

**PROJECT TITLE**

Increasing Drought Resilience Under Climate Change: Assessing Costs and Benefits, Developing Tools and Analyzing Motivations to Develop Local Groundwater Drought Reserves

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**I. PRELIMINARY MATERIALS****A. Project Abstract**

A sufficient and reliable water supply is crucial. This project evaluates a key adaptation strategy to reduce the risk of water shortages associated with climate-related extreme drought events – the establishment of local groundwater drought reserves.

Our proposed adaptation differs significantly from current groundwater banking approaches that focus on seasonal and short-term storage, depend on increasingly less reliable imported water,

and utilize unsustainable energy-intensive transmission systems. This project will provide insights into the incentives needed to develop proactive strategies to increase drought resilience, and this model can be applied more widely in other regions where groundwater is a source of supply and where vulnerability to droughts and concomitant water shortages is high. This research project consists of three components:

- Identification of factors that motivate agencies and community members, in areas with long-term groundwater overdraft and significant conflicts over water, to reduce drought vulnerability through improved groundwater management and the development of a drought reserve;
- Analysis of the impacts of establishing and sustaining a local drought reserve versus a no-reserve option, and an outline of an integrated modeling approach to calculate financial costs and benefits;
- Development of web-based tools to assist local agencies and communities in calculating metrics to determine sustainable groundwater thresholds for a groundwater reserve.

Our study sites are areas of coastal California where groundwater is an important source of supply, imported water is either limited or not available and, importantly, where a potential reserve could be both located and used during a drought. Research will identify factors that influence the drought strategies of three regions confronting long-term groundwater overdraft, water quality issues and tensions over water management with the goal of providing insight into the conditions that can improve drought resilience. Two additional areas along the California coast, where groundwater is a source of supply and overdraft may be a future problem, will serve as prototypes for the economic analysis and tool development components of the project. Research will contribute to a greater understanding of how to reduce drought vulnerability, incentivize the establishment of local groundwater reserves as a proactive drought adaptation strategy, and encourage more sustainable management of this critical resource.

Our project aligns with NOAA's vision to: "create and sustain enhanced resilience in ecosystems, communities, and economies," and NOAA's NGSP plan to: inform science, service, and stewardship decisions and encourage sustained and reliable adaptation choices supported by a public that understands its vulnerabilities to a changing climate and makes informed decisions with respect to climate impacts on water resources. It supports NIDIS' goals to "move from a reactive to a more proactive approach to managing drought risks and impacts," and to provide information and analyses that will result in "better informed and more timely drought-related decisions leading to reduced impacts and costs." It addresses the SARP goal to "identify how non-structural approaches, including socioeconomic and institutional approaches to water resource management could increase adaptive capacity for managing climate risks."

## **B. Objectives and Approach**

Research relating to water resource utilization under climate change points to investment in local resource development as a way to reduce the risk of water shortages associated with drought. Our research builds on recent work by PI Langridge and team to identify factors that are significant in a region's approach to increasing drought resilience including developing local groundwater drought reserves. The broad objectives of this research are to investigate and evaluate:

- I. Factors that motivate regions with long-term groundwater declines and conflicts over water to reduce overdraft and increase drought resilience
- II. Impacts and financial costs and benefits of a groundwater drought reserve versus a no-reserve option
- III. Approaches to determine thresholds and other parameters for development of a reserve
- IV. Training of student researchers; development of sustainable groundwater information for non- technical audiences; participation in public events

Specific objectives are to provide:

### **I. An in-depth study of water management in the Pajaro Valley**

Illuminate the conditions that incentivize one region, the Pajaro Valley, where groundwater overdraft is ongoing and conflicts over water are significant, to improve management of this critical resource. This is an essential first step to increasing the region's capacity to adapt to drought and associated water shortages through the development of local drought reserves.

Research will consider not just agency issues but a wider range of stakeholder concerns. Three main types of qualitative data-collection activities will be used in this study: 1) secondary data sources; 2) individual semi-structured interviews; and 3) participant observation at community meetings and events. This research project entails a four-phased approach.

