TAILORING WATER SERVICES IN REMOTE AND ISOLATED INDIGENOUS AUSTRALIAN COMMUNITIES

by

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Executive Summary

Freshwater is an essential global resource, but climate change and human development have degraded the water quality and quantity. A large percentage of the global population is experiencing water stress from water scarcity leading governments and organizations around the globe to re-evaluate their water management plans. However, these plans do not always address the needs and concerns of Indigenous populations who face a variety of challenges stemming from historical disadvantages.

Indigenous Australians are one such group whose well-being is impacted by water stress and experiences issues with water services. In Australia, water demand has been increasing with population growth and socioeconomic development. This heightened demand has led to degradation of freshwater resources on the continent. Indigenous Australians living in remote and isolated communities experience specific issues with water service delivery and water resource management due to their geographic location, remoteness, and socioeconomic disadvantages.

Through quantitative and qualitative analysis, this study examined if certain water use drivers can be considered when water providers create and implement management plans to offer sustainable services to remote and isolated Indigenous communities. This report addressed three sub-questions:

1. What stated outdoor watering practices and technologies are associated with higher levels of outdoor water use?
2. Does residential water use decrease with behavioral and technological intervention?
3. Are high water users less concerned about water security? Do water use levels reflect an individual's belief of their water security?

Water use drivers were examined by analyzing household surveys, smart water meter readings, and follow up household interviews from three rural Indigenous Australian communities. Both quantitative and qualitative data was assessed. Water use was quantified through daily total water end-use per household, daily total water end-use per person, daily outdoor water end-use per household, and daily outdoor water end-use per person.

Statistical findings do not show significant overall patterning in drivers for water use either through behavior or technology. A trial of targeted demand water management including community education and local government water reduction commitments in one community appeared to have preliminary effects on household water use. Interestingly, concern about water security did not significantly impact water use. Throughout the analysis, community was a statistically significant indicator of household water end-use. More research needs to be done to gather baseline water use data in remote and isolated Indigenous Australian communities to identify water use drivers and better inform service provision. The findings in this report indicate that cultural, social, economic, and environment consideration of individual Indigenous Australian communities could aid service providers in sustainable water management through a targeted demand strategy tailored to communities.

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Table of Contents

1.0 – Introduction

1.1 – Background

Environmental solutions and the stakeholders involved in environmental policy decisions on an international, national, regional, and local level have been rapidly evolving over the past three decades due to an emphasis on co-benefits between improving environmental conditions and human conditions. Historically, environmental and conservation movements focused on advocacy for nature (Brosius et al., 1998). In 1980, during the World Conservation Strategy meeting, internationally recognized organizations reflected the growing connection between advocacy for nature and advocacy for human rights by combining conservation and human development as an approach to environmental solutions (Dove, 2006). This combination of environmental and social causes influenced the way many organizations and governments intertwine environmental protection and sustainability solutions. However, it was not apparent in the World Conservations Strategy meeting what type of human development would be included in conservation initiatives.

Indigenous populations can benefit from both conservation and human development initiatives, but are not always a part of either due to their power and status in society and politics. Indigenous peoples are generally sub-populations in the geographic area and society they reside in, and are groups of people who retain their own "social, cultural, economic and political characteristics that are distinct from those of the dominant societies in which they live" (U.N. Permanent Forum on Indigenous Issues, 2006, p. 1). In the 1980s, the Commonwealth Department of Aboriginal Affairs accepted a definition of an Indigenous Australian as "a person of Aboriginal or Torres Strait Islander descent who identifies as Aboriginal or Torres Strait

Islander and is accepted as such by the community in which he or she lives" (Australian Institute of Aboriginal and Torres Strait Islander Studies, 2015, n.p.).

Beginning in 1957 at the Indigenous and Tribal Populations Convention during the 40th General Conference of the International Labour Organisation, governments around the world formally joined together acknowledging that national policy does not always adequately address the needs of Indigenous peoples. Global development groups have begun to ensure that Indigenous communities participate in development of their own areas and communities, and this has led to more participatory research involving Indigenous peoples (Dove, 2006, p. 200). As Indigenous well-being is linked with environmental health, environmental policy and management decisions can have a major effect on Indigenous communities (Garnett et al., 2009; Rigby et al., 2011).

In Australia, Indigenous communities in rural areas face specific environmental and social challenges in regards to essential services including water and energy utilities (Beal & Stewart, 2015). Water and energy demands in remote and isolated Indigenous Australian communities are becoming more strained with climate change and scarcity of natural resources on the continent and globally. Australia is one of the highest per capita water users in the world with the average per person water use of 72 gallons per day (McGee, 2013). In comparison to the national average, Indigenous Australian communities use anywhere between 130 and about 211 gallons per person per day, which is double the national average (Pearce et al., 2007; Beal et al., 2016). This high water use, along with other limited water supply options, has put a strain on water resources and government funding towards water services in remote and isolated

Indigenous communities. In view of these emerging issues, it is crucial to understand what is driving water demand in these communities.

This master's project seeks to understand drivers of water use through statistical data analysis on quantitative and qualitative data gathered in three rural Indigenous communities in Australia. Through this research, I ask: What are the main drivers of residential water use in remote and isolated Indigenous Australian communities and can they be reduced through targeted water demand management?

Community-based water management projects with Indigenous inclusion and cultural considerations have been used in case studies throughout Australia as a way to address high water use in Indigenous communities, but it is unclear whether these management trials are targeting the needs and uniqueness of the variety of Indigenous communities within the country (Fisher et al., 2011; Garnett et al., 2009; Jackson et al., 2014; Grey-Gardner, 2008). In this project, I assessed the issue of water resources globally and in Australia to understand the importance and timeliness of sustainable water resource management as well as the connections of Indigenous populations to their environment. Through research on Indigenous conditions, I examined underlying social, economic, political, and environmental problems faced by these communities that impacts their involvement with environmental management and policies. I then analyzed household water end-use data, household surveys, and individual interviews to determine if there are specific behaviors, beliefs, or practices that can be considered when essential service providers create water management plans and implement services to offer sustainable water services to remote and isolated Indigenous communities.

1.2 – Literature Review

1.2.1 – The State of Worldwide Water Resources

Freshwater is an essential resource for humans, plants, animals, and other non-human entities, but the quantity and quality of freshwater resources has been impacted by human use and development. Humans continually alter the water cycle through water supply delivery systems, dam construction, and water withdrawal (Haddeland et al., 2014). Additionally, increasing water demands have been found to outweigh water system pressures from global warming for the near future (Haddeland et al., 2014; Vorosmarty et al., 2000). Current models indicate that a large percentage of the global population is experiencing water stress from water scarcity (Vorosmarty et al., 2000; Gaddis et al., 2012). While populations in arid regions will be faced with water scarcity, populations in tropical regions and urban areas will face public health issues from increased water pollution and stresses on sanitation systems with a seasonal increase in precipitation (Vorosmarty et al., 2000; Gaddis et al., 2012).

As efforts are made to improve the human condition globally, there will be a heavier reliance on freshwater withdrawals. Alcamo et al. (2007) found that increasing water stress was primarily caused by growing water withdrawals, which has been mainly driven by income growth. The Millennium Ecosystem Assessment, undertaken by the United Nations in 2005 in conjunction with governments and researchers around the world, also found that as human well-being and economic development improves, ecosystems generally experience degradation (Dooley, 2005). Vorosmarty et al. (2000) surmised several years earlier that a population's vulnerability to water stress is based upon population growth and economic development. In their work, Alcamo et al. (2007) studied how socioeconomic and demographic changes in populations can affect the future supply of water resources and in their models, income growth contributed to an increase in global withdrawals by thousands of km^3 per year. As nation-states and global organizations work to increase socioeconomic status, health, and environment of populations, there is likely to be further strain on water resources if measures are not taken to also address water resource changes.

Climate change factors, such as temperature fluctuations and precipitation changes, will also directly impact global water resources. Significance of human impact on global water supply differs from river basin to river basin, but climate change stands to magnify alterations in the water cycle (Haddeland et al., 2014). These climate change impacts include “the volume and variability of river discharge, changes in seasonal availability of water supply, and altered rates of sedimentation in rivers” (Alcamo et al., 2007, p. 247). Both groundwater and surface water resources will be effected by changes in Earth’s climate, with decreases in groundwater recharge, evapotranspiration, and runoff majorly impacting groundwater resources and the ability for those groundwater sources to inflow surface water systems (Earman & Dettinger, 2011).

Precipitation and temperature fluctuations due to climate change have shown to have a significant effect on the availability of water supplies and what areas are dealing with higher levels of water stress going into the future (Alcamo et al., 2007; Arnell, 2004; Gaddis et al., 2012). However, predictions around future climate conditions and population composition makes modeling and forecasting future water system conditions difficult (Earman & Dettinger, 2011; Alcamo et at., 2007; Vorosmarty et al., 2000; Carpenter et al., 2009). Conclusions differ around how much freshwater resources will be impacted, but it is clear that there will be alterations to surface water and groundwater systems into the future. Due to the dependence of Earthly life on freshwater, it is increasingly important to understand how water is being used, at what rate, and how this precious resource can be sustained into the future.

1.2.2 – Climate Vulnerability

While negative ramifications from environmental degradation are felt by everyone globally, there are specific groups that stand to be most negatively impacted by climate changes. Indigenous sub-populations in developed countries like Australia, North America, Canada, Finland, and Sweden "live beyond the modern industrial norm and for a multitude of reasons are socially excluded from wider national society" (Finn & Jackson, 2011, p. 1233). These specific groups may not conform to the social, economic, technological, or political systems of dominant Western society, so they live outside of politically considered social norms and economic systems (Australian Institute of Aboriginal and Torres Strait Islander Studies, 2015).

It is these populations especially that will experience negative outcomes from natural resource development and will be vulnerable to resource availability stress (Finn & Jackson, 2011; Vorosmarty et al., 2000). A 2008 report by the International Union for the Conservation of Nature stated that Indigenous populations living on small islands, coastal plains, mountain areas, tropical forests, and drylands are most likely to be affected currently and in the future by climate change, and that these changes will greatly impact their livelihoods and cultures (Macchi et al., 2008). The livelihoods, social and cultural structures, and well-being of Indigenous populations will be vulnerable to increasing climate changes going into the future.

