Alternative Desalination Process Better Suited for PV

By John Benson

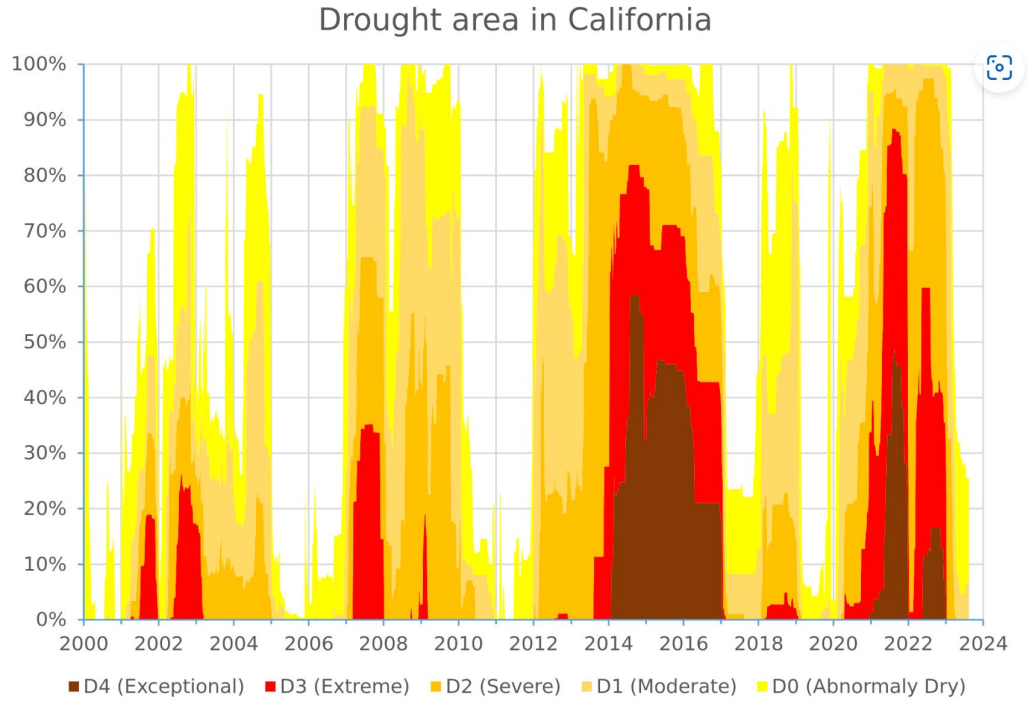
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1. Introduction

Relatively pure water is an important ingredient for almost everything. In almost every residence it is used for washing clothes, dishes, residential surfaces and occupants. Drinking? Some buy bottled water, but I would guess that such residents still drink some tap water. Although i will not go into the gory details about how commercial and industrial firms use water, there are a huge number of functions it performs for each.

One of the main advantages of water is its price: it's really inexpensive. Where I live in the SF Bay Area, we get most of our water from rain-fall on nearby mountains, but we get little rain from May through September. However, as I'm writing this, it's Star Wars Day (May the fourth be with you), and it's raining. During drought years some communities are forced to use salty or brackish water and desalinate it, which increases its price. Reverse Osmosis is the most popular process for desalinating water, whether it is brackish water or sea-water.

For non-Californians there is one issue that I need to clarify, before I describe our drought frequency. As you might guess from the above "…May through September…" comment, we get almost all of our rain in October through April. Thus, our rain-year crosses over two years. Our last dry-spell (I wouldn't classify it as a drought) was in the rain-years 2020/2021 and 2021/2022. The rain-years 2022/2023 and 2023/2024 have had above normal precipitation. However, our droughts are frequent (see the chart below).[1]



[1] Wikipedia Article, "Droughts in California," https://en.wikipedia.org/wiki/Droughts_in_California#

The last post I had on a subject similar to this one was in September 2022, and that is summarized and linked below.

