1. Modeling framework for water resources management under uncertain conditions

NOAA Climate and Societal Interactions Sectoral Applications Research Program
Water Resource Management
WRRC - HRC

Eylon Shamir, Eshamir@hrc-lab.org
Hydrologic Research Center
12555 High Bluff Drive suite 255
San Diego, CA 92130
Tel: (858) 461 4560
www.hrc-web.org
The Hydrologic Research Center is a public benefit nonprofit organization.

HRC’s goal is to help bridge the gap between scientific research and applications for the solution of important societal problems that involve water.
Definition Uncertainty

Uncertainty: The lack of certainty, a state of having limited knowledge where it is impossible to exactly describe the existing state, a future outcome, or more than one possible outcome.

http://www.cartoonsbyjosh.com/uncertainty.html
Input - Output of the Micro-basins

Groundwater level

Streamflow
Climate dependent
IN

Withdrawal
Human Dependent
OUT

Erwin, ADWR, Modeling report No 15
Seasonal Precipitation & Streamflow complications for future planning.
Summer-Winter Streamflow Hydrographs

**Winter (1/4/95)**

**Summer (8/27/99)**

Days

Discharge (cfs)

Streamflow (cfs)

WINTER 1996

SUMMER 1996
Trends in summer (July-Aug) flow

Rain Count: Slope = -0.11 (event/yr)

Flow Count: Slope = -0.07 (Event/yr)

Rain Total Flow: Slope = -0.01 mm per Yr

Flow Summer Precipitations: Slope = -4.4 mm per Yr
Trends in summer (July-Aug) flow

Pool and Coes 1999 similar trend in Charleston gauge San Pedro

Objectives of NOAA (SARP) Project

1. Develop water resources decision support modeling framework that addresses future climate uncertainties

2. Increase stakeholders capacity to adapt water planning and management to future climate uncertainties

3. Establish transferability of the modeling approach and capacity building approach
HRC 2005 study
[Sponsored by AZDWR /SCAMA]

- Develop a method that produces likely future streamflow scenarios at the Nogales USGS Gauge site.

  - Develop a modeling system that represents the physical basin processes.
  - Generate an ensemble of likely future streamflow scenarios
  - Evaluate the future streamflow scenarios ensemble
A Proposed Modeling Framework

Model (machine) that represents the uncertainty in climate. Generates Ensemble of Likely Streamflow scenarios.

Risk Analysis

Threshold

Groundwater level

Chance to drop below the t-hold

Aquifer

Water withdrawal Historical/ Future Scenarios

Well

Threshold
Study Area & Modeling Scheme

\[ Q_2 = Q_1 - I_1 \]

- Santa Cruz River
- Buena Vista (2740 ac/ft)
- Kino Springs (4020 ac/ft)
- Highway 82 (5910 ac/ft)
- Guevavi (7950 ac/ft)
Simulation of Precipitation Vs. Streamflow

- **Precipitation (Pros)**
  - Better linked to climatic forcing and global circulation
  - Less affected by geomorphological changes and human activity in regional scale.
  - Independent of the basin antecedent condition

- **Precipitation (Cons)**
  - Point measurement rather than areal measurement that contributes to the flow.
  - Requires a model (additional uncertainty) to transform into streamflow
Hourly precipitation model components

- Winter Hourly Precipitation (Dec 68 - Feb 69)
- Summer Hourly Precipitation (Jul 69 - Aug 69)

Precipitation events
Precipitation clusters
Clusters inter-arrival time
Example: Rainfall Seasonal Categories

- **SUMMER**
  - Cumulative Distribution vs. Storms Total (mm/storm)
  - Trends for Dry, Medium, Wet categories

- **WINTER**
  - Cumulative Distribution vs. Storms Inter Arrival Time (Days)
  - Trends for Dry, Medium, Wet categories
Likely Rainfall Scenarios
Performance of 100 likely Realizations

Nogales Rain Gauge 1949-2010
Modeling Scheme

- Basin: Hourly rainfall Generator of likely scenarios
- Border Crossing: Daily streamflow model
- Micro basins: Groundwater Storage changes
- Long term assessment for various management schemes

- Raingauge data
- Mesoscale model
- Gauge Streamflow data
- Groundwater data
- Paleo reconstruction of Tree Ring
- Future climate scenarios from output of dynamically downscaled climate models
- AZDWR Groundwater Model
Example of Possible Results
Various water consumption scenarios

Median

Uncertainty Bounds

<table>
<thead>
<tr>
<th>Threshold 25% of the storage</th>
<th>Threshold 50% of the storage</th>
<th>Threshold 75% of the storage</th>
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</thead>
<tbody>
<tr>
<td>Buena Vista</td>
<td>Kino Springs</td>
<td>Hy 82</td>
</tr>
<tr>
<td>Guevavi</td>
<td></td>
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</tr>
</tbody>
</table>

