OUTLINE

1. Introduction
2. Climate Scenarios
3. Weather Generator
4. Surface Water
5. Discussion
1. Downscaled Climate Projections

2. Surface Water Modeling

3. Groundwater Modeling

Process Overview

Precipitation & Temperature

Weather Generator

SAC-SMA

RECHARGE

TAMA
**Worse:** Based on **RCP 8.5** DD data

**Dynamically Downscaled (DD):** WRF Weather Research and Forecasting Model
(https://www.mmm.ucar.edu/weather-research-and-forecasting-model)

**Best:** Based on **RCP 4.5** SD data

**Statistically Downscaled (SD):** LOCA Localized Constructed Analogs (http://loca.ucsd.edu/)

DD not available for RCP 4.5

\[ \text{Emissions Scenarios} \]
RCP 8.5
RCP 4.5

**RCP = Representative Concentration Pathways**
From CMIP5 climate model intercomparison
LOCA Best Practices and Limitations

For more information on the ensemble of LOCA projections and analysis over the LSCR basin, see the draft report titled: "Lower Santa Cruz River Basin Study LOCA-derived Hydroclimate Assessment."

- LOCA developers and user-community do not recommend using single projections for analysis.

- LOCA does not reflect the physics of the atmospheric patterns in the same way that dynamical downscaling does. Selecting a GCM that is well performing for a region does not guarantee that the processes for which it was selected are retained.

- Here, larger monsoon season precipitation events are not well represented in the LOCA MPI projections, while other projections may better reflect the magnitude of monsoon precipitation.

- The weather generator was built around a models ability to capture these seasonal and synoptic events.
**HISTORICAL**

Daily Precipitation

**Best:** Based on RCP 4.5 SD data

**Worse:** Based on RCP 8.5 DD data

*Note the importance of comparing within the same dataset.*
**Future Climate – Analysis Periods**

**Historical:** 1970-1999
- SAC-SMA calibration period
- Prior to 2006 start of GCM “Futures”

“**2030’s**” Future: 2020-2049
- Near future

“**2060’s**” Future: 2050-2079
- Far future
- Lower Santa Cruz study through 2060
- Aligns with Colorado River Basin Study analysis through 2060
Review of Climate Metrics

1. Extreme events: intensity and frequency, temperature and precipitation
2. Monsoon onset
3. Dry period onset
Monsoon Season

- Onset defined by the first of three days with a mean daily dewpoint temperature greater than a threshold.
- Demise is defined here as the day after the last three consecutive days above the dewpoint temperature threshold.
The dry season in Tucson is characterized by prolonged periods with low to no rainfall. The transition to this season typically occurs by the start of May and dry conditions persist until the start of the monsoon season.

Prolonged dry spells signified the transition out of the winter rains and into the dry season. Here, we used a two week dry spell, based on the historical SAC-SMA data and Tucson Airport weather station analysis.

Dry spell is consistent with the guidance of Michael Crimmins and uses a daily precipitation threshold of 0.01” to define events.

Additional constraints:
- Dry periods ending before May 1 cannot be considered the "dry foresummer" trigger
- Dry periods starting after June 15 cannot be considered the "dry foresummer" trigger
- May 1 dry period start enforced if metric failed to identify onset.
Future Climate
New Timing

*Note the importance of comparing within the same dataset.
Weather Generator Motivation

• Scale (spatial and temporal) that is relevant for local surface water modeling

• Natural precipitation variability is particularly important in this region. The weather generator is used to introduce variability around the broader climate projection trends.

• The resulting ensemble (large group) of likely rainfall timeseries represents a range of plausible amounts, daily patterns, and seasonality that will drive a resulting range of streamflows.
Precipitation Variability in the Tucson Area

Seasonal precipitation at the University of Arizona Campbell Road Farms, 1900 - 2000

Purpose: simulate plausible future weather possibilities based on climate projections for the Lower Santa Cruz River Basin

Validation data
- CBRFC’s SAC-SMA calibration dataset
- Categorized into three states (i.e. seasons)

Future climate scenarios
- Best case
  Near and Far Future
- Worse case
  Near and Far Future

Future time series of precipitation and temperature inputs to SAC-SMA surface water model.
Future Scenario 1: Daily Precipitation

Weather Generator Input Dataset

**Best:** Based on RCP 4.5 SD data

**Worse:** Based on RCP 8.5 DD data

*Note the variability of daily precipitation.

*Note the importance of comparing within the same dataset.