California's Water Challenges and Possible Solutions: *Our climate has changed. We are experiencing extreme, sustained drought conditions in California and across the American West caused by hotter, drier weather. Our warming climate means that a greater share of the rain and snowfall we receive will be absorbed by dry soils, consumed by thirsty plants, and evaporated into the air. This leaves less water to meet our needs.*

This is our new climate reality, and we must adapt…

https://energycentral.com/c/rm/california%E2%80%99s-water-challenges-and-possible-solutions

Readers should also mote that that California has been preparing for droughts for over a century, building many reservoirs all over the state to store water, since much of our water comes for the Sierra Nevada and Cascade Mountain Ranges in the form of winter snow. Unfortunately, a dry rain year generally means less "snow-pack" at the end of winter. Also note that California, and a few states to our east have extensive government agencies that spend large sums managing our water. These range from Federal Agencies to local government bodies. The local bodies also manage consumption during dry years,

The local bodies in my area have looked at investing in desalination systems in the past, but the payback for a really expensive reverse-osmosis system was not there.

Our state has also been investing heavily in solar energy (ditto your author). So, a desalination system that results in lower cost and scheduling that can live with the intermittent nature of photovoltaic power (without large expensive battery banks) would be a big plus. The system that we review in section 3 below may be that system.

2. Reverse Osmosis (RO) Technology

Note that much of the text below is from an earlier (2019) post.

As of late 2022 California had twelve operating desalination plants, including one of the largest in the world in Carlsbad (near San Diego). The Carlsbad plant was completed in 2015, can deliver 54 Million gallons a day of water and consumes 35 MW of electricity doing this.

Also, *California regulators this week approved a $140 million desalination plant that could convert up to 5 million gallons of seawater each day into drinking water, as the state grapples with a persistent megadrought and plummeting water supplies.*[2]

[2] Emma Newburger, CNBC, "California approves desalination plant as historic drought hits water supplies," Oct 14, 2022, https://www.cnbc.com/2022/10/14/california-approves-desalination-plant-as-drought-hits-water-supplies.html

The state's Coastal Commission on Thursday voted 11-0 to approve the Doheny Ocean Desalination Project in Orange County in Southern California. The plant could be functioning within the next five years and supply water for thousands of people in the South Coast Water District.

All of these plants use reverse osmosis, which is described below.

Reverse osmosis (RO) is a water purification process that uses a partially permeable membrane to remove unwanted molecules and larger particles from drinking water. Reverse osmosis can remove many types of dissolved and suspended chemicals as well as biological ones (principally bacteria) from water. The result is that water with dissolved compounds and particulates is retained on the pressurized side of the membrane and the pure water is allowed to pass to the other side. To be "selective", this membrane should not allow large molecules or ions through the pores, but should allow smaller molecules such as water to pass.

A reverse osmosis system has four primary processes:

Pretreatment: The incoming feedwater is pretreated to be compatible with the membranes by removing most suspended solids (that would clog the membranes), adjusting the pH, and adding a threshold inhibitor to control scaling caused by constituents such as calcium sulphate.

Pressurization: The pump raises the pressure of the pretreated feedwater to an operating pressure appropriate for the membrane and the salinity of the feedwater. Much of the energy used by reverse osmosis is consumed by this pressurization process.

