Alternative Futures

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

by

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and

Thomas Maddock III

Evaluation of Alternative Futures Study conducted by IMADSES, and the University of Arizona Institute, Harvard Graduate School of Design, Department of Defense, Desert Research

Alternatives Futures Study conducted by area

Influence the hydrology and biodiversity of the rapidly developing Upper San Pedro Basin mitigate

Explores how urban growth and change in the

Alternative Futures Study
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Explores how urban growth and change in the rapidly developing Upper San Pedro Basin might influence the hydrology and biodiversity of the area. The Alternative Futures study was conducted by the Department of Defense, Desert Research Institute, IMADSES, and The University of Arizona. It evaluates individual scenarios from the present time (1997-2000) to 20 years in the future. This provides stakeholders in the area with information regarding issues and planning choices, and their possible consequences.

Location of Study Area

- Influence the hydrology and biodiversity of the rapidly developing Upper San Pedro Basin might influence the hydrology and biodiversity of the area.
Model Creation

Well Pumping

Streams and Diversion

Evapotranspiration

Agricultural Recharge

Mountain Front Recharge

Boundaries and Layering

Modeling Methods
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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
- All shapes conform to Universal Transverse Mercator (UTM) coordinate system
- Points, arcs, and polygons represent map features
- Shapes linked to attribute information contained in a database format
- ArcView used to view and create point, line, and polygonal shapes

Numerical model
Infused the conceptual model

- GMS automates grid construction, mesh, and mesh and post-processing
- GMS assists in conceptual model creation, mesh and post-processing
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GMS interface between GIS applications and hydrologic computer models including MODFLOW

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Defuse Groundwater Modeling System (GMS)

American Datum (NAD) 1927

Upper San Pedro Basin Geology

Conceptual model Geographic Information System (GIS)
San Pedro Basin

Conceptualized Cross Section of the Upper San Pedro Basin

Hillshade of Upper San Pedro Basin
Layer Properties

Layer 1
- Large areas which have a steeper than 3.0 degree slope
- Bottom elevation extends to below 2500 meters (8200 feet) below surface elevation in central portion
- K ranges from 46.45 to 18.06 m²/day, K of 0.1524
- Specific yield of the upper basin fill were given the constant value 0.08
- Storage coefficient of 0.0001
- Bottom of Layer 1 extends 305 meters (1000 feet) below surface elevation

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

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
- Specific yield of the upper basin fill were given the constant value 0.08
- Storage coefficient of 0.0001
- Layer 4
Evapotranspiration

Mountain Front Recharge Basins and Cells
Evapotranspiration Rates

- Mesquite Bosque = 1.027x10^{-3} m/day
- Cottonwood/Willow = 2.074x10^{-3} m/day

Mix Cottonwood-Willow-Mesquite Bosque = 1.551x10^{-3} m/day

Agricultural Recharge

Riparian Vegetation Polygons and Evapotranspiration Cells
Alternative Futures

Agricultural and Riparian Areas

Agricultural Recharge Cells
Agricultural Lands, Irrigation Wells, and Agricultural Recharge Cells

Agricultural and Riparian Areas
Streams and Diversions in the Upper San Pedro Basin
Well Selection

- All known wells belong to Cananea mine
- Unknown wells assumed to be domestic
- Observation wells removed

Mexican Wells

- All other unknown wells are considered domestic
- Irrigation wells within the floodplain are considered
- Unused/irrigation wells were assigned as domestic wells
- All other unused wells with no associated test pumping rate were considered domestic wells outside of the
  floodplain

- Unused wells with less than 100 gpm test pumping rate
- Unused wells within 1000m of the floodplain having
  less pumping rate were considered irrigation wells
- Irrigation wells with greater than or equal to 100 gpm (gpm) test pumping rate

- All known wells belong to Cananea mine

Water Use Type

- Public Supply
- Irrigation
- Domestic
- Stock
- Industrial

GWSI:
- 1940-1979
- 1980-1997
- 1998-2003
### Stress Periods

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### Final Wells

![Map of Final Wells](image.png)
Calibration and Sensitivity

Distribution of Pumping by Type
### Steady State and Transient Streamflow Calibration Results

#### Baseflows Estimated by Previous Studies (cfs)

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#### Model Computed Baseflows (cfs)

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### Well Locations with Pre-1960 Water Level Measurements

- Palominas
- Charleston
- The Narrows
- Redington

*Well Locations with Pre-1960 Water Level Measurements*

### Alternate Futures

- Region
- Narrows
- Charleston
- Palominas

*Well Locations Estimated by Previous Studies (cfs) (Vionnet, 1992 and Jahnke, 1994)*
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 1990 Water Level Measurements

1990 Water Level, Model Boundaries

Residuals (m)

Graphs showing observed and computed heads (meters above msl) with residuals.
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

Stream Gage Location
Palominas Charleston The Narrows Redington

Error Type
Head Error (meters)
Calibrated Error

Mean Error
Mean Absolute Error
Root Mean Square Error
Final Results and Analysis

Floodplain Vertical Conductance

Sensitivity Analysis:

Stream Gage Location

Stream Flow (cfs)

Calibrated Flow (cfs)

VC x 0.01

VC x 0.1

VC x 10

VC x 100

VC x 1000

Error Type

Head Error (meters)

Mean Error

Mean Absolute Error

Root Mean Square Error
Simulated Steady State Water Levels

Dewatering and Cones of Depression
Population increase in Arizona should be one half greater than forecast -- 2020 population is 11,111,500.

Fort Huachuca remains open and doubles its current population. Mining activity in Cananea, Sonora doubles.

The population of Cananea, Sonora doubles.

An INA should be established within the Upper San Pedro Basin; all existing irrigated agriculture and proposed irrigated agriculture within 1 mile of the San Pedro River is prohibited.

Areas along the San Pedro River to the south that are not protected as part of the SPNCA should be purchased for conservation purposes.

Domestic water consumption from public/company sources should remain at 1995 levels (60 gallons per day) and from individually owned sources should remain at 1995 levels (125 gallons per day).

Ranching in the Upper San Pedro Basin should continue at its present intensity and locations.

Sonora’s conservation areas remain unchanged.

Mining activity in Cananea, Sonora doubles.

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Ranching in the Upper San Pedro Basin should continue at its present intensity and locations.

Sonora’s conservation areas remain unchanged.
Population increase in Arizona should be one half less that 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 purposes.

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) to maintain a sustainable ecosystem.

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 Casas del Zorro and the Mexican border should be purchased for conservation purposes.

Mexico should establish an extension of the SPRNCA in Sonora, conserve habitat, and establish an extension of the SPRNCA in Sonora, conserve habitat. Mexico should establish an extension of the SPRNCA in Sonora, conserve habitat, and the Mexican government should purchase land for conservation purposes.

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Conclusions
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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, and Naco, Arizona in 1997.
- Water levels show some recovery in the SPRNCA by 1997.

Formation of significant cones of depression near many communities

- Cone in excess of 40 meters near Cananea, Sonora in 1997.
- Cone in excess of 25 meters beneath Sierra Vista.

Large losses of groundwater storage

- Over 65% of the water pumped in 1997 was taken from evapotranspiration, and thus from the riparian vegetation along the floodplain of the San Pedro River.
- Over 15% of the water pumped in 1997 was taken from evapotranspiration by riparian vegetation, and thus from the riparian vegetation along the floodplain of the San Pedro River.

The model indicates that the flow characteristic area in the San Pedro Basin in 1997 was taken from 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.