater are discharged into the sea unused. In 2025, Los Angeles starkly illustrated this dilemma, simultaneously battling devastating wildfires and flash floods. Over 7 inches (178 mm) of rainfall triggered significant flooding as shown in **Figure 3**, yet most of this water flowed directly into the Pacific Ocean without being captured or utilized.

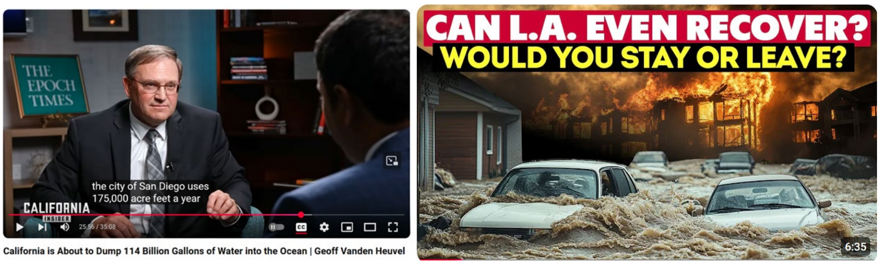

Figure 3. California dumps 431 GL based on Geoff Heuvel and fire/flood coexistence in 2025.

This phenomenon is not unique to California. It recurs annually in cities and coastlines around the world, highlighting the limitations of conventional, land-based water management. In response, visionary leaders, governments, and research organizations have begun to reject outdated approaches and advocate for a paradigm shift toward sea-based water solutions. Prominent global examples of this emerging strategy are presented in **Table 2** and **Figure 4** and **Figure 5**.

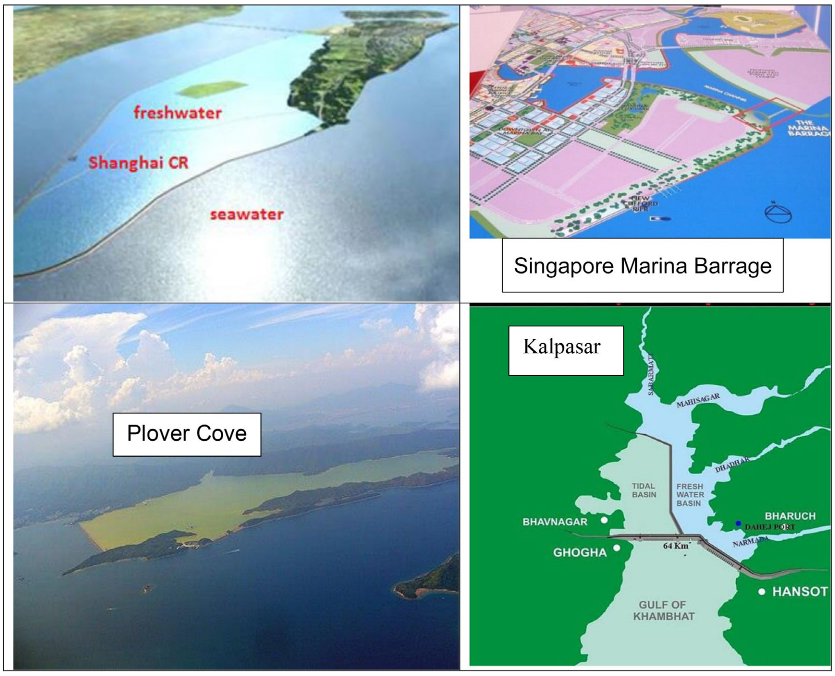

Figure 4. Coastal reservoirs in Singapore, Hong Kong SAR, Shanghai and Gujarat, India for urban water and agricultural purposes, source from Yang [1] and Wikipedia https://en.wikipedia.org/wiki/Coastal_reservoir.

Figure 5. Over 1000 km long seabed pipelines used for liquid transport in the world.

Table 2. Selected global coastal reservoir projects.

Project	City	Purpose	Capacity/service (GL = 10^6 m^3)	Year completed	Remarks
Plover Cove	Hong Kong SAR	Drinking	230	1968	World's first CR for urban use
Qingcaosha	Shanghai	Drinking	525	2010	Supplies 25 million people (~2× LA population)
Marina Barrage	Singapore	Drinking, flood, recreation	8.5/3.2	2008	Integrated urban water solution
Kalpasar	Gujarat (India)	Agriculture	10,000	Pending	World's largest planned CR
Cisadane	Jakarta (Indonesia)	Drinking (sea-level rise)	200 - 500	Pending	Key supply for island industry

Sources: Yang [1], PUB Singapore [2], Kalpasar Department, HK SAR Water Supplies Dept.

Although Hong Kong SAR receives abundant annual rainfall—up to 2400 mm per year—it frequently faces drinking water shortages due to the rapid runoff of rainwater into the sea, much like the flooding observed in Los Angeles in January 2025, where valuable freshwater was lost to the Pacific Ocean. To address this paradox, Plover Cove Reservoir [1] was developed as the world's first coastal reservoir dedicated to urban drinking water supply. Built by enclosing a seawater bay and gradually flushing out the saltwater, it was replenished with freshwater from rainfall and upstream inflows. Plover Cove demonstrated the technical feasibility and strategic value of coastal impoundments, particularly in densely populated, topographically limited regions where conventional inland reservoirs are not viable.

