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When Wells Run Dry: Water and Tourism Along the Western Coast of Nicaragua

Gary Thomas LaVanchy
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WHEN WELLS RUN DRY: WATER AND TOURISM ALONG THE WESTERN COAST OF NICARAGUA

A Dissertation
Presented to
The Faculty of Natural Sciences and Mathematics
University of Denver

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

by
Gary Thomas LaVanchy
August 2015
Advisor: Matthew J. Taylor
ABSTRACT

This dissertation uses a political ecology approach to examine the relationship between tourism development and groundwater in southwest Nicaragua. Tourism in Nicaragua is a booming industry bolstered by ‘unspoiled’ natural beauty, low crime rates, and government incentives. This growth has led to increased infrastructure, revenue, and employment opportunities for many local communities along the Pacific coast. Not surprisingly, it has also brought concomitant issues of deeper poverty, widening gaps between rich and poor, and competition over natural resources. Adequate provisions of freshwater are necessary to sustain the production and reproduction of tourism; however, it remains uncertain if groundwater supplies can keep pace with demand. The objective of this research is to assess water supply availability amidst tourism development in the Playa Gigante area. It addresses the questions: 1) are local groundwater supplies sufficient to sustain the demand for freshwater imposed by increased tourism development? and 2) is there a power relationship between tourism development and control over local freshwater that would prove inequitable to local populations?

Integrating the findings of groundwater monitoring, geological mapping, and ethnographic and survey research from a representative stretch of Pacific coastline, this dissertation shows that diminishing recharge and increased groundwater consumption is creating conflict between stakeholders with various levels of knowledge, power, and
access. Although national laws are structured to protect the environment and ensure equitable access to groundwater, the current scramble to secure water has powerful implications on social relations and power structures associated with tourism development. This dissertation concludes that marginalization due to environmental degradation is attributable to the nexus of a political promotion of tourism, poorly enforced state water policies, insufficient water research, and climate change. Greater technical attention to hydrological dynamics and collaboration amongst stakeholders are necessary for equitable access to groundwater, environmental sustainability, and profitability of tourism.
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I am grateful to the many people who helped me during this undertaking. Many colleagues and faculty discussed with me themes and scholarship pertinent to this dissertation and gave me helpful feedback, including Joseph Hoover, Dr. Hillary Hamann, and Dr. Michael Daniels. Kate Williams provided input, companionship, and a helping hand during fieldwork. Dr. Matthew Taylor gave me everything I had hoped for in an advisor—indefatigable support, timely and critical feedback, friendship, and conversation on the waves of Playa Amarillo. Dr. Jim Clark gave consistent encouragement and invaluable help with hydrologic modeling.

In Gigante, I am indebted to the men and women who granted access to their wells and made this work possible. Particularly, I would like to express appreciation to Maximo Jesus Quedo Gutierrez for his friendship, help with data collection, and role as portal to the community and their wells.

Most of all I wish to thank my family for their constant support and understanding. Dad, Mom, Wes, Yvette, Yvonne, Jennifer, and Cindy have sustained me with their sympathy, patience, and largesse.

G. T. L

Denver, Colorado

June 21, 2015
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PREFACE

I have chosen a series of related, publishable chapters for my dissertation to streamline the process of disseminating knowledge. Although assembled as a cohesive work in this dissertation, each of the main chapters can stand alone in their arguments and treatment of an issue. A mixed-methods approach for research was chosen because of its explanatory capacity through pairing quantitative and qualitative approaches. My own experience of fieldwork in West Africa and Nicaragua, as well as a review of contemporary geographic research tells me that human-environment relationships must be addressed through a combination of methods and tools that brings together quantitative and qualitative data. Absence of either approach results in limited or even biased understanding of a given issue, and thereby diminishes likelihood for solutions or positive change. In the case of this dissertation, the issue of water security can only be sufficiently understood with inquiry that includes empirical measurement of water quantities over time and evaluation of the experiences and perspectives of the range of stakeholders. This convergent approach allowed me to gain a more robust understanding of the situation through triangulation of research findings and exploration of divergent evidence from either methodology. In other words, in using both qualitative and quantitative methods I was able to question and/or validate the findings of one method with that of the other. This allowed then for iterative research where each approach revealed results that informed subsequent steps of inquiry.
Playa Gigante, in the municipality of Tola, Nicaragua, is the main focus of this dissertation. However, the community is not an isolated social, political or economic entity but relates to the country of Nicaragua in many different ways. It is geophysically and climatically connected to surrounding watersheds, it is influenced significantly by the political history of the Sandinista movement, and it shoulders the blessing/curse of the neoliberal aims of tourism for economic development in the second poorest country in the western hemisphere.

