Managed Aquifer Recharge in California
Long-Term Projects & New Emphasis Under SGMA

Call to Increase Recharge in California to Reach Sustainability

Timothy K. Parker, PG, CEG, CHG
Principal Hydrogeologist, Parker Groundwater
Sacramento, CA tim@pg-tim.com

Photo: www.MavensNotebook.org

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Outline

- California Setting
- Legal Framework
- Long-Term MAR
- New Developments

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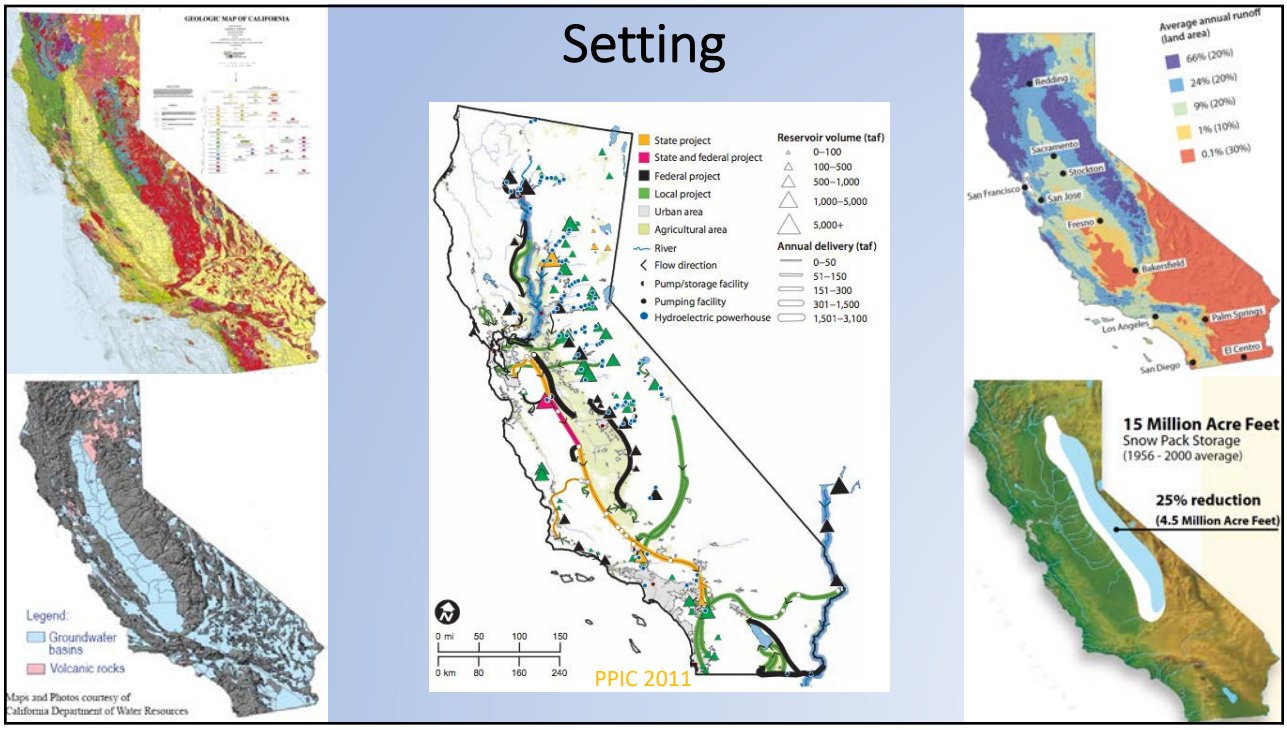
Setting
GEOLOGIC MAP OF CALIFORNIA
Legend:
Groundwater basins
Volcanic rocks
Maps and Photos courtesy of California Department of Water Resources
State project
State and federal project
Federal project
Local project
Urban area
Agricultural area
River
Flow direction
Pump/storage facility
Pumping facility
Hydroelectric powerhouse
Reservoir volume (taf)
0–100
100–500
500–1,000
1,000–5,000
5,000+
Annual delivery (taf)
0–50
51–150
151–300
301–1,500
1,501–3,100
0 mi 50 100 150
0 km 80 160 240
PPIC 2011
Average annual runoff (land area)
66% (20%)
24% (20%)
9% (20%)
1% (10%)
0.1% (30%)
Redding
Sacramento
Stockton
San Francisco
San Jose
Fresno
Bakersfield
Los Angeles
Palm Springs
El Centro
San Diego
15 Million Acre Feet
Snow Pack Storage
(1956 - 2000 average)
25% reduction
(4.5 Million Acre Feet)

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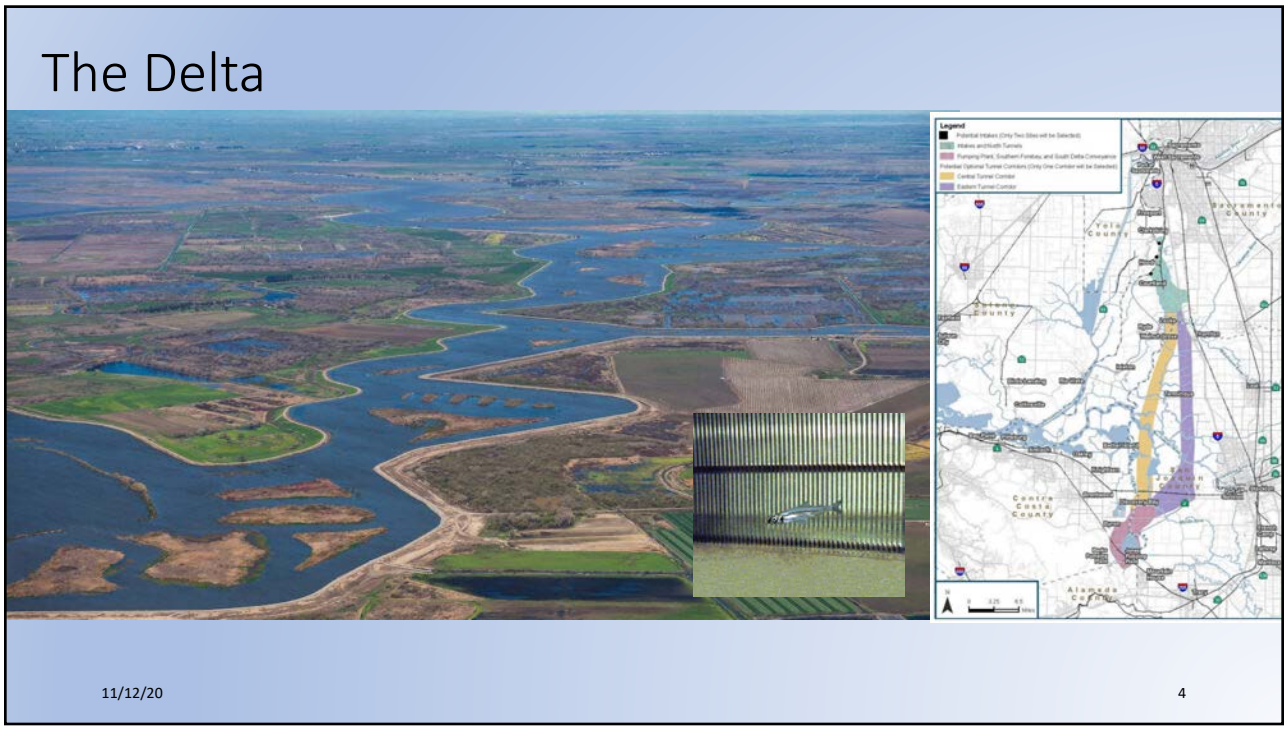
The Delta
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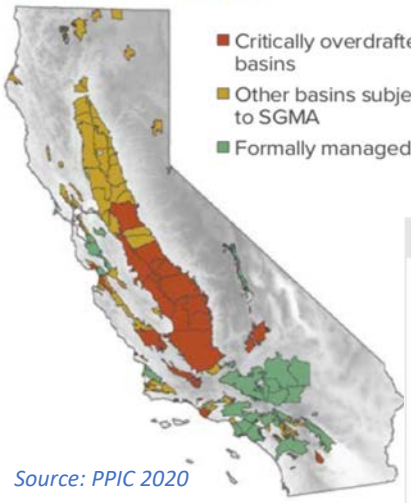
Setting

California's Water Grid

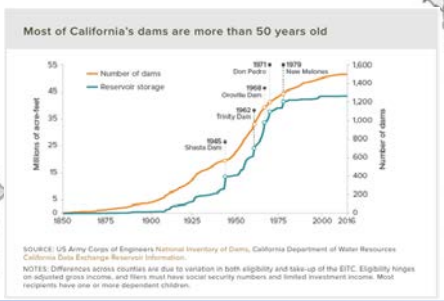
GW 850MAF to 1500MAF

Main groundwater basins



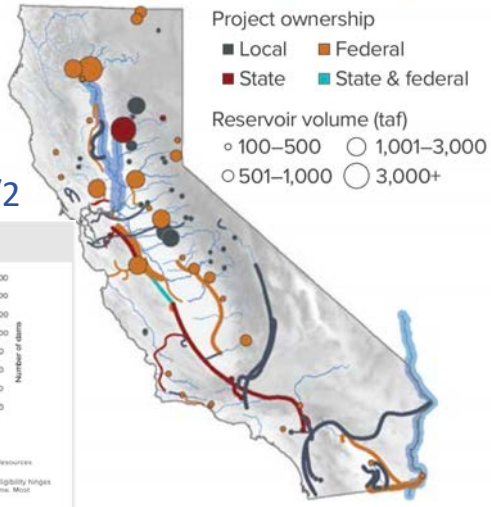
Source: PPIC 2020

1500/240-60%/90/2/2



SW 50MAF

Main above-ground storage and conveyance



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Legal Framework Water Rights

