Evaluating Stream Depletions in Small Watersheds and Headwaters of California-stream Depletion Risk Assessment Framework & Tools

High level analysis of groundwater-surface water connectivity and impact to surface waters from well pumping.

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Overview

• Task and Background
• What is sDRAFT?
• Groundwater Basics
• Previous Efforts

• Qualitative Approach
  • V-BET Tool
  • Risk Zones

• Quantitative Approach
  • Analytical vs. Numerical Models
  • Best Analytical Model matches
  • Mark West Creek- Example Application
Task
Evaluate approaches to narrow down and prioritize areas with likely groundwater-surface water interactions and where groundwater diversions could impact surface flows. Develop a state-wide, cookie cutter, desktop approach that can be applied in headwaters, small watersheds or areas with threatened and endangered anadromous fish habitat.

Why?
• Cannabis Policy- Board may develop additional requirements for groundwater diversions in locations where there are a significant number of groundwater diversions, or where diverters are switching from surface to groundwater, and the diversions have the potential to negatively impact surface flows. (p52)
• Many Cannabis Cultivators using wells
• Many local jurisdictions approve well permits without or with limited review (slowly starting to change)
• SGMA does not cover upland areas, only applies to High and Medium Priority alluvial basins (High and Medium= ~17% of CA; Alluvial Basins= ~38% of CA)- SGMA covers most extraction by volume, but not species impacts
• Create focused discussion in non-SGMA areas, generate background/discussion materials, engage experts in quantifying impacts
stream Depletion Risk Assessment Framework & Tools (sDRAFT)

- **Statewide** framework within which the risk of streamflow depletion by groundwater well pumping can be qualitatively and quantitively assessed. (not crop specific)
- Developed for use in upland river valleys, canyons and headwater areas, but does include some guidance for large lowland alluvial basins not covered by SGMA.
- Coarse high level approach to quickly estimate impacts to surface waters
  - Uses statewide publicly available datasets, and makes numerous simplifying assumptions
- Uses **landscape analysis** (not geology) to identify areas of likely connectivity.
- Tools are identified to simplify the process and provide consistency in application.
- Simplifies real-world conditions to optimize available resources

**Framework**: Risk Zones, Modeling Decision Chart

**Tools**: V-BET & Analytical Models (where/how to implement them)

*sDRAFT is in development stage and will evolve*
• Mimics topography but subdued in uplands
• Closest to surface (most accessible) in lowlands
• Flows from high elevation to Low elevation -or- from high pressure to low pressure
• Surface water bodies are expressions of the water table intersecting the ground surface
Total Volume Pumped
26 gpm x 30 days = 3.5 acre-feet

Pumped volume from Aquifer Storage (Cone of Depression)-2 acre-feet

Pumped volume from Stream Depletion-1.5 acre-feet

After pumping stops streamflow depletion recharges lost aquifer storage @30 Days= 1.5 acre-feet @1 yr= 3.1 acre-feet @2 yr= 3.2 acre-feet

In this example, modeled stream depletion ends 3.13 years after pumping ceased. The total streamflow depletion was 3.24 acre-feet. 0.26 acre-feet of aquifer storage was not replaced. Without recharge from precipitation or other sources, loss of storage volume would cause lowering of the water table elevation and possibly compression of the dewatered aquifer matrix.
Withdrawal Impact Continuum

“All Water discharged by wells is balanced by a loss of water somewhere” - C.V. Theis 1940

Sinks & Special Cases

- No stream impacts (e.g., closed basin, drains to ocean)

Most wells

- Interception of groundwater discharge or Diverted Discharge: Low magnitude, long duration impact (baseflow reduction)
- Mixed streamflow capture and interception of discharge

Water Rights

- ~100% Streamflow Capture or Induced Infiltration: High magnitude, short duration impact (pulse reduction)

Stream Depletion as % of pumping rate

Policy Context

- Mechanism of impact
- Magnitude and Duration of impact
- Shape of impact curve
Previous efforts informing sDRAFT development