In 1996, the United Nations [1] predicted that Shanghai would be among six global megacities facing acute water shortages in the 21st century due to increasing pollution and degraded water sources. Similarly, China's Ministry of Water Resources identified Shanghai as one of seven cities experiencing a water crisis driven by water quality challenges. As in California, several conventional solutions were considered—desalination, wastewater reuse, and long-distance water diversion. However, it was the sea-based water solution that ultimately prevailed [3], while the other options gradually lost momentum due to cost, energy demands, and environmental concerns. The result was the construction of the Qingcaosha Reservoir from 2008, located at the mouth of the Yangtze River. Today, it stands as the largest operational coastal reservoir in the world, capable of delivering up to 7.2 million cubic meters of freshwater per day. The reservoir supplies water to approximately 25 million residents, equivalent to more than half of California's population. By selecting high quality water before mixing with saltwater, Qingcaosha demonstrates the technical feasibility, ecological compatibility, and large-scale impact of coastal reservoirs in meeting the demands of megacities.

Gujarat, India shares many similarities with California, particularly in its arid climate, limited rainfall, and the presence of seasonal rivers that discharge freshwater into the sea—a scenario common in Southern California. Recognizing the limitations of land-based water infrastructure, the Indian government has embraced the concept of sea-based water solutions and proposed the Kalpasar Project [1], which stands as the most ambitious coastal reservoir initiative ever conceived. The Kalpasar Project envisions the construction of a 30-kilometer dam across the Gulf of Khambhat, integrating not only water storage infrastructure but also transportation corridors (highways and railways) and facilities for clean energy generation. With an estimated investment of US$12.75 billion, the project aims to enclose and convert a segment of seawater into a 16 billion cubic meter freshwater reservoir. Once completed, Kalpasar is expected to support irrigation across millions of hectares and provide urban water supply to Gujarat's rapidly growing cities. Although the project has faced delays due to environmental clearances and technical assessments, it remains the largest coastal reservoir ever proposed and a landmark example of how sea-based water infrastructure can transform water security in arid, coastal regions.

To transport freshwater from coastal reservoirs to divert water along coastline, the seabed pipelines could be considered as a novel and highly efficient alternative to conventional land-based aqueducts as shown in **Table 3**. A compelling precedent is the Nord Stream pipeline system [1], which, although designed for natural gas transport, demonstrates the engineering feasibility of long-distance, pressurized fluid conveyance beneath the sea. The Nord Stream comprises two parallel pipelines, each spanning approximately 1,230 km across the Baltic Sea, connecting Vyborg, Russia to Greifswald, Germany via the Gulf of Finland. Each pipeline has a total annual capacity of 55 km^3, making it the longest operational subsea pipeline in the world. Constructed with 12-meter-long concrete-weight coated steel pipe sections, each weighing about 23 tonnes, the project was completed at a cost of €7.4 billion (US $9.76 billion) and is operated by Nord Stream AG. The successful implementation of Nord Stream underscores the technical and logistical viability of seabed pipelines for large-scale, cross-border fluid transport. In the context of California, this model can be adapted for freshwater transfer, using gravity-assisted or low-energy pressurized pipelines laid along the Pacific seabed.

Table 3. Advantages of seabed pipelines for water transfer.

Feature	Seabed pipeline	Land based water diversion
Land acquisition	Minimum	Extensive and costly
Evaporation losses	Very low	High in arid zones
Environmental disruption	Submerged, low impact	High
Energy efficiency	Without elevation level	High elevation difference
Climate resilience	Saltwater resistant	Vulnerable to drought and heat

Such infrastructure could enable efficient redistribution of water from northern coastal reservoirs (e.g., near San Francisco Bay) to high-demand regions in the south, including Los Angeles and San Diego. This integrated sea-based water network would provide a climate-resilient, low-impact, and energy-efficient solution to California's long-standing water supply imbalance, especially as traditional aqueduct systems face rising environmental, economic, and energy constraints.

Together, coastal reservoirs and seabed pipelines offer a scalable, climate-resilient alternative to traditional water supply systems. They unlock floodwater that is currently wasted to the ocean, enable equitable regional distribution, and minimize ecological disruption. These sea-based strategies represent a paradigm shift that California—and many coastal nations—must consider seriously to meet the growing demands of the 21st century.

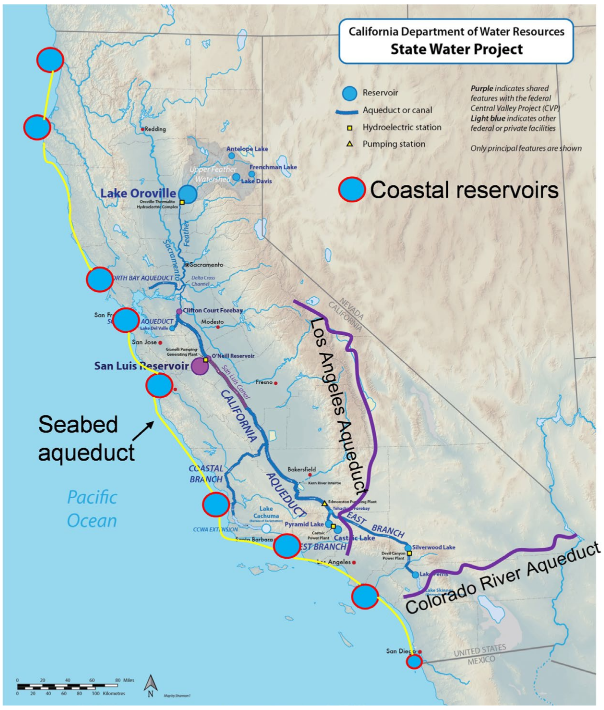

Figure 6. Proposed interlinked coastal reservoirs to secure California water supply, source from California State Water Project, Wikimedia commons: https://commons.wikimedia.org/wiki/File:California_State_Water_Project.png.