1.2.3 – Access and Participation in Water Management

Environmental management, and political decision-making in general, has been evolving in many countries, leading to a different way in which the public has access to and can participate in environmental management. In 2007, the United Nations General Assembly officially called on global states to recognize the importance and power of Indigenous populations in governmental decisions through the adoption of the Declaration on the Rights of Indigenous Peoples (UNDRIP). UNDRIP (2007) makes clear the inclusion of Indigenous populations in environmental decisions and protection of community values through:

- The cooperation of governments and Indigenous peoples,
- Control of Indigenous peoples over "developments affecting them and their lands, territories and resources,"
- Recognizing that "indigenous knowledge, cultures and traditional practices contributes to sustainable and equitable development and proper management of the environment,"
- State government's use of international instruments to consult and cooperate with affected Indigenous people

The UNDRIP lays out the ideas and incorporation of Indigenous populations in policy and decision-making for improved human well-being. The assertion that "Indigenous people are equal to all other people" (U.N. General Assembly, 2007, p. 1) indicates that whatever rights other citizens can exercise in the policy and decision-making process should be made available to Indigenous populations as well, if they should so choose to take part.

There are multiple current examples throughout the world where Indigenous communities are involved in water management policies and processes as stakeholders. In the U.S., the management of the flow and allocation of water from the Klamath River Basin in Oregon and California has engaged multiple local stakeholders in the planning process and tried to incorporate the needs and concerns of the different groups involved (Horangic et al., 2016). Native American tribes located around the river have been heavily involved in the plan for water allocation and river management both through formal government planning processes and through independent legal action (Breslow, 2014). The Okanagan River Basin and Columbia River Basin in Canada are two water systems that are being heavily shaped by climate change and are trying to look at management solutions at a more local level to address the different adaptation difficulties experienced by various stakeholders (Cohen et al., 2006). "Increasingly, water issues are dealt with on the scale of watersheds," which leads to the emphasis on involving local actors (Cash & Moser, 2000, p. 112). In many countries, as exemplified with the U.S. and Canada, as competition for water resources increases, multiple stakeholders including Indigenous peoples are being and need to be included in the planning process to make long-term and sustainable environmental decisions.

1.2.4 – Challenges to Indigenous Inclusion in Environmental Management

Governmental bodies can have difficulty incorporating Indigenous communities into national political processes as they often face historical socioeconomic disadvantages, ranging from employment opportunities to access to the mainstream economy (Concu, 2012). The delegation of Indigenous communities to a lower socioeconomic status through historic and institutional prejudices separates these communities from involvement in political decision-making. While national policy may dictate public participation, this does not necessarily ensure that disadvantaged groups will be able to take part in public participation in political decision-making. Social systems in a country can exclude those who may be disadvantaged economically or outside of dominant societal norms, which influences the way that policies affect those communities. Many governments around the world have yet to tackle socioeconomic impacts on Indigenous peoples as a part of environmental policy (Jackson et al., 2011).

While national governments do attempt to incorporate multiple cultural identities and systems into political efforts through targeting disadvantaged groups, these efforts have been decreasing in some democratic countries such as Australia and Canada because simply incorporating various cultural groups in political decisions fails to address institutional racism and socioeconomic hierarchies (Kymlicka, 2010). Underlying institutional prejudices continue to shape policy and environmental management, which impacts the well-being of disadvantaged groups. In the United States, the government relocation of Native Americans from their ancestral land and continual exclusion from national policy has caused conflict between the government and Native American groups (Tsosie, 1996). A history of Indigenous mistreatment and marginalization by most national governments has made it difficult for Indigenous groups to obtain true representation in political decisions and agency interactions (Carter & Hill, 2007; Beard et al., 2013; Tan et al., 2010). These ingrained histories and failed attempts by governmental bodies to address the complexities of socioeconomic disadvantages faced by Indigenous peoples can have a negative effect on the way that Indigenous peoples interact with government bodies and service providers.

1.2.5 – Drinking Water Issues in Australia

Human demand for land and water has led to degradation of freshwater resources in Australia (Jackson et al., 2014). Freshwater degradation also shapes socio-economic conditions of various groups (Jackson et al., 2014). In Australia, water supplies vary greatly between the continent's regions and cities due to differing climates and terrains (Council of Australian Governments, 2004). The country has experienced both extreme rainfall events and droughts over the last decade due to climatic changes and a mix of El Nino and La Nina events, with a trend to lower rainfall in recent years (Australian Bureau of Meteorology, 2012; Australian Bureau of Statistics, 2007). Australian soil and groundwater storage experiences significant water loss from evapotranspiration, with about 85-95% of rainfall evaporating into the atmosphere either directly from land surface, the top layer of soil, or transpired by plants (Australian Bureau of Meteorology, 2012).

Australia, like many other countries, is experiencing an increased demand for water, which is impacting surface and groundwater systems (Council of Australian Governments, 2004). Droughts and water restrictions have been observed in Australia since 2012 as a reflection of decreased water resources (Australian Bureau of Statistics, 2007). Water is a scarce resource across most of Australia, and the country relies heavily on rainfall as water supplies in above ground and below ground storage systems (Australian Bureau of Statistics, 2007). Population growth in the country has driven an even greater demand on water resources impacted by climate change (Australian Bureau of Statistics, 2007). Between 2011 and 2016, the population of Australia grew from 21,507,717 to 23,401,892 people, which is a country population increase of about 2 million people or 9% population increase for the 5 years (Australian Bureau of Statistics, 2011, 2016). As a result, the government has placed more emphasis on the sustainable management of water resources (Council of Australian Governments, 2004).

1.2.6 – Disadvantages Faced by Indigenous Australians

1.2.6.1 – Past History and Trends

Indigenous well-being is connected to environmental health, physical and mental health, economic development, and educational attainment (Gaddis et al., 2012). The colonial legacy in Australia, as in other nations with Indigenous peoples, has left behind a social, political, and economic system that disadvantages Indigenous peoples (Altman, 2000). The colonization of Australia included social, economic, and resource exclusion of Indigenous Australians as well as racial/cultural discrimination. Colonizers and the Australian government restricted the independence of Indigenous populations through segregation, resettlement, and assimilation in policy approaches between the European settlement of the continent in 1788 to modern reforms in the 1970s (Australian Law Reform Condition, 1986). Due to historical policy, a sense of powerlessness is often voiced by Indigenous peoples, especially in regards to community decisions (Burgess et al., 2005; Grey-Gardner, 2008; Lane & Corbett, 2005). This feeling along with the historical oppression Indigenous peoples have faced since colonization compounds their reliance on the Australian government and those whom they feel have power over management and governance in their communities.

The inability of policies to address Indigenous well-being is not simply a lack of resources or effective implementation, but is a problem with the underlying values and ideological paradigms of Australian government relations with Indigenous peoples (Robbins, 2003, p. 3). Historical government abuse and marginalization of Indigenous Australian communities has become ingrained in the bureaucratic structure, and as a result, respectful and effective communication between Indigenous peoples and the Australia government is a challenge (Carter & Hill, 2007). Challenges with communication and interactions between Indigenous Australians and the government can lead to issues with adequate environmental policies and service provision.

Geographic location also impacts the well-being of Indigenous Australian communities. While the majority of Indigenous Australians live in large to medium sized cities, about 27% of Indigenous Australians live in small rural towns, pastoral stations, or outstations where many maintain aspects of an Indigenous economy (Altman, 2000; Altman & Fogarty, 2010). In these rural areas, Indigenous populations face more economic, health, and service access challenges than Indigenous populations residing in urban areas (Robbins, 2003; Quine et al., 2003; Dixon & Welch, 2000; Horton et al., 2010). Indigenous Australians in remote and isolated communities also experience inadequate housing and lack of clean water in addition to educational disadvantages (Burgess et al., 2005). Altman (2000) states that in the last 50 years, there have been increased efforts to upgrade public services to remote and isolated Indigenous communities. However, further research found that these areas still do not have the same access to government-provided facility services as other Australian populations (Altman, 2000; Quine et al., 2003; Hunter, 1999).

While some Indigenous communities have been able to remain on their ancestral country, the colonial history of Australia has left behind a model of moving Indigenous populations to shared central locations that are easily serviced (Burgess et al., 2005). Resettlement policies directed Indigenous funding to these central locations to discourage settlement in remote locations. This has led to a lack of adequate services in rural settlements and depopulation of traditional Indigenous areas has changed the environmental management of rural areas of Australia (Burgess et al., 2005; Garnett et al., 2009). The lack of Indigenous environmental management practices has changed the biodiversity, productivity, and habitat health of depopulated traditional Indigenous areas (Burgess et al., 2005; Garnett et al., 2009).

As a part of Indigenous reconciliation programs in Australia to make up for historical abuses, the government has attempted to close the social and economic gap between non-Indigenous peoples and Indigenous peoples through various development programs. The government is pursuing development policy through the Indigenous Advancement Strategy, which focuses on:

- Jobs, the environment, and the economy;
- Education and children;
- Safety;
- Culture and capacity; and
- Remote Australia specific strategies (Department of the Prime Minister and Cabinet, 2014)

While reconciliation programs try to improve well-being and socioeconomic conditions of Indigenous Australian peoples, historical colonial legacies in Australia have created a system in which Indigenous peoples rely heavily on the government for income, housing, health services, and education (Hunter, 1999; Burgess et al., 2005; Equal Opportunity Commission, 2013; Sanders, 2002). In the 1994 National Aboriginal and Torres Strait Islander Survey found that 55% of all Indigenous persons relied on government payments as their main source of income

(Altman, 2000; Daly & Smith, 1999). Housing is also a service provided by the government, as only 33% of Indigenous households in 1996 were owner owned or in the process of being purchased by the owners (Altman, 2000). Remote and isolated Indigenous households also have a different composition than many urban households, with more people per household in addition to more multi-family households (Daly & Smith, 1999). This specific social aspect could exacerbate certain public services and resource use, in particular to this project, the effect of household size on water use within the household.

1.2.6.2 – Current Relations Between Government and Indigenous Peoples

More recently, the Australian government has been increasing their inclusion of Indigenous populations in policy and political initiatives to complement reconciliation initiatives and programs. However, this approach has become more "monolithic and monopolistic" as the government has become less likely to incorporate Indigenous diversity into policy and decision-making, compounding on historical Indigenous prejudice (Altman & Fogarty, 2010, p. 109). Due to this singular policy approach, government services are rarely tailored to the cultural, social, environmental, and economic needs of diverse Indigenous communities (Altman & Fogarty, 2010). While Canada, the U.S., New Zealand, and Australia consistently have high Human Development Index rankings, the Indigenous populations in those countries consistently have low health and socioeconomic status and only rank at a medium human development level (Cooke et al., 2010). Cooke et al. (2010) found that between 1990 and 2000, the HDI scores of Indigenous Australians decreased while the HDI scores of non-Indigenous Australians increased.