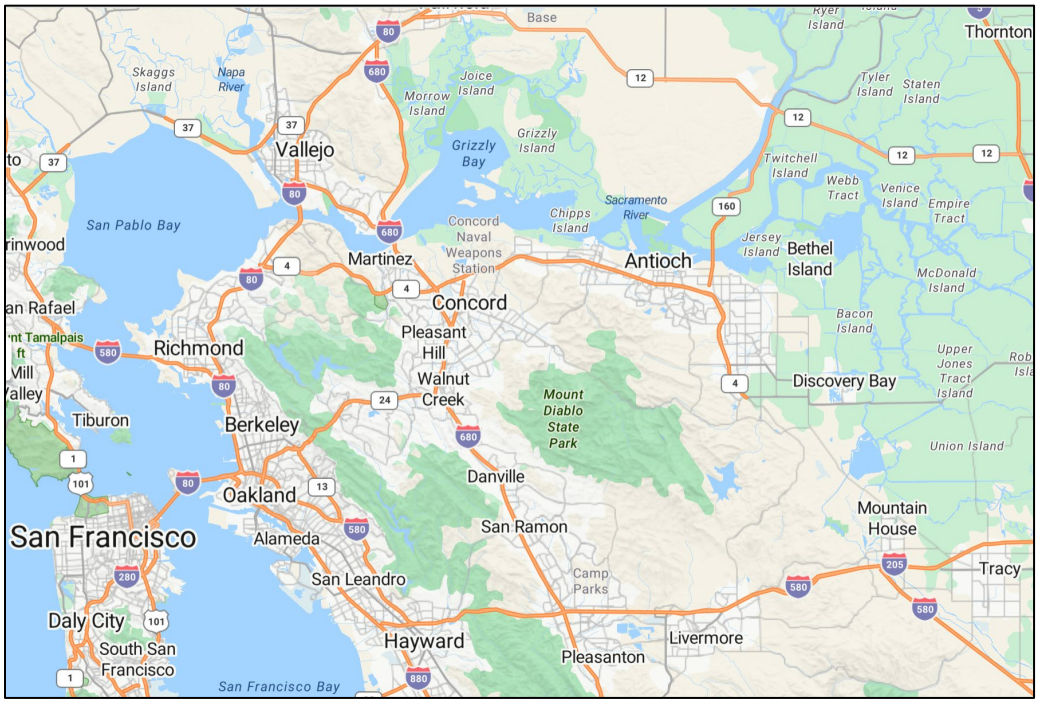
Separation: The pores in permeable membranes are large enough for pure water molecules to pass through but strongly resist the passage of molecules with ionically-bound salts and particulates. Applying pressurized feedwater to the membrane assembly results in a freshwater product stream passing through the membrane and a brine stream remaining on the pressurized side. Ultimately the brine stream is discarded once it reaches the target concentration. Because no membrane is perfect in its rejection of dissolved salts, a small percentage of salt passes through the membrane and remains in the product water. Reverse osmosis membranes come in a variety of configurations. They are generally made of cellulose acetate, aromatic polyamides, or, nowadays, thin film polymer composites. Reverse osmosis systems are used for brackish water and seawater desalination, although the specific membrane and the construction of the pressure vessel vary according to the different operating pressures used for the type of feedwater.

Stabilization: The product water from the membrane assembly usually requires pH adjustment and degasification before being transferred to the distribution system for potable water. The product passes through an aeration column in which the pH is elevated from a value of approximately 5 (acidic, due to dissolved gases) to a value close to 7 (neutral).

3. Electrodialysis Reversal (EDR) Technology

Globally, 1.6 billion people in rural regions face water scarcity. Expanding freshwater access via brackish groundwater desalination can provide additional resources to address this challenge. In this study, we have developed a time-variant electrodialysis reversal (EDR) technology that flexibly uses available solar energy for desalination. Our proposed photovoltaic-powered desalination system can vary pumping and EDR power to match the availability of intermittent solar power, maximizing the desalination rate. Our results show improved system performance with the direct use of 77% of available solar energy—91% more than in conventional systems—and a 92% reduction in battery reliance. In a village-scale desalination case study in India, these system improvements lead to a 22% reduction in water cost, making the technology competitive with the currently used on-grid, village-scale reverse osmosis systems that are mainly powered by fossil fuels. Future advances could further reduce costs, providing an improved, sustainable solution to water scarcity in remote areas.[3]

Author's comment: There are (at least) two natural sources of brackish water, groundwater as described above, and water from the "mixed" zone where a freshwater stream or river flows into the ocean or a salt-water bay. The last is where we would get ours, since we are close to the Sacramento-San Joaquin Delta (see map below). Note the San Joaquin River enters the delta from the E-SE and the Sacramento River from the NE. San Pablo Bay is tidally influenced, so it's mostly seawater. The desalination facility being considered for the inland north-to-central SF Bay Area is planned [4]near Antioch.