Fieldwork in Playa Gigante, hereafter referred to as Gigante, covered a period of five years, between 2010-2015. Long term contacts and friendships ensured that research could be pursued despite the revolving door of tourists and expatriates, and the growing perception of water scarcity and concomitant suspicion of outsiders by locals. Due to the history of land grabbing along the southwest coast, many residents of Gigante have grown wary of the intent of outsiders towards resources such as land, water, and fishing. This wariness has been amplified through the concession granted to a Chinese consortium in 2013 to build an interoceanic canal. The proposed canal opening to the Pacific Ocean is a mere seven kilometers from the community of Gigante and has propagated additional concerns for land security. I am quite certain that if I were to attempt to initiate groundwater data collection in Gigante today, I would not be allowed free access in the manner I was afforded over four years ago.

Collectively, the proliferation of tourism development along the western coast and the initiation of canal construction have resulted in significant environmental and social change. For some, this has been unsettling, while others perceive change for the better. Several hard-working and gifted graduate students are currently researching aspects of
the social and economical changes around Gigante. I look forward to reading their conclusions. To be sure, it is difficult to say exactly what this area will look like, environmentally or socially, in a decade’s time. As a researcher, this has been an incredible opportunity to get in on the ‘ground floor’ to create a baseline for comparison of these changes in the years ahead. My research is fundamentally about change in groundwater supply—from both a physical and social standpoint.
CHAPTER ONE: INTRODUCTION

And why must we develop tourism in this God-forsaken country? Because it’s the path to salvation for the national economy.

—Comandante Tomás Borge, 2003\(^1\)

There is no more water anywhere, and the poor people are the ones who suffer.

—Maria, 2015\(^2\)

Most people in the region of Tola, Nicaragua depend on groundwater to sustain their lives and livelihood since perennial streams are few and in some locations, non-existent. As recent as five years ago, few people (local or foreign) gave much thought to water security, though much of the southwest coast of Nicaragua shares similar geology and climate—collective constraints on groundwater recharge. Only recently, in the wake of intensive tourism growth has the issue of water security become acute. Increased demand and several years of below average rainfall means increased effort and time for locals who must walk further to wells with sufficient water supply. This compounding of work for daily water needs inevitably leads to diminished use of water and subsequent

\(^1\) As cited in Babb, 2004, p. 541.

\(^2\) Personal interview, March 23, 2015. (Author’s translation).
potential health risks. Accessing reliable sources of groundwater adds considerable stress and expenses for tourism enterprises using deeper and often distant wells to meet their ever-growing demands. The success of these businesses, reliant upon steady water supply, has direct implications on jobs and livelihoods for local populations.

Environmental and social change in Playa Gigante (hereafter referred to as Gigante) is better understood by looking at the larger narrative and scale of Nicaraguan events such as the civil war that culminated in 1979 with the victory of the left-leaning Frente Sandinista de Liberación Nacional (FSLN), the subsequent counter-revolution (known as the Contra War) throughout the 1980s, and the ensuing decade of neoliberal governments with massive privatization and imposed structural adjustments. Hunt (2011) and others (Broegaard, 2005; Cupples, 1992; Hawkesworth & García-Pérez, 2003; Jonakin, 1996) have argued that this political upheaval, coupled with several natural disasters, left Nicaragua’s population vulnerable to the struggles of environmental degradation, pervasive wealth disparities, land insecurity, and a high foreign debt ratio.

