Managing Groundwater for Drought, Clean Water, Food Security, and Ecosystems

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http://groundwater.ucdavis.edu
Annual P [inches]
Annual P [inches]

Tri-annual P [inches]
Drought History

California Department of Water Resources;
Drought Response Update Fall 2014
California Precipitation 1896 – 2016:
Preceding Multiyear Average [inches]

Harter and Tolley, UC Davis (annual precipitation data courtesy of Tim Ross, DWR; http://www.wrcc.dri.edu/cgi-bin/divplot2_form.pl?0405
Central Water Hub: Sacramento – San Joaquin Delta
fractured bedrock of California’s mountain ranges

Sediments
=> result of erosion, water, wind,
lake deposition, ocean bay deposition
Monthly Landscape Water Budget
October – September

Tule River Basin, Tulare County

1980 - NORMAL

groundwater extraction
river water
rain
crops/plants
recharge

Ruud, Harter et al., 2003, 2004
Monthly Landscape Water Budget
October – September

Tule River Basin, Tulare County

1980 - NORMAL

groundwater extraction

1998 - WET

crops/plants

Ruud, Harter et al., 2003, 2004
Monthly Landscape Water Budget
October – September
Tule River Basin, Tulare County

1977 - DRY
1980 - NORMAL
1998 - WET

groundwater extraction
river water
rain
crops/plants
recharge

Ruud, Harter et al., 2003, 2004
From: DWR California Water Plan 2013 - Draft (Bulletin 160-2013)
Estimating Groundwater Flows Across Subbasin / Political Boundaries

Ruud et al., 2003; http://groundwater.ucdavis.edu/files/136420.pdf
Interbasin Flows in the Central Valley

<table>
<thead>
<tr>
<th>Subregion</th>
<th>Average Annual Interbasin Flow 1980-1993 (TAF/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CVHM 312.1</td>
</tr>
<tr>
<td>2</td>
<td>44.2</td>
</tr>
<tr>
<td>3</td>
<td>-225.8</td>
</tr>
<tr>
<td>4</td>
<td>558.6</td>
</tr>
<tr>
<td>5</td>
<td>-184.9</td>
</tr>
<tr>
<td>6</td>
<td>-47.2</td>
</tr>
<tr>
<td>7</td>
<td>19.4</td>
</tr>
<tr>
<td>8</td>
<td>50.3</td>
</tr>
<tr>
<td>9</td>
<td>237.7</td>
</tr>
<tr>
<td>10</td>
<td>-79.9</td>
</tr>
<tr>
<td>11</td>
<td>-54.9</td>
</tr>
<tr>
<td>12</td>
<td>-73.4</td>
</tr>
<tr>
<td>13</td>
<td>-0.8</td>
</tr>
<tr>
<td>14</td>
<td>85.2</td>
</tr>
<tr>
<td>15</td>
<td>621.8</td>
</tr>
<tr>
<td>16</td>
<td>-196.1</td>
</tr>
<tr>
<td>17</td>
<td>-176.8</td>
</tr>
<tr>
<td>18</td>
<td>-20.1</td>
</tr>
<tr>
<td>19</td>
<td>212.2</td>
</tr>
<tr>
<td>20</td>
<td>-164.4</td>
</tr>
<tr>
<td>21</td>
<td>-292.9</td>
</tr>
<tr>
<td>SAC TOTAL</td>
<td>140.2</td>
</tr>
<tr>
<td>SJ TOTAL</td>
<td>-209</td>
</tr>
<tr>
<td>Tulare TOTAL</td>
<td>68.9</td>
</tr>
<tr>
<td>CV TOTAL</td>
<td>0</td>
</tr>
</tbody>
</table>

Groundwater Levels during Drought
Groundwater Levels during Drought

Groundwater Levels for Well 20S22E05L001M

40 ft/y
Water Level Hydrographs, Big Valley
Water Level Change
Spring 2009 – Spring 2014
Change in Groundwater Level

Record Low 20th Century to Drought 2008-2014

http://www.water.ca.gov/waterconditions/docs/Drought_Response-Groundwater_Basins_April30_Final_BC.pdf
Change in Groundwater Storage in the Central Valley, 1920 - 2010

-150 km$^3$ (-130 MAF)


From: Lester Snow, CA Water Foundation
Consequences of Groundwater Overdraft...