California Constitution Article X, Section 2 and State Water Code require that all water belongs to the state and that all water use be both "reasonable and beneficial" and not wasted

Surface Water

- **1914** – surface water permitted
- **Riparian** – land touches water source – part and parcel
- **Appropriative** – first in time - use away from point of diversion
  - Pre-1914 – no permit required
  - Subject to loss for nonuse
- **Prescriptive** – acquired thru adverse possession of another's water right – court awarded

Groundwater

- **2014** – SGMA
- **Correlative** – landowners have right to install well and start pumping
- **Appropriative** – first in time - use away from point of diversion
  - Pre-1914 – no permit required
  - Subject to loss for nonuse
- **Prescriptive** – acquired thru adverse possession of another's water right - court awarded

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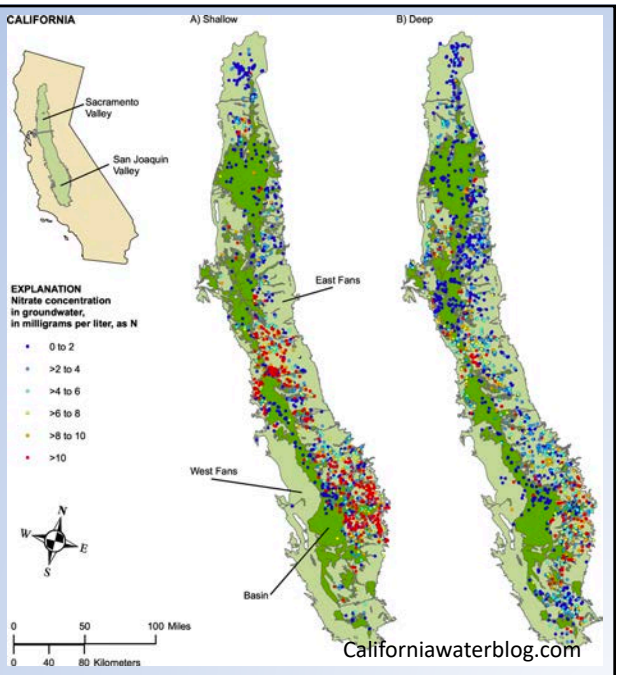
The Precursor: Nitrate in Wells

CA LAO.CA.GOV



Californiawaterblog.com

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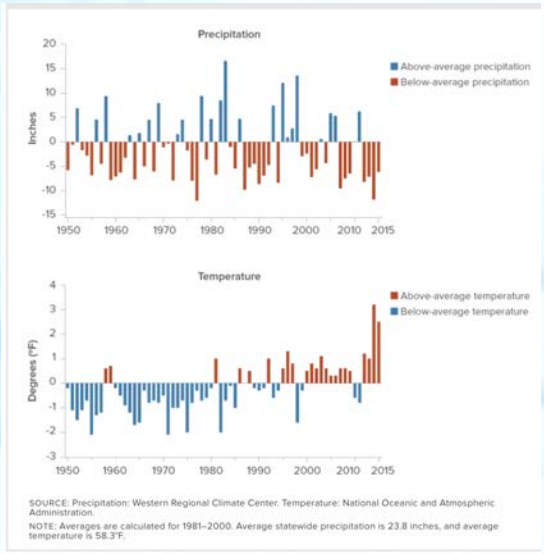
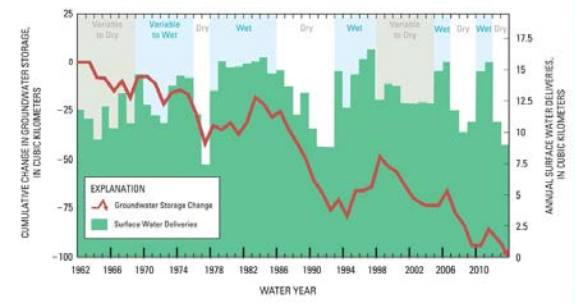
Perfect Storm Led to Landmark GW Law



Public Policy Institute of California www.PPIC.org



Central Valley Storage Loss

GW Pumping Induced Subsidence

USGS www.usgs.gov

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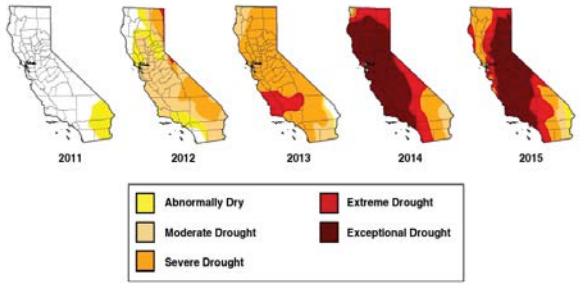
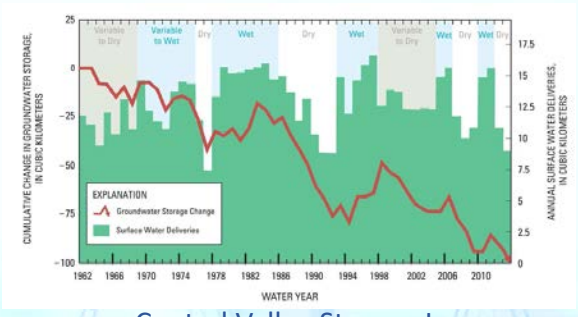
Perfect Storm Led to Landmark GW Law

Statewide Drought Measurements From U.S. Drought Monitor, Taken Around October 1 Each Year[a]



[a] The U.S. Drought Monitor estimates drought intensity based on several indicators, including soil moisture, streamflow, and precipitation. October 1 is the beginning of the state's "water year" for annual precipitation calculations.

Public Policy Institute of California www.PPIC.org



Central Valley Storage Loss

GW Pumping Induced Subsidence

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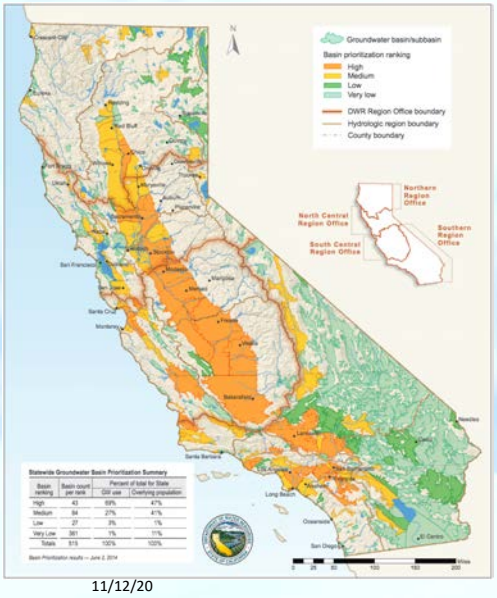
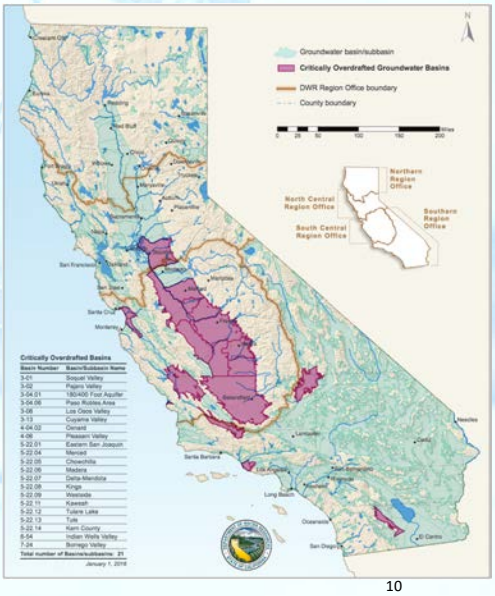
Legal Framework Sustainable Groundwater Management Act

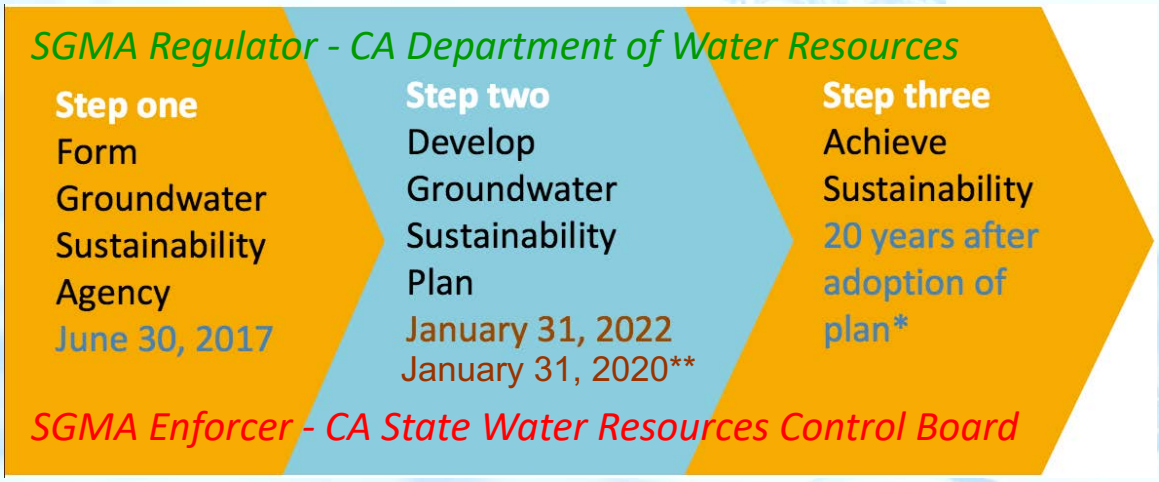


Prioritization

- Population and Density
- Current and Projected Growth
- Number Public Supply Wells
- GW Reliance
- Other adversity including GDEs



Legal Framework Sustainable Groundwater Management Act



* DWR may grant up to two, five-year extensions on implementation upon showing good cause and progress.
** Critically overdrafted basins have two years less for GSP and to achieve sustainability.

