Feasibility of Agricultural Groundwater Banking and its impact on groundwater storage

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California Extremes

2017 FLOODS

2012-2016 DROUGHT

U.S. Drought Monitor
October, 2015

Sources: DWR 2017, temblor.net, droughtmonitor.unl.edu
State of groundwater resources in the Central Valley, California

Groundwater storage withdrawal (-) and recovery (+) (million acre-feet)

- Sacramento Valley
- Eastside streams
- Sacramento-San Joaquin Delta
- San Joaquin River Basin
- Tulare Basin
- Central Valley

Water year:
- 1922
- 1925
- 1928
- 1931
- 1934
- 1937
- 1940
- 1943
- 1946
- 1949
- 1952
- 1955
- 1958
- 1961
- 1964
- 1967
- 1970
- 1973
- 1976
- 1979
- 1982
- 1985
- 1988
- 1991
- 1994
- 1997
- 2000
- 2003
- 2006
- 2008

Harter 2015, CalAg
Agricultural Groundwater Banking

• Farmland is flooded during the winter using surface water to recharge the underlying groundwater
• Large spreading areas are needed to capture runoff from the few (6-10) storms that bring rainfall in California
• 8 million acres of farm land that could serve as spreading grounds
• Existing irrigation infrastructure could be used to move water from streams to farmland
Agricultural Groundwater Banking

- COST
- LOCATION
- LAWS & PERMITS
- STORAGE & RECOVERY
- WATER QUALITY
- CROP
- SOIL
- WATER AVAILABILITY

AGRICULTURAL GROUNDWATER BANKING

Map showing locations of agricultural crops such as Alfalfa, Almond, Pistachio, and Pecans in California.
Flooding Tolerance Studies
Crop Suitability - Alfalfa

- **Alfalfa** supports $7.6 billion dairy industry
- In 2013 largest acreage crop in CA (~ 1 million acres) → high likelihood to find land on suitable soils
- Relatively low use of fertilizers, pesticides → low risk for leaching
- Flood irrigation with surface water most common (75%) → allows fast spreading of large water amounts
- Conducted flooding experiments in two locations in winter of 2014/15; repeated experiments in Scott Valley in 2015/16
On-Farm recharge experiments - Alfalfa

- Three winter water application rates:
  - **Continuous** – every day
  - **High** – 3-5 water applications per week
  - **Low** – 1-3 water applications per week
  - **Standard** - no winter water application

- Use Thornthwaite-Mather soil water balance model to estimate **deep percolation** and losses to evapotranspiration and soil storage

- Use 1D van Genuchten-Mualem model to estimate recharge into deeper soil

\[ \text{AWC} = \text{available water content} \]
On-Farm recharge experiments - Alfalfa

2014/15 dry year:
- Early dry-out in standard plot
- Recharge increases plant available water
- Loss to ET, soil storage is 1-7%
- Total recharge was 135 AF

2015/16 Above normal year:
- Late dry-out
- No benefit for plant available water
- Loss to ET soil storage is 1-2%
- Total recharge was 107 AF

Dahlke et al. 2017, CalAg
On-Farm recharge experiments - Alfalfa

- Water table rose up to 6 ft in response to winter recharge
- Application of up to 26 ft of water caused no discernible difference in alfalfa yield
Crop Suitability - Almonds

- Tree stem water potential (SWP) indicates that trees in the flood treatment remained more hydrated than the control trees.
- There were no statistically significant differences in yield (Nonpareil almond variety).

![Graph showing SWP and yield data for Modesto and Delhi soil types.](image)
Crop Suitability - Almonds

- Application of 60 cm (2 ft) of water in Dec.-Jan.
- Root zone remained saturated up to 48 hr after recharge events
Crop Suitability - Almonds

Flood Treatment

Control

\[ NO_3^- = NO_3^- - N \times 4.43 \]
Crop Suitability - Almonds

Flood Treatment

\[ \text{NO}_3^- = \text{NO}_3^- - N \times 4.43 \]

Control

Modeesto site
Surface Water Availability for Recharge
High-magnitude streamflow assessment for groundwater recharge

• Historical daily streamflow records for 93 stream gauges (13 unimpaired, 80 impaired)
• 90\textsuperscript{th} percentile used to designate high-magnitude flows (HMF), determined from full historical record
• Metrics: magnitude, duration, frequency and timing
• Analysis is conducted for:
  • different time periods (annual, Nov – Apr, Dec – Feb)
Metrics for Time Series Analysis

**Magnitude:**
- Volume of flow above the 90th percentile

**Duration:**
- Number of days above the 90th percentile per time period

**Frequency:**
- Number of peaks above the 90th percentile within period (intra-annual)
- Number of years with flow above the 90th percentile (inter-annual)

**Timing:**
- Day of Hydrologic Year (DOHY) that peak event occurs
High-magnitude flows for groundwater recharge

**Average total flow above 90th percentile**

<table>
<thead>
<tr>
<th>Outlet</th>
<th>Dec-Feb</th>
<th>Nov-Apr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sac Valley</td>
<td>1.15 MAF</td>
<td>1.88 MAF</td>
</tr>
<tr>
<td>SJ Valley</td>
<td>0.5 MAF</td>
<td>0.97 MAF</td>
</tr>
</tbody>
</table>