• Seawater intrusion
• Increased pumping cost & cost of drilling new wells
• Land subsidence
• Water quality degradation
• Surface water depletion
• Impact to groundwater dependent ecosystems

...Long Before Running Out of Groundwater!
Seawater Intrusion

Groundwater Levels during Drought: Irvine

“San Diego Creek” well: 50 ft amsl

“Duck Pond” well: 17 ft amsl

Water Level Elevation [ft amsl]
Salinas Valley 180 Foot Aquifer

Salinas Valley 400 Foot Aquifer

Brown & Caldwell, MCWRA, January 2015
Because of low river flows, depleted reservoirs, and declining aquifers, farmers and homeowners are drilling more and deeper wells to supply water. This map shows the number of new wells drilled by county during the first nine months of 2014. The largest increase in new wells centers on the Central Valley, coinciding with the largest declines in the water table.

Sources: California Department of Water Resources, "California's Statewide Groundwater Elevation Monitoring Program."
Land Subsidence

California Department of Water Resources; Drought Response Update Fall 2014
Land Subsidence: San Joaquin Valley
California Groundwater Rights: Background

• Correlative Rights Doctrine – safe yield of groundwater basin shared by overlying users
  o Katz v. Wilkinshaw, 1908
• California constitutional mandate for beneficial use (1928)
• Special districts (20 different types, about 2,300 districts)
  o Water districts, irrigation districts, private water companies, reclamation districts, water conservation
districts, water replenishment districts, water storage districts, etc.
• County police power – controls groundwater exports
  o Baldwin vs. Tehama County, 1994
• The Courts: basin adjudication / “physical solution” – controls extraction
  o Many Southern California (sub)basins, mid 20th century
  o City of Barstow vs. Mojave Water Agency, 2000:
    • Right of water users to negotiate physical “equitable, practical” solution, regardless
      of water rights
    • Individual water rights holders cannot be forced into a voluntary agreement
California Groundwater Rights: Background

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  - City of Barstow vs. Mojave Water Agency, 2000:
    - Right of water users to negotiate physical “equitable, practical” solution, regardless of water rights
    - Individual water rights holders cannot be forced into a voluntary agreement
- State groundwater management:
  - Voluntary local groundwater management plans: AB 3030 (1992)
  - Sustainable Groundwater Management Act of 2014: mandatory & expanded local control
Sustainable Groundwater Management Act of 2014

SEC. 2.

Section 113 is added to the Water Code, to read:

113.

It is the policy of the state that groundwater resources be managed sustainably for long-term reliability and multiple economic, social, and environmental benefits for current and future beneficial uses.

Sustainable groundwater management is best achieved locally through the development, implementation, and updating of plans and programs based on the best available science.

[emphasis added]
Sustainability = No “Undesirable Results”

10721. Unless the context otherwise requires, the following definitions govern the construction of this part:

(u) “Sustainable groundwater management” means the management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results.

(w) “Undesirable result” means one or more of the following effects caused by groundwater conditions occurring throughout the basin (Section 10721 (w)):

1. **Chronic lowering of groundwater levels** indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.

2. Significant and unreasonable reduction of groundwater storage.

3. Significant and unreasonable seawater intrusion.

4. Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies.

5. Significant and unreasonable land subsidence that substantially interferes with surface land uses.

6. **Surface water depletions** that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

[emphasis added]
So What Exactly Will Happen?
So What Exactly Will Happen?

- **First Step:** forming a Groundwater Sustainability Agency (GSA)
  - By June 2017
Medium and High Priority Groundwater Basins

Statewide Groundwater Basin Prioritization Summary

<table>
<thead>
<tr>
<th>Basin Ranking</th>
<th>Basin Count per Rank</th>
<th>Percent of Total for State</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GW Use</td>
</tr>
<tr>
<td>High</td>
<td>43</td>
<td>69%</td>
</tr>
<tr>
<td>Medium</td>
<td>84</td>
<td>27%</td>
</tr>
<tr>
<td>Low</td>
<td>27</td>
<td>3%</td>
</tr>
<tr>
<td>Very Low</td>
<td>361</td>
<td>1%</td>
</tr>
<tr>
<td>Totals</td>
<td>515</td>
<td>100%</td>
</tr>
</tbody>
</table>

Basin Prioritization results – June 2, 2014

CASGEM Groundwater Basin Prioritization

- High
- Medium
- Low
- Very Low

California Department of Water Resources, 2015
Existing Groundwater Management Plans: Inventory and Assessment (No or Limited Implementation)