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Legal Framework Sustainable Groundwater Management Act

Groundwater Sustainability Plans must contain:

- Description of the GSA, member agencies, powers and jurisdiction
- Description of basin geology, hydrology, climate, demography, land use planning coordination, and basin water budget and sustainable yield
- ***Define how sustainability will be set and measured***
- Identify programs, projects (conceptual and developed), and management actions to be taken to achieve sustainability
- Implementation plan including funding and finance

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Legal Framework Sustainable Groundwater Management Act

Define how sustainability will be set and measured

1) *Undesirable Results* – qualitative description of what is unacceptable
2) *Measurable Objective* – quantitative metric of desired condition
3) *Minimum Threshold* – quantitative metric where undesirable results becomes significant and unreasonable and action is taken

For All Pertinent Sustainability Indicators:

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Legal Framework Sustainable Groundwater Management Act

Legislative Intent that:

- Groundwater basins be locally managed, that groundwater is a local resource
- Groundwater storage be increased statewide and remove unnecessary impediments to recharge

Groundwater Sustainability Plan Regulations require that GSPs contain the following:

- Description of conjunctive use programs
- Recharge area maps
- Identification of potential recharge areas and discharge areas (springs, seeps, wetlands)

And that GSAs report:

- Surface water supplies used or available for use for recharge to be reported on annual basis
- Water budget inputs and outputs

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Legal Framework Sustainable Groundwater Management Act

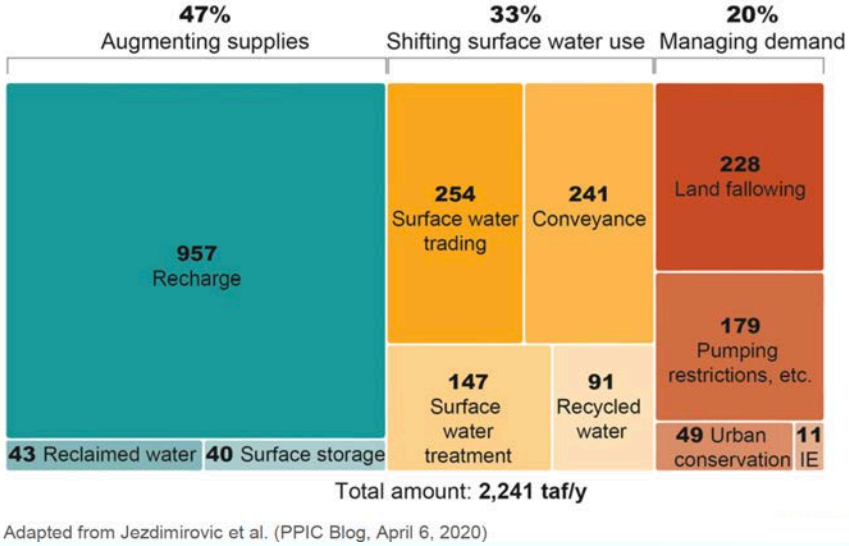
Next Steps

- COD Basin GSPs were submitted in January
  - DWR has two years to review and comment
  - COD Basin GSAs are implementing GSPs
- Litigation has been filed challenging SGMA and GSPs
- Remaining SGMA basins are preparing GSPs, due January 31, 2022

Legal Framework Sustainable Groundwater Management Act

Critically Overdrafted Basin Groundwater Sustainability Plans (TAF/year)

- Most have mixed portfolios, but recharge is the major management action, few incentives for demand side management
- Most do not have shallow well protections
- Many allow continued significant subsidence



Adapted from Jezdimirovic et al. (PPIC Blog, April 6, 2020)

Legal Framework Policies, Statutes, Regulations, Affecting MAR

2020 Water Resiliency Portfolio

- Streamline recharge efforts
- State funding for recharge
- Technology for mapping recharge areas

State Water Boards-Water Quality

- Porter Cologne (Water Code §13000)
- Basin Plans
- Irrigated Lands Regulatory Program (ILRP), Dairy Program
- Drinking Water Policy (Resolution 88-63)
- Water Code §2100

State Regulations and Permitting

- Underground Storage Supplement
- Recycled Water Policy
  - Recharge Wells using Recycled Water
  - Infiltration Basins using Recycled Water
- General Waste Discharge Requirements for ASR that Inject (Chlorinated) Drinking Water
- Streamlined Stormwater Permitting for Recharge

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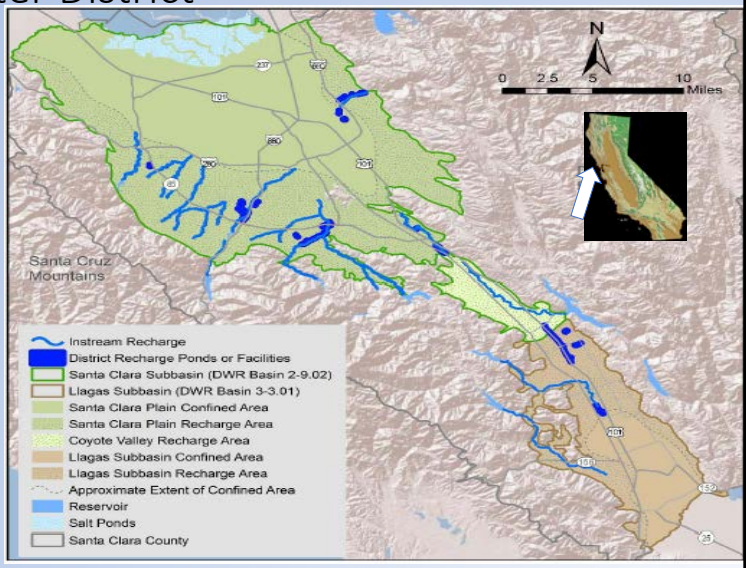
Long-Term MAR in California
Santa Clara Valley Water District

- Established in 1930s to address land subsidence and associated flooding from San Francisco Bay
- Land subsidence about 13 feet in San Jose between 1915-1970
- 393 acres of recharge ponds
- 91 miles of controlled in-stream recharge
- Recharge approximately 100,00 acre-feet per year



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Long-Term MAR in California

Santa Clara Valley Water District

- Approximately half the supply comes from groundwater
- Direct and in lieu recharge
- Sources of water include stormwater water, recycled water and imported water

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Long-Term MAR in California

Leaky Acres – City of Fresno & Clovis, Fresno Irrigation District

- Initiated in the 1970s to address falling groundwater levels
- Clovis – 85-acre recharge basin
- Fresno – 224 acres of recharge ponds
- Fresno Flood Irrigation District operates 700-mile canal and nearly 600-acres of recharge ponds

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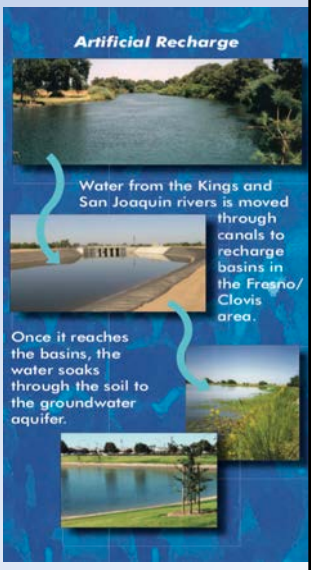
Long-Term MAR in California

