Simulation of Groundwater Conditions in the Upper San Pedro Basin for the Evaluation of Alternative Futures

by

Tomas Charles Goode
and
Thomas Maddock III

Alternative Futures Study

- Explores how urban growth and change in the rapidly developing Upper San Pedro Basin might influence the hydrology and biodiversity of the area

- Alternative Futures study conducted by Department of Defense, Desert Research Institute, Harvard Graduate School of Design, IMADSES, and The University of Arizona

- Evaluation of individual scenarios from the present time (1997-2000) to 20 years in the future (2020)

- Provides information to stakeholders in the area regarding issues and planning choices, and their possible consequences

The hydrological component of the study presented here stands alone, and impacts to the hydrologic system are evaluated in their own context

Location of Study Area

- [Map of the study area]

- [Legend and scale for the map]
Model Creation

- Modeling Methods
- Boundaries and Layering
- Mountain Front Recharge
- Agricultural Recharge
- Evapotranspiration
- Streams and Diversions
- Well Pumping

Modeling Methods

- **Conceptual model Geographic Information System (GIS)**
  - ArcView used to view and create point, line, and polygonal shapes (coverages)
  - Shapes linked to attribute information contained in a database format (topology)
  - Points, arcs, and polygons represent map features within a coverage
  - All shapes conform to Universal Transverse Mercator (UTM) coordinate system using North American Datum (NAD) 1927
- **Numerical model infused the conceptual model into a finite difference grid using Department of Defense Groundwater Modeling System (GMS)**
  - GMS interface between GIS applications and hydrologic computer models including MODFLOW and others
  - GMS assists in conceptual model creation, mesh and grid generation, geostatistics, and post-processing
  - GMS automates grid construction, facilitates generation of head contours, and allows model representation in real-world coordinates

Upper San Pedro Basin Geology
Layer Properties

- **Layer 1**
  - Large areas which have a steeper than 3.0 degree slope
  - $K$ ranges from 0.03 to nearly 4.0 m/day
  - Specific yield of the upper basin fill were given the constant value 0.08
  - Storage coefficient of 0.0001

- **Layer 2 & 3**
  - Constant floodplain thickness of 35 meters
  - Bottom of Layer 2 extends out from bottom edge of floodplain
  - $K$ ranges from 0.1 to over 10 m/day for upper basin fill; floodplain given constant 50 m/day
  - Specific yield of the floodplain basin fill were given the constant values of 0.15 and 0.08
  - Bottom of Layer 3 is 305 meters (1000 feet) below surface elevation

- **Layer 4**
  - $T$ ranges from 46.45 to 418.06 m²/day ($K$ of 0.1524 m/day)
  - Bottom elevation extends to below 2500 meters (8200 feet) below surface elevation in central portion of basin
Numerical Model Grid (MODFLOW)

Mountain Front Recharge

Mountain Front Recharge Basins and Cells

Evapotranspiration
Riparian Vegetation Polygons and Evapotranspiration Cells

Evapotranspiration Rates
Mesquite Bosque = $1.027 \times 10^{-3}$ m/day
Cottonwood/Willow = $2.074 \times 10^{-3}$ m/day
Mix Cottonwood-Willow-Mesquite Bosque = $1.551 \times 10^{-3}$ m/day

Agricultural Recharge

Agricultural and Riparian Areas

Agricultural Lands, Irrigation Wells, and Agricultural Recharge Cells
Streams and Diversions in the Upper San Pedro Basin

Well Selection

- Well Registry 1980-1997
- GWSI 1940-1979
- Water Use Type
  - Public Supply, Irrigation, Domestic, Stock, Industrial, Commercial, Institutional
- Unknown/Unused Wells
  - Unused wells within 1000m of the floodplain, having greater than or equal to 100 gallon per minute (gpm) test pumping rate were considered irrigation wells
  - Unused wells with less that 100 gpm test pumping rate were considered domestic wells outside of the floodplain
  - All other unused wells with no associated test pumping rate were assigned as domestic wells
  - Unknown wells within the floodplain are considered irrigation wells
  - All other unknown wells are considered domestic wells
- Mexican Wells
  - Observation wells removed
  - Unknown wells assumed to be domestic
  - All known wells belong to Cananea mine
### Final Wells

![Map of final wells](image)