Former Sandinista revolutionary leader Daniel Ortega was re-elected to presidency in 2006 and 2012 and maintains an intriguing political platform based on socialistic values of the past, while embracing capitalistic market economy initiatives such as tourism and maquiladoras. Across the country, huge billboards with socialist political rhetoric (e.g. “Christianity, Socialism, and Solidarity with everyone, for the good of everyone”) stand amidst modern billboards heralding tourism. This would seem an unlikely stance for the former leader of a revolution who stood at odds with Ronald Reagan, the consummate capitalist, during the 1980s. Time magazine described Ortega as “The man who makes Reagan see Red” (Time, March 1986). Yet three decades later, Ortega is back in power
and turning to tourism to generate much-needed jobs for the economy and to alleviate poverty (Carroll, 2007). It is this turn to tourism that has led to competition over water resources in Gigante—a resource for which none of the competing users have sufficient data on quantity or reliability. This then places the environment, peasant populations, and the success of tourism at risk.

**Framework, Methods and Literature Review**

This dissertation employs a political ecology perspective throughout, most notably in the first two articles (chapters 2 & 3). Although not a theory per se, political ecology provides a unifying framework to guide research agendas and answer questions of environmental change in a manner that accounts for political and economic contingencies. Political ecology is a suitable framework for investigating nature-society issues precisely because it allows me as a researcher to go beyond the simple ‘facts’ of empirically derived data or ‘local’ qualitative perspectives on water quantity. These data on groundwater resources are helpful to assess the spatial and temporal dynamics of water availability and the controlling factors of geology and climate; however, the complimentary and deeper study into the political and economic structures that induce the movement of people and promote tourism growth in Gigante allows the dissertation to trace the arc of power differentials out along multiple scales to explain implications of power and money on poverty and water security. Taking a political ecology approach allows the dissertation to include a robust, social science component to this human-environment interaction study on water.

Data on groundwater quantities and usage was largely gathered at individual wells through empirical measurements and interviews with well owners. A well inventory was
created using a global positioning system (GPS) and a geographic information system (GIS), whereby well locations were mapped and water levels for wet and dry seasons were recorded for 2012 to 2015. Qualitative information about water quantities and usage was gathered through 82 semi-structured interviews with local residents at their well as groundwater levels were measured biannually in shallow household wells using a water level meter (Heron Little Dipper). Additional information about tourism growth and related water usage was gathered in 12 structured interviews with tourism developers, private landowners, and expatriates living in Gigante.

**History of human-environment interaction research**

To be sure, there is a long trajectory of ontological and epistemological thought on relationships between humans and nature. My research questions and subsequent methodologies are situated within this intellectual space and share a relationship with the broader discourse of human-environment interaction research. The origins of such research within the North American academy can be traced back to William Morris Davis, a physical geography instructor at Harvard University (1879-1911) and founder of the American Association of Geographers. Davis advocated for a relational focus on nature and society, with the physical environment as the starting point. This was a natural point of departure for a researcher of physical landforms and their evolution. However, this precipitated a linear approach to the relationship between nature and society, with the environment acting as the cause (independent variable) and the response of society as the effect (dependent variable). This period of geographic thinking was heavily influenced by Charles Darwin’s work on the evolution of species, which brought particular focus on environmentally induced change in animals over time (Stoddart, 1986). For geographers,
this approach to nature and society relationships grew into an explanatory framework known as environmental determinism, where nature determined the actions and reactions of humans. In time, this approach proved problematic as cultural data were relationally attributed to environmental conditioning without any verifiable scientific methodology. Ellsworth Huntington and Ellen Churchill Semple were among the leading proponents of this framework during the early part of the 20th century, contributing, among other things, subjective arguments that promoted stereotypes and justified imperialism (Peet, 1985).

