The Challenge of Integrating Groundwater in a Significant Way Into California's Water Supply Portfolio

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2Land, Air and Water Resources, UC Davis
3Tetra Tech, Inc., Lafayette, CA

The Water Budget

\[ F = \begin{cases} \cdot \text{Precipitation}(t) = F(\text{Climate}) + F(\text{Climate Change}) \\ \cdot \text{Infiltration}(t) = F(\text{Soils, Geology, etc}) \\ \cdot \text{Evapotranspiration}(t) = F(\text{Climate}) + F(\text{Climate Change}) \\ \cdot \text{Other}(t) \end{cases} \]

\[ F = \begin{cases} \cdot \text{Capacity}(t) \\ \cdot \text{Conveyance}(t) \\ \cdot \text{Management}(t) \\ \cdot \text{Inefficiencies}(t) \\ \cdot \text{Costs}(t) \end{cases} \]

\[ F = \begin{cases} \cdot \text{Demand of Sectors}(t) = F(\text{Wealth, etc}) \\ \cdot \text{Recycling}(t) \\ \cdot \text{Reuse}(t) \\ \cdot \text{Conservation} \\ \cdot \text{Hard Needs} \\ \cdot \text{Soft Needs} = F(\text{Wealth, etc}) \\ \cdot \text{Costs}(t) \end{cases} \]

Reservoir Operation - Today

- Surface Water Supply
  - From Sierra runoff
- Demand
  - Agricultural demand dominates demand
- Reservoirs
  - Managed to mitigate floods and meet demand curve

Water Supply – Precipitation + Reservoirs + Snowpack + Groundwater

Water Supply – Watershed of the Sacramento-San Joaquin Delta and Regions that Use Delta

Watershed of the Sacramento-San Joaquin Delta and Regions that Use Delta

- Delta Target:
  - 2000 Acre-Feet
  - 75% to Ag
  - 25% to Urban
- CVP Target:
  - 5.5 M Acre-Feet
  - 70% to Ag
  - 30% to Urban
- State Target:
  - 0.75 M Acre-Feet
  - 30% to Ag
  - 70% to Urban

Reservoir Conditions

Reservoir Conditions

CVP Target:
- Winter: 810 Acre-Feet
- Summer: 790 Acre-Feet
- 75% to Ag
- 25% to Urban

State Target:
- Winter: 310 Acre-Feet
- Summer: 310 Acre-Feet
- 75% to Ag
- 25% to Urban

Total SWP Annual Delivery (1000 Acre-FT), DWR 2015
DWR Water Plan Update 160-13 (2013):

Means: 2001-10

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Dry</th>
<th>Wet</th>
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<tbody>
<tr>
<td>Outputs</td>
<td>197.9</td>
<td>163.3</td>
<td>258.1</td>
</tr>
<tr>
<td>Inputs</td>
<td>189.9</td>
<td>147.6</td>
<td>257.6</td>
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</table>

∆Supply: -8.0 - 15.7 - 0.5

∆GW: -9.0 - 11.9 - 5.1

* Much of this is overdraft. All units are Maf.

Climate change first discussed in 2005, not used for projections.


<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Units</th>
<th>Irrigated Farms</th>
<th>Any land irrigated</th>
<th>Nonirrigated Farms</th>
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<td>Land in farms (acres)</td>
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<td>2012</td>
<td>2007 (106,140 MAF)</td>
<td>2012 (107,212 MAF)</td>
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<td>Irrigated land</td>
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<td>2007 (7,861,964)</td>
<td>2012 (7,661,964)</td>
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<td>Market value of agricultural products sold (Maf)</td>
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<tr>
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<td></td>
<td>2012</td>
<td>2007 (1,402,554)</td>
<td>2012 (1,372,554)</td>
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Characteristics

| Land in farms (acres)    | 2012             | 2007 (106,140 MAF) | 2012 (107,212 MAF) |
| Irrigated land           | 2012             | 2007 (7,861,964)   | 2012 (7,661,964)   |
| Market value of agricultural products sold (Maf) | | 3,129,260 | 3,129,260 |
| Total farm production expenses (Maf) | | 3,447,072 | 3,447,072 |
| GW pumping               | 2012             | 2007 (1,402,554)  | 2012 (1,372,554)  |
| Environmental flows      | 2012             | 2007 (572,233)    | 2012 (552,233)    |

The Water Budget

Runoff = F(Precipitation) + F(Infiltration) + F(Evapotranspiration) + Other

Surface Storage = F(Capacity) + F(Reservoirs) + F(Concentration) + F(Management) + F(Improvement) + Cost

Use = F(Demand of Sectors) + F(Recycling) + F(Reuse) + F(Sustainability) + F(Health) + Cost

Reservoir Operation - Today

Surface Water Supply

Demand

Reservoirs

Managed to mitigate floods and meet demand curve

On-Farm Flood Recharge

Wheel of Questions (Dahlke)

Water Project Cost Comparison

(Recharge: Groundwater Second Act, Water in the West)
Results: Magnitude

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<tr>
<th>Outlet</th>
<th>Dec-Feb</th>
<th>Nov-Apr</th>
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<tbody>
<tr>
<td>Sac Valley</td>
<td>4.2 MAF</td>
<td>7 MAF</td>
</tr>
<tr>
<td>SJ Valley</td>
<td>1 MAF</td>
<td>2.2 MAF</td>
</tr>
</tbody>
</table>

Results are based on post-impairment period.