Increased government programming and services aimed at Indigenous groups has also led to increased government funding going towards Indigenous Australians, but current programs do not seem to have improved the overall economic, health, or education standing of Indigenous Australians. Social indicators evaluating employment, income, housing, education, and health status as measures of well-being, show that Indigenous Australians continue to be the "most marginal group in Australian society" (Altman, 2000, p. v; Lane & Corbett, 2005). Among the wealthier nations trying to improve the well-being of Indigenous peoples, Australia ranks the lowest in social indicators (Garnett et al., 2009, p. 53). Additionally, there has been rapid growth in self-identifying Indigenous population numbers as the Australian Census data indicates that from 2001 to 2016, the Aboriginal and/or Torres Strait Islander population rose from 410,003 people, 2.2% of the population, to 649,171 people, 2.8% of the Australian population (Australian Bureau of Statistics, 2001; Australian Bureau of Statistics, 2016). This growth has led to financial strain of government resources (Altman, 2000).

Despite government efforts through reconciliation programs like National Sorry Day and Reconciliation Action Plans, Indigenous populations in Australia continue to experience community development issues and lower health and well-being than non-Indigenous Australian populations. Social indicator evaluations indicate that the government needs to be deliberate and effective with their funding and decision-making processes. Cooke et al. (2010) found that, to increase the overall well-being of Indigenous populations, efforts need to be made to jointly increase the social, economic, and health of Indigenous peoples through multifaceted and interdisciplinary programs. Re-thinking policy and service provisions instead of conforming decisions for Indigenous populations to a Western format may be able to solve entrenched development issues, which will improve both well-being and environmental outcomes.

1.2.7 – Water Services Research in Rural Indigenous Australian Communities

In the past decade, there has been a growth in environmental management studies focused on Indigenous Australian populations. These studies have frequently linked environmental management and environmental health to overall Indigenous well-being and emphasized the influence of Indigenous socioeconomic status, culture, and health on local environmental perceptions and management plans (Garnett et al., 2009; Jackson et al., 2014; Rigby et al., 2011; Fisher et al., 2011). Recent studies also stress how little power Indigenous Australian communities have over water service and management decisions (Grey-Gardner, 2008; Fisher et al., 2011; Marshall, 2008; Robbins, 2003; Jackson et al., 2014).

A common method used by previous and on-going research on water services in rural Indigenous Australian communities is community participation in various steps of management planning and implementation. Rigby et al. (2011) talked with Indigenous communities in rural New South Wales to track their views of prolonged droughts in the area to better understand how the droughts affected their social and economic well-being. Concern for country drove these communities to develop community programs around water saving (Rigby et al., 2011). Similarly, Grey-Gardner (2008) found that, once communities were involved in assessing the risks to water supply quantity and quality from increasing water scarcity issues, community members were more willing and better able to make management decisions around water savings and maintenance of water delivery systems. Fisher et al. (2011) concluded from their research in communities in Western Australia, Queensland, South Australia, and the Northern Territory that, even if services are more effectively administered at a regional level in comparison to a community level, service provision is better in communities that are actively involved in the maintenance and management of water and power services. The theme of Indigenous Australian communities being very responsive to direct involvement in water program creation and implementation was also seen in Beattie et al.'s (2008) research on water safety-training programs in rural Australian communities. Community engagement in water management planning and implementation seemed to greatly improve community buy-in to water services provided by outside entities and improved maintenance schemes for water infrastructure in rural Indigenous communities.

2.0 – Methods

I used a combination of quantitative and qualitative methodology to analyze water use in three remote and isolated Indigenous communities in Australia. Previous research on water consumption in Indigenous Australian households has shown the importance and value of utilizing a mixed methods approach to capture both the technical side of water consumption and the socioeconomic side of water consumption (Beal et al., 2014; Yuen, 2004). This project utilized both data that had been previously collected by RICES through initial household surveys and smart water meter data as well as data that I helped develop data collection methods for and gather data with the RICES's team.

My project analysis is heavily quantitative, based upon statistical analysis of data previously collected through household surveys and household smart water meter readings (Beal et al., 2018). Qualitative data from follow up individual interviews and stakeholder meetings and workshops that I helped to design and collect was used to inform quantitative analysis and provide anecdotal data. This approach is based upon the Remote and Isolated Communities Essential Services Project (Beal et al., 2018), which was the originating study from which this project emerged.

2.1 – RICES Background

All of the qualitative and quantitative data utilized in analysis for this master's project was obtained through the work of the Remote and Isolated Communities Essential Services Project, or RICES. RICES is a three-year project headed by a small research team from Griffith University in Brisbane/Gold Coast, Queensland Australia. The aim of RICES was to examine water and energy use in remote Indigenous communities in Northern Australia and identify strategies to reduce consumption of energy and water by these communities (Beal & Stewart, 2015). Researchers from Griffith University partnered with various governmental entities, industry and service providers, and Indigenous groups and governance bodies (Beal, 2017). The project team hoped to achieve this aim by:

i) "Present[ing] baseline water consumption profiles for the remote communities in the study;

ii) Identify[ing] high water end-uses and their drivers; and

iii) Determin[ing] key considerations for a participatory-based water demand management approach based on insights from (i) and (ii)" (Beal et al., 2018).

I travelled to Queensland, Australia as a research intern for RICES from June-August 2017. I undertook the task of detailed statistical analysis on high resolution water-end use data in order to ID drivers of high water use. This analysis aided in the formation of household strategies for reducing water consumption in the communities. During this internship, I also assisted in creating community-specific education strategies and co-developed an intervention plan for C2.

This master's project builds upon the collected data of RICES by asking related questions of water use patterns that RICES was not able to assess specifically. I obtained ethical clearance from IRB to conduct research in Australia and to use the data collected through the RICES Project. The team in Australia received ethical clearance through the Griffith University Indigenous Research Unit and cleared by the Human Ethics office (GU Ref No: ENG/ 15/14/HREC).

2.2 – Data Collection

2.2.1 – Participating Communities

Three rural Indigenous communities agreed to participate in RICES. To protect the identities of residents and leaders within these small rural communities, the names of the participating communities have been de-identified and will be referred to as Community 1 (C1), Community 2 (C2), and Community 3 (C3). These three communities were chosen due to geographical, technical, and social/cultural selection criteria. The criteria for RICES participating communities were:

1. Communities were representative of the underlying geographic, economic, and environmental challenges of supplying reliable water and energy to rural areas;

2. Communities needed to have "reliable telecommunication capabilities in order for the digital meters and loggers to remotely transfer large volumes of data efficiently and securely" (Beal et al., 2018, p. 2427); and
3. There needed to be a platform of existing trust and understanding between the community, including Traditional Owners, local council, and community representatives, and RICES team members and industry partners.

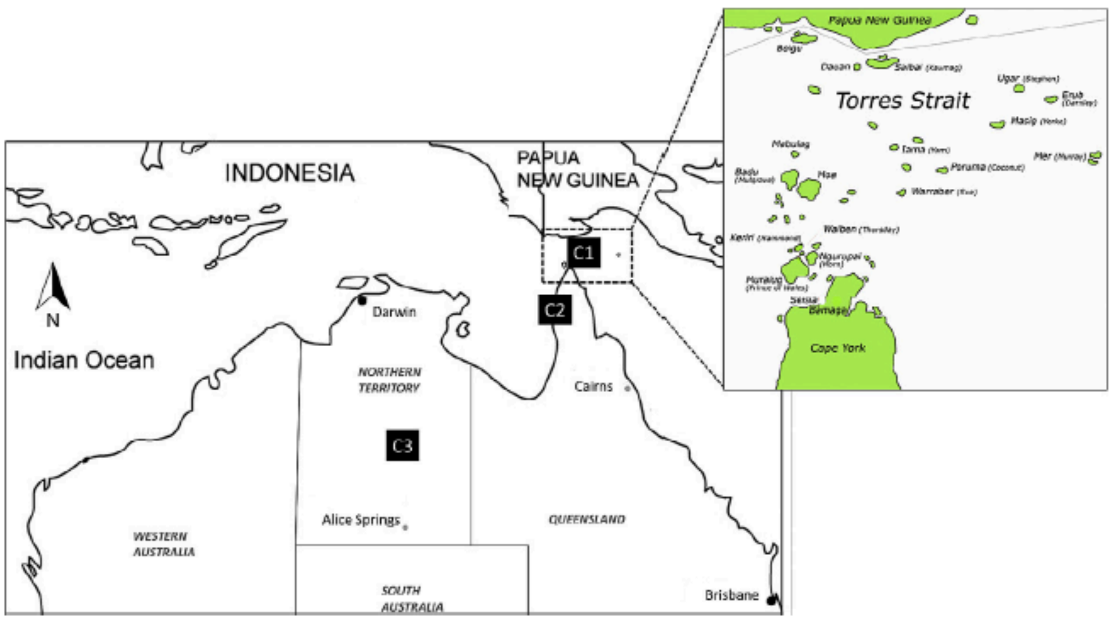

Figure 1: Location of participating communities to RICES with inset of Torres Strait Islands (Beal et al., 2018)

Table 1
Summary of population, water and energy supply characteristics for project communities.

	C1	C2	C3	Comments/sources
Population profile				
Population	254	269	444	From ABS (2016).
Approx. no. of households	58	71	70	C1 and C2 have a new housing project that will see a 10−25% increase, respectively.
RICES Project				
- Households[a]	22 (38%)	17 (24%)	12 (17%)	From participant surveys.
- Adults	72	38	39	
- Children[b]	49	20	20	
Average household occupancy[c]	5.8	3.4	5.8	
Governance arrangements				
Local government	Indigenous regional council	Indigenous shire council	Non-indigenous regional council	The only council based within community is in C2
Other organisations	Federal regional authority, Prescribed Bodies Corporate	Prescribed Bodies Corporate,	Local authority committee, Central Land Council	There are various Elder, men's women's, health, arts and sporting groups within each community.
Water supply and treatment				
Desalination plant	Y	N	N	
Surface water supply	Y – seasonal only	N	N	C1 supplements original surface water supply with desalination plant throughout the year.
Water treatment	Desalination and chlorination	Sand filters and chlorination	Advanced filtration and chlorination	C3 has a new treatment system due to poor quality groundwater.
Access to supply	Intermittent	Continuous	Continuous	C1 limited to 9 h a day during dry season week days.
Wastewater treatment	Biological aeration and UV disinfection	On-site septic systems	Anaerobic settling ponds	C1 has a new treatment system after septic systems were thought to contaminate aquifer.
Water rates	Non-residential only	Non-residential only	Non-residential only	All communities do not pay for residential water consumption.