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Groundwater Management Plans (GWMP)</td>
<td>119</td>
</tr>
<tr>
<td>Total Area (square miles)</td>
<td>158,600</td>
</tr>
<tr>
<td>Coverage of All GWMPs (%)</td>
<td>20%</td>
</tr>
<tr>
<td>B118 Alluvial Basin Area (square miles)</td>
<td>61,900</td>
</tr>
<tr>
<td>Coverage of All GWMPs in B118 Basins Area (%)</td>
<td>42%</td>
</tr>
<tr>
<td>Senate Bill (SB) 1938 GWMPs Overlying B118 Alluvial Basins</td>
<td></td>
</tr>
<tr>
<td>SB 1938 GWMPs</td>
<td>83</td>
</tr>
<tr>
<td>SB 1938 GWMP Coverage in B118 Basin Area (%)</td>
<td>32%</td>
</tr>
<tr>
<td>SB 1938 GWMPs that include all CA Water Code Requirements</td>
<td>35</td>
</tr>
<tr>
<td>Coverage of SB 1938 GWMPs that include all CA Water Code Requirements in B118 Basin Area (%)</td>
<td>17%</td>
</tr>
</tbody>
</table>

Groundwater Management Plans

- **AB 359**
- **SB 1938**
- **AB 3030**

California Department of Water Resources, 2015
Critically Overdrafted Basins – Plans Due in 2020
Who can be a GSA?

• Exempt:
  o Adjudicated basins (mostly in southern CA)
  o Functional equivalent of a GSA, adjudicated basin

• Any local public agency
  o Cities
  o Counties
  o Water / irrigation districts
  o Other public agencies with responsibility for:
    • water supply,
    • water management, or
    • land use
  o NEW special acts districts (created by legislature, then CEQA, LAFCO, public vote) => Paso Robles
GSA Formation: Next Steps

• County: Groundwater Advisory Committee
• Stimulate dialogue / communication among local agencies, key stakeholders (e.g., Farm Bureau)
• Engage broad range of interested parties
• Gather information about the basin / find out where the information is / what is available
• Understand what Groundwater Sustainability Planning entails
• Look over the fence and see what’s happening elsewhere
• Transparency, transparency, transparency
• DEADLINE: June 30, 2017
So What Exactly Will Happen?

• **First Step:** forming a Groundwater Sustainability Agency (GSA)
  o By June 2017

• **Second Step:** developing a Groundwater Sustainability Plan (GSP)
  o Within 5 years of GSA formation
Key Elements of (Local/regional) California Groundwater Management Plans

- Context / Basin Description
- Public and agency involvement
- Basin management objectives
- Monitoring
- Accountability and review

Sustainable Groundwater Mgmt Act:
- Enforcement mandate
- Empowerment for demand management (in addition to supply management)
- Integration with surface water management
- Integration with water quality management (source control, remediation, containment)
- Integration with landuse planning
- Local control / enforcement, with state oversight / enforcement
Groundwater Management Portfolio: Overview

• Data collection, monitoring, modeling, assessment
• Supply management
• Demand management
• Stakeholder engagement and management
Monitoring and Assessment

Groundwater Sustainability Agencies have *discretionary* authority to:
- Conduct studies
- Register & monitor wells
- Set well spacing requirements
- Require extraction reporting
- Regulate extractions
- Implement capital projects
- Assess fees to cover costs

Some exemptions for smaller private well owners

*COURTESY* - Marcus Trotta, Sonoma County Water Agency, 2015
- Healthy
  - **Health Maintenance**
    - Nutrition
    - Exercise
    - Relationships/social engagement
    - Monitoring & Assessment

- Sustainable Groundwater
  - **Groundwater Management**
    - Adaptive supply management
    - Adaptive demand management
    - Stakeholder engagement
    - Monitoring & Assessment

- Reversible undesirable impacts
  - **Extraordinary Measures**
    - Supply enhancement / demand reduction
    - Additional monitoring & assessment

- Major undesirable impacts
  - **Emergency Mode**
    - SGMA Chapter 11
    - Probationary Status

- Critically ill
  - **Treatment Mode**
    - Medication / therapy
    - Additional monitoring & Doctor’s assessment