**Human & cultural ecology**

Later geographical thought and inquiry was critical of environmental determinism and sought to bring a balanced perspective to understanding the relationship between nature and society. The work of Harlan Barrows during the 1920s led to a framework known as human ecology, where human behavior was interpreted as an adjustment to nature, rather than determined by nature. During this same period, the work of Carl Sauer promoted a framework known as cultural ecology, where human agency influenced the natural landscape while simultaneously being constrained by nature (Sauer, 1956). His fieldwork-based research and inductive approach brought needed attention to the ways in which humans altered the environment and guided geographic thought on human-environment interaction research in North American geography during the 1960s. Sauer rejected positivism, thereby conceding the realities of contingency within environmental and cultural change. His approach, later known as the “Berkeley School of Thought,” endures today and is considered a major contribution to the formation and evolution of political ecology.
Also within this decade, biologist Rachel Carson (1962) brought exceptional clarity to the issue of human induced environmental degradation in her book *Silent Spring*. Her activism contributed to a national environmental movement (Earth Day) and subsequent changes in government policies such as the National Environmental Protection Act (1969), the Clean Air Act (1970), the Clean Air Act (1972), and the establishment of the U.S. Environmental Protection Agency (1972).

**Political Ecology**

Political ecology emerged within this trajectory during the 1970s as a blend of human ecology and political economy, the latter as derivatives of dependency theory (e.g. Frank) and world system theory (e.g. Wallerstein) with special emphasis on power, global class system, and core/periphery frameworks. This structural Marxist approach allowed for power to be placed at the center of analysis and for structures of inequality to explain nature-society interactions (Biersack, 2006). In this way, subjugation and exploitation of local populations and ecologies was linked to the larger political, economic, and social structures of the global capitalistic system. Several studies within this first wave of political ecology are worth noting as path-breaking to the field and foundational to subsequent inquiry. Bernard Nietschmann examined the social and environmental change of the Miskito Indians of eastern Nicaragua for his dissertation at the University of Wisconsin. Rather than ascribe a neo-Malthusian explanation to a local ecological crisis, he focused on “how forces generated from larger and more complex social and economic systems have changed, disrupted, and are destroying the ecological and social stability of the Miskito system” (1973, p. 2). This analysis of the inequalities
of capitalism ran counter to mainstream environmental research that sought explanation largely in demographic factors.

Michael Watts also added a turning point within cultural ecology with his dissertation fieldwork on food, famine, and politics in West Africa. *Silent Violence: Food, Famine and Peasantry in Northern Nigeria* explained food security and famine in Hausaland in terms of peasant culture, agrarian capitalism, and colonial history, rather than resource scarcity or population pressures. According to Watts (1983), a moral economy existed in Hausa culture that mitigated the risks associated with agricultural production. This changed with market penetration during colonialism. He argued that this moral economy eroded as peasants became tied to commodity production, leaving communities “vulnerable to both market crisis and a capricious climate.”

(p. xxiii). This historical emphasis on the oppressive, extractive dimensions of British colonialism by Watts provided a broadening of inquiry and explanation into human-environmental interactions and reflected a poststructuralist shift in political ecology where both nature and human agency were viewed as contingent and problematic.

Piers Blaikie addressed the widespread, yet misunderstood nature of global soil erosion and its relationship to peasants and pastoralists through the development of capitalism. *The Political Economy of Soil Erosion in Developing Countries* powerfully described the discourse of development and underdevelopment as “inequalities between the majority of the rural populations affected by soil erosion and other more powerful groups in access to adequate economic opportunities” (Blaikie, 1985, p. 3). For Blaikie, the problem of soil erosion was as much a socio-political problem as it was environmental, with conservation policies being as much the cause as solution. An
additional contribution of this work to the study of human-environmental interaction was its capacity to draw together epistemologies and ideologies of physical and social processes within a singular study of ecology (soil erosion). Blaikie (1985) argued for combining a “place-based” analysis of a particular ecological issue with a “non-place-based” analysis of the social dimension of production. Blaikie and Brookfield (1987) furthered analyses of land degradation in their coedited volume *Land Degradation and Society*. Collectively, these works were decidedly social in terms of causes and solutions, indicating a fundamental shift from technical (natural science) to social preoccupation. Citing a long tradition of failed attempts by ‘scientists’ to ameliorate degradation and rural poverty, the editors nonetheless called for collaboration and communication between the natural and social sciences due to the complexities involved in measuring dynamic processes and interpreting them through various theories of social process.