Building on the insights provided, the SCED Specialist Group has proposed a sea-based water solution for California (Yang, 2022), featuring coastal reservoirs positioned at river mouths and interconnected via seabed pipelines, as illustrated in **Figure 6**. It is necessary to discuss the technical, environmental, and economic feasibility of the proposed system.

This study applies a first-order engineering assessment to evaluate the feasibility of sea-based water solutions for California. The analysis integrates hydrological data, case studies, and cost scaling from comparable international projects. Hydrological data are derived from published literature and California water resources datasets [4] [5]. Coastal river discharge estimates are based on major California river systems discharging to the Pacific Ocean, including contributions via the San Francisco Bay system. Long-term average annual values are used (primarily 1960-2020) to represent typical hydrologic conditions, acknowledging significant interannual variability. Only rivers that discharge into the Pacific Ocean along the California coastline are included. Transboundary rivers (e.g., Klamath, Tijuana) are included with acknowledgment of upstream contributions outside California. Rivers located entirely outside California have been excluded. The following unit conversion is used: 1 acre-foot = 1233 m^3; 1 km^3 = 10^9 m^3 = 1000 GL. This framework provides order-of-magnitude estimates suitable for strategic planning rather than detailed design.

3. California Is Not Running Out of Water—Water Is Running Out to the Sea

To understand why land-based water solutions are failing California—and why sea-based solutions are scientifically sound—we must first examine the state's water availability. This reveals California's fundamental paradox: it possesses abundant water resources, yet allows a substantial portion to flow unused into the ocean.

Both President Trump and Governor Gavin Newsom appear to operate under the same underlying assumption: that the freshwater runoff discharged to the sea is untouchable and cannot be developed. This leads to a policy framework where the state must choose whom to prioritize—people or fish [6] (or more broadly, the environment).

However, the sea-based water solution challenges this zero-sum thinking. It proposes a system in which environmental flows are maintained, but a portion of the excess runoff is harvested downstream—at the river mouths—before mixing with seawater, and stored in coastal reservoirs (CRs). If implemented properly, and if runoff volumes are sufficient, coastal cities could rely on these CRs for their water supply, reducing dependence on distant or overburdened sources.

Ultimately, the feasibility and success of sea-based solutions depend on one critical factor: water availability. And the data shows that California has more than enough water—it simply needs a smarter, more integrated way to manage it.

Despite popular belief, California is not inherently water-scarce. Annual precipitation in California is highly variable, with a statewide annual average of 22.9 inches (582 mm/yr) of precipitation. California's interconnected water system is the world's largest, managing over 40,000,000 acre-feet (49 km^3) of water per year, centered on six main systems of aqueducts and infrastructure projects [7]. The state receives more than 200 km^3 of precipitation annually, and over 60 - 80 km^3 of freshwater flows through its rivers each year and its historical variation is shown in **Figure 7**. The urban water usage [5] is about 10.6 km^3/yr5, about 13% of the total runoff only.

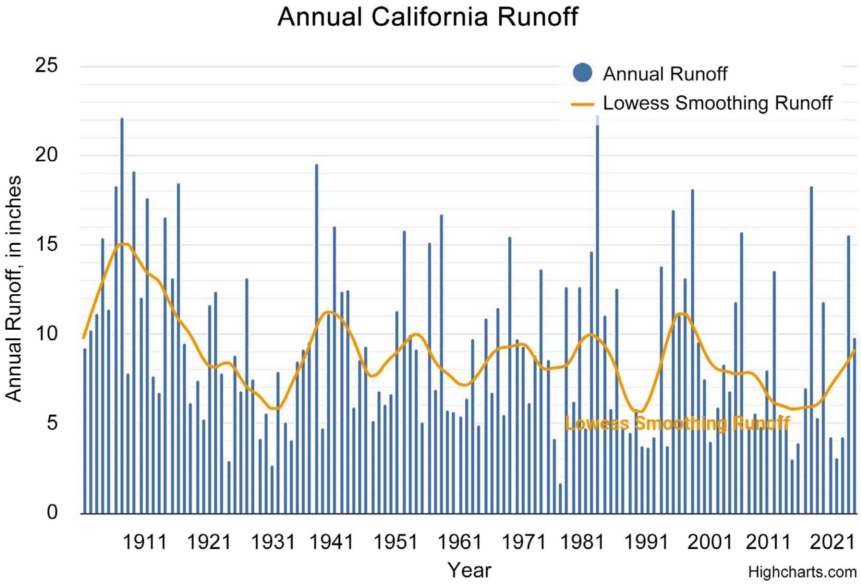

Figure 7. Annual California Runoff from 1900-2021.