- Death
  - **Emergency Mode**
    - Emergency Room
    - Surgery

- Groundwater unusable/unavailable

Thomas Harter, Univ. of California, 2015
<table>
<thead>
<tr>
<th>Undesirable Result &amp; Measurable Objective</th>
<th>Metric</th>
<th>Possible Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronic lowering of groundwater levels: maintain desired range</td>
<td>Water level at key locations</td>
<td>• No less than at any time AFTER earlier mitigation of undesirable results and PRIOR to 2015, OR&lt;br&gt;• No less than at any time prior to 2015, OR&lt;br&gt;• No less than at any time prior to 2042, OR&lt;br&gt;• Any fixed level arrived at through local/state political consensus about “significant and unreasonable”, driven by economic cost:&lt;br&gt;  • Significant and unreasonable increase in pumping cost&lt;br&gt;  • Significant and unreasonable cost of new well installation / well deepening</td>
</tr>
<tr>
<td>Reduction in groundwater storage: maintain desired range</td>
<td>Water level at key locations</td>
<td></td>
</tr>
<tr>
<td>Seawater intrusion: Stop or reverse water quality degradation</td>
<td>Water level at key locations or GW Salinity</td>
<td>Identify seawater intrusion threat via geologic and geochemical characterization &amp; modeling =&gt; define safe water level thresholds for land subsidence. Threshold:&lt;br&gt;  • Higher than land subsidence-driven threshold or any of the above, whichever is higher</td>
</tr>
<tr>
<td>Degraded water quality: no harm to SWRCB regs</td>
<td>Porter-Cologne/anti-degradation</td>
<td>• set by current and future RWB regulations&lt;br&gt;• Use modeling and assessment to link groundwater management actions to RWB objectives</td>
</tr>
<tr>
<td>Land subsidence: stop or minimize subsidence</td>
<td>Water level at key locations</td>
<td>Identify subsidence threat via geologic characterization &amp; modeling =&gt; define safe water level thresholds for land subsidence. Threshold:&lt;br&gt;  • Higher than land subsidence-driven threshold or any of the above, whichever is higher</td>
</tr>
<tr>
<td>Depletion of interconnected surface water &amp; adverse impacts on SW beneficial uses: minimum required streamflow</td>
<td>Water level at key locations (within 1 mile of stream?), surface critical low flows at key locations &amp; times</td>
<td>Use modeling and assessment to link impact of groundwater management/use to beneficial uses of surface water =&gt; set thresholds&lt;br&gt;  • No less than at any time AFTER earlier mitigation of undesirable results and PRIOR to 2015 =&gt; no further assessment needed&lt;br&gt;  • Higher than surface water beneficial use-driven thresholds or any of the above, whichever is higher</td>
</tr>
</tbody>
</table>

Thomas Harter, Univ. of California, 2015
RelaRonship between Measurable Objectives (MO) and Management Practices

Groundwater Sustainability Plan
- Monitoring & Assessment
- Stakeholder engagement
- Adaptive supply management
- Adaptive demand management

Measurement / Monitoring
Certainty

Management Impact
Uncertainty

Thomas Harter, Univ. of California, 2015
Relationship between Measurable Objectives (MO) and Management Practices

Measurement / Monitoring
Certainty

Groundwater Sustainability Plan
- Monitoring & Assessment
- Stakeholder engagement
- Adaptive supply management
- Adaptive demand management

Local Adaptive & Integrated Regional Water Management

State Minimum Regulation

Uncertainty

Thomas Harter, Univ. of California, 2015
Core Link between Local Planning Effort and State Oversight: Monitoring & Modeling/Assessment

Thomas Harter, Univ. of California, 2015
Seawater Intrusion
Seawater Intrusion
Storage for Local Use:
Water Replenishment District of So. Cal. (founded in 1959)

Over 400 Wells Pumping 240,000 acre feet per year (78 billion gallons/year) by Cities and Private Co.

=> also to prevent seawater intrusion!

WRD and Maven’s Notebook, 2013
Long-Term Storage via Import/Export: Groundwater Bank

Kern County Water Bank

MWD Southern California

From: Hanak et al., PPIC 2012
From: Ted Johnson, WRD 2013

Yuba River: Infrastructure, such as this water recharge pipe, allow water districts and agencies to manage surface water and groundwater within the same hydrologic area as a single resource, using one source to balance the other when surface water or groundwater levels are low. This can reduce water emissions and groundwater pumping, enhance local supply, and increase the amount of water available for transfer.
Orange County: Groundwater Recharge Portfolio

Orange County Water District, 2014
Managing GW Storage to Prevent Seawater Intrusion: Orange County Water District

Manage the basin like a reservoir

Orange County Water District, 2014
Water Balance by California Region (2010)

California Department of Water Resources
Water Plan Update 2013
Groundwater Banking for Environmental Flows: Scott Valley, Siskiyou County
So What Exactly Will Happen?

