Irrigated lands water budget

Stephen Hundt
Context
The modeling process

Define problem
- Literature review
- Preliminary analyses
- Data collection

Develop conceptual model
- Processes/budget
- Boundary conditions
- Hydrogeologic framework
- Data collection

Develop mathematical model
- Choose model code
- Choose how to represent processes and boundary conditions
- Construct the model

Calibration
- History matching
- Sensitivity analysis
- Data collection

Assessment of problem using model

After Reilly (2001) TWRI 3,B8
Recharge from precipitation and applied irrigation are significant portion of total inflows.

Pumping is a large outflow.

**Inflows**
(Urban, 2004)

- Canal Seepage
- Septic
- Other
- Precipitation & Flood Irrigation
- Underflow/Lake Lowell Seepage
- Stream Seepage

**Outflows**
(Urban, 2004)

- Rivers & Drains
- Stock Watering
- Rural Domestic
- Industrial Municipal Irrigation
- Agriculture
- Domestic & Industrial
Recharge from precipitation and applied irrigation are significant portion of total inflows.

Pumping is a large outflow.

### Groundwater budget, mean 1967-1997 conditions

<table>
<thead>
<tr>
<th>Budget Component</th>
<th>Inflows</th>
<th>Outflows</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Volume (acre-ft/yr)</td>
<td>Percentage of total inflow</td>
<td>Volume (acre-ft/yr)</td>
<td>Percentage of total outflow</td>
</tr>
<tr>
<td>Canal seepage</td>
<td>702,375</td>
<td>48%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Total on-farm infiltration (irrigation and precipitation)</td>
<td>674,699</td>
<td>46%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Tributary underflow (north of Payette River)</td>
<td>59,389</td>
<td>4.1%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Direct precipitation (non-irrigated lands)</td>
<td>23,470</td>
<td>1.6%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Direct precipitation (domestic, commercial, municipal, and industrial lands)</td>
<td>1,793</td>
<td>0.12%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Groundwater discharge to drains</td>
<td>--</td>
<td>--</td>
<td>785,216</td>
<td>51%</td>
</tr>
<tr>
<td>Groundwater discharge to rivers</td>
<td>--</td>
<td>--</td>
<td>501,802</td>
<td>33%</td>
</tr>
<tr>
<td>Pumping (irrigation)</td>
<td>--</td>
<td>--</td>
<td>136,147</td>
<td>8.9%</td>
</tr>
<tr>
<td>Pumping (domestic, commercial, municipal, and industrial)</td>
<td>--</td>
<td>--</td>
<td>85,834</td>
<td>5.6%</td>
</tr>
<tr>
<td>Aquifer discharge to wetlands</td>
<td>--</td>
<td>--</td>
<td>21,339</td>
<td>1.4%</td>
</tr>
<tr>
<td>Aquifer discharge to Lake Lowell</td>
<td>--</td>
<td>--</td>
<td>3,752</td>
<td>0.24%</td>
</tr>
<tr>
<td>Totals</td>
<td>1,461,726</td>
<td>1,534,090</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Schmidt and others (2008) and Sukow (2012)
What we need
Groundwater fluxes due to irrigation

Deep percolation of applied irrigation water

(modified from Faunt, 2009)
Groundwater fluxes due to irrigation

Groundwater pumping

(modified from Faunt, 2009)
Related groundwater fluxes

Canal leakage

(Modified from Faunt, 2009)
How we get there
Ideal: direct measurements of fluxes
Water budget approach

Calculate component(s) of interest as remainder of a water balance formula.
Water budget approach

Calculate component(s) of interest as remainder of a water balance formula

\[ \text{In} - \text{Out} = \pm \Delta \text{Storage} \]

- precipitation
- surface water deliveries
- groundwater deliveries
- groundwater uptake
- evaporation (irrigation and bare soil)
- transpiration
- runoff
- deep percolation to groundwater

Agricultural Soil

(modified from Faunt, 2009)
<table>
<thead>
<tr>
<th>Unknown</th>
<th>~Known</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unmeasured well rates (most)</td>
<td>Municipal well rates (some)</td>
</tr>
<tr>
<td>Canal leakage volumes</td>
<td>Evapotranspiration</td>
</tr>
<tr>
<td>Deep percolation of irrigation water (incidental recharge)</td>
<td>Precipitation</td>
</tr>
<tr>
<td></td>
<td>Surface water diversions &amp; destinations</td>
</tr>
<tr>
<td></td>
<td>Land use</td>
</tr>
<tr>
<td></td>
<td>Well locations, classification, and screen depths (many)</td>
</tr>
<tr>
<td>Throughflow of canal water (tail water)</td>
<td></td>
</tr>
<tr>
<td>Soil moisture storage characteristics</td>
<td></td>
</tr>
</tbody>
</table>
Spatial scale
Distributed, district, or point

evapotranspiration, precipitation

surface water deliveries

well locations, well rates
Calculations

Input Data

Calculate budgets

Apply in model

aggregate to district level
distribute to model cells
Estimating component volumes
Surface water system budget