Hydrologic Logistical Considerations for Surface and Aquifer Water Storage

- Reservoir Storage: \( F = \{x_1, \ldots, x_n\} \)
  - Capacity
  - Supply \((t)\)
  - Demand \((t)\)
- Aquifer Storage: \( F = \{x_1, \ldots, x_n\} \)
  - Capacity
  - Supply \((t)\)
  - Demand \((t)\)
  - Aquifer lithology and layering

Reservoir Operation - Today

- Surface Water Supply
  - Peaks earlier
  - Less volume with more ET in higher elevations
  - More rapid runoff
  - Earlier end
- Demand
  - Longer growing season
  - More ET
  - More opportunities for dual or triple crops
- Reservoirs
  - Greater difficulty covering the gap

Reservoir Operation - Tomorrow Under Climate Change

- Surface Water Supply
  - Peaks earlier
  - Less volume with more ET in higher elevations
  - More rapid runoff
  - Earlier end
- Demand
  - Agricultural demand dominates demand
- Reservoirs
  - Managed to mitigate floods and meet demand curve
  - Off-Farm Flood Recharge – Conjunctive Use Strategy

Overcoming Statewide Overdraft – How many acres?

- Statewide: 8 MAF
- Acres
  - 100K to 10M
- Weeks of Infiltration
  - 10,000
- Infiltration Rate (in/d)
  - 10,000

Acres

<table>
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<tr>
<th>Weeks of Infiltration</th>
<th>10,000</th>
<th>2,000</th>
<th>4,000</th>
<th>6,000</th>
<th>8,000</th>
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<tr>
<td>Infiltration Rate (in/d)</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>12</td>
</tr>
</tbody>
</table>

100,000

5

8

10
Overcoming Statewide Overdraft – How much might it cost per acre of capture?

- Costs for Groundwater Recharge based upon 25%-75% of projects
- On-Farm Flood Recharge for Capture Component near low end based upon current data
- Conveyance Costs not included
- Expect Economies of Scale and Utilization to affect costs

<table>
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<tr>
<th>MAF</th>
<th>1,100</th>
<th>1,700</th>
<th>2,700</th>
<th>1,900</th>
<th>3,000</th>
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<tbody>
<tr>
<td>Costs</td>
<td>$167</td>
<td>$167</td>
<td>$167</td>
<td>$167</td>
<td>$167</td>
</tr>
</tbody>
</table>

Data Gaps and Information Needs

- Tighten Analyses with better information and data
- Amount of Overdraft
- Better understanding of Ecosystem Effects and Accomodations
- How much water can be captured
- Opportunities for Recharge locations
- Utilization of Water Districts for buffering / storing flows for recharge
- Energy impacts
- Costs
- Opportunities and (Legal/Societal/Hydrologic) constraints on Reoperation
- Others....

Formulating ONE Strategy

- Information (As far as I know)
  - Capacity = f(Acreage, Utilization)
  - Water Shortage in SJV (S), Water Surplus in Sacramento (N)
  - Greater productivity, yield and profits in SJV versus Sacramento

- Potential Strategy
  - Focused Recharge where have water.
    - More in Sacramento versus SJV (?)
  - Establish Water Market for N to S transfers
  - Re-operate water system to maximize Statewide Conjunctive use

Costs

- To overcome SMAF overdraft through improving Supply thru On-Farm Recharge
- Price Tag for On-Farm Recharge efforts needs to be determined but based upon other groundwater recharge technologies start around $5M but could be much higher
- Conveyance upgrades and infrastructure TBD
- Costs expected to be dependent upon utilization and locations
- Other Supply source could help mitigate or reduce costs of this program
- Surface storage alternatives (alone) expensive
- Conservation or Fallowing provide another means to reduce overdraft
- NRCS data suggests similar costs as On-Farm

Benefits

- Stabilize water supply and reduce uncertainty for all sectors
- Pricing water more upon its value and benefits
- Promotes innovation
- Allows local involvement and investment
- Moves forward on resource sustainability
- (What about equity?)
Questions?