• First Step: forming a Groundwater Sustainability Agency (GSA)
  o By June 2017

• Second Step: developing a Groundwater Sustainability Plan (GSP)
  o Within 5 years of GSA formation

• Third Step: implementing Groundwater Sustainability Plan
  o achieve sustainable management no later than 2040
total active public supply wells in California: 8,396
with contaminated groundwater (before treatment): 1,659

State Water Resources Control Board, AB2222 Report to Legislature, January 2013
Nitrate: Impacted regions within the Central Valley

red dots: wells above MCL for nitrate
Historic Nitrogen Fluxes

- Cropland Area (without Alfalfa)
- Synthetic Fertilizer
- Total Fertilizer
- Harvest
- Manure

**tons N/yr**

- 1940: 110,000
- 1950: 220,000
- 1960: 330,000
- 1970: 440,000
- 1980: 550,000
- 1990: 660,000
- 2000: 770,000
- 2010: 880,000

**Cropland Area**

- 1940: 1M ac
- 1950: 2M ac
- 1960: 3M ac
- 1970: 4M ac
- 1980: 5M ac
- 1990: 6M ac
- 2000: 7M ac
- 2010: 8M ac
Assume: All Manure Remains On-Dairy
Regulating Water Pollution Sources

Point Sources of Pollution

Surface Water Quality
Nonpoint Sources of Pollution

Ground Water Quality

1970s - now
Clean Water Act:
NPDES Permits
Regulating Water Pollution Sources

Point Sources of Pollution

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Superfund, TSCA, RCRA, FIFRA
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Ground Water Quality

Nonpoint Sources of Pollution

2000s - now
Clean Water Act: TMDL
Focus: Enforcement Monitoring

Example of Working with a Regulation: Speed Limit

Responsible Party: Driver
Feedback: Speedometer
Management Tool: Brakes
Enforcement: Radar Controls
Why is Nonpoint Source Pollution Different from Point Source Pollution of Groundwater?

• Scale
  - Millions of acres vs. 1-10 acres

• Intensity
  - Within ~1 order magnitude above MCL vs. many orders of magnitude above MCL

• Hydrologic Function
  - Recharge vs. non-leaky

• Frequency
  - Ongoing/seasonally repeated vs. incidental

• Heterogeneity & Adjacency
Focus: Enforcement Monitoring

Applying Point Source Approach to Nonpoint Source:

Responsible Party: Landowner

Feedback: missing

Management Tool: $$$ “agronomic”

Enforcement: Monitoring Wells
Focus: Enforcement Monitoring

Alternative Monitoring Approach to Nonpoint Source:

- Enforcement:
  - Annual Nitrogen Budget
  - Management Practice Assessment
  - Regional Trend Monitoring

- Responsible Party: Landowner

- Feedback:
  - Nutrient/Water Monitoring & Assessment

- Management Tool:
  - Water and Nutrient Management
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1970s - now
Clean Water Act: NPDES Permits

1980s - now
Superfund, TSCA, RCRA, FIFRA

2000s - now
Clean Water Act: TMDL

2010s - future
CA Porter-Cologne:
- Dairy Order
- ILRP/Ag Orders
- CV-SALTS

Nonpoint Sources of Pollution

Ground Water Quality
Future of Groundwater Management in Agricultural Regions:

Opportunity for creative solutions to **simultaneously** address

- groundwater supply enhancement
- groundwater quality improvement
- drinking water protection
- economic viability of agriculture

High irrigation efficiency + High nutrient use efficiency + **CLEAN** groundwater recharge
Online Resources

• [http://groundwater.ucdavis.edu/sgma](http://groundwater.ucdavis.edu/sgma)
• [http://groundwater.ucdavis.edu/calendar](http://groundwater.ucdavis.edu/calendar)
• [http://www.water.ca.gov/groundwater/casgem/](http://www.water.ca.gov/groundwater/casgem/) (California DWR groundwater level monitoring program)
• [http://www.water.ca.gov/waterconditions/drought/#](http://www.water.ca.gov/waterconditions/drought/#) (California DWR drought information)
• [http://www.waterboards.ca.gov/gama/geotracker_gama.shtml](http://www.waterboards.ca.gov/gama/geotracker_gama.shtml) (California groundwater quality information)
• Contact Dr. Thomas Harter at [ThHarter@ucdavis.edu](mailto:ThHarter@ucdavis.edu)
Food Grows Where Water Flows
Global Risk of GW Nitrate