Leaky Acres – City of Fresno & Clovis, Fresno Irrigation District

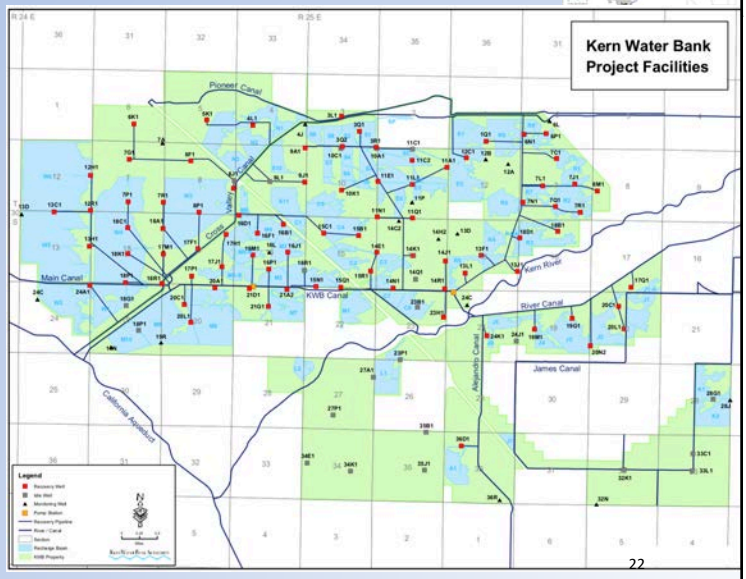
- In the 1930's groundwater was as shallow as 30 feet bgs, but now more on the order of 150 feet bgs
- Approximately 60,000 acre-feet/year recharged
- An additional 20,000 acre-feet stormwater recharged through Flood Control District recharge basins
- Recycled water use has also been increased for supplemtnal use, and not is over 25% of water supply in Clovis and 15% in Fresno

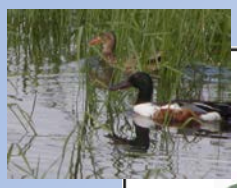


Long-Term MAR in California

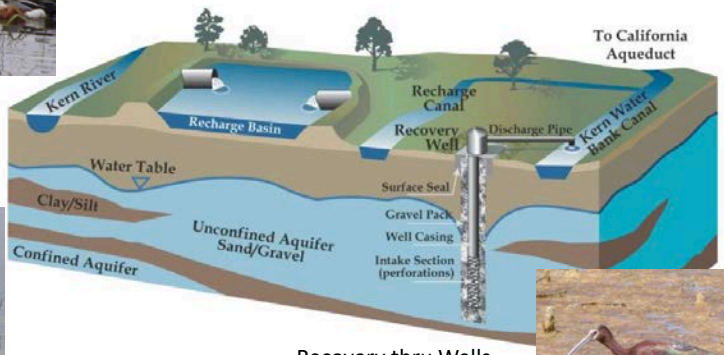
Kern Water Bank

- Established in 1988 by the State – 1994 thru Monterey Agreement became a separate non-state entity
- 20,000 acres of state and federally designated habitat
- Habitat conservation plan /natural community conservation plan
- Bank capacity ~10MAF
- 7,000 acres recharge ponds – recharge rate 0.3 ft/day
- 85 recovery wells – 5 cubic feet/sec
- 36 miles pipeline
- 6-mile canal
- Recharge more than 2.5MAF and recovery 1.5 MAF annually



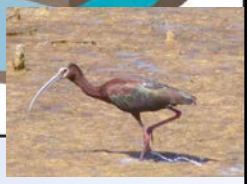


Recharge thru Ponds



Courtesy of Kern County Water Agency

Recovery thru Wells



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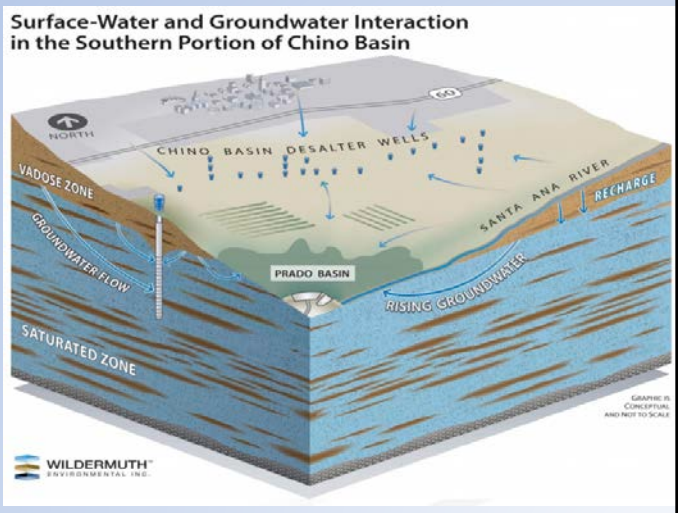
Long-Term MAR in California
Chino Basin Desalter Authority (CDA)

- CDA formed in 2001 under Joint Powers Agreement - 8 agencies
- CDA purifies brackish water extracted from the lower Chino Basin with the Chino I and II Desalter facilities and distributes drinking water to its member agencies
- Primary contaminants in the brackish water treated include nitrate, total dissolved solids (TDS), and volatile organic chemicals (VOCs) Nitrate and TDS contamination a result of agricultural and dairy operations in the southern portion of the Chino Basin
- A primary reason for the desalters is to lower the groundwater level and prevent contaminated water from entering the Santa Ana River and flowing to Orange County (Hydraulic Control)



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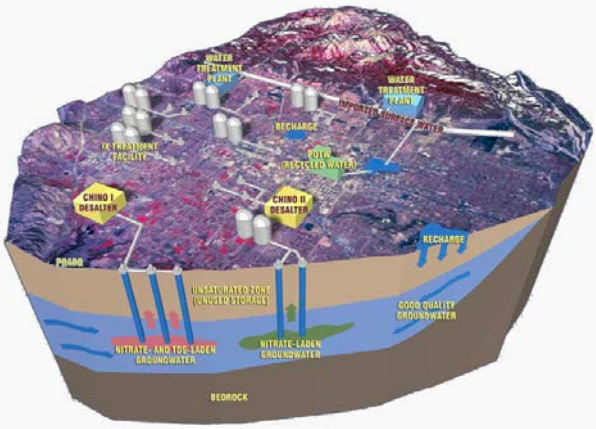
Long-Term MAR in California
Chino Basin Desalter Authority (CDA)

- Groundwater Production
  - 29,000 Acre Feet/Year by 22 Wells
- Treated Water - 24,600 Acre Feet/Year
- Two Desalters (22 million gallons/day (mgd) capacity)
  - Chino I – Constructed by SAWPA (2000)
    - Reverse Osmosis/Ion Exchange/Air Stripping
  - Chino II (2006):
    - Reverse Osmosis/Ion Exchange
- *Reverse Osmosis (TDS & Nitrate removal)*
- *Ion Exchange (Nitrate removal)*
- *Air Stripping (VOC removal*)



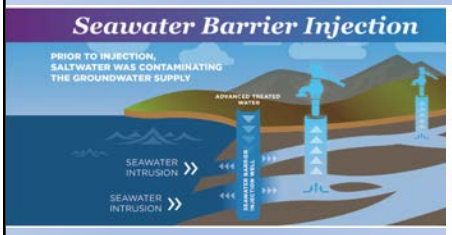
Long-Term MAR in California - WRD

Water Replenishment District of Southern California

- Created by Special Legislation in 1959 to manage, regulate and replenish West Coast and Central Basins
  - 43 Cities
  - Population ~4M
  - ~600,000 AF/Y Water Usage
  - ~250,000 AF/Y Groundwater
  - Over 400 Pumping Wells
- Water Interdependence Now
  - Maximize local stormwater and recycled water for replenishment and resiliency

Long-Term MAR in California – WRD

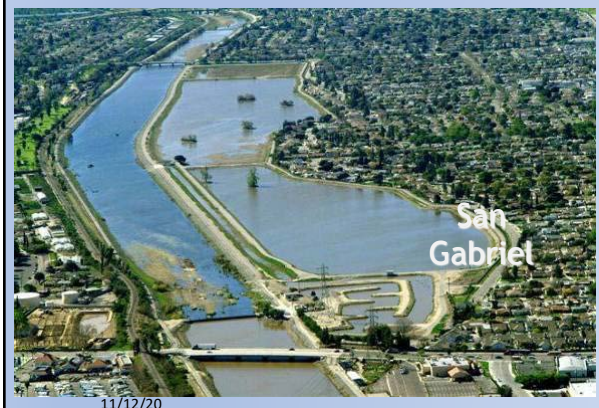
WRD Leo J. Vander Lans Advanced Water Treatment Facility



1950's Seawater Intrusion Barrier Testing

Long-Term MAR in California - WRD

1937



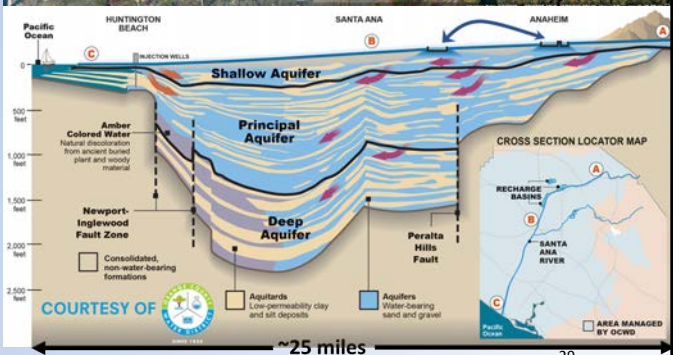
Facilities owned and operated by Los Angeles County Flood Control District

Size Both Basins: 1,000 Acres
Intake Capacity: 2,850 cfs
Storage Capacity: 5,200 af
Infiltration Rate: up to 1,200 cfs (2,400 afd)

