Modeling the Coupled Impacts of Climate and Land-Use Change on Groundwater Sustainability for Vulnerable Social and Ecological Coastal Communities

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Coupled Challenges to Groundwater Sustainability
Challenges for the Central Coast

- Climate change will alter precipitation patterns and increase temperatures → increased AET/PET & water demand

- Relatively undeveloped, and some areas experiencing rapid growth of vineyards

Neal Berg (in Langridge et al. 2018)
90% of regional water needs are supplied by groundwater

32% of subbasins are overdrafted (60% by area)
Coupled Challenges to Groundwater Sustainability

- Climate Change
- Land Use Change

Water Availability → Water Supply Conditions → Water Shortages → Community Vulnerability

Water Demand

Restrictions & Regulations
Climate Change Modeling

- Basin Characterization Model (BCM) v8
- Takes as inputs 10 global climate models’ precipitation and temperature variables
  - Ran two scenarios (RCP 4.5 & 8.5) to 2100
- Downscales these to 270 m
- Uses a physical hydrological model fit to historical streamflow, soil maps, etc., to partition precipitation into $AET/PET$, runoff, and recharge to aquifers

Flint & Flint 2014
Climate Change Impacts on Water Availability

For the Central Coast, **increasing variability and drought** will be the biggest challenge.

BCM shows slight increases in precipitation will slightly increase aquifer recharge in average water years (with substantial uncertainty).
Land Use Projections

- Land use is directly tied to water use, and likely to expand significantly in some areas
  - Both resources have limited availability that may increase conflicts

- Offer more than population projections
  - Conversions to/from crop types & urban areas
  - Land covers differ in their susceptibility to, and how they are impacted by, water shortages
  - Provide spatial pattern: areas and basins may differ in their social and ecological vulnerability
LUCAS Modeling Framework

- State-and-transition simulation modeling (STSM)
- Runs at 270 m resolution
- Sets “targets” for land cover change amounts
- Uses spatial multipliers to determine where land cover changes happen
- Estimates water demand per land cover class

Wilson et al. 2016
Wilson et al. 2017
Estimating Water Use

- Obtained per-cell water use of land cover classes in each county by dividing county-wide water use data by the class’ total area
  - Urban from USGS *Estimated Use of Water in the United States 2010*
  - Perennial & annual from CA DWR *Agricultural Land & Water Use Estimates* (mean 1989-2005)
“Business-As-Usual” model based on continuing recent trends
(1992-2016 rates from Farmland Mapping and Monitoring Program)

↑ Urban
↑ Perennial crops
↓ Annual crops
↓ Natural covers
Projected Annual Water Demand

- Urban +306,000 AF
- Annual -82,000 AF
- Perennial +149,000 AF
- Overall +373,000 AF

Wilson et al. in prep.
Percent Change in Water Demand per Basin
SGMA Will Transform This System

Climate Change

Land Use Change

Water Availability

Water Demand

Regulations

Water Supply Conditions

Water Shortages

Community Vulnerability

Water Mgmt. Rules, Plans, & Programs

Land Use Rules, Plans, & Programs
Assessing Adaptive Capacity with Stakeholder-driven Scenario Building

- Water use efficiency?
- Water imports, desalination, water recycling, etc.?
- Affordable housing initiatives?
- Focus on protected lands?
- Limits on agriculture?
Alternative Land Use Scenarios

SGMA plans can be operationalized into quantitative spatial land use change rules

“No new development if the basin reaches 85% of the available water supply” (Marina Coast Water District)

\[
\text{if } \text{water-demand} > 0.85 \times \text{supply} \\
\text{then } \text{development-probability} = 0
\]
Next Modeling Steps: Quantifying Feedbacks

Scenario-based water inputs

BCM

Climate Change

Land Use Change

LUCAS

Water Supply Conditions

Water Demand

Water Availability

Water Shortages

Community Vulnerability

2011 2100
Challenges for Region-scale Groundwater Security Projections

• Distributed-parameter groundwater flow models
  – Standard for assessing management options for individual aquifers
  – Physically based; can model complex water cycle interactions

• However, not well suited for regional modeling over multiple groundwater basins
  – Data-intensive, and many basins are data deficient
  – Prohibitive time and expertise requirements
Statistical Groundwater Modeling

- Butler et al. (2016) created a linear model of annual basin-wide average change in groundwater level (ΔWL) to estimate sustainable pumping
  - Assumed constant recharge & net inflow
- Miro & Famiglietti (2019) extended this to California
  - Fit two linear models for wet vs. dry years
  - Linked ΔWL to on-the-ground adverse impacts, as required by SGMA

\[ \Delta GWL = \frac{\text{net inflow}}{\text{area} \times S_s} + \frac{\text{recharge} - \text{pumping}}{\text{area} \times S_s} = b + a \times (\text{recharge} - \text{pumping}) \]
• Focusing on disadvantaged communities
  – SGMA requires GSAs to assess impacts of sustainability plans on these communities
  – Replicated Mack & Wrase (2017) model of projected water affordability, based on EPA recommendations

• Groundwater overdraft leads to falling water tables
  – Applying model of Pauloo et al. (2018) to estimate the number of domestic wells dried
• Focusing on groundwater-dependent ecosystems (GDEs)
  – SGMA requires GSAs to assess impacts to these springs, wetlands, & deep-rooted plant communities

• Support up to 90% of special status species within the Central Coast
  – 26 listed as threatened/endangered

• Falling water tables can dry habitats
  – Can extirpate populations of sensitive species, particularly during drought
% Change in water demand

Ecological sensitivity

Social sensitivity

Standardized & averaged

Hotspots of vulnerability to future groundwater shortages
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Wilson et al. (2017). Mediterranean California’s water use future under multiple scenarios of developed and agricultural land use change. PLOS ONE, 12, e0187181.