Note: 10 mg N/l = 10 kg N/km²/yr for each 1 mm/yr recharge

UN World Water Development Report II, 2006
Population Map of the World & Major GW Withdrawal Centers

Modified with world population map from: Nature 439, 800 (16 February 2006) | doi:10.1038/439800a
CA Ag Future: Demonstrated Groundwater Sustainability

Manage the basin like a reservoir

RECHARGE PORTFOLIO

Orange County Water District, 2014
CA Ag Future: Demonstrated Improvements in GW Quality

![Graph showing trend reversal in Danish groundwater quality](image)

Hanson et al., ES&T 2011: Trend reversal in Danish groundwater
Where Does Your Food Come From?

California’s drought affects the whole country’s fruits, veggies, and nuts.

Percentage of Total US Production by County:
- <10%
- 10-20%
- 20-30%
- >30%

Drought Status 3/2015

99% of all US almonds
99% all US walnuts
98% of all US pistachios
95% of all US broccoli
92% of all US strawberries
91% of all US grapes
90% of all US tomatoes
74% of all US lettuce


How Thirsty Is Your Food?

- One head of broccoli: 5.4 gallons of water
- One walnut: 4.9 gallons of water
- One head of lettuce: 3.5 gallons of water
- One tomato: 3.3 gallons of water
- One almond: 2.1 gallons of water
- One pistachio: 0.75 gallons of water
- One strawberry: 0.4 gallons of water
- One grape: 0.3 gallons of water

1/4 lb beef: 375 gal
1/4 lb chicken: 72 gal

Figures indicate how much water it takes to bring each crop to maturity in the US, if using only irrigated water. Data: Mckonnon, R.M. and Harebitor, A.Y.

National water footprint, by sector [cu. m/capita/year]
Global Fraction of Cropland, 1992


Plate 1. Global fractional cropland area at 5 min resolution. This is an updated version of the data set presented by Ramankutty and Foley [1998].
“Green” vs. “Blue” Water Use in Agriculture

Rainfed agriculture = 80% of cultivated land, 60% of crop production
Irrigated agriculture = 70% of applied water use, 90% of consumptive use
20% of cultivated land, 40% of crop production

Why use groundwater in agriculture?

- Ubiquity
- Upfront capital costs lower than surface water irrigation systems
- Affordable / no large organization needed
- Gov’mt subsidies (rural energy, pumps)
- Irrigation on demand
- Much higher value crops
- Drought resilience
- Water scarcity meets increasing food & feed demand (more [concentrated] animal ag)

Total Water Use Map

Cubic kilometres a year

- More than 100
- 50-100
- 10-50
- Less than 10

Source: FAO-AQUASTAT.

*modified from*

**Largest Groundwater Users**
(80% of global)
- India
- China
- United States
- Iran
- Bangladesh
- Pakistan

**Global Use:**
- 4,000 km$^3$
- 3,200 MAF

+ 6,400 km$^3$
+ 5,100 MAF
from rain to ag
Trends in Groundwater Use

From: Shah et al, 2007
CA: 13-25 km³/ 10-20 MAF

The monthly storage changes are shown as anomalies for the period April 2002–May 2013, with 24-month smoothing. Image: J. T. Reager, NASA Jet Propulsion Laboratory, California Institute of Technology, USA.
Groundwater Overdraft

Scanlon et al., PNAS 2012

Rodell et al., Nature 2009
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Ground Water Quality

Nonpoint Sources of Pollution

2000s - now
Clean Water Act: TMDL
Focus: Enforcement Monitoring

Example of Working with a Regulation: Speed Limit

Responsible Party: Driver

Feedback: Speedometer

Management Tool: Brakes

Enforcement: Radar Controls
Why is Nonpoint Source Pollution Different from Point Source Pollution of Groundwater?