Phase One is a broad situation assessment utilizing secondary data sources such as organizational documents, litigation documents, and media sources to identify key issues around groundwater in the study area. Guiding research questions informed by the situation assessment will be drafted during this phase.

Phase Two involves identifying and categorizing groundwater stakeholders in the community with respect to decision-making influence and leverage, and developing interview questions. This phase includes semi-structured individual interviews and participant observation. Representative and chain-referral sampling strategies will be used to identify interviewees.

Phase Three begins analysis of factors that motivate communities to improve groundwater management and initiate proactive adaptation strategies to increase drought resilience through establishment of drought reserves and to identify areas of common ground which might reduce conflict. Qualitative data analysis of interviews and notes from community meetings and events will be analyzed using deductive and inductive approaches with the qualitative research analysis software NVivo 10.

Phase Four will involve meeting with stakeholders to discuss findings.

### **II. An assessment of the impacts, costs and benefits of establishing and sustaining a local groundwater reserve as compared to a no-reserve option**

Valuation will involve developing an economic profile and then assessing the impacts and costs of drought related water shortages. The intent is to inform policy decisions regarding the benefits

of local drought reserve development. Where feasible, existing agency modeling tools will be used to draw on analytical processes that are endorsed and already invested-in by agency personnel. Soquel Creek will serve as a municipal case study and the Pajaro Valley as an agricultural case study.

Additional considerations include:

- Who will be paying the cost and/or receiving the benefits and are their geographic distinctions including location and size?
- The groundwater level for a reserve that avoids overdraft impacts – saltwater intrusion in the case of Soquel Creek and Pajaro Valley - and allows for an additional reserve supply where drawdown during a drought will not trigger an overdraft impact.
- The size of the reserve utilizing a set of planning assumptions with respect to future local demand, supply; demand during droughts of specific duration and severity; and groundwater basin characteristics.
- Pumping costs – can be a function of pump efficiency, the cost of energy supplying the pump, the depth to the water table, the permeability of the aquifer, and wear and tear.
- Environmental costs, including the reduction or disappearance of base flows in streams and spring flows affecting freshwater and anadromous species, degeneration of wetlands, land subsidence and groundwater quality.
- Adaptivity - so when conditions change the model can be adjusted (e.g. for uncertainties including climate change and future energy costs).

### **III. Approaches to determine thresholds and other parameters for sustainable groundwater management and the development of a reserve**

Several different models, WEAP, MODFLOW and LCPSM (Least Cost Simulation Model), along with already existing agency models will be explored to simulate interactions between multiple water users and the effects of alternative policies, while tracking the impacts of changes in climate variables on the surface and groundwater hydrology. This data will help to inform thresholds and other parameters to both reduce groundwater overdraft and develop a reserve.

### **IV. Education activities**

Training of undergraduate and graduate student researchers; development of information and documentation for non-technical audiences; participation in public forums and other events

## **II. ACCOMPLISHMENTS**

### **A. General**

#### **Graduate Students**

- Two graduate students who worked a total of 6 quarters: Abigail Brown and Kirsten Rudestam,

#### **Research Team Meetings**

PI and two graduate students met 1-2 times a month for review and discussion of research. Additionally, we followed up on our Pajaro Summit (described below), contacting staff at the Pajaro Valley Groundwater Management Agency for further discussions.

Pajaro Summit: We had a major meeting on June 5, 2014 bringing together senior researchers and graduate students from our project and other projects to share information and to generate increased collaboration, both within academia and in the Pajaro Valley communities. Our goal is to come together to share our research with others and provide an interdisciplinary overview of the benefits/challenges related to managing groundwater in the valley, create a network for future possible co-collaboration, and contribute to meeting the diverse water needs of those living in the valley.

### **Website Development**

- Graduate student Brown moved the old Langridge Lab website to a new platform and performed website updates. <http://droughtreserves.ucsc.edu>.

### **Drought Research**

- Graduate students Brown and Rudestam and PI Langridge conducted a number of interviews with staff at California water districts to continue to assess responses to California's current drought.