**Average flow above 90th percentile during wet years**

<table>
<thead>
<tr>
<th>Outlet</th>
<th>Dec-Feb</th>
<th>Nov-Apr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sac Valley</td>
<td>1.75 MAF</td>
<td>3.01 MAF</td>
</tr>
<tr>
<td>SJ Valley</td>
<td>0.65 MAF</td>
<td>1.21 MAF</td>
</tr>
</tbody>
</table>

- A single, average wet year in the Sacramento Valley can provide two-times the annual groundwater overdraft.
- 30% of years are “wet” (post-impairment record)
Caveat – True Availability of High-Magnitude Flows, Timing, Frequency
Kern River HMF availability
Streamflow Availability Rating for Recharge (STARR)

- STARR index indicates the most suitable watersheds for ag-recharge in terms of water availability relatively to other watersheds.
- Uses 3 terms:
  - \( V/A \) = HMF volume / watershed area
  - \( D/P \) = number of HMF days / number of days in period
  - \( YWF \) = fraction of years with HMF
- Terms are ranked individually into six equal-area classes and weighted using Rank Ordered Centroid method:
  \[
  \text{STARR} = 0.61 \times \text{ranked}(YWF) + 0.28 \times \text{ranked}(\frac{V}{A}) + 0.11 \times \text{ranked}(\frac{D}{P})
  \]
- STARR values are divided into 6 equal-interval classes from excellent to poor surface water availability.
- Created for the same time periods as the metric analyses.
Decision Support Tools on Soil Suitability
Soil characteristics:

- Hydraulic conductivity
- Occurrence of restrictive layers
- Topographic Limitations (slope)
- Chemical Limitations
- Surface Condition (e.g. crusts, erodibility)

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

O’Geen et al. 2015, CalAg
Soil Agricultural Groundwater Banking Index

**TABLE 2. Summary of the areal extent of Soil Agricultural Groundwater Banking Index groups generated from soil survey data**

<table>
<thead>
<tr>
<th>SAGBI group</th>
<th>Original SSURGO data</th>
<th>SSURGO modified by deep tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>acres</td>
<td>%*</td>
</tr>
<tr>
<td>Excellent</td>
<td>1,477,191</td>
<td>8</td>
</tr>
<tr>
<td>Good</td>
<td>1,747,712</td>
<td>10</td>
</tr>
<tr>
<td>Moderately Good</td>
<td>1,786,972</td>
<td>10</td>
</tr>
<tr>
<td>Moderately Poor</td>
<td>1,343,250</td>
<td>8</td>
</tr>
<tr>
<td>Poor</td>
<td>4,866,942</td>
<td>28</td>
</tr>
<tr>
<td>Very Poor</td>
<td>6,375,277</td>
<td>36</td>
</tr>
<tr>
<td><strong>Total†</strong></td>
<td>17,597,345</td>
<td></td>
</tr>
</tbody>
</table>

O'Geen et al. 2015, CalAg
Soil Agricultural Groundwater Banking Index (O’Geen et al. 2015, CalAg)
Groundwater Modelling
Groundwater Modeling

- California Central Valley Groundwater-Surface Water Simulation Model
- Fine-mesh version (>35,000 elements), 1921-2009
- Diversion of high-magnitude flows onto soils rated as Excellent and Good in SAGBI
Groundwater Modeling

Diversion of high-magnitude flow (flow > 90\textsuperscript{th} percentile) at 42 nodes

The color ramp shows the number of diversion nodes each subregion receives water from.

Two scenarios:
1. Recharge of excess surface within local basin (e.g. within Sacramento River basin)
2. Recharge of excess surface water Central-Valley-wide (export through the Delta)
Cumulative applied water in each scenario

Excellent soils only

Excellent and good soils

Very few excellent recharge areas in Sacramento Valley

Cumulative applied water [TAF]
- < 5
- 5 - 10
- 10 - 20
- 20 - 50
- > 50

per element (~400 acres)
Change in groundwater storage

- 120 MAF – total excess surface flows diverted between 1921-2009 for recharge
- Groundwater storage gain over same period is about 30 MAF (1/5th of depletion)
- Most of recharged water returns back to stream

Loss of ~150 MAF

Base scenario (current depletion)
Relative gain in groundwater storage by region
• Difference between base scenario and recharge scenario

Recharge locations vs. stream locations
Where does all the water go?

- Cumulative streamflow gain from groundwater (1921-2009).
- Negative values represent a stream loss to groundwater.
Conclusions

• Alfalfa, almonds, pecans are promising crops if grown on suitable soils with high percolation rates

• In some alfalfa fields 26 ft of water could be recharged in 30 days without decline in yield

• High-magnitude flows potentially provide an untapped source of water during the winter months

• Short duration events and low frequency of high-magnitude flows suggests a need for coordinated efforts for the local-scale utilization

• Agricultural groundwater banking can increase instream flows, help mitigate floods, and improve groundwater supply for disadvantaged communities
THANKS!!

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