Long-Term MAR in California – OCWD

Orange County Water District

- Established in 1933 to
  - Protect rights to Santa Ana River flow
  - Manage OC Groundwater Basin
- Provide groundwater to
  - 19 municipal and sewer districts
  - 2.5 million residents
- Basin provides 77% of the water supply for north and central Orange County, or ~300,000 AF/Y
- Basin capacity ~40MAF



Long-Term MAR in California – OCWD

Main Recharge Sources

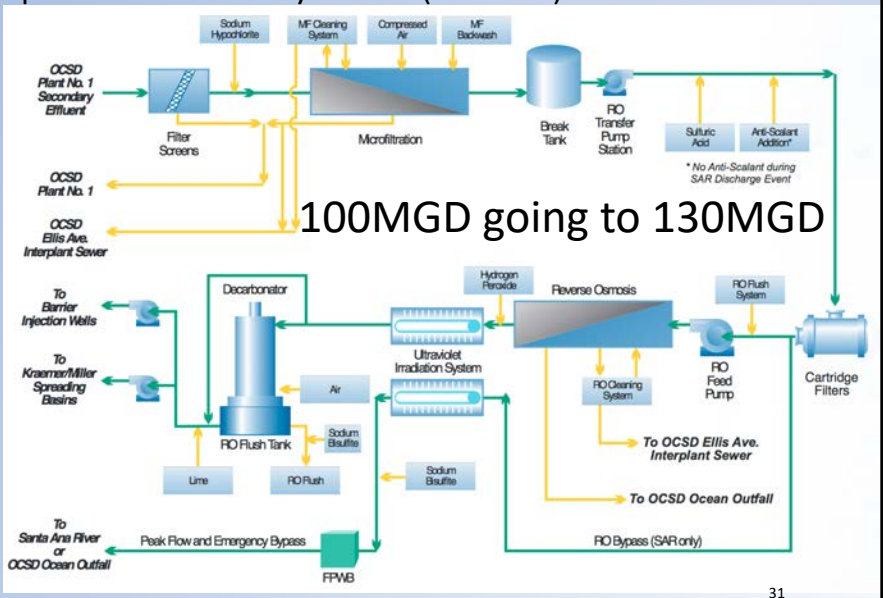
- River storm flows
- River base flows (largely treated effluent from Riverside and San Bernardino counties)
- Imported water (decreasing supply)
- Recycled water (increasing supply)

OCWD recharge facilities along Santa Ana River. Warner Basin in center/background.

Total Recharge: 250,000- 300,000 AFY

Long-Term MAR in California – OCWD
The Groundwater Replenishment System (GWRS)

- Operating since mid-1990s
- Preliminary/primary treatment – screening, grit chambers, clarifiers, biological sludge treatment
- Microfiltration
- Reverse osmosis
- High intensity ultraviolet light with hydrogen peroxide
- pH adjustment and decarbonation
- Calcium hydroxide stabilization



Santa Ana River (SAR)

- SAR baseflow is dominated by upstream tertiary wastewater discharges
- Occurrence of PFAS in conventionally treated, municipal wastewater is well-established in literature
- PFAS also detected in stormwater runoff to SAR

Extent of PFAS Impact in OCWD Service Area

Current California DDW NL/RLs:

Notification Levels:
PFOA = 5.1 ng/L
PFOS = 6.5 ng/L

Previous Response Level:
PFOA + PFOS = 70 ng/L

***RL was lowered Feb 2020 to:**
PFOA = 10 ng/L
PFOS = 40 ng/L

*Public Health Goal (PHG) process has begun

- **11 water retailers** (i.e., groundwater "Producers") in the OCWD service area (up to 71 wells) impacted by 10 ppt PFOA Response Level
- **Up to ~ 1/3 of groundwater basin** production (100,000 afy) unable to be served
- **~ >$50 million/year** additional alternative water supply cost for treated *imported* surface water

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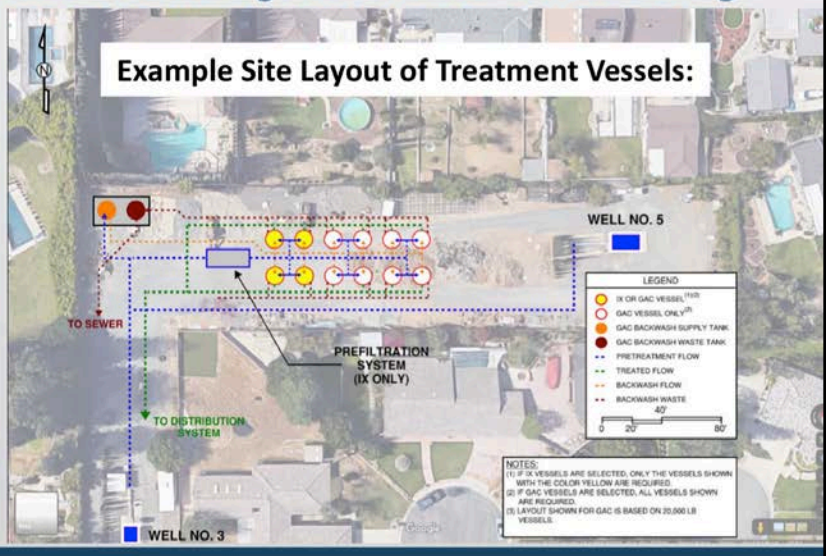
To Restore our Drinking Water Source – Design of Groundwater Treatment Systems is Underway

- 10 water retailers
- Goal: bring online within 1 to 3 years



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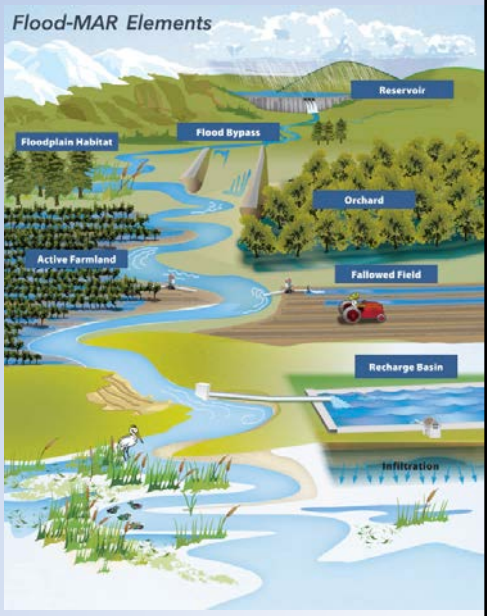
New Developments - MAR in California

FloodMAR

- State recognition that with California's most highly variable climate in the US, going from droughts to floods, year-by-year, that:
  - Increasing managed aquifer recharge critical
  - Increasing recharge where the most pumping occurs on agricultural lands is the most efficient
  - Challenges to recharge on agricultural land that need to be addressed
  - DWR initiated a process and ensured resources available by partnering with industry to develop the science needed to address the challenges
  - Large group of consultants, academics, agriculture and irrigation districts involved
  - NRCS studies with Terranova Ranch (Grower Don Cameron) in 2010



New Developments - MAR in California

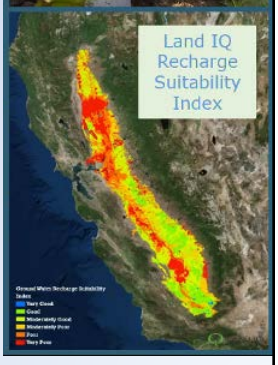
FloodMAR

What's Needed

- On-farm engineering and costs
- Corp tolerance to flooding
- Apply/enhance recharge suitability mapping
- Assess water quality challenges and solutions
- Consider existing policy and develop the science to support future sound policy decisions for on-farm managed aquifer recharge

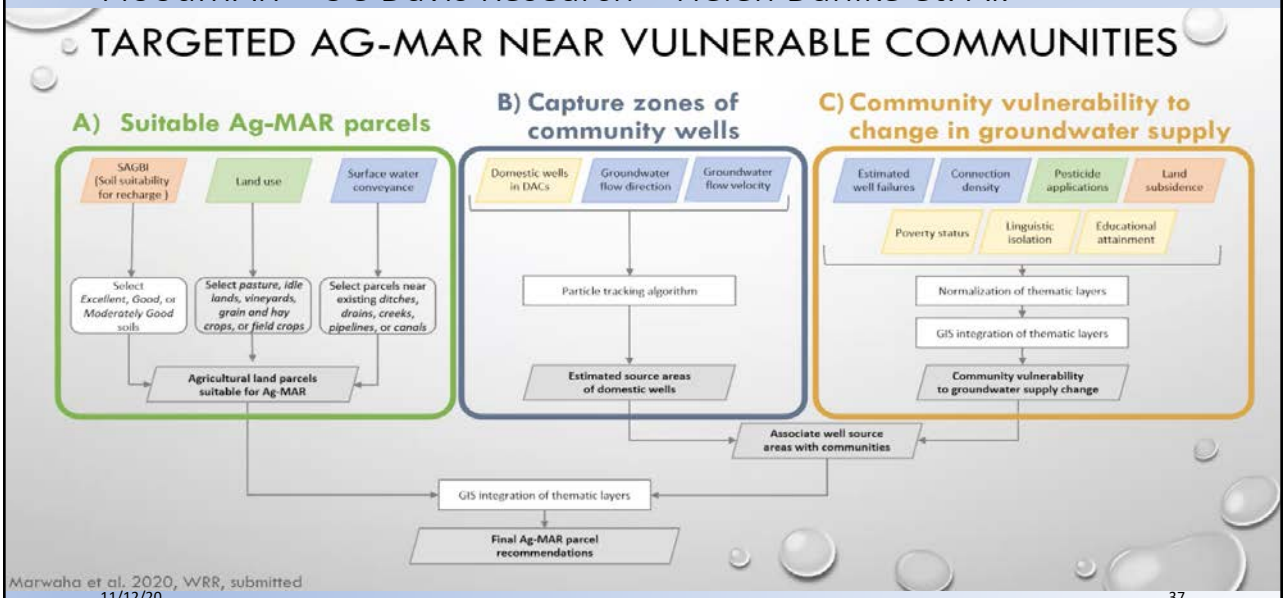
Initial Results (Bachand & Associates)