[a] In parentheses is the percentage (%) of total Aboriginal and Torres Strait Island households in community.
[b] Children are categorised as <18 years old at the time of the survey.
[c] At the time of survey but liable to change throughout the year.

Table 1 retrieved from Beal et al., 2018.

Table 2: Cultural identity and language composition of participating households in the RICES Project (information sourced from Beal et al., 2018).

		C1	C2	C3
Participating Households		21*	17	12
Cultural Identity				
	Aboriginal	0 (0%)	8 (47%)	11 (92%)
	Torres Strait Islander	19 (86%)	2 (12%)	0 (0%)
	Aboriginal & Torres Strait Islander	3 (14%)	7 (4%)	0 (0%)
	Non-Indigenous	0 (0%)	0 (0%)	1 (8%)
Main Language(s) Used in the Home				
	English	20 (95%)	16 (94%)	9 (75%)
	Creole	0 (0%)	3 (18%)	0 (0%)
	Warlpiri	0 (0%)	0 (0%)	4 (33%)
	Alawarre	0 (0%)	0 (0%)	1 (8%)
	Wik-mungkan	1 (5%)	1 (6%)	0 (0%)
	Not specified	5 (24%)	0 (0%)	3 (25%)

Note: parentheses is percentage of participating households in the community.
*Corrected according to collected data

Community 1 (C1) is an island in Coral Sea located in between the tip of Cape York and Papua New Guinea as a part of the Torres Strait Island group (Figure 1). The island has a tropical climate setting and can only be traveled to from the Australian mainland by plane. C1 has a population of 254 people divided into about 58 households (Table 1; Beal et al., 2018). While Table 1 indicates that 22 households participated in the project, there was only data for 21 of households due to a malfunction of water metering equipment at one household. The adjusted household participation for C1 shows that 36% of this community participated in the RICES Project. As an island, the community receives their water from surface water reservoir supply and a desalination plant, and does not benefit from continuous 24/7 water supply (Table 1; Beal et al., 2018).

Community 2 (C2) is a remote coastal town in on the Cape York Peninsula in a tropical area (Figure 1). Like C1, this community is considered off-grid for both water and electricity and is about an hour car ride from a small regional town (Beal et al., 2018). C2 contains their own Aboriginal Shire Council that implements and enforces local governance of the area. C2 has a population of 269 people, which is divided into about 71 households (Table 1; Beal et al., 2018). 17 households in this community participated in the RICES Project, comprising 24% of the C2 households. The community receives their water from a community bore groundwater supply.

Community 3 (C3) is located in Central Australia in an arid desert zone (Figure 1). It is the only community out of the three participating communities that is controlled locally by a non-Indigenous regional council (Table 1; Beal et al., 2018). C3 has a population of 444 people divided into about 70 households (Table 1; Beal et al., 2018). 12 households from this community participated in RICES, comprising 17% of community households. The community gets their water from groundwater supply (Table 1; Beal et al., 2018).

As seen in Table 1, all of the communities have differing community size, household size, governance structure, and water supply and treatment systems. Of those participating the project, cultural identity and language composition varied across communities (Table 2). While specific aspects of the participants between the three communities differed, previous research of Aboriginal and Torres Strait Island households indicate that the family composition, age, gender composition, and household composition were broadly representative of each of the communities (Beal et al., 2014; Beal et al., 2018; Yuen, 2004). Residents in the participating communities do not pay for their household water consumption.

2.2.2 – Household Survey Data

Structured interviews were conducted between March 2015 and June 2016 in each community with a representative member of participating households during the baseline data collection stage (stage 1) of RICES (Beal et al., 2018). Households were selected through recruitment in the three communities with help from local governments and utility representatives and employees within the communities. Snowball sampling methods and targeting of particular households was common in participation recruitment as these communities are small and anonymity between community members and those working within the community is rare.

Surveys allowed the research team to have face-to-face interactions with participants in order to gain community involvement and insight into the study, and sought to capture community behaviors, attitudes, and challenges to water supply and demand (Beal et al., 2018). Participants were asked to respond to a total of 78 items on the survey (Beal et al., 2018). Questions asked RICES participants about water use within their homes, including presence and use of appliances, frequency of water use, household water sources, water use behaviors, and water quality in addition to demographic data. Question format varied throughout the survey with a majority of questions in a multi-choice and open-ended format and others using a 5-point Likert Scale (Beal et al., 2018). Pictures were used to complement some of the questions when technology or appliance categories needed to be specified (Beal et al., 2018). All households who participated in the RICES Project answered a survey to the best of their ability, and answers for the three communities were compiled together into a secure spreadsheet.

2.2.3 – Smart Water Meter Data

Smart water meters were used to record residential water consumption and were installed by the RICES team. The smart meters were installed onto the water mains pipe for households in conjunction with the standardized regular meter that logged overall water use (Beal et al., 2018). Some extra meters were installed on a few households in the communities on the cold water inlet of the solar hot water system for the house (Beal et al., 2018); however, I did not use data from this subset of meters in this analysis.

Smart water meter readings could not be analyzed directly from the digital server, but needed to be disaggregated into water end-use categories. The RICES research team used the "Autoflow" computer program (Nguyen et al., 2015) to disaggregate water end-uses, incorporating pattern recognition to separate total water use into the end-use categories of shower, tap, clothes washing machine, bath, toilet, dishwasher, leaks, and outdoor (Beal et al., 2018). The disaggregated data were then averaged for a two-week period across the communities for ease of analysis and to gain an understanding of more general water use patterns within these communities.

2.2.4 – Interview Data & Meeting Observations

For this project, I helped collect interview data and also did participant-observation in meetings with government representatives. During stage two of RICES, I accompanied the research team to one of the participating communities in northern Queensland, C2. During this week-long trip, we met with Queensland Department of Housing and Public Works, local water collection agents, and an Aboriginal Council that was in charge of C2 to develop partnerships, gain water reduction commitments from community leaders, and to learn more about barriers and drivers for water reduction within the community. I took notes during these meetings, which were used to inform the background of the trial water demand management plans for participating households.

The RICES team, including me, also conducted follow up interviews with participating households from C2 to learn more about the importance of water to them and their community as well as get updates on their specific water use behaviors and drivers. The household interviews were a part of a pilot technology and behavior change intervention. Out of 17 households, we were able to interview 15 household respondents. To keep consistency of answers and match previous survey collection, we tried to interview the same household member who took the survey in stage 1 of RICES.

The interview was split into two parts to gather both qualitative and quantitative data. The first section asked a majority of open-ended questions with one topic ranking question about respondents' perceptions of household, community, and Australia-wide water use and water conservation (Appendix A). The second part of the interview provided a follow up to the initial household survey and asked for updated information about household appliances, demographics, leaks, and water use behaviors. This section of the interview had 16 follow up questions from the first survey that were checked with every respondent. After the follow up questions, respondents were asked general open-ended questions about their specific household water use and about strategies that could be used at their home. These questions were tailored to each household from their water end-use data, household demographic data, and specific stated water use behaviors.

2.3 – Data Analysis

The main research question of this project is: What are the main drivers of residential water use in remote and isolated Indigenous Australian communities and can they be reduced through targeted water demand management?

In order to answer the primary research question, I used statistical and qualitative analysis to probe the following sub-questions:

SQ1. What stated outdoor watering practices and technologies are associated with higher levels of outdoor water use?

SQ2. Does residential water use decrease with behavioral and technological intervention?

SQ3. Are high water users less concerned about water security? Do water use levels reflect an individual's belief of their water security?

2.3.1 – Statistical Analysis

Water end-use data for each of the participating households and responses from the first survey were entered into a single spreadsheet, which combined all households into a single data set. For this project, I created a separate spreadsheet with a condensed version of the RICES main dataset that included variables that were relevant to my research question and sub-questions along with demographic data. I added a variable named community ID where the respondents were split into their respective community location, which allowed for separate and combined analysis, and to help control for community factors.

I utilized StataIC 13, a statistical analysis software, to compare household water end-use to stated water using practices and behavior from survey responses. The main research question was broken into three sub-questions for statistical analysis. A variety of tests were conducted on the dataset to test the sub-questions. Total end-use and outdoor end-use values were used in analysis as dependent variables and survey responses were used as explanatory variables.

2.3.2 – Qualitative Analysis

Anecdotal qualitative data collected from the follow up interviews and meetings was utilized in this project to better inform patterns of household water use that were or were not observed from the water meter data. In this project, qualitative data was used to support or disconfirm quantitative statistical results. Overarching support from qualitative data was limited by the location in which the data was collected. This project only contained qualitative data from my trip with the RICES team to C2, so community member follow up interview data was specific to C2.

3.0 – Results

3.1 – Exploratory Data Analysis and Descriptive Statistics

This project assessed liters of total and outdoor water end-use per household (L/hh) and per person (L/pp) averaged over a two-week period. The two-week periods were not the same for each community due to staggered smart water meter installment dates during visits to participating communities, however, the two-week periods were consistent with climatic conditions in the three communities. Total and outdoor water end-use averages were taken between:

- Community 1: May 31-June 12, 2017
- Community 2: August 17-24, 2016
- Community 3: November 25-December 9, 2016

Included in statistical analysis were a variety of other variables that covered demographic data, water use behaviors and activities, outdoor water technology, perceptions of water quality, and feelings about water security. A list of the variables can be found in Appendix B.

There were 51 households involved in the study. Of those households, only 50 households answered the preliminary survey. Water meter readings were not recorded for all households in the dataset with 38 of the 51 households having recorded total and outdoor water end-use averages. The incomplete dataset for all 51 households was the result of smart water meter issues (e.g. poor signal strength, meter malfunction, or damage). These issues led to problems with meter data uploading to the server.