• Scale
  - Millions of acres vs. 1-10 acres

• Intensity
  - Within ~1 order magnitude above MCL vs. many orders of magnitude above MCL

• Hydrologic Function
  - Recharge vs. non-leaky

• Frequency
  - Ongoing/seasonally repeated vs. incidental

• Heterogeneity & Adjacency
Focus: Enforcement Monitoring

Applying Point Source Approach to Nonpoint Source:

- Responsible Party: Landowner
- Feedback: missing
- Management Tool: $$$ “agronomic”
- Enforcement: Monitoring Wells
Key Elements to Future “Groundwater” Monitoring of NPS

• Three-track monitoring:
  
  o **Enforcement**: Monitor/report key outcomes of farm management practices, e.g., *annual nitrogen budgets* – “proxy” for measuring “groundwater discharge”
  
  o **Research**: link “proxy monitoring” to actual groundwater discharge at intensely monitored sites & using models *(mgmt practice evaluation)*
  
  o **Assurance**: *Regional trend monitoring* network (e.g., GAMA)
STEP 1: GROUNDWATER ASSESSMENT
High Vulnerability Areas: Key Criteria (ESJV Coalition)

• Hydrogeologically high vulnerability
  o statistical analysis of groundwater nitrate occurrence based on hydrogeology,
    soils, depth to groundwater, landscape slope, recharge

• Further prioritization (high – 1, medium – 2, low – 3):
  o Exceedances of water quality objectives,
  o Proximity to areas contributing recharge to urban and rural communities that
    rely on groundwater as a source of supply,
  o Existing field and operational practices that are possibly the cause or source of
    groundwater quality degradation,
  o The largest acreage commodity types comprising up to at least 80 percent of
    irrigated agriculture in the high vulnerability areas,
  o Legacy or ambient groundwater conditions,
Eastern San Joaquin Valley Coalition: High Vulnerability Area
Another Vulnerability Scheme: Nitrate Hazard Index

Based on:
- Soil
- Crop
- Irrigation

Dzurella, Pettygrove et al.,
Journal Soil Water Conservation, 2015
STEP 2: MONITORING (three-pronged)

A: PROXY MONITORING: FARM NITROGEN FLUXES
Eastern San Joaquin Valley
Focus: Enforcement Monitoring

Alternative Monitoring Approach to Nonpoint Source:

- Responsible Party: Landowner
- Feedback: Nutrient/Water Monitoring & Assessment
- Management Tool: Water and Nutrient Management
- Enforcement: Annual Nitrogen Budget + Management Practice Assessment + Regional Trend Monitoring
Regulating Water Pollution Sources

Point Sources of Pollution
- 1970s - now
  Clean Water Act:
  NPDES Permits
- 1980s - now
  Superfund, TSCA, RCRA, FIFRA
- 2000s - now
  Clean Water Act:
  TMDL
- 2010s - future
  CA Porter-Cologne:
    Dairy Order
    ILRP/Ag Orders
    CV-SALTS

Surface Water Quality

Nonpoint Sources of Pollution

Ground Water Quality
Governance Models: Form follows Function

• The entire groundwater basin must be covered by one or multiple GSAs
• Likely governance:
  o Single water district, county, city
  o MOU or other contractual agreement between public agencies
  o JPA among public agencies
  o Special acts district
• Centralized GSA
• Distributed GSA
• Hybrid GSA
  o Central authority on some mandates, distributed authority on other mandates
  o One GSA, many GSPs
  o Many GSAs, one GSP
GSA Formation: What’s Next

• Stimulate dialogue / communication among local agencies, key stakeholders (e.g., Farm Bureau)
• Engage broad range of interested parties
• Gather information about the basin / find out where the information is / what is available
• Understand what Groundwater Sustainability Planning entails
• Consider facilitation services
• Look over the fence and see what’s happening elsewhere
• Transparency, transparency, transparency
• DEADLINE: June 30, 2017
Groundwater Management Organizations:
Key Action Areas for Innovative Thinking

• Planning process
  o Governance structures
  o Finding agreement on goals, reporting, enforcement, cooperation with neighboring agencies

• Cooperation and stakeholder involvement
  o Identifying and engaging participants / stakeholders
  o Structures for involving stakeholders
  o Avoiding / resolving disputes, dispute facilitation

• Collecting information about groundwater context
  o Improving groundwater information collection, analysis, presentation
  o Metering of extraction at the discretion of GSA

• Groundwater management portfolio

From: Nelson, Innovative GW Management, Stanford 2011
Groundwater Management Tools for Regional Organization

• Limiting Groundwater Use / Mandates:
  o Limit extraction
  o Mandate reductions in current pumping
  o Limit construction of new wells
  o Requiring water conservation measures
  o Fees to support management/infrastructure/communication efforts

• Infrastructure measures:
  o Water efficiency projects
  o Wastewater treatment and recycling
  o Importing water
  o Conjunctive use of surface water and groundwater
  o Groundwater banking
  o Monitoring networks, data collection, and data analysis/modeling