RECLAMATION
Future Scenario 2: Daily Precipitation

Weather Generator Input Dataset

Best: Based on RCP 4.5 SD data
Worse: Based on RCP 8.5 DD data

*Note the variability of daily precipitation.
*Note the importance of comparing within the same dataset.
FUTURE Seasonal Precipitation

Weather Generator Input Dataset

Best: Based on RCP 4.5 SD data
Worse: Based on RCP 8.5 DD data

*Note the variability of daily precipitation.
FUTURE Temperature

Weather Generator Input Dataset (Bias corrected)

Best: Based on RCP 4.5 SD data
Worse: Based on RCP 8.5 DD data
Surface Water Basin Configuration

- Lower Gila Basin
- San Pedro Basin
- Pinal County
- Pima County
- Santa Cruz Basin draining towards Phoenix
- SAC-SMA basins draining into Tucson Area
- Mexico

RECLAMATION
For each day of each scenario...

Daily Weather Generator

100 daily realizations

Maintains Input Spatial Patterns

To SAC-SMA
• A two-state Markov Model is defined to address wet and dry spells.
• Precipitation occurrence is defined as any daily precipitation greater than 0.01”.
• Transition probabilities are computed for each season (dry, monsoon, winter).
• This analysis is how the weather generator accounts for storm frequency by including the length of time between storm events.
Weather Generator Validation

SAC-SMA calibration dataset
Statistics presented by season.
Weather Generator Validation

SAC-SMA calibration dataset
Statistics presented by Julian day.
Validation Averages

SAC-SMA calibration dataset
Statistics presented by month.
Precipitation Seasonal Change – Basin Average

Weather Generator Output

Best: Based on RCP 4.5 SD data
Worse: Based on RCP 8.5 DD data
**Temperature Seasonal Change – Basin Average**

**Weather Generator Output**

**Best:** Based on RCP 4.5 SD data  
**Worse:** Based on RCP 8.5 DD data
Extreme Events
Top 10% of Daily Precipitation

Weather Generator Output
Extreme Events
Top 10% of Seasonal Max Temperature

Weather Generator Output

Extreme Seasonal Maximum Temperature - Best Case

Extreme Seasonal Maximum Temperature - Worse Case
Surface Water Model Refresher

• From: CBRFC’s SAC-SMA\textsuperscript{1} model
• Simulates basin runoff and soil moisture
• Spatially Lumped: based on mean basin inputs:
  – Precipitation,
  – Temperature,
  – Potential evapotranspiration (ET) and outputs:
    – runoff,
    – baseflow,
    – actual ET.
• Daily & Continuous: has memory of previous soil moisture in system.

1. Colorado Basin River Forecast Center – SACramento Soil Moisture Accounting
PET adjustment

- Sac-SMA requires monthly estimates of Potential Evapotranspiration (PET) for each elevation zone.

- PET was adjusted for each scenario by scaling the Sac-SMA calibration dataset values by the change in temperature between the historical and future periods.

Water Resources Research

The twenty-first century Colorado River hot drought and implications for the future

Bradley Udall, Jonathan Overpeck


'A hot drought': Warming is driving much of the Colorado River's decline, scientists say

Ian James, Arizona Republic  Published 10:54 a.m. MT Sept. 7, 2018 | Updated 1:48 p.m. MT Sept. 7, 2018
Surface Water Modeling Domain

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<thead>
<tr>
<th>Basin ID</th>
<th>Description</th>
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<tr>
<td>ACHA3</td>
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<tr>
<td>ATPA3</td>
<td>ALTAR WASH - NR THREE POINTS AZ</td>
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<tr>
<td>AVCA3</td>
<td>ARIVACA CRK AT ARIVACA AZ</td>
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<td>BWRA3</td>
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<td>BWTA3</td>
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<td>CDOA3</td>
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<td>SANTA CRUZ - TRICO RD AT MARANA NR</td>
</tr>
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Dry Season
Spatial Streamflow

Historical Flow
2030s Change
2060s Change

Best
Worse

Streamflow (ac-ft/season)

Fractional Change in Streamflow

-0.82 - -0.60
-0.60 - -0.30
-0.30 - 0.10
-0.10 - 0.10
0.10 - 0.30
0.30 - 1.00
1.00 - 10.00
Monsoon Season
Spatial Streamflow
Winter Season
Spatial Streamflow

Streamflow (ac-ft/season)

- 100 - 250
- 250 - 500
- 500 - 1000
- 1000 - 5000
- 5000 - 10000
- 10000 - 33400