Regional Infrastructure Considerations for Utilizing Recharge for Groundwater Banking
- Need to have it where water is available
- Available infrastructure helps
- Recharge = f(time, acreage)
- Need to get water where it is needed

The move to micro-irrigation to sustainably save water
- H1: Micro-irrigation allows successful farming and reasonable profits with water savings
- H2: Micro-irrigation increases irrigation use efficiency through
  - Reducing water per acre and/or
  - Increasing crop per drop
- H3: Micro-irrigation leads to greater yield per acre but similar water use per acre
- H4: Micro-irrigation reduces groundwater recharge
- H5: Micro-irrigation allows irrigation of non-level lands
- H6: Micro-irrigation allows broader regional groundwater overdraft
- H7: Micro-irrigation moves farmland outside the boundaries served by the CA and Federal water projects
- H8: Micro-irrigation increases energy use per crop yield unit
- H9: Micro-irrigation does not save water at the State scale
- H10: Micro-irrigation promotes inefficient resource use at the State scale

Change in irrigated acreage between 2007 and 2012

The move to micro-irrigation to sustainably save water

Ag-Recharge - Wheel of Questions

Agricultural Groundwater Banking:
- Utilizes flood flows and agricultural lands for recharging groundwater during winter months
- To capture runoff from high intensity, short-duration rainfall-runoff events large spreading areas are needed
- California’s Central Valley provides 6 million acres (~24,300 km²) of irrigated cropland that could serve as spreading grounds for ag-recharge

Identify crops suitable for ag-recharge that can tolerate additional water in the winter without appreciable yield effects

Conveyance and Exports

TODAY

Sacramento River
San Joaquin River
CVP (Federal) and SWP (State) Diversions
On-Farm Flood Capture
Definition and Vision

- Available = Physical, Legal
- Leveraging Private Lands
- Dual Use Farm and Flood
- Design into Farm Management
- Leveraging Community Resources

Capturing Available Flood Flows onto Farm Lands for Groundwater Recharge and to Mitigate Downstream Flood Risks

Flexible, Rapid and Expandable

Ac-FT of Capture for 100 Acres

Critical Overdrafted Groundwater Basins, 2016

Solar Radiation: 5.4 kWh/m²/day ~ 7400 kWh/acre/year
PV Efficiencies (NREL): states std = 800 kWh/acre/year (4%)

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  - Earlier end

- Demand
  - Longer growing season
  - More ET
  - More opportunities for dual or triple crops

- Reservoirs
  - Groundwater increases storage capacity
  - Bridges demand / supply curve gap
  - Accommodates greater inter-annual variability
DWR Water Plan Update 160-98 (1998): status and projections for future needs

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<tbody>
<tr>
<td>Demand</td>
<td>79.5</td>
<td>64.7</td>
<td>80.1</td>
<td>65.5</td>
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<tr>
<td>Supply (GW)</td>
<td>77.9</td>
<td>59.6</td>
<td>79.9</td>
<td>62.8</td>
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<tr>
<td>Supply – Demand</td>
<td>–1.6</td>
<td>–5.1</td>
<td>–0.2</td>
<td>–2.7</td>
</tr>
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</table>

Population (1995): 32.1 M
Population (2020): 47.5 M (+48%) estimated

All units are Maf

Reservoir Operation - Today

- Surface Water Supply
  - From Sierra runoff
- Demand
  - Agricultural demand dominates demand
- Reservoirs
  - Managed to mitigate floods and meet demand curve

Potential Energy Production

US Electricity Composition (Twh/yr, IEA/OECD, 2008)

<table>
<thead>
<tr>
<th>Fossil Fuel</th>
<th>Coal (TWh)</th>
<th>Oil (TWh)</th>
<th>Gas (TWh)</th>
<th>Subtotal (TWh)</th>
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<tbody>
<tr>
<td>Nuclear</td>
<td>3,101</td>
<td>58</td>
<td>1011</td>
<td>4,110</td>
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<tr>
<td>Renewable</td>
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<td></td>
<td></td>
<td>Subtotal</td>
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<tr>
<td>Hydro</td>
<td>282</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>56</td>
<td></td>
<td></td>
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<tr>
<td>Solar</td>
<td>1.6</td>
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<tr>
<td>Tide</td>
<td>257</td>
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<tr>
<td>Bio</td>
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<tr>
<td>Other*</td>
<td>73</td>
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<td></td>
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<tr>
<td>Subtotal</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Total</td>
<td>4,369</td>
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</tbody>
</table>

Large PV Solar Production: 8.4 Ac/GWh/yr NREL
CA irrigated acres: 7,500,000 acres
Estimated acres in CA: 5,625,000 acres
Energy Production if fallow 10%: 165 TWh/yr

Hypotheses

H1: Rice or Wetlands can mitigate subsidence and cost-effectively stabilize Delta Levees
Resource Utilization within Environmental Constraints: Opportunities for Solar in the CV

- **Opportunities**
  - By 2020, CA targeting 33% of energy by Renewable Sources
  - 10% by 2020
  - CEC estimates 3,000 acres to meet 2020 (2% of irrigated ag acres)
  - If 10% of CV irrigated ag converted to solar, 165 TWh would be produce annually; 4% of US
    current annual energy consumption
  - GHG benefits
  - Reduce water demand for marginal areas.

- **Challenges**
  - Load leveling
  - Infrastructure grid
  - Code issues
  - Energy Producers (e.g. PG&E)

A commercial announcement from…

…..Your Wireless Provider

![iPhone](https://www.mobi2.com/)

The iPhone Era