Recognizing this paradox, several prominent figures—including Elon Musk, President Donald Trump, and leading researchers—have highlighted the massive volumes of freshwater that are lost to the ocean each year. However, they all assumed that runoff discharged to the sea, particularly after fulfilling environmental needs, cannot be further developed or reused.

Some efforts have been made to capture this water indirectly, primarily through groundwater recharge strategies. Similar to China's failed "Spongy City" concept, California has invested approximately $280 million per year in infrastructure modifications such as removing concrete and asphalt to increase infiltration. The goal is to recharge 300,000 acre-feet (approximately 370 GL/year) of stormwater by 2045 [8]. Yet, this approach faces critical limitations. A substantial portion of recharged water may eventually flow back to the sea, and only a fraction—typically around one-third—can be effectively recovered for reuse. This raises questions about the cost-effectiveness and scalability of groundwater recharge as a primary solution to California's water crisis.

In contrast, a sea-based water solution, such as the use of coastal reservoirs, offers a more direct and scalable alternative. The essential first step in evaluating this approach is to accurately quantify the volume of freshwater runoff currently lost to the sea. While various estimates exist, a brief review of available data is provided below to assess the true potential of capturing this untapped resource.

According to the Pacific Institute, among the ten U.S. states with the greatest untapped water potential, California ranks ninth, with an estimated 2.27 million acre-feet (approximately 2800 GL/year) of urban stormwater runoff lost annually [9]. Within California, Los Angeles represents the single largest urban area for stormwater runoff potential in the western United States, ranking 19th nationally. More specifically, the study estimated that the Los Angeles–Long Beach region alone loses 490,000 acre-feet (600 GL/year) of freshwater runoff to the sea each year. Other major urban areas also contribute significantly to this loss:

- Sacramento: 201,000 acre-feet (247 GL/year);
- San Diego: 142,000 acre-feet (175 GL/year);
- San Jose: 87,700 acre-feet (108 GL/year).

These figures highlight the vast quantity of recoverable freshwater currently being discharged into the Pacific Ocean. Capturing even a portion of this runoff through sea-based infrastructure such as coastal reservoirs could substantially enhance California's urban water supply, particularly in coastal cities facing growing demand and climate-induced stress.

California is divided into ten major hydrologic regions, delineated primarily for the purpose of water resource management. These regions are naturally separated by mountain crests and span the state from north to south. They include: North Coast, Sacramento River, North Lahontan, San Francisco Bay, San Joaquin River, Central Coast, Tulare Lake, South Lahontan, South Coast, and Colorado River regions. Key hydrological characteristics [4] of these catchments are summarized in **Table 4**.

Table 4. California rainfall and runoff.

Main California watersheds		
Hydrologic region	**Annual precipitation**	**Annual runoff**
North Coast	55,900,000 acre-feet (69.0 km^3)	28,900,000 acre-feet (35.6 km^3)
Sacramento River	52,400,000 acre-feet (64.6 km^3)	22,400,000 acre-feet (27.6 km^3)
North Lahontan	6,000,000 acre-feet (7.4 km^3)	1,900,000 acre-feet (2.3 km^3)
San Francisco Bay	5,500,000 acre-feet (6.8 km^3)	1,200,000 acre-feet (1.5 km^3)
San Joaquin River	21,800,000 acre-feet (26.9 km^3)	7,900,000 acre-feet (9.7 km^3)
Central Coast	12,300,000 acre-feet (15.2 km^3)	2,500,000 acre-feet (3.1 km^3)
Tulare Lake	13,900,000 acre-feet (17.1 km^3)	3,300,000 acre-feet (4.1 km^3)
South Lahontan	9,300,000 acre-feet (11.5 km^3)	1,300,000 acre-feet (1.6 km^3)
South Coast	10,800,000 acre-feet (13.3 km^3)	1,200,000 acre-feet (1.5 km^3)
Colorado River	4,300,000 acre-feet (5.3 km^3)	200,000 acre-feet (0.25 km^3)
Total	237.5 km^3	87.3 km^3

acre-feet: https://en.wikipedia.org/wiki/Acre-foot.

A total of 44 rivers in California drain into the Pacific Ocean, spanning from the northernmost to the southernmost parts of the state. **Table 5** presents the key characteristics of these rivers, including their names, catchment areas, lengths, peak elevations, and annual flow volumes. The data is sourced from Milliman and Farnsworth [10].

Table 5. Basic characteristics of California rivers (ordered from north to south).

