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Link Foundation Energy Fellowship Report

1. Project Narrative

In the past two years since I was awarded the Link Energy Fellowship there have been a lot of significant developments, including the movement of my PhD advisor and our lab from Portland State University to the University of Colorado, Boulder; my graduation in June of this year from Portland State University; and my acceptance of a new (and exciting!) job opportunity with a company doing great work in the energy industry (details below). Another significant development is that the Household Air Pollution Intervention Network (HAPIN) Trial experienced significant delays between when the funding was first awarded by the National Institute of Health in 2016 and the implementation of project activities in the four country sites (Rwanda, Guatemala, India, and Peru). At the time of writing this report, our lab has been able to deploy sensors that are dynamically monitoring air quality and providing end-user feedback in fifty of the four hundred households participating in the HAPIN Trial. These sensors have collected baseline data to record household behavior prior to the distribution of natural gas cookstoves and are still in the process of recording post-intervention data to measure the impact of the cookstove distribution on household air quality. While I was able to contribute to the design and organization of the study protocol for the sensor study, I have also been able to work on additional projects through my involvement with the Sustainable Water, Energy, and Environmental Technologies Laboratory (SweetLab) that have contributed to my dissertation and several journal publications. I will focus on one of these projects in particular for this report.

Introduction: Increasing frequency and severity of drought is driving increased use of groundwater resources in arid regions of Northern Kenya, where approximately 2.5 million people depend on groundwater for personal use, livestock, and limited irrigation. As part of a broader effort to provide more sustainable water, sanitation, and hygiene services in the region, we have collected data related to site functionality and use for approximately 120 motorized boreholes across five counties. Using a multilevel model to account for geospatial and temporal clustering, we found that borehole sites, which counties had identified as strategic assets during drought, ran on average about 1.31 hours less per day compared to non-strategic borehole sites. As this finding was contrary to our hypothesis that strategic boreholes would exhibit greater use on average compared to non-strategic boreholes, we considered possible explanations for this discrepancy. We also used a coupled human and natural systems framework to explore how policies and program activities in a complex system depend on consistent and reliable feedback mechanisms (see Figure 1).

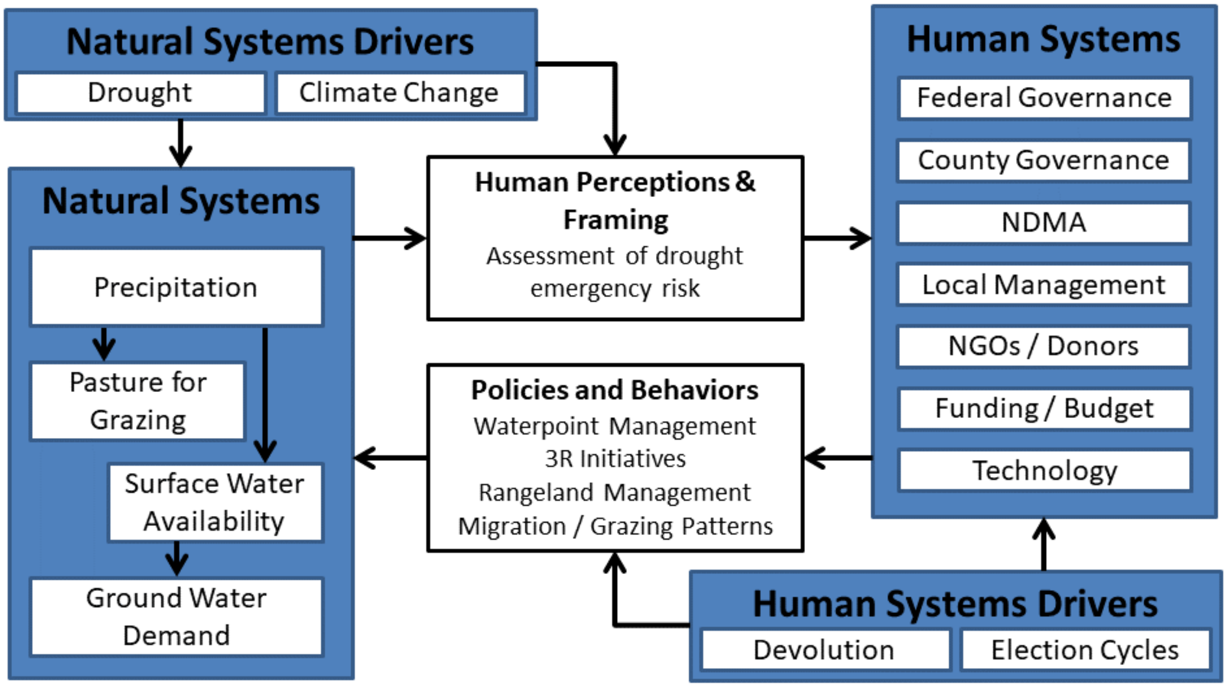

Figure 1: Coupled human and natural systems framework to model how perceptions, policies, and behaviors mediate the dynamic interactions between human and natural systems.