**Qualitative**

Stetson Engineers Inc., 2008
Joseph Sax, 2002
- Focus on identifying areas matching legal description (4 part test); not replicating effort, considering approach and discussion, comparing results

California Geologic Survey, 2012
- Compare results to Quaternary Surficial Deposits- SoCal

**Spatially identify** geologic units and/or areas of likely connectivity

**Quantitative**

Barlow and Leake, 2012 (Circ 1376)
Hantush, 1965
Huang et al, 2018
Huggins et al, 2018
Jenkins, 1968
Zipper et al, 2018
Zlotnik and Tartakovsky, 2008
And others

- **Compare** analytical models to numerical
- Some *calculators* provided
- Mostly focus on alluvial *basins*
- Little discussion of applicability in *uplands*
Qualitative Approach- Landscape analysis to identify Valley Floor (alluvium)

Gilbert, et al., 2016- **Valley Bottom Extraction Tool** (V-BET) {Suite of 3 tools (Network Builder, Project Builder, V-BET)}

**Platform**: ArcGIS    **Data Needs**: Topography (DEM) and Stream flowlines (NHD)

**Process**: Build flow network, Sub-Divides watershed based on drainage area, searches laterally from stream for slope break, generates polygon of valley bottom

**Purpose**: identify maximum possible extent of riparian vegetation; interpreting river character and behavior.
- Does not identify alluvium-bedrock contact
Validation- What Does V-BET identify?

1. Picked single set of input parameters and ran in 4 areas (Green Valley Ck, Mark West Ck, Sespe Ck., Ventura River)
2. Compared areas contained in Valley Bottom to Total Area of unit

<table>
<thead>
<tr>
<th>Stetson Maps</th>
<th>Green Valley</th>
<th>Mark West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent near-stream alluvial deposits (adjacent to bedrock)</td>
<td>70.4%</td>
<td>81.6%</td>
</tr>
<tr>
<td>Stream Channel Alluvial Deposits (not adjacent to bedrock)</td>
<td>88.5%</td>
<td>95.0%</td>
</tr>
<tr>
<td>Potential Stream Depletion Area (older alluvial deposits)</td>
<td>25.4%</td>
<td>34.2%</td>
</tr>
</tbody>
</table>

Values in these tables represent the percentage of the total unit in a watershed that falls within the Valley Bottom polygon.

Quaternary Deposits in Southern California

<table>
<thead>
<tr>
<th>Type</th>
<th>Age</th>
<th>Quaternary</th>
<th>Sespe Ck</th>
<th>Ventura River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wash</td>
<td>Qw</td>
<td>Youngest</td>
<td>88%</td>
<td>94%</td>
</tr>
<tr>
<td></td>
<td>Qyw</td>
<td>Younger</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Qow</td>
<td>Older</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Qow</td>
<td>Oldest</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Fan</td>
<td>Qf</td>
<td>Youngest</td>
<td>75.9%</td>
<td>63.1%</td>
</tr>
<tr>
<td></td>
<td>Qyf</td>
<td>Younger</td>
<td>71.4%</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Qof</td>
<td>Older</td>
<td>37.8%</td>
<td>27.5%</td>
</tr>
<tr>
<td></td>
<td>Qof</td>
<td>Oldest</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Valley</td>
<td>Qa</td>
<td>Youngest</td>
<td>80%</td>
<td>62%</td>
</tr>
<tr>
<td></td>
<td>Qya</td>
<td>Younger</td>
<td>77.2%</td>
<td>45.8%</td>
</tr>
<tr>
<td></td>
<td>Qoa</td>
<td>Older</td>
<td>38%</td>
<td>44.2%</td>
</tr>
<tr>
<td></td>
<td>Qoa</td>
<td>Oldest</td>
<td>0%</td>
<td>NA</td>
</tr>
<tr>
<td>Terrace</td>
<td>Qt</td>
<td>Youngest</td>
<td>NA</td>
<td>92.7%</td>
</tr>
<tr>
<td></td>
<td>Qyt</td>
<td>Younger</td>
<td>66%</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Qot</td>
<td>Older</td>
<td>25%</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Qot</td>
<td>Oldest</td>
<td>6.4%</td>
<td>NA</td>
</tr>
</tbody>
</table>