## **B. Research Objective Activities**

### **I. In-Depth Pajaro Study**

#### **Proposed:**

- Factors that motivate regions with long-term groundwater declines and conflicts over water to reduce overdraft and increase drought resilience – In-depth case study of water management in the Pajaro Valley Region.

#### **Accomplished:**

##### *Research Goals and Questions:*

- Brown, Rudestam, Langridge and Crow updated goals, objectives, research questions, and a timeline for this component of the project.
- We further developed our history of water use and management in the region including media articles and continued to update media coverage of ongoing water issues in the region
- Brown continued to monitor the litigation over groundwater in the region.

##### *Interviews:*

- We continued to identify key stakeholders and added them to our Excel document for on-going tracking purposes.
- We continued to update the interview guide
- Brown and Rudestam continued to conduct interviews with stakeholders in Pajaro Valley, and transcribed all the interviews.

##### *Coding:*

- Brown and Rudestam outlined qualitative sampling methodology and coded their transcribed semi-structured individual interviews using inductive and deductive methods and the software: NVivo 10.

1. Primary deductive codes were developed and an inductive coding approach was utilized

after coding for primary deductive codes to illuminate two primary themes:

2. Decision-making about groundwater management in Pajaro Valley - who makes decisions and who is excluded, and the processes of decision-making?

Examples of sub-themes for coding include:

- How do people engage with shared resources through decision-making networks (e.g. institutions, informal agendas, campaigns, educational programs, or other)?
- What are the qualities of these networks – do they provide exclusion, trust, reciprocity, or rivalry?
- Community perceptions of, and spatial identity within, the groundwater basin, as these relate to groundwater decision-making in the Pajaro Valley?
- How do respondents define and understand themselves in terms of geographic place, with specific issues, and with each other?
- How do respondents understand their geographic place and define “local” (e.g. neighborhood, basin, region, other)?
- What is the geographic location of their water concerns (scale) (e.g. Pajaro basin, personal well, coastal issues, California, global)?
- Are there spatial issues that impact decision-making (e.g. upland issues versus coastal issues)?
- What are the principal concerns of people around shared resources (e.g. water quality, water quantity, saltwater intrusion, or other)?

Results of the analysis were compiled and utilized to 1) assess whether decision-making in the valley is inclusive and participatory and 2) whether perceptions realistically compare with the actual physical reality of the groundwater basin as generated by the Pajaro model described next.

#### *Articles for Publication:*

- We framed several potential journal articles, continued to update paper ideas, and outlined four research papers.
- We began extensive qualitative literature reviews.

Rudestam completed her paper: Rudestam, Kirsten, Ruth Langridge and Abigail Brown, 2015, “The Commons as a dynamic variable in understanding strategic alliances of scale: a groundwater case study in Pajaro Valley, California,” and submitted it to the Journal of Environmental Science and Policy in February 2015. It was accepted subject to revisions. These were completed and the paper was accepted for publication in early May. The final version was published online: 22-MAY-2015.

Brown completed her paper on collaborative groundwater governance and exclusion in groundwater decision-making: Brown Abigail, Ruth Langridge and Kirsten Rudestam, “Coming to the Table: A Critical Analysis of Collaborative Governance in Groundwater Decision-making in Coastal California,” and submitted it to the Journal of Environmental Planning and Management. The paper is pending.

Langridge completed her paper, “Langridge, Ruth, 2015,” Accounting for Climate Change and Drought in Implementing Sustainable Groundwater Management,” and submitted it to Groundwater. The paper is pending.

## **II. Economic Analysis**

### **Proposed:**

- Impacts and financial costs and benefits of a groundwater drought reserve versus a no-reserve option.
- Approaches to determine thresholds and other parameters for sustainable groundwater management and the development of a reserve.