Political ecology as a research framework found further momentum in the 1990s as scholars from diverse institutional and academic backgrounds sought to address a litany of environmental problems and their influence on societies in the developing world. Raymond Bryant (1992) gave a thorough critique of political ecology as a research agenda as it gained popularity against the backdrop of mounting global environmental issues and diverse scholarship. Although still young as a research agenda, Bryant (1992) argued that political ecology offered substantive explanatory strengths but lacked “systematic definition” and a degree of coherence. Twenty years later, Robbins (2012) similarly pointed to lack of unity and coherence as defining qualities of the field. The diversity of the field often makes it hard to pinpoint common ground held by its practitioners, but Robbins described political ecology as a method that “mobilizes
concepts from broader schools of thought to explain otherwise confounding socio-environmental outcomes” (2012, p. 84).

**Criticisms**

Two major criticisms of political ecology over the span of its emergence are its *a priori* bias of the primacy of political factors in explaining environmental change and the absence of rigorous ecologic investigation. Vayda and Walters (1999) argued that political ecologists were too quick to ascribe culpability to a wider sphere of politics to the neglect of environmental complexities surrounding the change. Citing several research examples and dynamics of political movements, they castigated the field as a whole for its lack of ecologically centered questions and for prioritizing political factors through methodological bias. In their estimation, the vacuum of political scrutiny, which birthed the movement, had been transformed into a vacuum of ecology.

To this point, Walker (2005) asked the question, “where is the ecology?” in political ecology. In somewhat rhetorical fashion, Walker answered his question by providing an array of evidence in contemporary literature showing the inclusion of biophysical ecology. In point of fact, Walker argued the claims of Vayda and Walters were based solely on a few examples and did not reflect the field as a whole. Walker did concede, however, that ecology often was lacking as a central element and the present trajectory of the field pointed toward a future less explicit about ecology and more interpretive of discursive struggles. To the latter, Walker raised an important question echoed in other prominent reflections on theoretical growth within political ecology. That is, *what passes for environmental knowledge? And how is nature constructed?* This scrutiny lies within a broader trend within political ecology to treat bodies of texts as
discourse, or coherent knowledge fields, that “reflect and shape relations of power” (Neumann, 2005, p. 93-94). A discourse can then be analyzed for modes of thought, logics, or styles of expression to reveal bias or unequal treatment and marginalization.

Anthropologist Arturo Escobar (1996) championed a poststructural political ecology position through discursive analysis of environment and development. He argued that notions of global poverty and underdevelopment arose from discourses produced by Western technological viewpoints seeking to bring the global South into modern institutions and practices. In this context, nature is socially constructed from a positivist viewpoint and degradation is framed in simplistic and reductionist causal explanations. Feminist political ecology furthers the range of discursive products by treating gender as a “critical variable in shaping resource access and control, interacting with class, caste, race, culture, and ethnicity to shape processes of ecological change…” (SAGE, 2007). Schroeder (1999) and Rocheleau, Thomas-Slayter, & Wangari (1996) offer excellent examples of gendered approaches to resource access and control.

**Conclusion**

In summary, it should be noted that political ecology has maintained its usefulness in examining human-environmental interactions despite divergence along various theoretical pathways. This is, in part, explained by the ever-growing need for human-environment research (Turner, 2002) and the degree of complexity involved in deconstructing the human and environment elements of the inquiry. Each year, impressive studies are published that give us new and renewed insight into various ways that human agency mediates and is constrained in its relationships with nature.
Several studies were essential to my research on groundwater and tourism in Gigante in their ability to expand my understanding of theoretical perspectives and their capacity to help me organize and leverage issues into a coherent argument. Among these are Lichtenthäler’s (2003) insightful and thorough analysis of water resource allocation and management in Yemen, Stonich’s (1998) rendering of the relationship among tourism development, water, and environmental health in the Bay Islands, Honduras, Cole’s (2012) description of the political dimensions of inequitable water distribution and tourism in Bali, and the geographical analysis of tourism and sustainable water supply by Kent, Newnham, and Essex (2002).