(modified from Faunt, 2009)
Surface water system budget

\[ \text{In} - \text{Out} = \pm \Delta \text{Storage} \]

\[ \text{In} = \text{Out} \]

- Diversions (div)
- Precipitation (ppt)
- Evapotranspiration (et)
- Leakage (leak)
- Through flow (tail)
- Delivered (deliv)
- Net Deliveries (deliv)

\[ \text{div} + \text{ppt} = \text{et} + \text{leak} + \text{tail} + \text{deliv} \]
Surface water system budget: Inflows

\[ \text{div} + \text{ppt} = \text{et} + \text{leak} + \text{tail} + \text{deliv} \]
Surface water system budget: Inflows

Precipitation

$\text{div} + \text{ppt} = \text{et} + \text{leak} + \text{tail} + \text{deliv}$
Surface water system budget: Outflows

Evapotranspiration

\[ \text{div} + \text{ppt} = \text{et} + \text{leak} + \text{tail} + \text{deliv} \]
Surface water system budget:

Outflows

Canal leakage

\[ \text{div} + \text{ppt} = \text{et} + \text{leak} + \text{tail} + \text{deliv} \]
Surface water system budget: Outflows

Through flow / tail water

div + ppt = et + leak + tail + deliv

Budget component, in inches per month

USGS
Surface water system budget: Outflows

Deliveries

\[ \text{div + ppt} = \text{et} + \text{leak} + \text{tail} + \text{deliv} \]
Soil water budget

(modified from Faunt, 2009)
Soil water budget

\[
\text{In} - \text{Out} = \pm \Delta \text{Storage}
\]

\[
\text{In} = \text{Out}
\]

- Surface water irrigation (deliv)
- Precipitation (ppt)
- From soil moisture (soil)
- Groundwater irrigation (gw)

- Evapotranspiration (et)
- To soil moisture (soil)
- Infiltration (infil)

\[
deliv + ppt + gw + soil = et + soil + infil
\]
Soil water budget: Inflows

Surface water irrigation (deliveries)

\[ \text{deliv} + \text{ppt} + \text{gw} + \text{soil} = \text{et} + \text{infil} + \text{soil} \]
Soil water budget:
Inflows

Precipitation

deliv + ppt + gw + soil = et + infil + soil
Soil water budget: 

**Inflows**

\[ \text{deliv} + \text{ppt} + \text{gw} + \text{soil} = \text{et} + \text{infil} + \text{soil} \]

![Graph showing the budget components](image-url)
Soil water budget: Inflows

Soil moisture storage decrease

\[ \text{deliv} + \text{ppt} + \text{gw} + \text{soil} = \text{et} + \text{infil} + \text{soil} \]

Wait…
Soil water budget: Inflows

Groundwater irrigation

\[ \text{deliv} + \text{ppt} + \text{gw} + \text{soil} = \text{et} + \text{infil} + \text{soil} \]

Wait…
Soil water budget:
Outflows

Evapotranspiration

deliv + ppt + gw + soil = et + infil + soil
Soil water budget:
Outflows

Evapotranspiration

\[ \text{deliv} + \text{ppt} + \text{gw} + \text{soil} = \text{et} + \text{infil} + \text{soil} \]
Soil water budget:
Outflows

Evapotranspiration

\[ \text{deliv} + \text{ppt} + \text{gw} + \text{soil} = \text{et} + \text{infil} + \text{soil} \]
Soil water budget: Outflows

Deep percolation of irrigation water

\[
\text{deliv} + \text{ppt} + \text{gw} + \text{soil} = \text{et} + \text{infil} + \text{soil}
\]
Soil water budget:

Outflows

Soil moisture storage increase

\[ \text{deliv} + \text{ppt} + \text{gw} + \text{soil} = \text{et} + \text{infil} + \text{soil} \]

Wait…
Soil water budget: Remainder

Assuming no soil moisture storage

\[
deliv + ppt + gw + \text{soil} = et + \text{infil} + \text{soil}
\]
\[
deliv + ppt + gw = et + \text{infil}
\]
\[
gw = et + \text{infil} - \text{deliv} - ppt
\]
Soil water budget: Remainder

Assuming no soil moisture storage
Soil water budget: Remainder

Assuming no soil moisture storage

if $et + infil > ppt + deliv$:
Remainder = groundwater

if $et + infil < ppt + deliv$:
Remainder = infiltration

$et + infil - ppt - deliv$
Soil water budget: Remainder

Carrying over available soil moisture from winter to March

If $\text{et} + \text{infil} > \text{ppt} + \text{deliv}$:
Remainder = groundwater