### **Accomplished:**

Quinn led this component and continued to assess led several different potential models: WEAP, MODFLOW and LCPSM (Least Cost Simulation Model), along with already existing agency models. Our focus this year however was on the updated USGS model of Pajaro Valley Groundwater Basin (Hanson et al. 2014) that quantifies water availability and demand through the use of water budgets of all agricultural, urban and environmental uses. The budgets can be used to assess the impacts of system stressors such as climate change or changes in the allocation of water resources on the functioning of the current system including thresholds for management. The model can provide an analysis of uncertainty and sensitivity; it can provide flexibility to test policies, projects, remediation and adaptation, and it can serve as a vehicle for communication. Our intent is to utilize the model to translate simulation model outputs into a simplified conceptual model that stakeholders can understand, and provide this information to agricultural and urban stakeholders as well as agency staff to enable better informed decisions regarding the tradeoffs required to balance the needs of Pajaro communities with the long-term viability of the basin. We plan to continue work on this component during the summer.

## **III. Education and Training**

### **Proposed:**

Training of student researchers; development of information for non-technical audiences; participation in public events.

### **Accomplished:**

- Two graduate students working on the project. They outlined goals and objectives; wrote up extensive literature and media reviews; interviewed stakeholders; transcribed interviews, developed coding methodology; collected economic related data; developed a project website; and submitted articles for publication, one of which was already published journal articles for publication
- PI continued to participate extensively in government and university forums where she presented the team's research including:
  - Bay Delta Science Conference (BDSC), Sacramento CA., 2014, invited panelist, "Drought, Climate Science and Water Policy,"
  - Groundwater Resources Association, 2014, paper presentation "Accounting for Climate Change and Drought in Sustainable Groundwater Management

## **Publications and Citations for this project:**

### **Academic:**

Rudestam, Kirsten, Ruth Langridge and Abigail Brown, 2015, "The Commons as a dynamic variable in understanding strategic alliances of scale: a groundwater case study in Pajaro Valley, California," *Journal of Environmental Science and Policy*, (2015), pp. 33-40, DOI: 10.1016/j.envsci.2015.05.003

Rudestam, Kirsten and Ruth Langridge, 2014, "Sustainable Yield in Groundwater Management: Bridging Science and Mainstream Vernacular," *Ground Water* DOI: 10.1111/gwat.12160

### **Additional Citations on Climate Change, Water and Drought**

Lund, Jay, T. Harter, R. Gailey, G. Fogg, R. Frank, H. Dahlke, T. Ginn, S. Solis, T. Young, A. Fisher, R. Langridge, J. Viers, T. Harmon, P. Holden, A. Keller, M. Kiparsky, T. Greene, S. Mehl, J. Gurdak, S. Gorelick, R. Knight, 2015, "Creating effective groundwater sustainability plans," 2014, <http://californiawaterblog.com>

Fisher, A., G. Fogg, J. Viers, J. Lund, R. Langridge, P. Holder, 2013, "Groundwater and Climate Change in California, *GroundWaterBlog*, <http://californiawaterblog.com/2013/10/09/groundwater-and-climate-change-in-california/>

### **Media articles:**

Ivan Semeniuk, April 4, 2015, "From Bad to Worse," *Toronto Globe and Mail* <http://www.theglobeandmail.com/news/world/california-goes-from-bad-to-worse/article23778299/>

Gary Pitzer, "Overdrawn at the Bank: Managing California's Groundwater." January/February 2014, *Western Water*

Dan White, "Dry, dry again: UCSC researchers are confronting the challenges of consecutive dry years that have left California in the midst of a potential water crisis," 2014, *UC Santa Cruz Review*

Pamela Martineau, "State Food and Ag Board Examines California's Groundwater Challenges," 2014, *Groundwater All Water News*

Alec Rosenberg, "UC drought summit dives deep in state Capitol," 4/28/ 2014 *University of California Newsroom*

Elizabeth Case, "Drought summit examines California's water crisis," 4/25/2014, *The Davis Enterprise*

Maven's Minutes, "UC Drought Summit: State policy for future droughts," 2014,

<http://mavensnotebook.com/2014/05/22/uc-drought-summit-state-policy-for-future-droughts/>