Within the array of theoretical models that make up political ecology, I have chosen a pathway that draws on concepts articulated by Watts (1983), Blaikie & Brookfield (1987), Derman & Ferguson (2003), Perramond (2010), and Stonich (1998). Since tourism has been adopted as an economic tool by the Nicaraguan government, I argue that a political ecology approach is necessary to explain environmental change in Gigante. The following elements are central to my approach of understanding the relationship between environmental and social change:

1. Explaining why and how outcomes of environmental change (e.g. freshwater supply) are felt unevenly by different stakeholders.
2. Interpreting how power is expressed in monetary and political dimensions (locally and beyond).
3. Linking research to action to inform policy and encourage social justice.

Additionally, I share the perspective of Escobar (1996) that, “capitalist exploitation of people and the environment is organized according to the rules of the dominant
development discourse of the past 40 years, for which nature exists as raw material for economic growth activities” (p. 334). Since tourism in Nicaragua (employed as an economic development tool) is predicated on nature, I argue that groundwater, as a key ingredient to tourism success, is at risk of uninformed exploitation in southwest Nicaragua, consequently putting local populations and tourism enterprises in vulnerable positions.

Content

Each of the main chapters in this dissertation is meant to stand alone with sufficient theory, methods, arguments, and conclusion. As such, there remains a certain degree of overlap within the dissertation in terms of background, field site description, and relationships between tourism and water. The conclusion of the whole of the dissertation is found in the individual conclusions of each chapter and can be summarily stated as tourism has gained significant presence and represents a powerful tool of change within Nicaragua; however, the constraining factor of sufficient water may put it at odds with economic sustainability and with peasant populations.

To decipher the nature of long-term impacts, notions of homogeneity must be placed aside and critical evaluations involving social and environmental epistemologies must be undertaken. Questions of tourism legitimacy at the global level are much the same at the regional level. Who really benefits from tourism? Is it an effective tool for growing economic progress in developing countries? Will tourism perpetuate poverty or help narrow the gap between rich and poor? Will intensive tourist centers promote social evils or create equitable opportunities for employment and interaction? And what impacts will tourism and subsequent consumption have on the environment? These questions, and
many others, are beginning to be addressed in Nicaragua. More is needed. Tourism is not going way, either on a global level, or in Nicaragua. The question remains, how will it be channeled and managed to promote the most economic good with the least detrimental impact on society and the environment? Each of these three main chapters argues for more assessment and for greater collaboration among all stakeholders.

Chapter Two describes initial conflicts over water between locals and tourism operations within the discourse of common pool resources and backdrop of ineffective implementation of national water polices. It points to the anachronism of tourism in post-revolutionary Nicaragua and argues the need for further research, collaboration, and transparency. This chapter has been published online in the *International Journal of Water Resources Development*, print version forthcoming (doi:10.1080/07900627.2014.985819). Chapter Three further peels back the layers of human-environmental interaction in Gigante through a political ecology analysis of tourism that identifies power and access differentials on local and global scales. Returning to the point and trajectory of my research and the use of political ecology, it would be easy to explain water conflict in Gigante as primarily a factor of difference in wealth and power—the case of luxury tourism enterprises using their resources to capitalize on limited supplies of water to the exclusion of poor with less power. However, the reality is more complex and deserves multiple layers of scrutiny with diverse questions. The chapter is influenced by seminal studies from Stonich (1998) in Honduras and Nietschmann (1973) in Nicaragua that evaluated change in local social and environmental systems from outside forces. Chapter Four is a fuller hydrological study aimed at providing a tool for sustainability by describing hydrological trends, sustainable aquifer yields, and water management
recommendations. Chapter Five provides a summary of the dissertation, as well as
directions for future research.
CHAPTER 2: TOURISM AS TRAGEDY? COMMON PROBLEMS WITH WATER IN POST-REVOLUTIONARY NICARAGUA