Explanation of differences in results:
- Different goals behind efforts
- Differences in Stream Location (NHD vs 1:24k vs 1:100k)
- Most areas not captured by V-BET appear on valley walls when overlaid on 10-m DEM (used in V-BET)
- Compared to Stetson, V-BET does well at identifying areas of recent alluvial deposits
- Compared to Qal maps, V-BET does well at identifying more recent alluvium
The High Risk Zone can be defined without well information. Well location and depth are needed to separate the Medium and Low Risk Zones based on the well base in relation to streambed elevation (Low Risk wells can only intercept discharge).
Example of Full Risk Determination for Mark West Creek watershed (V-BET Scenario “MWC_new”; Buffers: 500 ft, 2000 ft, 1 mile, min 50 ft)
Quantitative-Comparative Modeling approach

**Goal**: Identify Analytical models (easy to implement) to best approximate well impacts to streams (Depletion)

- Identify the conceptual analytical models with existing calculators (# layers, f/p penetration, boundaries)
- Develop a Numerical model (MODFLOW) to match the conceptual model (then vary geometry)
- Approximate the Numerical model with the analytical calculators
- Compare results to identify the best analytical model for each scenario & overall
8 Conceptual analytical models with existing calculators

Jenkins 1968 (Variables = 5)

Hunt 1999 (Variables = 6)

Hunt 2009 (Variables = 10)

Hantush 1965 (Variables = 6)

Hunt 2003 (Variables = 10)

Ward & Lough 2011 (Variables = 9)

Butler 2001 (Variables = 7)

Hunt 2008 (Variables = 14)
The River Package (RIV) considers the streambed conductance and river head:

How RIV package considers different stream types:

<table>
<thead>
<tr>
<th>Functionality</th>
<th>Package or process Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPF</td>
<td>Layer-property flow package, With Flat bed-rock, top of layer, water table, all sides as no-flow boundaries, with symmetric cell sizes.</td>
</tr>
<tr>
<td>RIV</td>
<td>River Package, straight-line, river stage same as aquifer head, partially penetrating, with river bed below water table</td>
</tr>
<tr>
<td>WEL</td>
<td>Well package, constant pumping rate, fully penetrating</td>
</tr>
<tr>
<td>PCG</td>
<td>Preconditioned – Conjugate Gradient Package solver</td>
</tr>
<tr>
<td>DRN</td>
<td>Drain Package</td>
</tr>
<tr>
<td>STR</td>
<td>Stream Package</td>
</tr>
</tbody>
</table>

We used MODFLOW 2005 and Model Muse GUI with the following Packages (DRN and STR were used alternatively instead of RIV is few scenarios):
Analytical Models

Fully penetrating stream with no streambed resistance (Jenkins, 1968)

- Distance (R):
- Transmissivity (ft²/day):
- Storage Coefficient:
- Pumping Rate (gpm):
- Days of Pumping:

Jenkins (Glover)

https://mi.water.usgs.gov/software/groundwater/CalculateWell/index.html

Butler 2001 (Valley Walls)

http://www.kgs.ku.edu/StreamAg/Software/strp.html

Input

```
1 /OBS(no. of obs. wells)
10.0, 0.00 /XOBS1, YOBS1
825.00 /XPUMP, YPUMP
0.5 /RADIUS OF PUMPING WELL
625.0.15 /T AND S ZONE 1
625.0.15 /T AND S ZONE 2
625.0.15 /T AND S ZONE 3
2180.182.9 /LEFT BOUNDARY, RIGHT BOUNDARY
20 /WIDTH OF CENTER STRIP
25 0.01 /K AND THICKNESS OF STREAM BED
5000 0 1 11 /Q, STOPT, TAU, TAUSTEP, TAUINC
100 1 /NTAU, IPRINT
10 /N (NO. OF STEHFEST TERMS)
1.0E-9 /TLIMIT1 (REL. ERROR)
```