Descriptive statistics were created for total water use per household and per person as well as outdoor water use per household and per person. The histograms and box plots showed that end-use data was not normally distributed, and the positively skewed data was log transformed. Log transformation helped lessen the skew of the data and reduced the number of outlier households for the different water end-use categories (Figure 2 and 3).

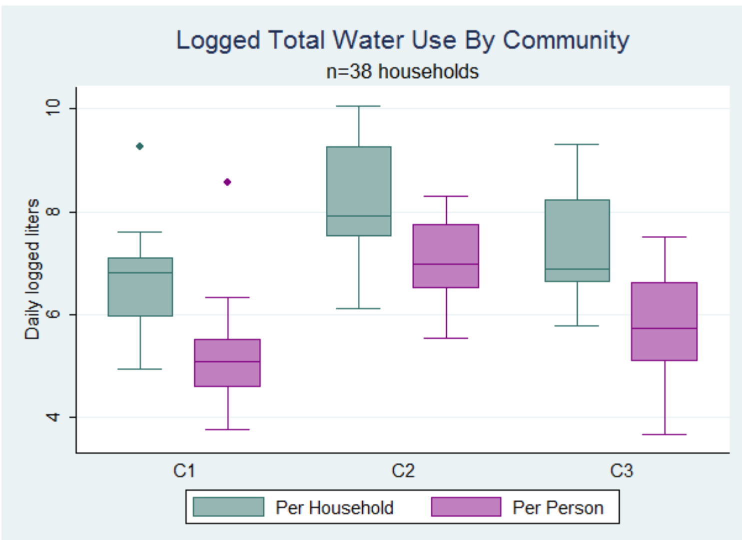

Figure 2: Logged daily total water end-use per household and per person separated by community (in liters)

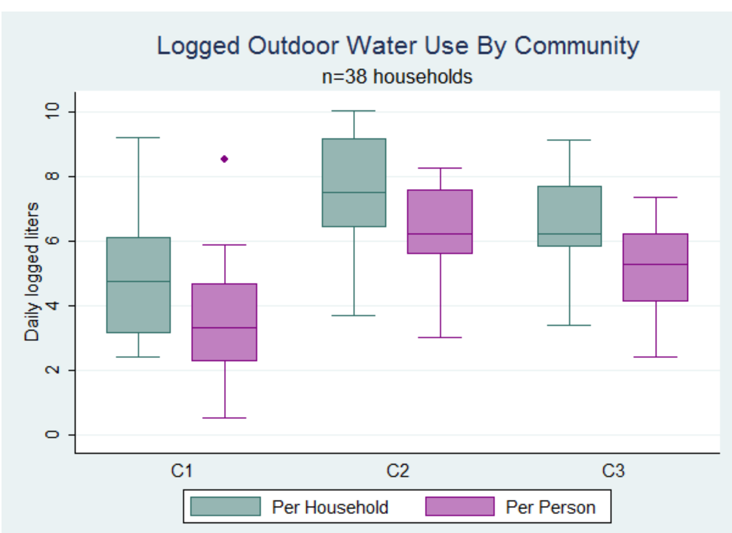

Figure 3: Logged daily outdoor water end-use per household and per person separated by community (in liters)

Descriptive statistics on the water use of each of the communities showed how similar or different water use was across the three communities. Community 2 had the highest average water end-use over all four independent variables (Table 3 and 4). One-way ANOVAs were conducted to initially test the impact of community ID on water use. These tests indicated that at least 1 community had daily total per person and per household water use that was statistically significantly different from the others at an *a priori* level of 5%. Community 2 was the differing community across the tests. The variability between the minimum and maximum water end-use for the four variables was large, and reflected how different household water use is in rural Indigenous communities.

Table 3. Average daily total water end-use by community

	Median (liters)	Range (liters)
Daily total per household		
Community 1	911	142 – 10,523
Community 2	2,721	460 – 23,506
Community 3	986	322 – 11,021
Daily total per person		
Community 1	163	43 – 5,262
Community 2	1,092	253 – 4,011
Community 3	308	38 – 1,837

Table 4. Average daily outdoor water end-use by community

	Median (liters)	Range (liters)
Daily outdoor per household		
Community 1	115	11 – 9,836
Community 2	1,799	40 – 23,014
Community 3	502	29 – 9,212
Daily outdoor per person		
Community 1	32	2 – 4,918
Community 2	507	20 – 3,836
Community 3	196	11 – 1,535

3.2 – Sub-Question 1: What stated outdoor watering practices and technologies are associated with higher levels of outdoor water use?

I expected households that stated that they did water their lawns generally would have higher outdoor water use than households that stated that they did not water their lawns. Similarly, I expected households that stated that they watered more frequently, more intensely throughout the day, and during high evaporation times during the midday and early afternoon to have higher outdoor water use per household. I also anticipated households that used more water-intensive technologies to have higher outdoor water use per household.

Both parametric and non-parametric tests were run to answer sub-question 1, including correlations, independent samples t-tests, paired samples t-test, one-way & two-way ANOVAs, and linear regressions, on daily logged outdoor end-use per household and outdoor end-use per person.

3.2.1 – Lawn watering

Respondents were asked during the initial survey if they watered their lawns all year, only during dry season, or not at all. After looking at a frequency histogram of the responses, a new variable was created that grouped all year lawn watering households and watering only during the day households for a binary yes water/no water variable. A two independent sample t-test was conducted with the binary watering variable as the grouping variable and outdoor water end-use per household and per person as the dependent variable to see if the mean outdoor water end-use of households who water their lawns was higher than the households who stated that they did not water their lawns. Neither the t-test on outdoor end-use per household, $t(35)=0.11$ and $p=0.54$, nor outdoor end-use per person, $t(35)= -0.01$ and $p=0.50$, were statistically significant, which indicated that households who have stated that they water their lawns do not use more outdoor water than households who have stated that they do not water their lawns.

3.2.2 – Frequency of lawn watering

Respondents were asked how often they water their lawns through a multiple choice question where they could select “monthly or less,” “1-2 times per month,” “1-2 times per week,” “3-5 times per week,” or “every day.” None of the survey respondents stated that they watered their lawns “monthly or less.” Initial box plots combining the outdoor water use of the three communities did not show a large difference between the different watering frequency groups per household or per person (Figure 4 and 5). The box plots also showed that there was a lot of variability within watering frequency groups.

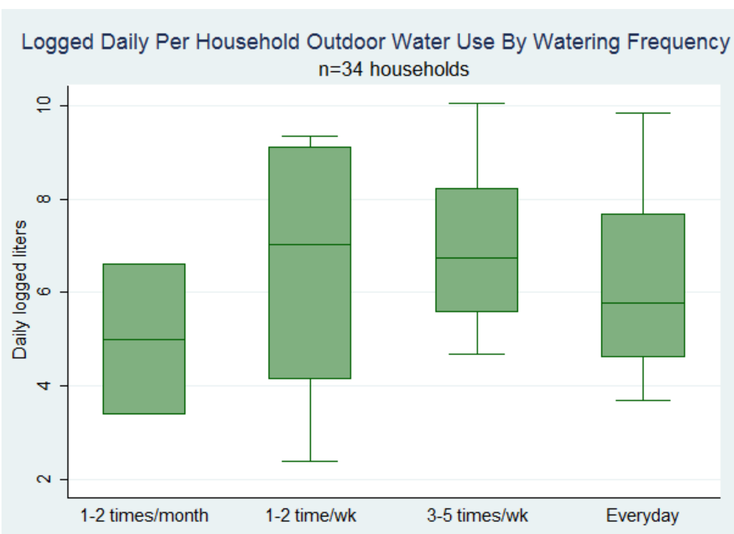

Figure 4: Logged outdoor water end-use per household grouped by watering frequency.

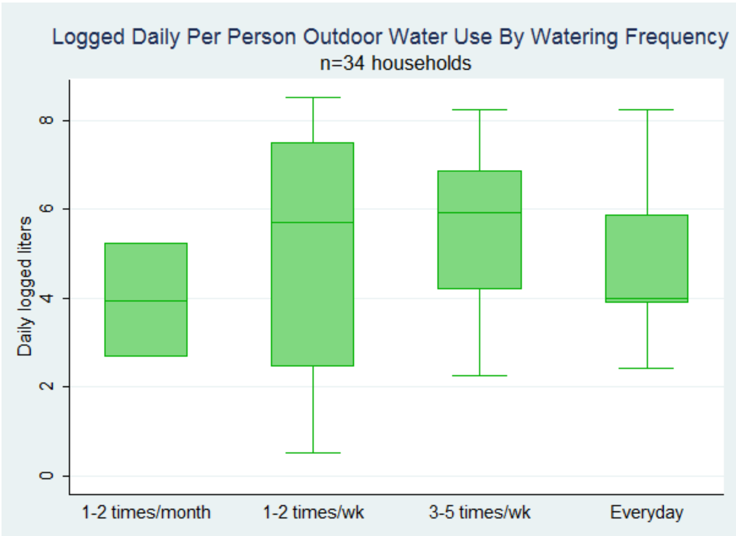

Figure 5: Logged outdoor water end-use per person grouped by watering frequency.

3.2.3 – Duration of lawn watering

To see if duration time of lawn watering impacted outdoor water end-use per household and/or per person, the initial household survey asked respondents about how long they water their lawns. Respondents could select "less than 2 hours a day," "more than 2 hours a day," "all night," "all day," "all day and all night" (24/7), "other," or not answer. Only 1 respondent each indicated that they watered their lawn "all night," "all day," or 24/7. One-way ANOVAs were conducted on outdoor water end-use per household and per person with watering duration as the grouping variable. The difference between watering duration groups for outdoor water end-use per household was not statistically significantly different. However, when a one-way ANOVA was conducted on outdoor water end-use per person, there was a statistically significant difference between watering duration groups. At least one of the watering duration groups had a different mean outdoor water end-use per person, $F(5, 28)=2.91$ and $p=0.031$.

In running a post-hoc Bonferroni test, the mean outdoor water end-use per person was statistically significantly different between respondents who stated that they water for more than

2 hours a day and respondents who stated that they water in some other way that was not given in the answer choices. This may indicate that the choices given to respondents were not worded correctly or did not reflect the actual water duration of participating households.

