The safe yield

• “safe yield (= perennial yield = basin yield)
  The maximum quantity of water that can be
  continuously withdrawn from a groundwater
  basin without adverse effect”.
  CDWR Bulletin 118, 2003
  The estimate is made over a representative period

Why the safe yield?

• The adjudication of groundwater rights commonly
  revolves about the safe yield;
• It is central to groundwater management as a
  baseline for groundwater extraction;
• The theory behind the safe yield is far from settled.

Representative climatic period

• must reflect long-term average hydrologic
  conditions;
• must include at least one period of overall wet
  conditions and at least one of overall dry
  conditions relative to average annual conditions;
• have an average precipitation that is close to the
  average precipitation for the entire period of
  record;
• the beginning of the representative period must
  be an interval of relatively dry conditions to
  preclude large initial aquifer storage that could
  anomalously reduce recharge

Two aquifers with ag service: different sizes

Small aquifer: Carpinteria California
SY ~ 0.4 x 10^6 m³/yr??
60-80%? is agricultural use??

Large aquifer: Edwards BFZ:
SY ~ 400 x 10^6 m³/yr; 30% is agricultural use


Fresh water use 7 of states Colorado River basin (year 2010)

Source data USGS 2014

Shifting land use from rangeland to gw irrigated wine grapes has put enormous pressure in groundwater basins of Central California

North: Santa Barbara County

Groundwater USGS 2012
OVERDRAFT: “... when the amount of water extracted exceeds the amount of ground water recharging the basin over the long term”: CDWR Bulletin 118-2003

Another key definition

- Recharge: water that enters groundwater storage
- Naturally or by human action

Long-term fluxes and groundwater basin balancing are needed for safe yield estimation.

Edwards: recharge is mainly by stream seepage across recharge zone; well extraction is measured; spring discharge is measured

Edwards aquifer groundwater balance: excellent data 1934-2015
Part of the struggle over Edwards GW

- Several impacted species, among which
- fountain darter (*Etheostoma fonticola*, a fish),
- the Comal Springs riffle beetle (*Heterelmis comalensis*),
- the Texas wild-rice (*Zizania texana*),
- and the Texas blind salamander (*Eurycea rathbuni*)

Methods to estimate safe yield (Loáiciga 2016)

- From inflow and outflow (annual average R, D, E over the climatically representative period)
  \[ Q_{safely} = R - D - E \quad \text{average annual fluxes} \]
- From average annual extraction and change in groundwater storage (annual average \( \Delta S, Q \) over the climatically representative period)
  \[ Q_{safely} = \Delta S + Q \quad \text{where} \quad \Delta S = \text{sum}(S_{storat} \times \text{Area} \times \Delta h) \]

Methods to estimate the safe yield continued

\[ \Delta h \text{ (basinwide) vs } Q \quad [\text{EDWARDS}] \]

(annual values)

\[ 1954-1989 \]

\[ \Delta h = -0.00886 Q + 3.7155 \]

\[ \text{Annual groundwater extraction} \left(10^6 \text{ m}^3\right) \]

\[ \text{Change in water level (m)} \]

\[ \text{Change in storage} \left(10^6 \text{ m}^3\right) \]

Methods to estimate the safe yield continued

\[ \Delta S \text{ vs } Q \quad \text{where} \quad \Delta S = \text{sum}(S_{storat} \times \text{Area} \times \Delta h) \quad [\text{EDWARDS}] \]

(annual values)

\[ 1954-1989 \]

\[ \Delta S = -1.57 Q + 704.45 \]

\[ \text{Annual groundwater extraction} \left(10^6 \text{ m}^3\right) \]

\[ \text{Change in storage} \left(10^6 \text{ m}^3\right) \]

Methods to estimate the safe yield continued

Mass-curve analysis: cumulative net recharge = sum(R-D-E)

<table>
<thead>
<tr>
<th>Calendar year</th>
<th>Cumulative change in storage (10^6 m^3)</th>
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</thead>
<tbody>
<tr>
<td>1930</td>
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<tr>
<td>1940</td>
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<tr>
<td>2020</td>
<td>500</td>
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</table>

Storage capacity (C) from cumulative change in storage: need LONG time series

This is a lower bound estimate of C, implies a relatively low Safe Yield; C \( \uparrow \) 5943 MCM

Or C = \text{sum}(S_{storat} \times \text{Area} \times \Delta h)
## Final Remarks

- To manage groundwater basin sustainably one must **measure** $Q$, $R$, $D$, $E$, $h$
- **Measure** the aquifer: $S_{stor}$, $T$; Area, thickness
- It may take many decades or centuries in climatically variable regions to ascertain the safe yield
- GW management must be **adaptive to climatic fluctuations**

### SUMMARY OF RESULTS  EDWARDS AQUIFER

<table>
<thead>
<tr>
<th>Method</th>
<th>period</th>
<th>$Q_{safe},10^6,\text{m}^3/\text{yr}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R - D - E$ (averages annual)</td>
<td>1954-1989</td>
<td>459</td>
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<tr>
<td></td>
<td>1934-2014</td>
<td>386</td>
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<td>$\Delta h,vs,Q$ (annual values)</td>
<td>1954-1989</td>
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<td>1934-2014</td>
<td>327</td>
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<tr>
<td>$\Delta S,vs,Q$ (annual values)</td>
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<td>1934-2014</td>
<td>384</td>
</tr>
<tr>
<td>Mass curve analysis</td>
<td>1954-1989</td>
<td>Not applicable</td>
</tr>
<tr>
<td></td>
<td>1934-2014</td>
<td>342</td>
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