Results: As seen in Figure 2, water system use was strongly tied to precipitation, although the influence of precipitation on water system use varied considerably by county. In counties with greater variability in use such as Marsabit and Garissa, there was significant ramping behavior whereby groundwater demand would increase significantly during the dry season and then drop precipitously after rainfall events. In counties with more consistent water system use such as Turkana and Isiolo, there were more systems that were run for predictable intervals (e.g., 12- or 24-h intervals). As a result, water system use in these counties was more influenced by system functionality than precipitation events.

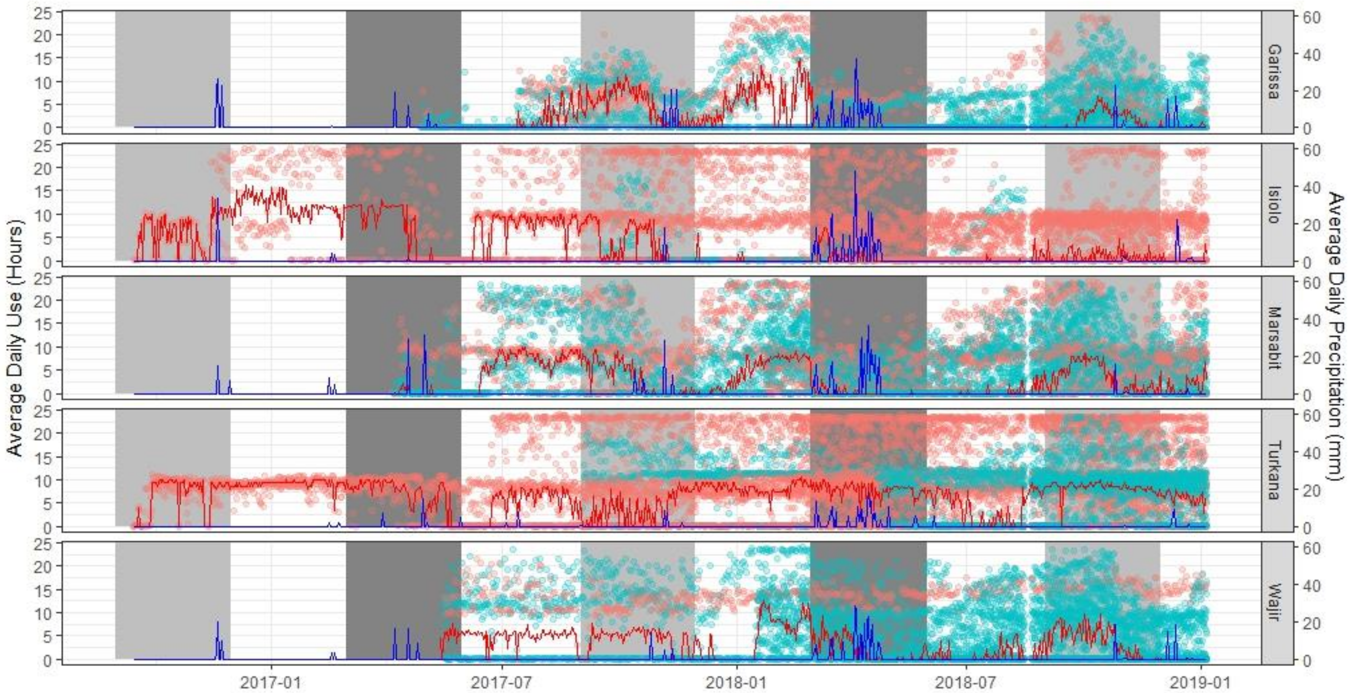

Figure 2: Left axis: average hours of daily water system use for each county from 2017 through 2018. The red line indicates average daily use across all boreholes for each county, whereas the blue and pink dots show the individual observations for strategic and non-strategic boreholes, respectively. Right axis: the blue line describes the average daily precipitation across all pump sites for each county. The dark grey region demarcates the primary rainy season (March through May) and the light grey region demarcates the secondary rainy season (September through November).

This investigation builds on previous studies that have shown how specialized institutions equipped with continuous monitoring technology can significantly improve the sustainability of water services in developing communities [18,26,32]. For example, Nagel et al. [26] conducted an experiment where functionality increased significantly (91%) while time to repair decreased (21 days) using sensor-informed maintenance compared to circuit-rider maintenance (73% functionality and 57 days to repair) or nominal maintenance methods (68% functionality and 152 days to repair). Similarly, Thomson et al. [32] used handpump sensors and a sensor-informed maintenance model to raise pump functionality to 98%, with 89% of repairs being completed within five days.