• Communication and networking measures
  o Facilitate stakeholder participation
  o Education
  o Data analysis and reporting
  o Secure funding (grants, project applications,....)
Role of the State: **Carrot**

- Department of Water Resources has a key role:
  - Technical assistance and funding (Prop 1: $100 million for SGMA)
  - Regulation
    - Groundwater basin boundary adjustments
    - Minimum guidelines for appropriate GSP
  - Control
    - Review and approve GSPs
    - Review implementation
Role of the State:  **Carrot & Stick**

- Department of Water Resources has a key role:
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  - Regulation
    - Groundwater basin boundary adjustments
    - Minimum guidelines for appropriate GSP
  - Control
    - Review and approve GSPs
    - Review implementation

- **State Water Resources Control Board:**
  - Enforcement where local control fails (after 2017)
    - “probationary status”
    - Public hearing and 180 days to fix the problem
  - After 180 days: SWRCB poses as interim GSA
    - Groundwater extraction reporting mandatory
    - Possibly temporary control of groundwater extraction
    - Development and implementation of interim GSP
  - When locals are ready: get authority back from state
California Groundwater Rights: Background

• Correlative Rights Doctrine – safe yield of groundwater basin shared by overlying users
  o Katz v. Wilkinshaw, 1908

• California constitutional mandate for beneficial use (1928)

• Special districts (20 different types, about 2,300 districts)
  o Water districts, irrigation districts, private water companies, reclamation districts, water conservation districts, water replenishment districts, water storage districts, etc.

• County police power – controls groundwater exports
  o Baldwin vs. Tehama County, 1994

• The Courts: basin adjudication / “physical solution” – controls extraction
  o Many Southern California (sub)basins, mid 20th century
  o City of Barstow vs. Mojave Water Agency, 2000:
    • Right of water users to negotiate physical “equitable, practical” solution, regardless of water rights
    • Individual water rights holders cannot be forced into a voluntary agreement

• State groundwater management:
  o Voluntary local groundwater management plans: AB 3030 (1992)
  o Sustainable Groundwater Management Act of 2014: mandatory & expanded local control

• => if local/regional control fails: State Water Resources Control Board

• The Courts
  o Streamlined adjudication (legislation in 2015?)
Groundwater Modeling: Central to Planning Effort

Water Use

And % Share of Groundwater-Irrigated Area

Water Source
- Fresh Water Use

Water Use
- Agriculture
- Domestic
- Industry

Center for Hydrometeorology and Remote Sensing, University of California, Irvine

Example: Agricultural Landuse Buffers

Mayzelle et al. J. of Water, 2015
Moving Towards Better Control of Nonpoint Sources (NPS) of Groundwater: Needs

• **SCIENCE NEEDS**
  - NPS source control methods
  - NPS pollution soil/groundwater fate, transport
  - NPS pollution assessment, monitoring tools

• **REGULATORY FRAMEWORK**
  - Enforcement: Paradigm shift in monitoring approaches

• **AGRICULTURE (largest NPS)**
  - Socio-cultural change needed to work within new regulatory frameworks
Investigate Impact of Alternative Management Practices

Relatively change in streamflow due to alternative future groundwater management scenarios

Foglia et al., WRR 2013
Summary of Key Challenges to Viticulture

• Participate and facilitate local GSA forming by engaging, informing stakeholders
• Increasing recharge in agriculture: Develop management practices to replace “poor irrigation efficiency” with “high irrigation efficiency AND clean groundwater recharge”
• Identify public well source areas and focus N management on those areas => great place to have vineyards with low N input
• Participate in ILRP coalitions: management practice evaluations that INCLUDE deep soil and/or groundwater N flux measurements
• Participate in ILRP coalitions: regional trend monitoring networks
Storage for Local Use: Santa Clara Valley Water District
Percentage of Total US Production by County

- <10%
- 10-20%
- 20-30%
- >30%

- Exceptional drought
- Extreme drought
- Severe drought
- Moderate drought
- Abnormally dry

99% of all US almonds
99% all US walnuts
98% of all US pistachios
95% of all US broccoli
92% of all US strawberries
91% of all US grapes
90% of all US tomatoes
74% of all US lettuce

Nitrate and salinity dynamics in the Central Valley

Figure 7-13

CVSALTS, Tasks 7 and 8 – Salt and Nitrate Analysis for the Central Valley Floor
Final Report, December 2013

M.C. Rains et al., 2006 and 2008