- Typical farm - 0.1% grade = about >3 ft drop over ½ mile
  - Poly pipe and silt fences to dam water
- Periodic and continuous flooding
  - 2-4 inches/day and up to 13 feet total initially
  - Improved 2020 practices up to 12 inches/day and 13-40 feet total
- Water quality - solution flushing of nutrients
  - Tomatoes about 10 times grapes – difference in nutrients needs
  - Flushing over time reduces concentration – sufficiently diluted on one decade



New Developments - MAR in California

FloodMAR – UC Davis Research – Helen Dahlke et. Al.



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New Developments - MAR in California

FloodMAR – Additional Information Planning Considerations

Policy/Political/Legal

- Local agreements
- Build trust and cooperation
- Water rights
- Water transfers
- Politics
- CA water legacy

(after Bachand & Associates)

Technical

- Infrastructure
  - Conveyance
  - Energy
- Local and Regional Integration
  - Communication
  - Design
  - Engineering
  - Monitoring and operation

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New Developments - MAR in California

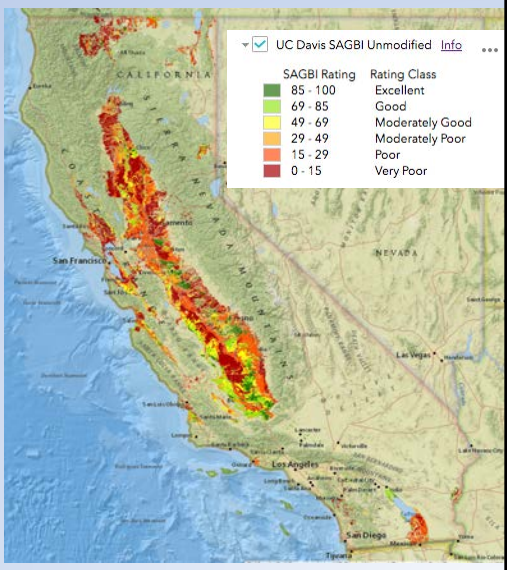
Technologies to Map MAR Suitability – Soils Mapping

Soil Agricultural Groundwater Banking Index

- Deep Percolation
- Root Zone Residence Time
- Chemical Limitations
- Topographic Limitations
- Surface Conditions
- Modified Version
  - Restrictive soil layers modified by deep tillage

https://casoilresource.lawr.ucdavis.edu/sagbi/

University of California Davis

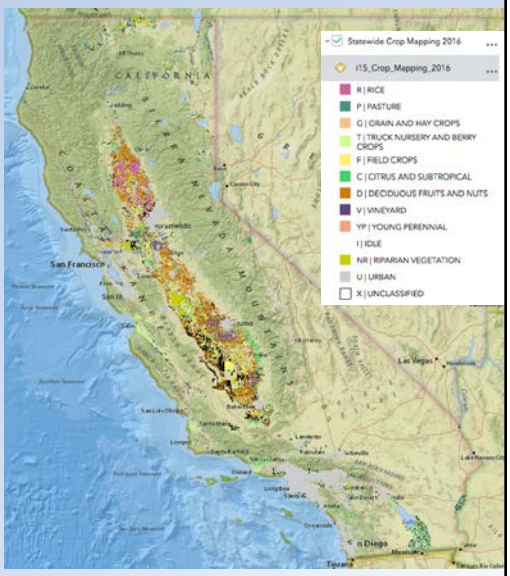


New Developments - MAR in California

Technologies to Map MAR Suitability – DWR Land Use Viewer

- Over 30 years of state and county land use datasets, as recent as 2014 for statewide – 2016 in QA/QC process and available online
- Land IQ does initial mapping based on a combination of aerial photography, remote sensing multi-spectral imagery, agronomic analysis and ground verification
  - USDA National Agriculture Imagery Program
  - Multiple Landsat 8 images
  - Sentinel satellite-based imagery
  - USGS National Elevation Dataset
  - USDA Crop Data Layer
- Overall mapping accuracy 96.6%, based on 15% overall field data checks performed

https://gis.water.ca.gov/app/CADWRLandUseViewer/

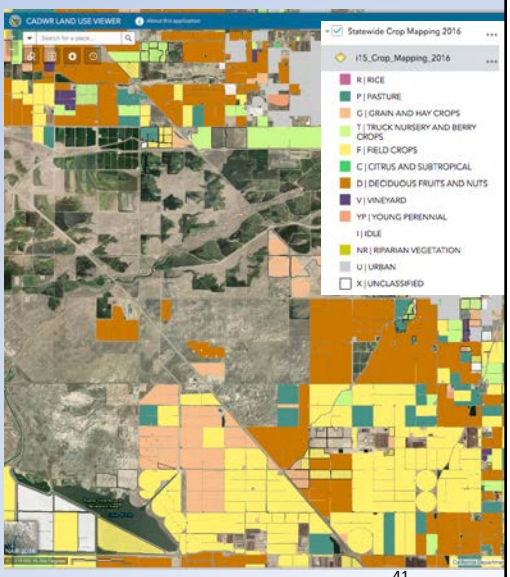


New Developments - MAR in California

Technologies to Map MAR Suitability – Annual Statewide Crop Mapping

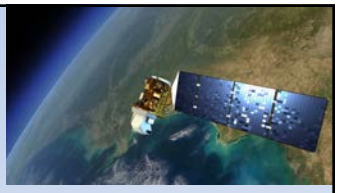
- Over 30 years of state and county land use datasets, as recent as 2014 for statewide – 2016 in QA/QC process and available online
- Land IQ does initial mapping based on a combination of aerial photography, remote sensing multi-spectral imagery, agronomic analysis and ground verification
  - USDA National Agriculture Imagery Program
  - Multiple Landsat 8 images
  - Sentinel satellite-based imagery
  - USGS National Elevation Dataset
  - USDA Crop Data Layer
- Overall locational mapping accuracy +/- 2m at a 96.6% confidence level, based on 15% overall field data checks performed

https://gis.water.ca.gov/app/CADWRLandUseViewer/



New Developments - MAR in California

Technologies to Increase Water for MAR – OpenET Platform



- Will make satellite-based data on evapotranspiration -- **a key water metric** -- widely accessible to farmers, landowners, and water managers

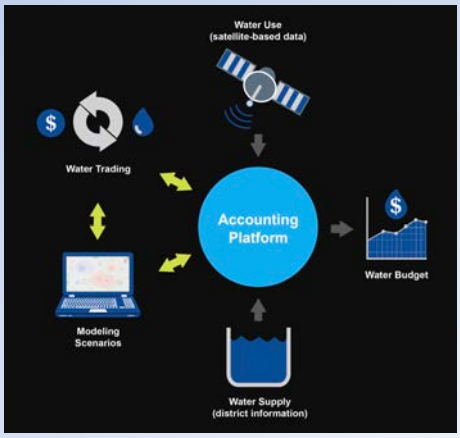
https://openetdata.org/

New Developments - MAR in California

Technologies to Increase Water for MAR – Water Accounting and Trading Platform

Piloted by Rosedale-Rio Bravo Water Storage District

- Open Platform, Multiple functions
- Water Use – OpenET satellite-based data to calculate evapotranspiration
- Water Budget – combines water supply and use data
  - Water managers can input supply data
- Water Trading – optional add-on function
- Modeling Scenarios – uses Groundwater Evaluation Tool (GET) to analyze options and benefits of different scenarios – links with USGS MODFLOW



Project Partners

New Developments - MAR in California

Technologies to Map MAR Suitability – Groundwater Associated Natural Communities

- Best Practices for GDEs Using the Natural Communities associated with groundwater dataset
- The Nature Conservancy, July 2019
- www.groundwaterresourcehub.org

Photo: Melinda Kelly, TNC

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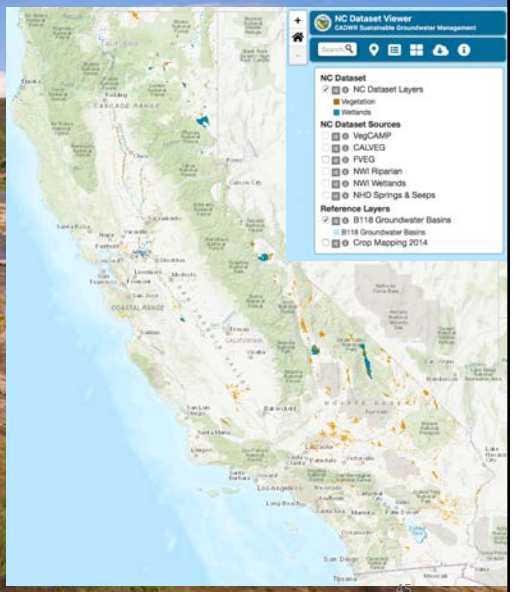