### Stress Periods

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<th>Years</th>
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<td>23</td>
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### Distribution of Pumping by Type

![Graph of pumping by type](image)

- **Mexican Industrial**
- **Mexican Domestic**
- **U.S. Public Supply**
- **U.S. Irrigation**
- **U.S. Domestic**
- **U.S. Military**
- **U.S. Stock**
- **U.S. Industrial, Commercial and Institutional**

### Calibration and Sensitivity

- [Alternative Futures](#)
Steady State and Transient Streamflow Calibration Results

### Baseflows Estimated by Previous Studies (cfs) (Vionnet, 1992 and Jahnke, 1994)

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<tr>
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### Model Computed Baseflows (cfs)

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Steady State Water Level Calibration Results

The Mean Error: 0.50
Mean Absolute Error: 9.92
Root Mean Square Error: 15.43

Well Locations with Pre-1960 Water Level Measurements

Well Locations with 1990 Water Level Measurements
Transient Water Level Calibration Results

The Mean Error: -8.49
Mean Absolute Error: 15.14
Root Mean Square Error: 22.76

Sensitivity Analysis:
Streambed Conductance

Sensitivity Analysis:
Floodplain Vertical Conductance

Final Results and Analysis
Population increase in Arizona should be one half greater than forecast -- 2020 population is 111,500
Fort Huachuca remains open and doubles its current resident population
Domestic water consumption public/company sources should remain at 1995 levels (60 gallons per day) and consumption from individually owned sources should also remain at 1995 levels (125 gallons per day)
An INA should be established within the Upper San Pedro Basin; all existing irrigated agriculture remains, but proposed irrigated agriculture within 1 mile of the San Pedro River is prohibited
Ranching in the Upper San Pedro Basin should continue at its present intensity and locations
Areas along the San Pedro River to the south that are not protected as part of the SPRNCA should be purchased for conservation purposes
The population of Cananea, Sonora doubles
Mining activity in Cananea, Sonora doubles
Sonora’s conservation areas remain unchanged
**Alternative Futures’ Constrained 2 Scenario**

- Population increase in Arizona should be one half less than forecast -- 2020 population is 78,500
- 90% of new population lives in Urban and 10% in Ex-Urban homes
- Fort Huachuca closes, Training Area managed for conservation
- Domestic water consumption public/company sources is decreased by 20% from 1995 levels (48 gallons per day) and consumption from individually owned sources should also be reduced 20% from 1995 levels (100 gallons per day)
- All irrigated agriculture in the Upper San Pedro Basin is removed
- Approximately half of the Cottonwood, willow and upland mesquite trees should be removed by the clearing of selected areas and that land managed to maintain a grassland ecosystem
- Areas along the San Pedro River that are not protected as part of the SPRNCA between Cascabel and the Mexican border should be purchased for conservation purposes
- Mexico should establish an extension of the SPRNCA in Sonora; conserved habitat should extend to the town of Jose Maria Morelos, Mexico

**Mass Balance Flux Components for Present and Future Scenarios**

<table>
<thead>
<tr>
<th></th>
<th>1940</th>
<th>1997-2000</th>
<th>Open 2 2020</th>
<th>Constrained 2 2020</th>
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<td>Total Pumping</td>
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**Drawdown Under Open 2 Scenario**

**Drawdown Under Constrained 2 Scenario**
Conclusions

- **Reduction of streamflow in the San Pedro River System**
  - 20 percent of the water pumped in the Upper San Pedro Basin in 1997 was taken from the San Pedro River System.
  - Baseflow is absent in many reaches near Benson in 1997.
  - The model indicates that the flow Charleston area in 1997, has been reduced by more than 30% since 1940.

- **Reduction of evapotranspiration by riparian vegetation along the floodplain of the San Pedro River**
  - Water levels show some recovery in the SPRNCA by 1997.
  - Over 15% of the water pumped in 1997 was taken from evapotranspiration, and thus from the riparian vegetation.

- **The formation of significant cones of depression near many communities**
  - Cone in excess of 25 meters beneath Sierra Vista, Arizona in 1997.
  - Cone in excess of 40 meters near Cananea, Sonora in 1997.
  - Smaller cones near St. David, Benson, and Naco.

- **Large losses of groundwater storage**
  - Over 65% of the water pumped in 1997 was taken from storage.