River name	Catchment area 10^3 km^2	Length (km)	Highest point(m)	Annual flow km^3/yr
Smith River	1.86	482	1524	3.33
Klamath	41	460	2900	15
Redwood Mad	0.73	90	1600	0.88
Eel	9.5	320	2300	7.7
Mattole	1		>1000	1.1
Navarro	0.8	64	>1000	2.3
Gualala	0.9		>1000	0.4
Russian	3.7	160	1300	2.1
Sacramento	72	640	4300	20
San Joaquin	83	560	4400	15
Pajaro	3.1		1700	0.08
Salinas	11	280	1900	0.3
Carmel	0.63	55	>1000	0.1
Santa Ynez	2	120	2200	0.1
Ventura	0.48	50	2000	0.053
Santa Clara	4.1	130	2000	0.12
Calleguas	0.84		1200	0.12
Malibu	0.27		930	0.021
Los Angles	2.1	80	2300	0.24
Santa Ana	6.3	150	3500	0.68
San Diego Creek	0.31	50	>500	0.029
San Juan Capistrano	0.3		1900	0.01
San Mateo	0.34		>500	0.005
Santa Margarita	1.9	80	2200	0.025
San Luis Rey	1.4	80	2100	0.03
San Dieguito	0.9	90	1700	0.002
San Diego	1.1	70	2100	0.014
Tijuana	4.5	190	1100	0.04
Total	256	4201		70

Table 5 shows that the total freshwater discharge from California coastal rivers is estimated to be approximately 70 km^3/year, noting that interannual variability may increase this value to 70 - 80 km^3/year in wet conditions. This estimate includes contributions from major systems such as the Sacramento–San Joaquin River discharge via San Francisco Bay—over 6.6 times greater than the state's current urban water use of 10.6 km^3/year. Even if only 10% of this runoff were harvested and stored in coastal reservoirs, which is sufficient to meet the urban needs of a future population of 50 million. This clearly demonstrates that California is not running out of water—rather, water is running out of California.

Given that the state's major population centers are located in the south, it is essential to assess how much runoff is available in Southern California. This region, commonly referred to as SoCal, includes ten counties: Los Angeles, San Diego, Orange, Riverside, San Bernardino, Kern, Ventura, Santa Barbara, San Luis Obispo, and Imperial. Although smaller in land area than Northern California, Southern California is more densely populated, with 23.76 million residents as of the 2020 census. It includes two of the state's most populous urban regions: Greater Los Angeles and San Diego County.

Defining the southern rivers as those south of the Santa Clara River (approximately 100 km northwest of the Los Angeles River mouth), the total available runoff in this region is estimated at just 1.3 km^3/year. However, current water demand in this region exceeds 6.3 km^3/year, revealing a significant shortfall that necessitates water diversion from the north.

The Sacramento and San Joaquin Rivers discharge approximately 35 km^3/year into the ocean. A strategic opportunity exists to intercept a portion of this flow using a coastal reservoir near San Francisco, and convey water to a coastal reservoir near Los Angeles, a distance of approximately 625 km—virtually the same length as the Los Angeles Aqueduct. However, in contrast to land-based conveyance systems, a seabed pipeline solution would likely entail lower construction costs and significantly reduced environmental impact.

To ensure consistency, this study adopts a unified set of water availability and demand metrics. California receives approximately 200 km^3/year of precipitation, of which about 60 - 80 km^3/year becomes surface runoff after evapotranspiration and infiltration. Of this, roughly 45 - 50 km^3/year is currently managed through infrastructure systems such as reservoirs and aqueducts. Urban water use, defined as municipal and industrial demand [5], is approximately 10 - 13 km^3/year. In this study, the focus is on the portion of runoff that reaches coastal outlets and is not fully utilized. Earlier overestimates that included non-California basins have been corrected; all runoff values presented here refer exclusively to California hydrologic systems. This indicates that even a modest fraction (5% - 10%) of coastal runoff could provide a meaningful contribution to urban water supply. This analysis underscores the scientific and logistical feasibility of sea-based water solutions, particularly the use of coastal reservoirs and interconnecting seabed pipelines to sustainably manage California's abundant but misallocated water resources.

4. Comparison of Land-Based and Sea-Based Water Solutions

California's current water supply system is heavily reliant on aging land-based infrastructure, including long-distance aqueducts, groundwater extraction, and inland reservoirs. However, the growing strain from climate change, population growth, and ecological obligations has exposed the system's limitations. In contrast, sea-based water solutions, particularly coastal reservoirs (CRs) and seabed pipelines, offer an emerging paradigm shift. This section compares these alternatives in terms of quantity, quality, cost, and impacts.

4.1. Quantity and Distribution

Figure 8 illustrates historical water use trends in California, while **Figure 9** shows the demand and supply mix in Los Angeles. Between 2006 and 2015, California's total water use averaged 43.0 million acre-feet (53 km^3/year), with 80% used for agriculture and 20% (10.6 km^3/year) for urban areas [5]. As the population is expected to reach nearly 50 million by 2050, urban water demand is projected to rise to 13.2 km^3/year.

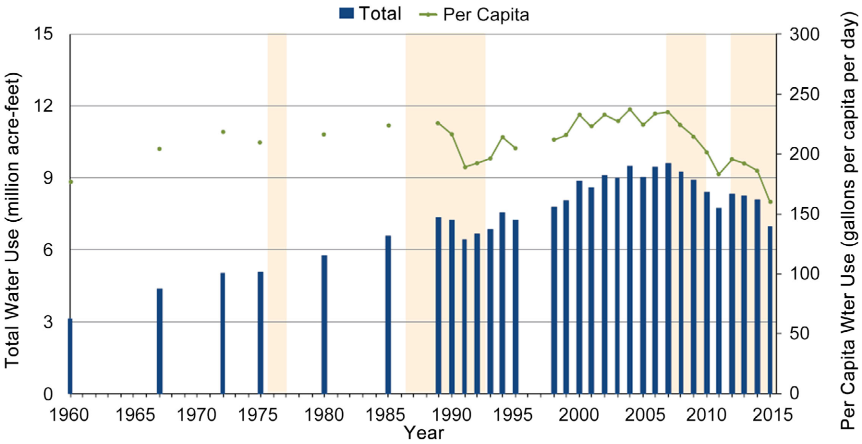

Figure 8. California total and per capita urban water use from 1960 to 2015. Data source from Cooley [5].