Two-way ANOVAs were run to control for community on watering duration. For mean daily outdoor water end-use per household, holding community constant, lawn watering duration differences between groups was not statistically significant, $F(5)=1.47$ and $p=0.23$, and community was not statistically significant, $F(2)=2.75$ and $p=0.08$. Per person daily outdoor water end-use followed similar results with lawn watering duration differences between groups not statistically significant controlling for community, $F(5)=1.84$ and $p=0.14$, however, community was statistically significant, $F(2)=4.14$ and $p=0.03$. This difference between the community-controlled test and the community combined test may indicate that community factors affect the outdoor water end-use and watering behaviors.

An important aspect of watering duration is the time of day that community members choose to water their lawns. Watering at the hottest time of the day or when there is the most sun outside generally leads to greater evaporation as the lawn is being watered. The RICES team identified two watering duration time periods from the survey answer choices that would be preferred for a greater chance of absorption into the ground, which was less than two hours per day or all night (Figure 6). Independent samples t-tests were run to test if households that water during the preferred times had lower mean outdoor water end-use per household. The test found that there is no significant difference between the mean outdoor end-use per household of household who water during preferred times and those that water during non-preferred times of high evaporation periods, t(15)= -1.26 and p=0.11.

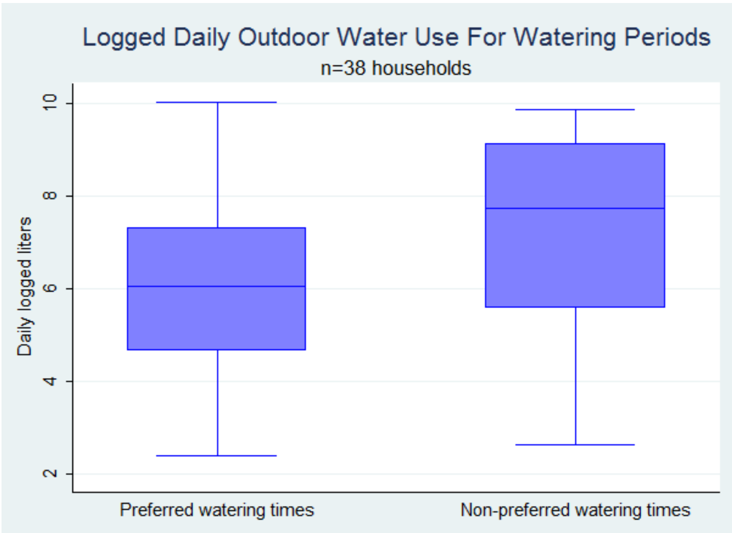

Figure 6: Logged outdoor water end-use per household for preferred vs. non-preferred watering times.

3.2.4 – Watering technology

The Australian government is funding and implementing programs to educate the public about water resources as a way to reduce water use and improve water quality. In Queensland, the government has implemented an initiative called Waterwise (Queensland Government, 2014). Educational materials for the public focus on both water use behavior changes and the installation/use of water-saving technology. The majority of strategies from the brochures and teaching materials appear to be focused on water-saving technology and how specific technology, such as dual flush toilets, water efficient washing machines, and water efficient shower heads, can save about 30-50 buckets of water (30-50 liters of water), leading to large water savings overall in Queensland (Queensland Government, 2017).

To get a better idea of what types of watering technology community members were using on their lawns, respondents were asked both about overall lawn watering technology and the type of tap that they use outside. For overall lawn watering technology, respondents could choose from "no watering technology," a "lawn sprinkler," a "dripper", a "hose," a "soaker hose," or a "combination." None of the participants stated that they used drippers or soaker hoses to water their lawns. For the type of tap used outside, respondents could choose from "hose only," "trigger," "nozzle," "tap only," or "combination." Three respondents did not answer the question.

Non-parametric Kruskal-Wallis tests were used due to the skewed distribution of the groups for both lawn watering technology and tap type on outdoor water end-use per household and per person. There was not a statistically significant difference in mean outdoor water end-use per household, $t(2)=0.54$ and $p=0.76$, or per person, $t(2)=2.68$ and $p=0.26$, between lawn watering technology groups. There was a weak statistically significant difference between tap type group on outdoor water end-use per household, $t(4)=9.68$ and $p=0.046$. On the other hand, there was not a statistically significant difference between tap type groups outdoor water end-use per person, $t(4)=9.39$ and $p=0.05$

Similarly to watering duration, two-way ANOVAs controlled for community on tap type to see if there was still significance in outdoor water end-use per person. There was not a statistically significant difference in outdoor water end-use per household when controlled for community, $F(4)=2.48$ and $p=0.07$, but community was significant, $F(2)=4.83$ and $p=0.02$. There was also not a statistically significant difference in outdoor water end-use per person between the different tap type group when controlled for community, $F(4)=2.55$ and $p=0.06$, but community was significant, $F(2)=6.61$ and $p=0.005$. These two-way ANOVA results further indicate that community factors affect the outdoor water end-use and watering behaviors.

Overall, only a couple of tests were statistically significant. The majority of test run for sub-question 1 indicated that outdoor watering behaviors and technology were not significant drivers of outdoor water use per household or per person.

3.3 – Sub-Question 2: Does residential water use decrease with behavioral and technological intervention?

Analysis for sub-question 2 focused on Community 2. At the time of this project, C2 was the only RICES partner community that had experienced a follow up visit by the research team with an intervention program piloted with the participating households to increase education about water use and trial technological and behavioral changes within the households. The intervention was two-pronged approach with efforts by the RICES research team and local Aboriginal Shire Council officials.

As a part of the intervention, the RICES team talked with respondents about their water use, showed them household water use averages in comparison to community water use averages, and trialed outdoor water-saving behavior and technology. I co-developed the trial water demand management plan for participating households in C2, which were technological and behavioral changes that were discussed with and agreed upon by participants. The local Aboriginal Shire Council also talked with residents and created community plans for water reduction. Before intervention and after intervention data was obtained through smart water meter readings and disaggregation software as discussed above in the Methods section. Before intervention data was the same C2 dataset that was used in overall tests across the three communities.

3.3.1 – T-test

A basic analysis was performed on before intervention and after intervention total water end-use data using a paired samples t-test. Before running the t-test, descriptive statistics were created for before and after total water end-use per household and per person.

Table 5: Average daily total water end-use before and after intervention

Summary Statistics Community 2: Before and After Intervention Average Daily Total Water End-use	Obs.	Mean (Liters)	Std. Dev.	Min. (Liters)	Max. (Liters)
Before total per household	15	6246.97	7147.97	460.30	23505.70
After total per household	15	3016.31	3150.06	343.40	10541
Before total per person	15	1704.97	1315.20	253.10	4011.20
After total per person	15	1001.81	1294.64	68.70	5270.50

Summary statistics show that there is a drop from average before intervention total end-use per household and per person to after total end-use per household and per person (Table 5). There is a large difference in water end-use between the minimum participant water users and the maximum participant water users in the communities. The data was also positively skewed, so I used log-transformed data. Initial box plots of daily total water end-use per household and per person indicates that there was a significant change in total water used from before the intervention to after the intervention (Figure 7).

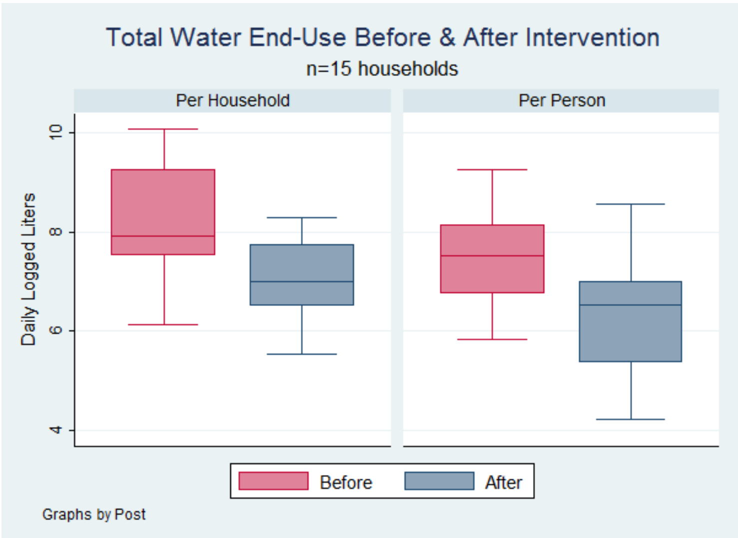

Figure 7: Total water end-use per household and per person before and after intervention.

Hypotheses were formed before conducting the paired samples t-test, with hypotheses language adjusted for per household and per person water use:

- H_o: Residential water use before and after the intervention is the same
- H_a: Residential water use after intervention is lower.

The paired samples t-test on per household daily total water end-use indicated that there was not a statistically significant difference at the 0.05 alpha level in the mean total water end-use before and after the intervention, $t(14)=1.663$ and $p=0.059$. From this result, the null fails to be rejected. However, the p-value is close to the *a priori* level of 0.05 with weak significance.

I also ran a paired samples t-test on per person daily total water end-use. From this test, the null hypothesis was rejected, indicating that there is a statistically significant difference between the before intervention and after intervention total per person water end-use, $t(14)=2.638$ and $p=0.01$. The median before intervention daily water usage is estimated to be 2.19 times that of daily water usage after the intervention. Per person daily total water end-use did decrease from before the intervention to after the intervention.

3.3.2 – Difference in Differences

During the RICES follow-up visit to Community 2, the team was not able to reach all of the participating households. Out of the 17 households in Community 2 that participated in the project, 2 were unavailable during our visit. This provided an opportunity through statistical tests to control for external community factors on water use after the intervention. Through the paired samples t-test, I could not specifically equate the decrease in total daily water end-use to research intervention alone because there might have been other influences on water use changes like climate differences, community aspects, and governance approaches.

I developed a difference-in-differences (DiD) model to control for factors not accounted for in the data by categorizing the two households that we had not met with in the follow-up visit as non-treatment households. There were two readings for each household, the before and after intervention total end-use amounts, and each entry was coded as pre or post in addition to treatment or control. The DiD overall fit of the models for per household or per person total water end-use was not significant and none of the coefficients on the variables were statistically significant. DiD models generally contain larger panel datasets, and my test only contained 30 entries. The outcome of the two DiD tests could be due to the number of observations or the small amount of control households.

When re-evaluating the meaning of "intervention" with the RICES team, we determined that the desired intervention approach that the team undertook in C2 did include external methods as a part of the research intervention due to the two-pronged intervention approach from the RICES team and local Council's outreach. In this re-evaluation of "intervention," a DiD approach would not fit the analysis of sub-question 2.