Photo: Melinda Kelly, TNC

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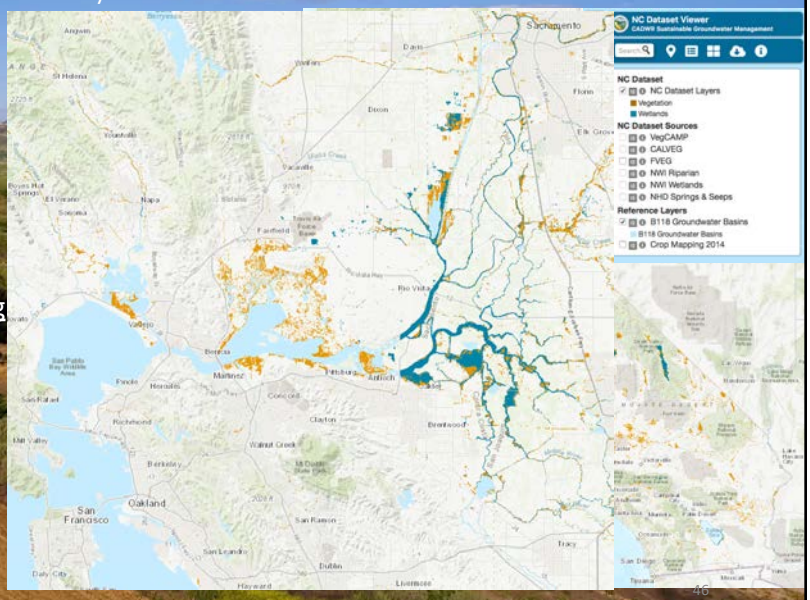

Photo: Melinda Kelly, TNC

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New Developments - MAR in California

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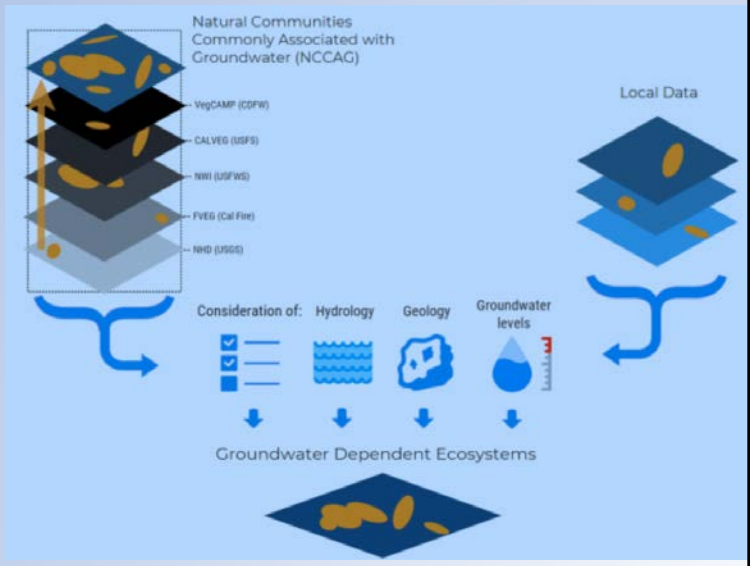
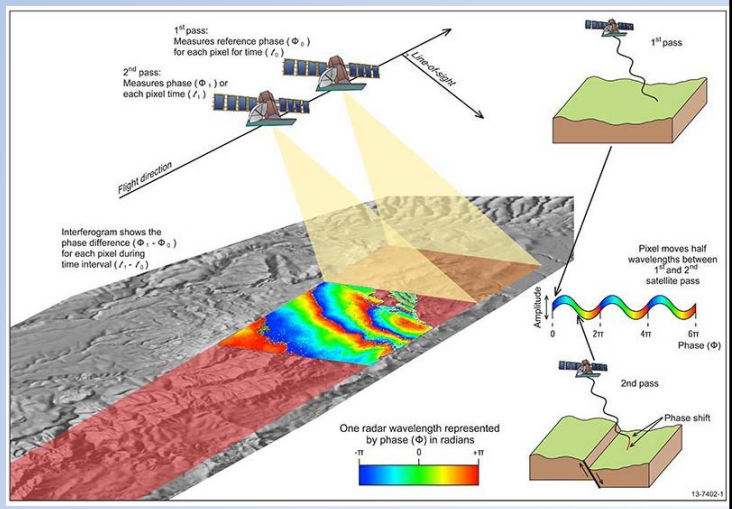


New Developments - MAR in California

Technologies to Map MAR Suitability – Interferometric Synthetic Aperture Radar

- InSAR uses two or more Synthetic Aperture Radar (SAR) images of an area to identify surface movements through time
- Remote sensing satellites that collect SAR imagery transmit pulses of microwave energy to the Earth's surface and record the amount of backscattered energy
- Use of microwave energy provides an all-weather capability because of its low sensitivity to clouds and rain

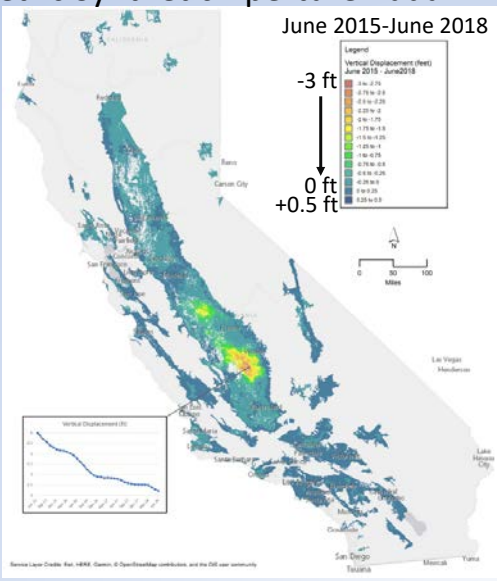


https://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/

New Developments - MAR in California

Technologies to Map MAR Suitability – Interferometric Synthetic Aperture Radar

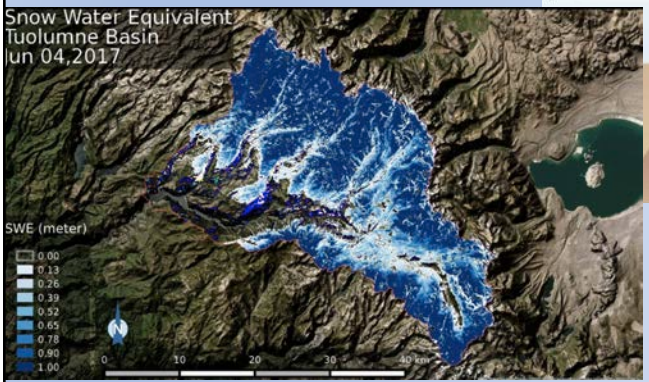
- State obtaining and analyzing InSAR data, making datasets freely available, to support SGMA program
- InSAR annual data based on water year (Oct-Sept) – also monthly data available
- Over time, results used to identify and measure subsidence related to groundwater extraction
- InSAR data has been ground-truthed with Continuous Global Positioning System (CGPS)
  - More than 1,000 in western US and 100's in CA
  - Generally set up for plate tectonics monitoring
  - Plate Boundary Observatory/UNAVCO
  - Scripps Orbit and Permanent Arrary Center (SOPAC)
  - Central Valley Spatial Reference Network

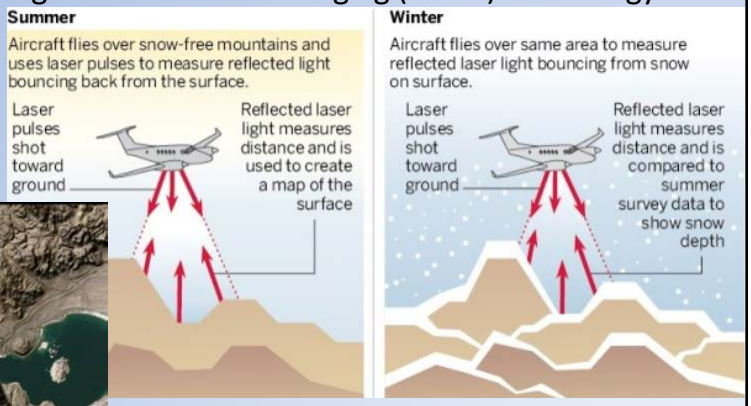


New Developments - MAR in California

Technologies to Map Snowpack– Light Detection and Ranging (LiDAR) Technology

- LiDAR is flown by plane over high mountain areas mapping:
  - Land surface when no snow present
  - Snow surface when present
  - Snow moisture content measured locally



