Background

- Groundwater Supply
- Groundwater Quality
- Regulations & Monitoring
- Dairy and groundwater impacts

U.S. Sand & Gravel Aquifers

GENERAL PROPERTIES (exceptions are the rule)
- K values = 1 m/d - 100 m/d
- gradients 0.1 - 1%
- effective porosity of 5-15%
- velocity: ~10^-1 m/a to ~10^1 m/a
- recharge rates: < 10 mm/a to 500 mm/a

CHALLENGES:
- overdraft: up to 0.1 m/a head loss (30 - 200 mm/a gw loss)
- subsidence up to 1 m per 10-50 m drawdown
- pollution: 0.2 - 0.5 mg N/L annual increase in nitrate-N

United States Aquifer Map

fractured bedrock of California’s mountain ranges

- result of erosion, water, wind, lake deposition, ocean bay deposition
Largest Water Users
- India
- China
- United States
- Pakistan
- Japan
- Thailand
- Indonesia
- Bangladesh
- Mexico
- Russian Federation

Largest Groundwater Users (80% of global)
- India
- China

100 km³ = 80 MAF

Global Use:
- 4,000 km³
- 3,200 MAF

CA:
- 4,000 km³
- 3,200 MAF

+6,400 km³
+5,100 MAF

from rain to ag

Global total:
2,100 km³ (0.65 MAF, 6% rainfed, 94% irrigated)

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

Annual Water Use – California, USA, World

California and USA: USGS Circular 1268 (for year 2000); http://pubs.usgs.gov/circ/2004/circ1268/
World: Pacific Institute 2008-2009 World Water Report, Table 2-1

Groundwater for Irrigation

(G1) Irrigation Water Withdrawals, year 2000

Population Map of the World & Major GW Withdrawal Centers

Modified with world population map from: Nature 435, 830 (16 February 2005) doi:10.1038/nature03956

Total irrigated area / consumptive use: 300 Mha / 1,277 km³
GW irrigated area / consumptive use: 112 Mha / 545 km³

Groundwater Quality

- Groundwater Supply
- Groundwater Quality
- Regulations and Monitoring
- Dairy and groundwater impacts

Global Groundwater Nitrate

(1) Mobilizable Nitrogen Loads

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

UN World Water Development Report II, 2006

Model for shallow groundwater

Model for deep groundwater used as drinking water (50 m simulation depth)

EXPLANATION
Predicted nitrate concentration, in milligrams per liter on N

EXPLANATION
Predicted nitrate concentration, in milligrams per liter on N

Groundwater Nitrate in the Hollister Area and Salinas Valley

Central Coast Nitrate in Salinas Valley

CVSALTS, High Resolution Ambient Water Quality Mapping, Draft, May 2016

Central Coast Cooperative Groundwater Quality Report, June 2012, Central Coast RWB website

Dubrovsky et al., USGS, 2010
Assume: All Manure Remains On-Dairy

Nitrate Contamination Will Persist

- Nitrate contamination will worsen for years/decades
- Direct remediation of groundwater is extremely costly

Estimated locations of the area’s roughly 400 regulated community public and state-documented state small water systems and of 74,000 unregulated self-supplied water systems. Source: Honeycutt et al. 2012, CDPH PICME 2010.
Future Groundwater Nitrate at Continued Current Nitrate Loading

Exceedance Probability, Nitrate above 45 mg/L (MCL)

Percent of wells exceeding the nitrate MCL

Eastern Tulare Lake Basin

Eastern Tulare Lake Basin

Regulations and Monitoring

- Groundwater Supply
- Groundwater Quality
- GW Quality: Regulations and Monitoring
- Dairy and groundwater impacts

Regulating Water Pollution Sources

Point Sources of Pollution

1970s - now
Clean Water Act: NPDES Permits

1980s - now
Superfund, TSCA, RCRA, FIFRA

Surface Water Quality

Ground Water Quality

2000s - now
Clean Water Act: TMDL

Nonpoint Sources of Pollution

Regulatory Approaches to Groundwater Protection and Monitoring

Modified from: EOS, Transactions, AGU 2001

Harter, California Agriculture, 2015

- Identify impacts (human health, environment, economy) and risk drivers
- Identify & prioritize parties to be regulated (universal v structured/categories)