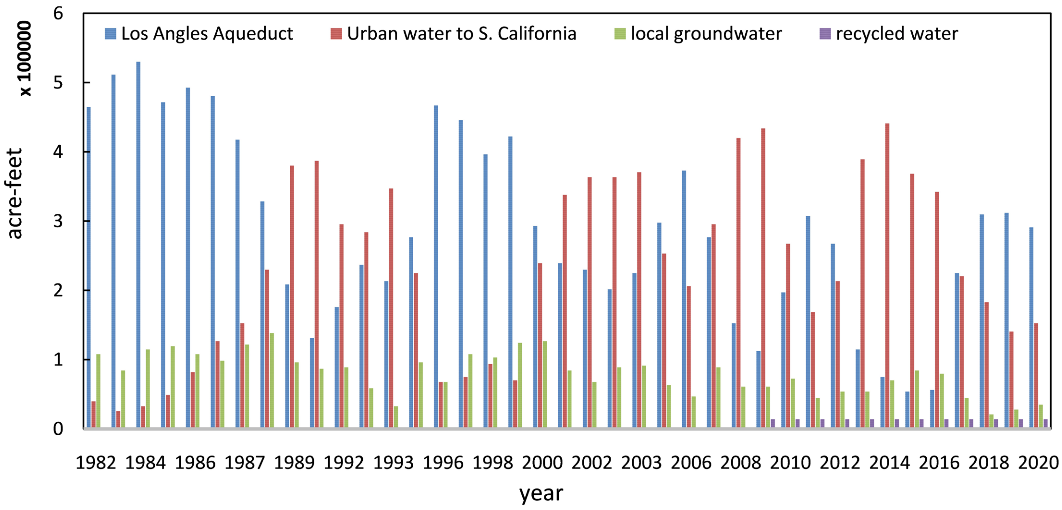

Figure 9. A 38-year history of water use and supply modes for Los Angles.

Currently, the Los Angeles region has a total supply capacity of just 860 GL/year (700,000 acre-feet), insufficient to meet future demands. If Southern California continues to rely on upstream transfers, the competition for water with agricultural users will intensify. However, Table 5 shows that coastal reservoirs at the mouths of the Los Angeles and Santa Ana Rivers can collectively yield 0.92 km^3/year (750,000 acre-feet/year), surpassing the region's current supply.

Moreover, freshwater stored in a coastal reservoir near San Francisco Bay could be conveyed to Southern California via seabed pipelines. This would reduce dependence on existing aqueducts and free up upstream water for agricultural use. In this scenario, coastal cities receive water from local runoff and ocean-fed systems, while inland water sources are reserved exclusively for agriculture—creating a balanced and equitable distribution model.

4.2. Quality and Treatment Synergies

A key concern with coastal reservoirs is water quality variability. However, Singapore has shown that partially fresh runoff can be effectively treated and used as feedwater for desalination. This integration significantly reduces both energy consumption and brine outfall when compared to direct seawater desalination.

4.3. Environmental Impacts

Land-based solutions such as dams and aqueducts disrupt river ecosystems, draw down groundwater, and exacerbate land subsidence. Desalination, while increasingly popular, is energy-intensive and produces brine waste. In contrast, coastal reservoirs harvest only excess runoff—preserving upstream environmental flows—while seabed pipelines operate with minimal terrestrial without land inundation and people displacement.

To prevent the growing gap between supply and demand, California [11] has already diversified its portfolio. Notably, in December 2015, Poseidon Water completed the Claude "Bud" Lewis Carlsbad Desalination Plant, producing up to 190,000 m^3/day (70 GL/year) and serving approximately 8% of San Diego County's demand. Six other plants were operational by the end of 2015, with nine more proposed.

Given these developments, it is critical to evaluate both land-based and sea-based options in terms of water availability, long-term resilience, and economic viability. This comparison is essential not just for future planning but also for avoiding the political and environmental conflicts that intensified during the 2025 wildfire crisis—exemplified by the polarizing debate between President Trump and Governor Newsom over water use priorities.

Table 5 confirms that CRs at the Los Angeles and Santa Ana river mouths could supply 0.92 km^3/year—more than the current total supply in the Los Angeles region. Although water quality varies, desalination plants can treat low-grade runoff, as demonstrated in Singapore. This approach lowers desalination costs by using water with lower salinity than seawater.

Similarly, transporting freshwater from a San Francisco Bay CR to Southern California using seabed pipelines would reduce reliance on aging inland aqueducts, while reallocating upstream water for agricultural purposes. In this way, sea-based infrastructure supports both urban water security and inland farming resilience.

To explore these possibilities, two scenarios are considered:

1) A single CR capturing runoff from the Los Angeles and Santa Ana Rivers, linked to an existing desalination facility.