Pumpage (% of reservoir capacity)

Buena Vista

Kino Springs

Hy 82

Guevavi

Pumpage (% of reservoir capacity)
Another Example: Risk for Consecutive monthly stress

Ensemble with 1000 realizations

Consecutive Months Below 50% (An arbitrary threshold)
Groundwater Level under different Pumpage Scenarios

FIGURE 4. Simulated Heads at Tumacacori for a Selected Realization (Realization #2)

Nelson, K. WATER RESOURCE RISK ANALYSIS MODELING IN THE SANTA CRUZ AMA, Arizona Department of Water Resources Arizona Hydrological Society 2009


http://www.hrc-lab.org/projects/dsp_projectSubPage.php?subpage=santacruz
2. Incorporating climate change information into the water resources management model

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Likely Precipitation Scenario Model

- Winter / Summer
- Wet
- Medium
- Dry

Inter-arrival time of clusters

Duration of clusters

Chance for hour rainfall

Hourly rainfall magnitude

Paleo Tree Ring Reconstruction
Annual/Seasonal Data

Climate model Scenario
Annual/seasonal to sub daily
Precipitation estimates from tree-rings

Winter

Reconstructed Nogales Winter PPT

Annual

Current record

Gaussian Smoothed

Precipitation

Meko 2005
Proxies Derived from Tree rings

Image Analysis Technique:

Several attempts have been made at using image-analysis techniques to provide a proxy measure of density.

You can see the difference between a light and a dense ring by eye.

Can this difference be measured using optical techniques?

See Campbell et al., 2011
Ensemble of 100 realizations using the tree ring reconstruction of precipitation
Future Climate

CLIMATE SUMMIT

WHAT IF IT'S A BIG HOAX AND WE CREATE A BETTER WORLD FOR NOTHING?

- ENERGY INDEPENDENCE
- PRESERVE RAINFORESTS
- SUSTAINABILITY
- GREEN JOBS
- LIVABLE CITIES
- RENEWABLES
- CLEAN WATER, AIR
- HEALTHY CHILDREN
- ETC. ETC.
Need for Downscaling:
GCM scales are about 100 - 150 km²
Sources of Downscaled Climate Precipitation Datasets Available for this Project

- Dynamically downscaled two climate models to 35 km2, 6-hour, 1950-2100, A1B emission scenario (Middle of the road):
  1. Hadley center (HADCM3)
  2. Max Plunk (MPLAECHEM)

- Data from NARRCAP: Multiple models at 50km2 at 3hour resolution 1970-2000 and 2040-2070

- Regional reanalysis 1950-2010 will be also available at 35km2, 6-hours
Likely Precipitation Scenario Model

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Fall / Spring
1. Compare downscaled model with observation record for the historical period

2. Compare Future and Historic climate model simulations
   - Storm arrival frequency
   - Duration of storms
   - Magnitude of rainfall events
   - Frequency of Wet/Medium/Dry for Winter/Summer

3. Modify the Synthetic model to represent the difference between Past and Future
Synthetic rainfall model modification based on downscaled Climate Model Projections

- Storm arrivals
- Duration of storms
- Magnitude of rainfall events
- Frequency of Wet/medium and Dry for Winter/Summer

Downscaled Climate Model

Historical Period

Local Observed Records

Synthetic Rainfall Generation Model for Historical Likely Scenarios

Future Period

Comparison between distributions

Synthetic Rainfall Generation Model for Future Likely Scenarios
### Kickoff
- Presentation of the available modeling framework developed at 2005
- Update and revise the modeling framework with newly available data
- Initial analysis of the downscaled climate model output and suggest method for integration
- Developing a suggested case study to be presented in the next workshop
- Understand stakeholders’ concerns and receive feedback

### Milestone
- Update and revise the modeling framework based on comments from the Kickoff Workshop
- Progress and development for implementation of climate scenarios in the modeling framework—articulate the climate effect on the region
- Presentation of results from the case study
- Recruit ideas for potential new candidate regions

### Capstone
- Presentation of the revised case study
- Final results conclusion and recommendation for future actions.
- Present initial analysis for candidate locations
Considerations for a Case Study

- Future water demand projections (dependence on climate variability?)
- What are appropriate performance metrics?
  - GW level Thresholds (a range)?
  - period of stress?
- Can we use this tool to inform the AWS regulation process?
“The storm start when the drop start dropping when the drop stop dropping then the storm starts stopping”

Dr. Suess
Steps to generate future likely streamflow scenarios

- Rain prediction over the basin
- Streamflow in the Santa Cruz
- Water demand of new developments
- Groundwater replenishment
- Economic and Social consequence for taking or not taking action
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