Variables shown in red

```
Butler 2001(Valley Walls)
```

Output

Days vs. Depletion in cfs

<table>
<thead>
<tr>
<th>Analytical Model</th>
<th>Online</th>
<th>DOS.exe</th>
<th>R Studio</th>
<th>Intermittent or Continuous Pumping</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jenkins (Glover)</td>
<td>X</td>
<td>X+online</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Hantush</td>
<td>X</td>
<td>X+online</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Hunt-'99</td>
<td>X</td>
<td>X+online</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Hunt-'03</td>
<td>X</td>
<td>X+online</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Butler</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
Analytical models validation vs numerical (which looks best)?

LW500’-1W-180d- 128’ Setback

LW2640’-1W-365d- 300’ Setback

LW10,000’-1W-180d- 2480’ Setback

LW500-1W-365d-3L- Hunt’09

LW1000-1W-365-3L  Ward & Laugh

LW1000-1W-180d-2L

Pumping Rate

10 gpm

ModFlow

Jenkins

Hantush

Hunt-99

Butler

Days

0 50 100 150

depletion in cfs

Days

0 100 200 300

depletion in cfs

Days

0 100 200 300

depletion in cfs

Days

0 100 200 300

depletion in cfs

Days

0 100 200 300

depletion in cfs

Days

0 100 200 300

depletion in cfs

Days

0 100 200 300

depletion in cfs
### Recommended Analytical Models

<table>
<thead>
<tr>
<th>High Risk Zone</th>
<th>Medium or Low Risk Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valley Bottom Width $&gt;1,000$ ft wide $^2$</td>
<td>Valley Bottom Width $&lt;1,000$ ft wide</td>
</tr>
<tr>
<td>Alluvial or Non-Alluvial (deep) well</td>
<td>Alluvial Well</td>
</tr>
<tr>
<td>Non-Alluvial (deep) Well</td>
<td>Sub-Watershed Width $^4$ $&lt;1,000$ ft wide</td>
</tr>
<tr>
<td>Sub-Watershed Width $^4$ $&gt;1,000$ ft wide</td>
<td></td>
</tr>
</tbody>
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</tr>
<tr>
<td>Sub-Watershed Width $^4$ $&gt;1,000$ ft wide</td>
<td></td>
</tr>
</tbody>
</table>

- **Jenkins Model**
- **Butler Model**
- **Butler Model**
- **Butler Model**
- **Jenkins model**

Models use parameters from aquifer screened by well

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1. Subject to change based on additional modeling results or new calculators, and will likely vary geographically
2. Additional scenarios with varying aquifer parameters may modify transition distance threshold
3. Modeling ignored alluvium and aquitards
4. Sub-watershed cross section width
Example application in Mark West Creek using modified Emergency Regulation Data

1. Run V-BET tool to ID High Risk Zone
2. Identify Well Locations and details
3. Estimate Aquifer Parameters
4. Determine Analytical Model Use (chart)
5. Run Model for each well
6. Estimate streamflow
7. Plot results (individual or cumulative)

Mark West Creek
Headwaters-2.5 km²

High Risk
Medium Risk
Low Risk

Simulated Cannabis Well

Total Pumped= 72.03 acre-feet
Total Stream Depletion= 60.59 acre-feet
Stream Depletion Duration= ~45 years
Loss of Aquifer Storage= 11.45 acre-feet

Legacy Depletions from previous pumping
streamflow Depletion Risk Assessment Framework & Tools

Next Steps...

• Solicit feedback
• Develop additional examples to demonstrate Decision Support
• Complete documentation of sDRAFT
• Develop general guidance on this topic:
  • Assemble statewide (coarse) datasets (identify procedures to enrich locally)
  • Pre-stage some data or products to make usable

Questions?

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