The Basics of Management Policy & Regulation

- Responsible party: Driver
- Feedback: Speedometer
- Management tool: Brakes
- Enforcement: Radar controls

from: http://www.ems-i.com
Application to Nonpoint Source Pollution

- Identify risks: e.g., Groundwater Assessment Reports (ILRP)
- Identify parties to be regulated, e.g., vulnerability zones (ILRP)

<table>
<thead>
<tr>
<th>Responsible party:</th>
<th>Feedback:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landowner</td>
<td>Nutrient/water monitoring and assessment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Management tool:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water and nutrient management</td>
<td></td>
</tr>
</tbody>
</table>

Enforcement:
- Annual nitrogen budget + Management practice assessment
- Regional trend analysis

Vision for Regulating Nonpoint Sources of Groundwater

- **SCIENCE**
  - NPS source control
  - NPS pollution soil/groundwater fate, transport
  - NPS pollution assessment, monitoring

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

- **AGRICULTURE (largest NPS!)**
  - Socio-cultural change needed to work within new regulatory framework

SAGBI Accounting for Deep Tillage

<table>
<thead>
<tr>
<th>Suitability Group</th>
<th>Area (Acres)</th>
<th>Total Area (%)</th>
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</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>1,525,296</td>
<td>9</td>
</tr>
<tr>
<td>Good</td>
<td>1,928,650</td>
<td>11</td>
</tr>
<tr>
<td>Mod. Good</td>
<td>2,184,882</td>
<td>12</td>
</tr>
<tr>
<td>Mod. Poor</td>
<td>1,379,282</td>
<td>8</td>
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<tr>
<td>Poor</td>
<td>4,609,128</td>
<td>26</td>
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<tr>
<td>Very Poor</td>
<td>5,993,345</td>
<td>34</td>
</tr>
<tr>
<td>Total</td>
<td>17,620,582</td>
<td>100</td>
</tr>
</tbody>
</table>

Dairy and Groundwater Quality

- Groundwater Supply
- Groundwater Quality
- Regulations and Monitoring
- Dairy and groundwater impacts

2012 Western US Dairy Cow Inventory

1. Central Valley, CA: 1,580,723 Cows
   - Includes Farms, Dairy, Milk, Eggs, Beets, Onion, Laxberries, Sunflowers, Spinach, Grandchamp and Rooster Farms
2. Magic Valley, ID: 411,653 Cows
   - Includes Cattle, Grazing, one or two, Minden and Their Farms
3. TX / NM: 357,288 Cows
   - Includes Cows and Associated Cattle in Area and nearby Cattle, Dairy, Beef, Rodeo, etc., Hunting, Land, and Farm Cattle in TX
Farm Sources of Diffuse GW Pollution: Example - Dairies

Sources of N:
- Feedlot
- Lagoon
- Storage areas
- Manured fields
- Fertilized fields
- Various crops
- Septic system

Dairy Manure Annual Salt Loading to Groundwater

<table>
<thead>
<tr>
<th>Irrigation Water Source</th>
<th>Salt Input, kg ha(^{-1})</th>
<th>Annual Salt Loading kg ha(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Winter Forage</td>
<td>130 – 220 μS/cm</td>
</tr>
<tr>
<td></td>
<td>Summer Corn</td>
<td>310</td>
</tr>
<tr>
<td>East Side Sources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1356</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wastewater + East Side</td>
<td>1356</td>
<td>2284</td>
</tr>
<tr>
<td>1,200 – 1,900 μS/cm</td>
<td></td>
<td></td>
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<tr>
<td>West Side Sources</td>
<td>828</td>
<td>2983</td>
</tr>
<tr>
<td>3794</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wastewater + West Side</td>
<td>2000</td>
<td>4792</td>
</tr>
<tr>
<td>6452</td>
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</tbody>
</table>

Computed using “Watsuit” Model. Crop uptake is considered. Agronomic manure application rates. Scenario: Annual Summer Corn/Winter Forage Double Cropping with 250 and 150 lbs per acre of N inputs, respectively; annual water inputs are rainfall 12 inches (30.48 cm), winter irrigation 10 inches (25.4 cm), and summer irrigation 36 inches (91.44 cm); and leaching fraction is 0.3. (UC Committee of Consultants Report, UC ANR Communications, 2007; http://anrcatalog.ucdavis.edu/DairyCattle/9004.aspx )

Pollutants by Dairy Management Unit

Manure Application Drives Field N

Testing Field BMPs: Case Studies

Campbell and Harter et al., GRA, 2006