2) Two CRs—one at San Francisco and one at Los Angeles—connected by seabed pipelines to facilitate regional redistribution.

Shanghai's Qingcaosha CR serves as a benchmark, with a surface area of 66.15 km^2, storage capacity of 527 GL, and daily supply of 6.6 GL. Its 48.4 km dike includes two sluices and cost ¥6.45 billion (≈US$1.0 billion) in 2010.

Based on this model, estimated costs for California include:

- **Scenario 1:** US$1.0 billion for one CR at Los Angeles (desalination plant already built)
- **Scenario 2:** US$2.0 billion for two CRs, plus US$5.5 billion for seabed pipelines

For Shanghai, its complete sea-based system—CRs, pipelines, and pumps—costed at ¥17 billion (≈US$2.6 billion), without CRs, the pipeline and pumps (see **Figure 10**) costed US$1.6 billion. The network would include eight raw water plants (16.17 GL/day capacity), 36 public treatment works (11.45 GL/day), and 30,000 km of distribution pipes [12].

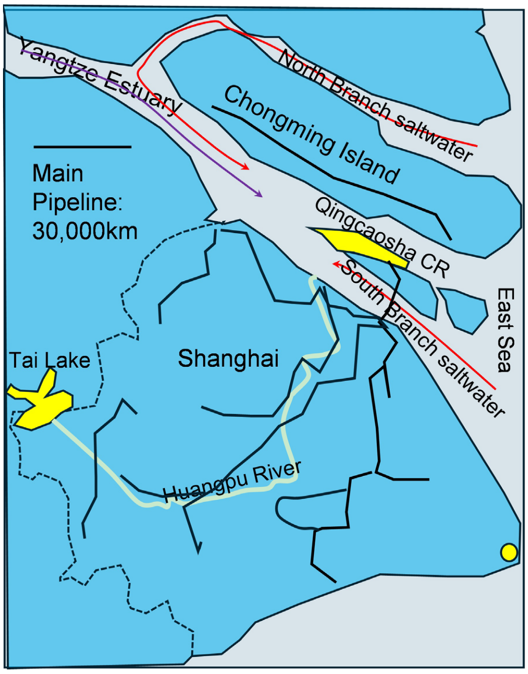

Figure 10. The distribution of raw water plants, water treatment plants and water delivery pipes in Shanghai, source from Li *et al.* [12].

Singapore's fourth desalination plant [2] (see **Figure 11**) uses CR water and seawater, operating at S$1.08/m^3 (≈US$0.82/m^3)—a reference for Scenario 1. Singapore's integrated CR-desalination system, already operational, proves that combining sea-based storage with modern treatment technology reduces energy and enhances system resilience.

Figure 11. Marina Coastal Reservoir feeds desalination plant in Singapore, source from https://worldlandscapearchitect.com/marina-east-desalination-plant-singapore-tierra-design-studio/?v=8bcc25c96aa5.

Table 6 illustrates that sea-based solutions offer significantly higher yields at lower cost and with less environmental impact. For example, California's proposed water tunnel is expected to cost US$20 billion to deliver 0.5 km^3/year. The proposed tunnel—45 miles (72 km) long and 36 feet (11 meters) wide—would convey 161 million gallons per hour.

Table 6. Comparison of land-based and sea-based water solution for south California.

Solution	Construction cost (US$b)	Max. supply (km^3/yr)	Envir. Impact	Estimated operational cost (US$/m^3)
1 CR at LA	1.0 + 0 (desalination)	0.92	minimum on fish (delta smelt) or groundwater	0.82
2 CRs at LA & San Francisco	2.0 + 5.5 (seabed pipelines)	10.6	minimum on fish (delta smelt) or groundwater	Same as Aquesduct
Los Angeles Aqueduct	(existing)	0.62	Very high	N.A
California Aqueduct	Additional 20 billion for a tunnel	≈additional 0.5	Very high	N.A.
Colorado River Aqueduct	Existing	1.48	Very high	N.A.
Groundwater recharging	0.3/yr	0.37	Minimum	N.A.
Wastewater reuse	N.A.	0.048	Minimum	N.A.

By comparison, a US$1 billion CR system could deliver 0.92 km^3/year—almost twice the volume at just 5% of the cost. Additionally, sea-based systems reduce pressure on upstream sources, indirectly boosting agricultural supply.

The Nord Stream 2 seabed pipeline—from Russia to Germany—cost approximately US$11 billion and spans 1230 km [13]. Given that the distance between San Francisco and Los Angeles is about half that, a comparable freshwater transfer system, including pumping stations, is estimated at around US$5.5 billion as noted in **Table 6**. With careful planning and environmentally sensitive design, coastal reservoirs can be implemented with minimal ecological disruption—even to vulnerable species such as the Delta smelt.

California's land-based water diversion projects tend to be more expansive and capital-intensive. The Los Angeles Aqueduct, measuring 674 km in length with a 3.7-meter diameter, delivers up to 620 GL/year (as shown in **Figure 9**). The California Aqueduct, which stretches 715 km, is the subject of a proposed US$20 billion tunnel project under the Newsom administration [14]. Without this tunnel, water deliveries are projected to decline by 22% by 2070. If completed, the tunnel could provide an additional 400,000 acre-feet (≈0.5 km^3) of water annually, as reflected in **Table 6**. Additionally, the Colorado River Aqueduct extends 389 km and supplies approximately 1.48 km^3/year.