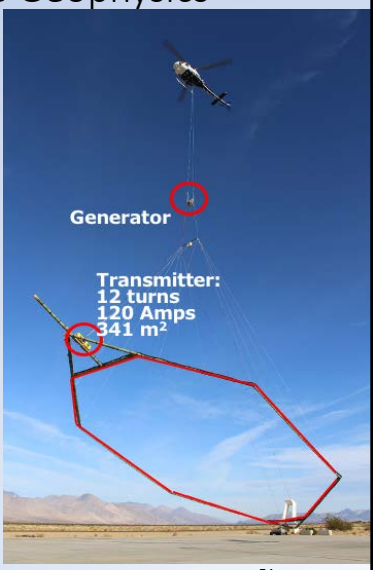


- Results provide more accurate measurements of snowmelt runoff
- Allows improved reservoir management for floods
- Allows increased water available for groundwater recharge

New Developments - MAR in California

Technologies to Map MAR Suitability – Airborne Geophysics

- Airborne Electromagnetic Method
  - 30 m (~100 feet) above the ground surface
  - 80 km/hr (50 mph)
  - Mapped Denmark where technology developed
  - Typical depths of investigation 1000-1500 feet bgs (300-500 meter bgs)
  - Horizontal resolution 60 m (~200 ft)
  - Vertical resolution ~3 m (10 ft) at surface increasing to ~50 m (160 ft) at 500 m bgs
  - On board sensors/instruments:
    - Electromagnetic
    - Magnetic
    - DGPS
    - Inclinometer
    - Laser scanner
    - Ground surface video



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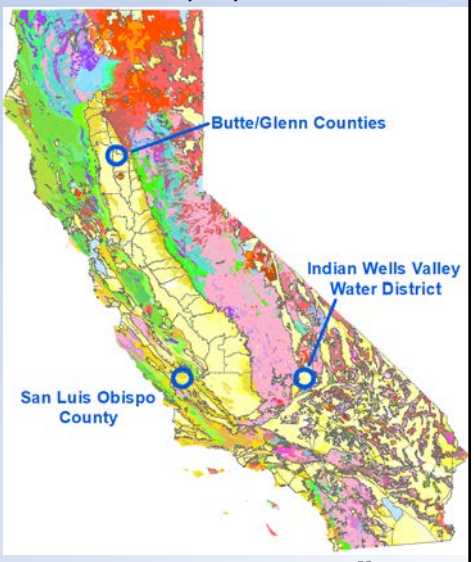
New Developments - MAR in California

Technologies to Map MAR Suitability – Airborne Geophysics

- **Stanford Groundwater Architecture Project**
  1. Engage with local agency to identify groundwater management questions
  2. Develop the Data Management System
  3. Compile existing data
  4. Design the AEM survey
  5. Acquire the AEM data
  6. Analyze the AEM data to obtain the resistivity model
  7. Interpret the resistivity models to extract the needed information
  8. Integrate all data to generate the conceptual model
  9. Answer management questions, acknowledging uncertainty
- **State Request for Proposals to Map SGMA Basins issued October – *Selection Pending***



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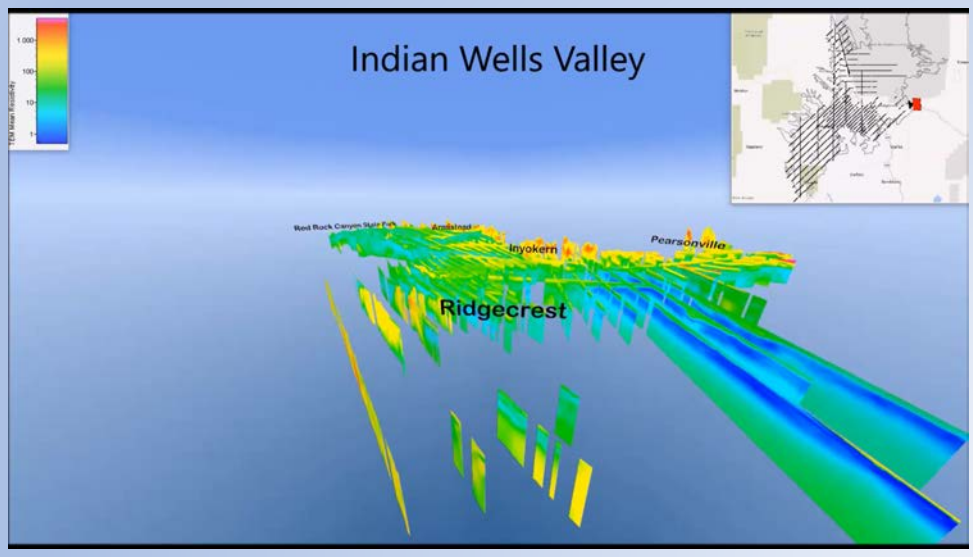
New Developments - MAR in California

Technologies to Map MAR Suitability – Airborne Geophysics



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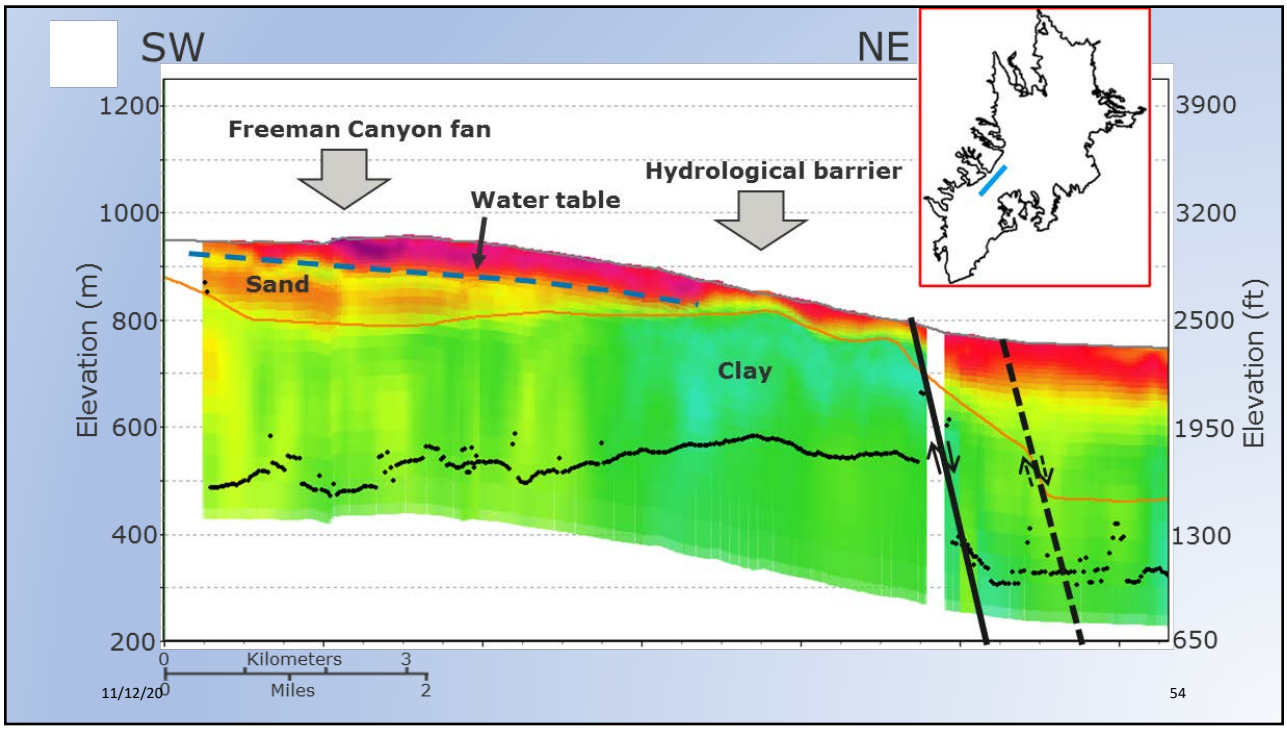

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Summary - MAR in California

- California now has a legal framework in place that hopefully will set the course for sustainability
- MAR is a critical element to achieve sustainability, and California has a long history of long-term successful MAR
- State and local provided technology increases the ability and probability of success
- There are many challenges but California has a demonstrated will, investment, and record of success

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Links to California Information and Data

- https://data.cnra.ca.gov/dataset
- DWR – www.water.ca.gov
- https://groundwaterresourcehub.org
- PPIC – www.ppic.org
- https://www.waterboards.ca.gov/waterrights/
- http://leginfo.legislature.ca.gov/
- https://lao.ca.gov/Publications/Report/4294
- https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management
- https://gis.water.ca.gov/app/NCDatasetViewer/
- https://waterresilience.ca.gov/
- https://gis.water.ca.gov/app/CADWRLandUseViewer/
- https://gratviewer.earthgenome.org/
- https://waterplatform.edf.org/
- https://www.waterboards.ca.gov/water_issues/programs/asr/
- https://water.ca.gov/Programs/All-Programs/Flood-MAR
- https://www.waterboards.ca.gov/water_issues/programs/nitrate_project/
- https://www.usgs.gov/centers/ca-water
- https://openetdata.org/

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Organizations Making California Progress Viable

- Stanford Water in the West
- S.D Bechtel Jr. Foundation
- Environmental Defense Fund
- The Nature Conservancy
- Sustainable Conservation
- Walton Family Foundation
- Water Foundation
- Morgan Family Foundation
- The Dirk and Charlene Kabcenell Foundation
- Stanford Earth
- Water Funder Initiative
- Lucille Packard Foundation
- Association of California Water Agencies

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