If $\text{et} + \text{infil} < \text{ppt} + \text{deliv}$:
Remainder = infiltration
<table>
<thead>
<tr>
<th>Quantity</th>
<th>Source</th>
<th>Estimation Method</th>
<th>Adjustable Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW Diversion</td>
<td>Data</td>
<td>Watermaster</td>
<td>No</td>
</tr>
<tr>
<td>Canal precipitation</td>
<td>Assumption</td>
<td>= 0</td>
<td>No</td>
</tr>
<tr>
<td>Canal evapotranspiration</td>
<td>Data</td>
<td>METRIC</td>
<td>No</td>
</tr>
<tr>
<td>Canal leakage</td>
<td>Assumption</td>
<td>% diversion</td>
<td>Yes</td>
</tr>
<tr>
<td>Tail water</td>
<td>Data / estimate</td>
<td>???</td>
<td>No</td>
</tr>
<tr>
<td>Delivered water</td>
<td>Budget residual</td>
<td>Budget residual</td>
<td>No</td>
</tr>
<tr>
<td>Field precipitation</td>
<td>Data</td>
<td>PRISM dataset</td>
<td>No</td>
</tr>
<tr>
<td>Deep percolation of irrigation water</td>
<td>Assumption</td>
<td>% ET + excess supply</td>
<td>Yes</td>
</tr>
<tr>
<td>To and from soil</td>
<td>Assumption</td>
<td>Carry excess ppt to meet March ET</td>
<td>No</td>
</tr>
<tr>
<td>Field evapotranspiration</td>
<td>Data</td>
<td>METRIC</td>
<td>No</td>
</tr>
<tr>
<td>Groundwater deliveries</td>
<td>Budget residual</td>
<td>Budget residual</td>
<td>No</td>
</tr>
</tbody>
</table>
Spatial distribution
Deep percolation of irrigation (incidental recharge)

Distribute proportional to district ET
- Varies monthly
Deep percolation of irrigation (incidental recharge)

Distribute proportional to district ET
- Varies monthly
Deep percolation of irrigation (incidental recharge)

Distribute proportional to district ET
- Varies monthly
Deep percolation of irrigation (incidental recharge)

Distribute proportional to district ET
- Varies monthly
Deep percolation of irrigation (incidental recharge)

Distribute proportional to district ET
- Varies monthly
Deep percolation of irrigation (incidental recharge)

April ET
Deep percolation of irrigation (incidental recharge)

June ET
Deep percolation of irrigation (incidental recharge)

September ET
Deep percolation of irrigation (incidental recharge)

Irrigated Area
Deep percolation of irrigation (incidental recharge)

Area Proportion
Canal leakage

Proportional to district irrigated area
- Will change with each land use dataset

OR

Proportional to district major canal length
- Invariant
Canal leakage

Proportional to district irrigated area
- Will change with each land use dataset

OR

Proportional to district major canal length
- Invariant
Deep percolation of irrigation (incidental recharge)

Distribute proportional to district ET
- Varies monthly
Canal leakage

Proportional to district irrigated area
- Will change with each land use dataset

OR

Proportional to district major canal length
- Invariant
Canal leakage

Proportional to district irrigated area
- Will change with each land use dataset

OR

Proportional to district major canal length
- Invariant
Pumping distribution: measured
Pumping distribution: unmeasured

Areal distribution of wells
Pumping distribution: unmeasured

Distribution of pumping in row, column
Pumping distribution: unmeasured

Vertical distribution (row, column, layer)

- One representative pumping well in each cell based upon nearby well logs
- Not all well logs checked

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1.5</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5.5</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>3.5</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Pumping distribution: unmeasured
Vertical distribution: Layer 1
Pumping distribution: unmeasured

Vertical distribution: Layer 2
Pumping distribution: unmeasured

Vertical distribution: Layer 3
Pumping distribution: unmeasured
Vertical distribution: Layer 4
Pumping distribution: unmeasured

Vertical distribution: Layer 5
Pumping by Layer

Proportional to transmissivity

\[ Q_{j,i,k} = \frac{T_{j,i,k}}{\sum_{k=1}^{NL} T_{j,i,k}} Q_{TOT} \]

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>0</th>
<th>4</th>
<th>10</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow (m³/day)</td>
<td>1.5</td>
<td>5.5</td>
<td>5</td>
<td>3.5</td>
</tr>
<tr>
<td>Layer</td>
<td>3</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Summary
<table>
<thead>
<tr>
<th>Flux</th>
<th>Adjustable Parameters Affecting Volume</th>
<th>Spatial Distribution</th>
<th>Adjustable Parameters Affecting Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canal Leakage</td>
<td>Leakage factor (proportion of SW delivery to district)</td>
<td>Proportional to area or canal length</td>
<td>-</td>
</tr>
<tr>
<td>Deep percolation of irrigation</td>
<td>Percolation factor (proportion of district ET)</td>
<td>Proportional to ET</td>
<td>-</td>
</tr>
<tr>
<td>Groundwater pumping (row, col)</td>
<td>Leakage factor, percolation factor</td>
<td>Proportional to GW right</td>
<td>-</td>
</tr>
<tr>
<td>Groundwater pumping (layer)</td>
<td>&quot;&quot;</td>
<td>Proportional to layer screen length * cell hydraulic conductivity</td>
<td>Hydraulic conductivity (horizontal)</td>
</tr>
</tbody>
</table>
Thanks for listening!