Although we found that the strategic boreholes that were monitored in this study were being used less than expected, it is possible that this discrepancy is due to a lack of demand for or utilization of improved water services. This investigation builds on a growing literature demonstrating how ground water demand varies significantly depending on precipitation events and the availability of surface water sources [22,28,35]. As outlined by Thomson et al. [35], the implications of fluctuating demand for basic water services are significant because previous studies have suggested that high adherence to safe water is necessary to realize sustained health benefits [36–39]. As discussed in Thomson et al., the apparent tendency of households to switch from improved to unimproved water sources based on surface water availability merits further investigation. Much like stove stacking with cookstoves [40], water source stacking challenges the assumption that keeping waterpoints functional will be sufficient to decrease the burden of disease from water-borne illnesses [35]. The apparent elasticity of demand also suggests that operation and maintenance be focused where and when demand is least elastic: during dry periods, in areas with limited surface water availability, or in areas where demand for clean water is already high.

Significance and Impact: Fostering resilience to drought emergencies is a complex task, and the effort to improve sustainable water services describes just one facet of a broader movement to build capacity and reduce vulnerability in Kenya's northern counties. However, sustainable water services have a disproportionate impact on the severity of drought disasters, as the inability to access safe or improved water services has ramifications that are felt rapidly and touch all other aspects of community life in rural regions [10]. While traditional drought strategies have focused on food supplies and getting humanitarian aid to the places where it is needed in a timely manner, recent strategies have shifted their focus to preventing drought emergencies by fostering resilience, building capacity, and developing early warning and rapid response systems to avoid the worst effects of drought emergencies: inter-communal conflict over scarce resources, the destruction of community assets, and the loss of human lives [7].

Much of this investigation focused on the unique role that meso-level institutions and initiatives can play in reducing the vulnerability of communities in arid regions to drought disasters. While we emphasized the value of using continuous waterpoint monitoring data to inform and mobilize support for the operation and maintenance activities of local county water offices, we acknowledge that water security cannot be reduced to waterpoint management. Given that these activities take place on a complex and adaptive ecological and social landscape, it will be important to explore how funding and resources for waterpoint management can be balanced with the other initiatives being undertaken by each county to increase drought resilience. Since all of these initiatives are tightly interlinked—for example, surface water catchments can increase surface water availability and groundwater recharge, and sustainable rangeland management can reduce the need for human and livestock migration—it will be important to consider whether the sum of these activities is greater than any of their individual contributions.

2. List of Scholarly Outcomes

Turman-Bryant, Nick, Corey Nagel, Lauren Stover, Christian Muragijimana, and Evan A. Thomas. "Improved Drought Resilience Through Continuous Water Service Monitoring and Specialized Institutions - A Longitudinal Analysis of Water Service Delivery Across Motorized Boreholes in Northern Kenya." *Sustainability*, 11(11), 3046. https://doi.org/10.3390/su11113046.

Turman-Bryant, Nick, Taylor Sharpe, Corey Nagel, Lauren Stover, Evan A. Thomas. "Toilet Alarms: A Novel Application of Latrine Sensors and Machine Learning for Optimizing Sanitation Services in Informal Settlements." *Development Engineering*. In review.

Turman-Bryant, Nick, Thomas F. Clasen, Kathryn Fankauser, Evan A. Thomas. (2018) "Measuring Progress Toward Sanitation and Hygiene Targets: A Critical Review of Monitoring Methodologies and Technologies." *Waterlines*, 37:3, pp. 229-247. http://dx.doi.org/10.3362/1756-3488.18-00008

3. Statement of how discretionary funds were spent.

The fellowship funds were applied toward living expenses over the past two years.

4. **How did the fellowship make a difference? Describe any ways that the direction of the Fellow's thesis, or the Fellow's professional development, was changed or impacted by virtue of receiving a Link Foundation Fellowship.**

The fellowship had a huge impact on my ability to focus on my research. While I was able to present at and participate in conferences and network within the field of basic household services (e.g., the Water and Health Conference at UNC Chapel Hill, the Joint Statistical Meeting in Vancouver B.C., and the ETHOS cookstove conference in Seattle), I was also able to make two significant field visits (once to Ethiopia and once to Kenya). I was also able to submit multiple dissertation chapters for publication while finishing my degree. The added flexibility provided by the fellowship funding also allowed me to explore in greater depth the appropriate methodologies for analyzing and deriving insights from the data generated by these projects. In particular, I was able to improve my coding ability in both R and Python over the past two years, as well as acquire a variety of data science and machine learning skills. This has had a significant impact on my professional development, as I have recently accepted an offer to work as a data scientist with ICF. Using the skills I have acquired over the past four years (thanks in large part to my work with the Sustainable Water, Energy, and Environmental Technologies lab that this fellowship enabled), I will be working with ICF's analytics studio and demand side analytics team to identify energy efficiency opportunities for electrical utilities, to coordinate the design and implementation of smart grid initiatives, and to explore how utilities can use sensor data to improve how information is collected and used to manage distributed generation resources being added to the grid.

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