Results from the paired samples t-test was most appropriate to answer sub-question 2. For total per household daily water use, water use after the intervention was not significantly lower than water use before the intervention. However, per person total daily water use was significantly lower after the intervention.

3.4 – Sub-Question 3: Are high water users less concerned about water security? Do water use levels reflect an individual's belief of their water security?

During initial surveys, respondents from participating households were asked about their concern about water security for their household and for their community in two separate questions. The RICES team hypothesized that a household's level of concern for the security of continued clean water supply within their community and to their household would influence the amount of water used by the household. A pattern of high water use would make sense for households that stated that they had low concern for water security since low concern would mean that they do not fear that their water supply will run out.

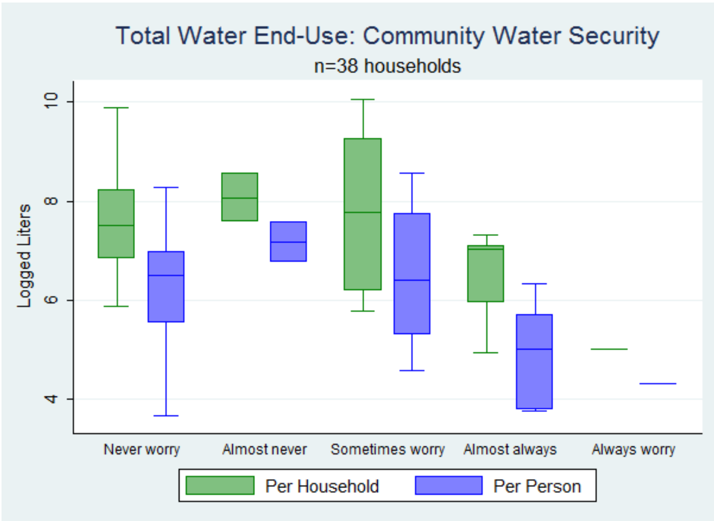

Figure 8: Logged daily per household and per person total water end-use by concern for community water security

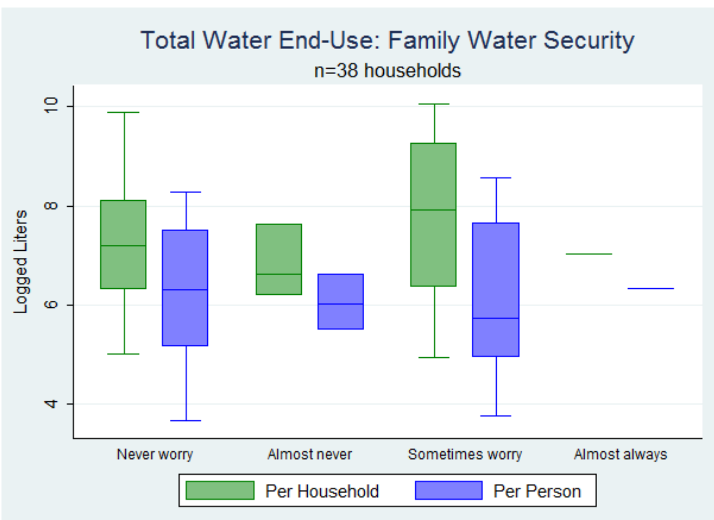

Figure 9: Logged daily per household and per person total water end-use by concern for household/family water security

Respondents could answer that they "never worried," "almost never worried," "sometimes worried," "almost always worried," and "always worried." The majority of respondents, 88%, stated that they "never worried" or "sometimes worried" for both community and household/family water security. One respondent did not answer for either question. Boxplots of the total water end-use per household and per person for both community water security and family water security concern showed a variety in water use amounts within groups (Figure 8 and 9). Interestingly, more respondents seemed to show more concern for their own family's water security than security of water supply for the community overall. For community water security concern, there does appear to be lower total water use for the respondents that stated they worry almost always, which is group 3 (Figure 8).

To test the hypothesis that lower water security concern would influence higher water use, a series of linear regressions were conducted. In the regressions, logged total water end-use per household or per person was the dependent variable. For explanatory variables in the models, concern for community or family water security was the main variable being tests for an effect and community, people per household, whether the household drinks tap water all the time or some of the time (with household not drinking tap water at all left out of the model), and respondent rating of water quality were used as well for controls. The regressions were run with robust standard errors to account for possible issues with heteroscedasticity.

3.4.1 – Community Water Security

A linear regression was conducted on total per household water end-use and total per person household water end-use to see if more worry for community water security indicated higher or lower total water end-use. Worry for community water security was not statistically significant as an indicator of total per household water end-use, holding all other variables constant, t(37)= -0.85, p=0.4, and overall model fit of R^2 =0.21 and p=0.02. Similarly, worry for community water security was not statistically significant as an indicator of total per person water end-use, holding all other variables constant, t(37)= -0.53 and p=0.602, and overall model fit R^2 =0.33 and p<0.001 .

3.4.2 – Household Water Security

I ran a linear regression on total per household water end-use and total per person household water end-use to see if more worry for family water security indicated higher or lower total water end-use. Holding all other variables constant, respondent worry about water security for their family is not statistically significant on total water end-use per household, t(37)=1.85 and p=0.074, and overall model fit of R^2 =0.27 and p=0.02. Similarly, holding all other variables constant, respondent worry about water security for their family is not statistically significant on total water end-use per household, t(37)=1.82 and p=0.079, and overall model fit of R^2 =0.39 and p<0.001.

3.4.3 – Endogeneity

Endogeneity was a concern with these tests; there was the possibility that a household used more water, which led them to have greater or lesser concern for water security. To decrease the chance of endogeneity in the models, an instrumental variable approach was tried. However, the initial household survey did not capture variables that could be used as instrumental variables for water security, so I could not run an instrumental variable regression and instead ran regular regression models.

4.0 – Discussion

T-test, correlations, ANOVAs, and linear regressions were conducted in statistical analysis to test water use behaviors and technologies as indicators of outdoor and total water end-use. Descriptive statistics were calculated before running statistical tests, which included summary statistics for water end-use across several explanatory variables, histograms, and boxplots.

Boxplots for many of the tests showed the variability within grouping variables as well as across the different explanatory variable answer options.

4.1 – Sub-Question 1

Sub-question 1 asked if there were stated outdoor watering practices and technologies that were associated with higher levels of outdoor water use. There were a couple of statistically significant findings from sub-question 1. Watering duration for “less than 2 hours,” “more than 2 hours,” “all night,” “all day,” 24/7, and “other” did have statistically significantly different outdoor water end-use per person; post-hoc results from this test showed a difference between households were the respondent stated that they watered for more than 2 hours and households were the respondent stated that they had a watering duration other than the indicated answers on the survey, so it was difficult to draw any conclusions about the effect of watering duration on outdoor water end-use.

Tap type also influenced outdoor water end-use per person. A non-parametric one-way ANOVA indicated that at least one tap type group was statistically significantly different, so what respondents used to water the lawn, whether with just a hose, the exposed outdoor tap, or control ends on the hose like a trigger or nozzle, did influence the amount of outdoor water being used per person.

However, a majority of the tests indicated that there were no statistically significant practices/behaviors or technologies that were associated with higher per household or per person outdoor water end-use. This could be a result of confusion with the wording or category breaks of the given answer choices. In the follow up visit to C2, when talking with the participants and in visits to the community store, it was clear that the participating communities do not always have access to water-saving technologies for indoor or outdoor water use. A meeting with the Queensland Department of Housing and Public Works reinforced the absence of water-saving lawn technologies I observed as a representative expressed that many rural Aboriginal and Torres Strait Island communities do not have access to technology or hardware stores as populations in urban areas do (Personal communication, July 17, 2017). This lack of access to purchase water-saving technologies promoted by government agencies could be driving higher water use, and may have influenced the results of my statistical tests as participants would not have alternatives to choose from.

The overall non-significance of the majority of sub-question 1 tests could also have been influenced by social desirability bias. Social desirability bias is when respondents answer survey or interview questions how they think will be perceived as acceptable. Since the participants knew that the research team was from Griffith University and working with the government to lower water use, there is a possibility that some respondents were compelled to minimize their water use responses to please the research team.

4.2 – Sub-Question 2

Sub-question 2 assessed before and after data for Community 2 from the year before and a few months after the RICES team conducted follow up visits to participants and the local Aboriginal Shire Council. Initial boxplots and summary statistics did show a decrease in total water end-use per household and per person from before the intervention to after the intervention. The difference between before and after intervention total water end-use per person was statistically significant. With more data, the other tests might have statistically supported the decrease seen in boxplots. "Intervention" included a joined effort of the RICES research team and the Council of Community 2. Results from both quantitative and qualitative data analyses indicated that remote and isolated Indigenous Australian communities will likely need a multi-faceted water reduction approach with data-based education, community workshops for community discussion and input, and local government and service provider outreach to communities and work within communities to make an impact on water use at the household level.

4.3 – Sub-Question 3

Water security was a difficult factor to test in this analysis. The initial household survey was not designed in a way to thoroughly assess the impact of worry for family and community water security on household water end-use. I expected worry about water security to impact daily total water use. Basic linear regressions showed that neither worry over community water security nor worry over family water security had a statistically significant impact on total water end-use per household or per person. More research would need to be done on this topic to draw any conclusions about perceptions of water security as an indicator of household water use, but would be important in understanding how remote and isolated Indigenous Australian communities view the state of their water resources.

Water leaks and appliances that need to be fixed or updated can influence total water end-use for households. A spike in water use could have been caused by a leak at a participating household, which would cause the total water end-use for that household to be a higher amount than normal.

Since the community participants in the project mostly lived in government-subsidized housing, householders generally had to wait on a government leak alert process for someone to come to their home and fix the leak. In talking with residents in C2, leaks were fixed on a variety of time scales from the same day to months later. Leaks could have influenced the statistical tests, and this is something the RICES team and I sought to minimize in C2 during follow up interviews when we asked if the household had experienced any leaks in the last year and how long the repair process took if it was reported. Leak water end-use values were disaggregated from meter data, but were not used in this project analysis due to leak maintenance not being controlled by community members past resident leak reporting (Queensland Department of Housing and Public Works, personal communication, July 17, 2017).