Groundwater has historically contributed up to 23% of Los Angeles's water supply, particularly during drought periods such as 2012-2016. In response to mounting water stress, the city [15] introduced a parcel tax in 2018 of 2.5 cents per square foot of impermeable surface to fund stormwater capture infrastructure—generating approximately US$300 million annually. The goal is to capture 370 GL/year (300,000 acre-feet) by 2045, enhancing local water self-sufficiency.

Wastewater reuse is also gaining prominence. Los Angeles initiated tertiary water treatment in 1960 and began using treated effluent for irrigation in 1979. By the 2019-2020 fiscal year, around 180 sites across the city reused 36,392 acre-feet (48 GL/year) of treated wastewater for irrigation, industrial use, and environmental restoration.

The shift from land-based to sea-based water management is no longer conceptual—it is a practical, proven, and urgently needed evolution in California's water strategy. Coastal reservoirs offer a scientifically grounded, economically efficient, and environmentally sustainable solution. By capturing freshwater runoff before it escapes to the ocean and delivering it through gravity-assisted seabed pipelines, CRs provide reliable supply to coastal cities while preserving upstream flows for agriculture. This integrated approach aligns with climate adaptation goals and international best practices. California must seize this opportunity to modernize its water system—before the next crisis hits.

It is also evident from **Table 6** that sea-based water solutions clearly outperform land-based options in terms of water volume, cost-efficiency, and environmental footprint. For instance, the proposed California water tunnel is expected to cost US$20 billion to deliver 0.5 km^3/year of water. In contrast, a single coastal reservoir system can provide 0.92 km^3/year at just US$1 billion—nearly twice the volume at only 5% of the cost. Additionally, sea-based solutions can indirectly enhance upstream water availability for agriculture by reducing reliance on traditional water transfers. The tunnel, designed to span 45 miles (72 km) and 36 feet (11 meters) in diameter, is capable of transporting over 161 million gallons of water per hour. Meanwhile, the coastal reservoir-desalination model, successfully adopted in Singapore, has demonstrated a substantial reduction in energy use and operational costs by utilizing partially fresh runoff instead of seawater as feedstock.

Finally, it is important to emphasize that large-scale land-based infrastructure projects often face significant delays due to complex permitting, legal battles over land acquisition, and challenges related to relocating affected communities. These issues are particularly pronounced in developed regions like California—as evidenced by the prolonged timeline and controversies surrounding the California High-Speed Rail project. In contrast, sea-based solutions demonstrate far greater efficiency in execution. Shanghai completed the Qingcaosha Coastal Reservoir in just two years (2008-2010), and Nord Stream 2 was constructed between 2018 and 2021. From a political, logistical, and environmental standpoint, California increasingly appears to have only one viable path forward: embracing sea-based water solutions.

The recent development of “Long Island” coastal reservoir project [16] [17] with about $100 billion has endorsed Yang’s prediction [18] in early 2000s that sooner or later Singapore will develop coastal reservoirs surrounding its land for its survival. The national policy for Singapore should be converted from a little red dot in seawater to a green oasis surrounded by freshwater.

While sea-based water solutions offer significant potential, several California-specific constraints must be considered. First, estuarine water quality varies seasonally, with elevated salinity and pollutant loads during low-flow periods, which may affect treatment requirements. Second, seasonal and interannual variability in runoff, driven by Mediterranean climate patterns, introduces uncertainty in supply reliability, particularly during drought years. Third, marine permitting and regulatory approvals in California are complex, involving multiple state and federal agencies, which may extend project timelines. Fourth, sedimentation at river mouths may reduce storage efficiency and require ongoing dredging or sediment management. Finally, coastal and seismic risks, including offshore fault activity and sea-level rise, must be incorporated into design and construction.

These factors indicate that coastal reservoirs should be considered a complementary component of California’s water portfolio rather than a standalone solution, and warrant further detailed site-specific investigation.

5. Conclusions and Recommendations

California’s water crisis stems not from a lack of water, but from a failure to capture and distribute it efficiently. With over 60 - 80 km^3/year of freshwater runoff discharged into the Pacific Ocean, and only 10.6 km^3/year used for urban water purposes, the current system is clearly unsustainable. Land-based infrastructure—though historically essential—is reaching its operational and political limits due to rising costs, environmental constraints, and protracted permitting processes.

In contrast, **coastal reservoirs (CRs)** and **seabed pipelines** offer a scientifically grounded, economically viable, and environmentally responsible path forward. CRs capture freshwater runoff before it is lost to the ocean, while seabed pipelines enable efficient redistribution to coastal cities with minimal ecological footprint. Unlike traditional aqueducts and tunnels, sea-based systems avoid land acquisition battles and reduce the risk of displacement or groundwater depletion.

The success of similar systems in Shanghai and Singapore demonstrates both the technical and operational viability of this approach. Implemented correctly, sea-based solutions could transform California from a drought-prone state to a global leader in sustainable water management.

With climate pressures mounting and traditional systems faltering, California must act decisively to prepare for the next disaster. Sea-based water solutions are no longer a futuristic concept—they are a proven, pragmatic response to today's crisis. The time to invest is now.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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