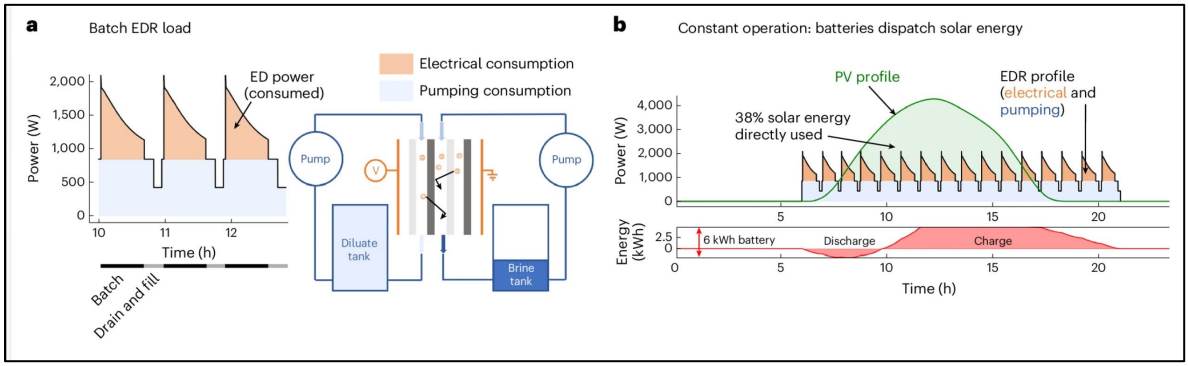


[3] Wei He, Anne-Claire Le Henaff, Susan Amrose, Tonio Buonassisi, Ian Marius Peters & Amos G. Winter V, Nature Water, "flexible batch electrodialysis for low-cost solar-powered brackish water desalination," March 26, 2024, https://www.nature.com/articles/s44221-024-00213-w

[4] "Projected Brackish Water Desalination Projects in California," Feb 2024, https://water.ca.gov/-/media/DWR-Website/Web-Pages/Work-With-Us/Grants-And-Loans/Desalination/Files/Water-Supply-Strategy-Brackish-Desalination-Projects_02-16-24_v2.pdf

Reverse osmosis (RO) systems and electrodialysis reversal (EDR) are two widely used techniques in brackish water desalination. An EDR module is made up of a stack of ion exchange membranes and uses an electric field to move ions from the diluate[5] flow channels to the brine flow channels between each membrane (Fig. 1a). This electric field can be intermittently reversed to prevent the build-up of scale on the membrane, thus adding 'R' to EDR.

Fig. 1: Batch photovoltaic EDR systems in constant operation: mismatch between power generated and power consumed.



a, Schematic of a batch EDR module (right) and the typical EDR power consumption profile (left) repeated during each batch when a constant voltage and flow rate are applied. The voltage applied to the EDR stack drives ions across the ion exchange membranes from the diluate channels to the concentrate channels. b, Daily PV and EDR power profiles when solar panels are coupled to the EDR module in constant operation (top). The mismatch between the solar power and EDR power profiles requires a 6 kWh battery capacity (for a representative community-scale system) to discharge solar energy (bottom). The corresponding integrated flow into the battery during the day is shown in red. The x axis label in the bottom plot also applies to the top plot.

Solar desalination systems must address the intermittency of solar power, often managed by costly, high-maintenance batteries, posing challenges in resource-limited communities. EDR, more energy efficient and with higher water recovery than RO, is advantageous for renewable-powered desalination. Wright and Winter[6] suggested that EDR could operate with half of the solar and battery capacity needed for a comparable PV-RO system, achieving up to 90% water recovery. In this context, we have developed a flexible EDR technology that adapts to the variability of solar energy, potentially reducing the costs for PV-EDR brackish water desalination systems.

Final author's comment: Reference 3 is extremely long, and attempts to examine every case of grid supply and local battery energy storage system availability. This is beyond the scope of this paper. Any potential user considering a desalinization application should evaluate the specific characteristics of that application for each method being considered. Feel free to dive into reference 3 (via the above link) to see if there is additional information that is relevant to any specific application.

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[5] Rarely do I run into a word I've never seen before, and rarer-still do I ask my Bing search engine about it and cannot get a reasonable answer, but the word "diluate" did this trick. I finally found a good definition (I hope) of that word, plus another word I had never seen before. "*The diluate is the liquid to be diluted and the diluent is what is used to dilute it.*" https://www.researchgate.net/figure/Fig-2-Dilution-technique-The-diluate-is-the-liquid-to-be-diluted-and-the-diluent-is-what_fig6_281255463

[6] Wright, N. C. & Winter, A. G. Justification for community-scale photovoltaic-powered electrodialysis desalination systems for inland rural villages in India. Desalination 352, 82–91 (2014).