4.4 – Community Variability

Statistical analysis showed that communities are so variable that general trends are hard to pinpoint, mostly due to a small dataset. Even in the follow up visit with participants from C2, respondents did not agree on the state of water and water conservation in Australia, much less their own community. Three of the 15 respondents stated the general idea that water resources in Australian and in communities should be monitored and used sustainability. One of the respondents even differed with their view of water conservation efforts from the family level to Australia-wide in stating that being careful with water was not really important for their family, but that it is more important for Australia more broadly to be careful with their water use (C17, personal communication, July 2017).

When controlling for community in ANOVAs or regressions, there was no statistical significance in indicators of household water use. Even amongst the communities, proximity to governance structures and service providers, geographic location and climate, community coherence, and household size varied greatly. In expanding this research to other rural Indigenous Australian communities, variability of community factors is likely to increase significantly, making it difficult to find common patterns or behaviors across communities that can describe household water use. The inconsistent findings in this project support past research indicating that cultural, societal, and economic factors of individual communities should be considered in water services to create targeted demand water management plans, as trialed as a part of sub-question 2.

5.0 – Recommendations

From the qualitative and quantitative analyses, there were no clear drivers of higher water use to help for a targeted water demand strategy for Indigenous Australian communities. However, the data did indicate that, while more water use research should be conducted at the household-level, there are a few recommendations that could be incorporated into water service, including the incorporation of cultural and social water values, flexibility and cohesion of policy at different levels, and increasing community unity and capacity for water management.

In the visit to Community 2, the RICES team asked participants: "When you think of the word WATER, what does it mean to you? What value does it have for you and your family?" The purpose of this two-part open-ended question was to explore the meaning and value of water quantity, quality, and availability to community members. Unfortunately, this question was not easily answered by participants and we received a variety of answers from brief statements like "it's important" (C211, personal communication, July 2017) or showers come to mind (C28, personal communication, July 2017) to more complex connections between water, energy, culture, and livelihoods (C217, personal communication, July 2017; C26, personal communication, July 2017; C23, personal communication, July 2017). There is already established literature on Indigenous water values and policy that requires consideration of water values. While there are policies in place that outline the incorporation of Indigenous water values into water management, it is not clear if water service providers are held to this policy (Department of Agriculture and Water Resources, 2004; Department of the Environment, 2016). More should be done to integrate these values and community perceptions into local water service provision. The difference between Indigenous water values, due to cultural and societal considerations, may be different than non-Indigenous populations and should be considered when developing water management plans if these values impact water end-use.

Policy and structural biases can also impact environmental decision-making and individual water use behaviors. While all Indigenous Australians face social disadvantages, Indigenous peoples living in rural settings face even greater disadvantages (Hunter, 2008). In order to address Indigenous water service issues, social disadvantages need to be addressed. A variety of government agencies, both Indigenous and non-Indigenous, will need to be involved to create holistic environmental solutions (Hunter, 2008). In this project, paired samples t-tests examined C2's total water end-use before and after a combined water reduction intervention of academic water use research, educational visits with households and community workshops, and policies and outreach from local government. The Queensland Department of Housing and Public Works also connected government service struggles experienced by remote and isolated Indigenous communities with water use. To reduce water use in remote and isolated Indigenous communities and to increase Indigenous well-being, water service policy needs to be flexible and allow for different level of government decision-making so that local, regional, state, and national agencies work together.

Interviews with C2 participants indicated that community cohesion, social hierarchy, and belief systems can be a large influence in the way in which Indigenous communities interact with their environment. The three RICES communities possessed differing governance structures, Aboriginal and Torres Strait Island cultures, and feelings of social cohesion. One respondent in Community 2 mentioned how social disharmony within their community prevented meaningful and impactful education, health, economic, and water programs (C217, personal communication, July 2017). "Participatory principles advocate the use of existing community capacities including their tangible diverse practices, and often more importantly, their intangible values such as group identity, innovation and social harmony" (Carter & Hill, 2007, p. 43). These tangible and intangible beliefs, practices, and values can have major effects on how Indigenous groups interact in policy processes and how they perceive environmental management. Anecdotal data from this project indicated that government service providers do not always factor existing community capacity when creating programs and service plans. An increase in participatory research and processes in service planning could help increase the long-term impact of services on rural Indigenous communities.

6.0 – Conclusion

Human well-being has been shown to be closely linked with ecosystem health. Work to increase global human well-being has impacts on environmental resources and systems (Carpenter et al., 2009; Alcamo et al., 2007; Dooley, 2005). It is becoming increasingly important for politicians and decision-makers to gather evidence around environmental and human development solutions that are built on social-ecological research efforts (Carpenter et al., 2009). As such multi-discipline solutions are becoming more prevalent, it is also important to incorporate social and cultural differences into environmental policy and management to account for the differences in human well-being around the world.

As shown through this preliminary research and others, remote and isolated Indigenous Australian communities are large water users relative to nation-wide averages from more urban settings. Going into the future, water resources are going to become scarcer globally and delivery to rural areas costlier. More research and integrative work should be done to truly understand these communities and their needs, and to collaborate with them on water-saving strategies that will not impair their livelihoods.

Remote and isolated Indigenous Australian communities also have differing needs and uses for water than urban areas, as shown by qualitative and quantitative data analysis in this project and through the Remote and Isolated Community Essential Services Project (RICES). This project analyzed drivers of residential water use in remote and isolated Indigenous Australian communities to see if shared behavioral and technological drivers amongst communities could be used in targeted water demand management to reduce household water use. Statistical and quantitative analysis showed that it is difficult to find overarching patterns in water use behaviors or technologies that impacted high water use. Social, cultural, economic, and environmental variability within and between communities appeared to overpower statistically significant findings, and community was significant throughout statistical analysis.

In consideration of community specific needs and uses, it would be difficult to apply a general water service model to remote and isolated Indigenous communities as a whole. Community considerations need to be taken into account when trying to reduce water consumption in these rural areas. As seen from this project, behaviors and technologies were different even within small communities. Environmentally, socially, and economically, these communities are greatly impacted by the availability and quality of government-provided services. More information should be gathered about the individual needs and cultural and societal components of rural Indigenous Australian communities, and incorporated into service provision plans to both improve water resources in the country and assist Indigenous well-being.

6.1 – Limitations

Consistent with past studies analyzing water services for rural Indigenous Australian communities (Rigby et al., 2011; Fisher et al., 2011; Grey-Gardner, 2008), there were several limitations to this project. These limitations included sample size, language barriers, and assumptions during statistical analysis.

As rural communities are generally small in comparison to an urban area, studies of this nature tend to have issues with small sample size. The small sample size in this project limited the comprehensive statistical analysis of community water use. While the number of participating households from the three partner communities comprised at least 15% of the community populations individually, which is statistically valid as a representative sample population ratio, the amount of households that were involved in the study is still very low for strong statistical outcomes. This issue with small sample size may have influenced significance findings from the analysis.

While conducting follow up interviews in C2, the RICES team and I did not have an Indigenous Australian liaison during interviews, which could have led to language barriers (though other RICES data collection did involve Indigenous community partners). This could have been a limitation when collecting qualitative data from households as studies have shown that, when doing projects with minority, disenfranchised, and/or Indigenous groups, it is more helpful and more socially acceptable to involve a community member or similarly identifying person as a liaison and in-person collaborator for research and work in communities (Ball, 2005; Styres & Zinga, 2013; Seal, 2016; Barney, 2016). All survey respondents spoke some English, but English was not always their first language (Beal et al., 2018). Out of all participating households, 36% of survey respondents stated that another language was used as a main language in the home, either alone, with another Indigenous language, or concurrently with English. The follow up interviews were conducted in English, so there was a possibility of respondents not understanding the wording of questions and/or were not sure how to communicate their response in English.

Another limitation of this project was assumptions made during statistical analysis. Throughout the analysis, I assumed that log transformation created normally distributed data. Box plots on logged daily total water end-use per household and per person and logged daily outdoor water end-use per household and per person confirmed this assumption generally, but formal statistical tests were not run to confirm this. Throughout data analysis, there was also a limitation to the tests that could be run due to categorical data, so I might not have been able to fully test behavioral and technological drivers of high water use.

Appendix

Appendix A: Household Interviews

Interview Questions

Perceptions of water and energy

1. SHOW PRINT OUT IMAGES AND ASK: Thinking about each of these areas of community, what is the most important issue for you? Keep asking until exhausted – some kind of order.

a. Local Jobs

b. Paying for power

c. Cultural business

d. Health care

e. Water being wasted

f. Sports and recreation

g. Community wellbeing

Can you tell me why ____ is the most important to you? Can you tell me why _____ is above the others?

[Get clarification if they thinking about themselves, their family, the community etc.]

2. When you think of the word WATER, what does it mean to you? What value does it have for you or your family?

[Explore meanings and value placed on water availability, quality and quantity]

3. When you think of the word POWER or ELECTRICITY, what does it mean to you, what value does it have for you or your family?

[Explore meanings and value placed on availability, reliability and quantity]

4. Do you think being careful with how much WATER you use is necessary:

5. Do you think being careful with how much POWER you use is necessary:

WATER POWER

a. For your family?

b. For your community?

c. For Australia more broadly?

If YES, why?

If NO, why not?

6. (If this hasn't already come up, ask…) What problems do you think there might be or have experienced from wasting water (for you or others) in the community? (Explore negative consequences/outcomes).

7. What problems do you think there might be or have experienced from wasting power (for you or others) in the community? (Explore negative consequences/outcomes).

Appendix B: Variables

Variable	Type of Variable
Community ID	Categorical
People per household (pp/hh)	Continuous
Gender	Categorical
Age	Categorical
Adults (household residents over 18 years old)	Discrete
Children over 10	Discrete
Children under 10	Discrete
Number of children in household	Discrete
Number of outdoor taps	Discrete
Water lawn	Categorical
Frequency of lawn watering	Categorical
Duration of lawn watering	Categorical
Lawn watering technology	Categorical
Tap type	Categorical
Outdoor tap use	Categorical
Presence of rainwater tank	Categorical
Number of rainwater tanks	Discrete
Drink tap water	Categorical
Perception of water quality	Categorical
Worry for family water security	Categorical
Worry for community water security	Categorical
Agreement with water restrictions	Categorical
Daily total water end-use per household (L/hh)	Continuous
Daily total water end-use per person (L/pp)	Continuous
Daily outdoor water end-use per household (L/hh)	Continuous
Daily outdoor water end-use per person (L/pp)	Continuous
Daily total water end-use per household before intervention	Continuous

Daily total water end-use per person after intervention	Continuous

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