Fractional Change in Streamflow

-0.60 - -0.40
-0.40 - -0.20
-0.20 - -0.10
-0.10 - 0.10
0.10 - 0.20
0.20 - 0.40
0.40 - 1.81
Streamflow Example

RILLITO CREEK AT LA CHOLLA BLVD

Average Seasonal Streamflow (ac-ft/season)

Best Case

Worse Case

RECLAMATION
Streamflow
No-Flow Days
Worse Case
Streamflow No-Flow Days
Worse Case for 2030s

2030's - Top 5 increase in dry days (#)

- Davidson Canyon (DAVA3) May 12
- Davidson Canyon (DAVA3) June 11
- Santa Cruz nr Nogales (SCNA3) April 10
- Santa Cruz nr Lochiel (SCLA3) April 10
- Sabino Creek (SBCA3) May 10
Streamflow
No-Flow Days
Worse Case for 2060s

2060's - Top 5 increase in dry days (#)

<table>
<thead>
<tr>
<th>Location</th>
<th>Month</th>
<th>Increase</th>
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<tr>
<td>Sabino Creek</td>
<td>May</td>
<td>10</td>
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<td>Sabino Creek</td>
<td>August</td>
<td>10</td>
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<td>Sabino Creek</td>
<td>April</td>
<td>9</td>
</tr>
<tr>
<td>Santa Cruz nr Lochiel</td>
<td>August</td>
<td>9</td>
</tr>
<tr>
<td>Santa Cruz nr Nogales</td>
<td>August</td>
<td>9</td>
</tr>
</tbody>
</table>

Historical Days

2030's Change
0-12 more no-flow days

2060's Change
-2-10 change in no-flow days
Next Steps

1. Develop recharge scenarios for groundwater modeling
2. Prepare input for Environmental Subteam’s riparian vegetation assessment
Summary

• Models and scenarios consistently identify increases in temperature, with larger increases in the worse scenario.

• The best case provides a scenario with relatively minimal change in seasonal precipitation; in the worse case scenario, total precipitation decreases in the monsoon and winter wet seasons.

• The number of no-flow days per month consistently increases in the worse case.
RECLAMATION

Managing Water in the West

Lindsay Beaurp
lbearup@usbr.gov
Didn’t use HD approach as previously discussed because of the character of extremes in the LSCR basin. The “tails” of the distribution were such that we felt it altered the signals from the DD models inappropriately.
Dry Spells

Tucson Airport

Number of Dry Spells
- Dec
- Nov
- Oct
- Sep
- Aug
- Jul
- Jun
- May
- Apr
- Mar
- Feb
- Jan

Length of Dry Spells

Wet
Dry
Monsoon

SAC-SMA

- Dec
- Nov
- Oct
- Sep
- Aug
- Jul
- Jun
- May
- Apr
- Mar
- Feb
- Jan

LOCA

- Dec
- Nov
- Oct
- Sep
- Aug
- Jul
- Jun
- May
- Apr
- Mar
- Feb
- Jan

WRF

- Dec
- Nov
- Oct
- Sep
- Aug
- Jul
- Jun
- May
- Apr
- Mar
- Feb
- Jan
Dry Season Onset

- Winter
- Wet
- Dry
- Monsoon

Bar charts showing the number of dry period start dates for SAC-SMA, LOCA, and WRF models. The dry threshold is set to 14 days.
New Timing for Future Climate

Days in each season by month

- SAC: SMA
- LOCA
- WRF

RECLAMATION
Extreme temperature changes most unique in monsoon.
What’s going on with LOCA mpi 4.5?

Seasonality based on incomplete information (Dewpoint not available for this projection)

While the resulting seasonality looks consistent with expectations, the July precipitation from the LOCA downscaled MPI 4.5 data is consistently low…
First: What’s going on with LOCA mpi 4.5?

July precipitation has a large number of small events and is missing larger events;

NO precip events in the monsoon season exceeds 0.8 inches! (sac-SMA is 2.3”)
Second: What’s going on with LOCA mpi 4.5?

Consistent with data averaged from LOCA grid directly. Highest July value is 0.9” on 7/23/1976 and goes down from there.

Random historical LOCA day of full grid shown here for reference.
Thirdly: What’s going on with LOCA mpi 4.5?

Although when summed to a monthly timescale the large number of small events adds up to reasonable precip…
Extreme Events
Bottom 10% of Seasonal Min Temperature

Weather Generator Output

Extreme Seasonal Minimum Temperature - Best Case

Extreme Seasonal Minimum Temperature - Worse Case