Introduction

Water resources are essential to the support of life and livelihoods, yet the challenges of its supply and demand persist in both undeveloped and developed regions of the world. Issues of water security and the critical role of groundwater resource management are perpetual points of international news, debate, conversation, and research (Friedman, 2013; Gleick & Palaniappan, 2010). Nearly half of the world’s population is expected to be living in areas of high water stress by 2030, due, in part, to expected increase in use from agricultural expansion, industrialization, and population increase (Seckler et al., 1999; WWAP, 2012). This consumptive increase is exacerbated by forecasted impacts of global climate change on the spatial and temporal variability of precipitation—particularly as it relates to recharge of surface and groundwater in regions all around the world (Cooley et al., 2012; Kundzewicz et al., 2008).

Many countries throughout Latin America are faced with rising pressures of water provisioning due to population growth, increasing urbanization, tourism, and climate change (OECD, 2012; Van Noorloos, 2011; World Bank, 1998). The ensuing water stress and scarcity is complicated by policy governing usage, privatization, and economic recession. Over the past decade, several Latin American countries have re-structured
national laws to define groundwater as a public good in order to ensure equity and sustainability. Although these laws provide citizens with a constitutional guarantee of equitable access to water, it remains unclear if this ‘commons’ strategy will fulfil its intended outcomes when growing demands are confronted with diminishing supplies. The common pool nature of groundwater makes it particularly challenging to manage and potentially vulnerable to a tragedy of the commons (Brentwood & Robar, 2004). This paper uses the following definition of common property:

A good or resource (e.g., bandwidth, pasture, oceans) whose characteristics make it difficult to fully enclose or partition, making it possible for non-owners to enjoy resource benefits and owners to sustain costs from the actions of others, typically necessitating some form of creative institutional management (Robbins et al., 2014, p. 55).

Tourism is a US$1.159 billion global industry (UNWTO, 2014) that continues to grow as global commodity chains are strengthened and communication networks grow in their capacity to attract visitors to distant locales. This ‘push’ end of the tourism growth equation is complemented by a ‘pull’ component of increased revenues for host locations. This form of economic stimulus is often an attractive means for increasing national revenues and boosting foreign direct investment in many developing countries (Messerli, 2011; Oyewole, 2009; Stonich, 1998). International donor agencies, such as the World Bank, United States Agency for International Development (USAID), and the Inter-American Development Bank (IADB), have played key roles in extending tourism as a form of development throughout Latin America. The efficacy and impact of tourism as a development tool has been critiqued by a range of scholars (economists, geographers, sociologists, and anthropologists) on a variety of levels (economic, political, social,
cultural, and environmental). Regardless of how tourism is interpreted, outcomes (positive or negative) are inextricably linked to the provisional support of freshwater resources. Adequate supplies are necessary for a range of uses (drinking, bathing, flushing a toilet, spas, recreation, food production, and garden and landscape maintenance) and contribute to the overall well-being of tourists and the tourism industry. However, in many destinations the rapid growth of tourism appears to be at odds with sustainable supplies of water resources (Gössling et al., 2012; Holden, 2000). These conflicts over supply and demand have direct bearing on the environmental and socio-economic well-being of tourist destinations.

This chapter examines the increasing demand placed on limited water resources by a rapidly growing tourism sector in the Playa Gigante area. It argues that tourism in Playa Gigante is (1) a product of national interest in tourism and a world-class coastal and surf setting, (2) is dependent upon the common property regime of groundwater, and (3) is at odds with the provisioning capacity of the local aquifer. The case of Playa Gigante is presented since it represents a liminal example within the broader global nexus of tourism and water. Conclusions and recommendations are offered that might allow this case study to be an example of water management success.

**Water and Tourism in Nicaragua: an overview**

Like most of Central America, Nicaragua (Figure 2.1) relies heavily upon groundwater for its source of potable water supply. Groundwater currently provides Nicaraguans with an estimated 95% of their potable needs, compared to 30-50% for most other regions of the world (Bethune et al., 2007; Bundschuh et al., 2007). As a whole, Nicaragua is known as a ‘water-rich’ country due to abundant reserves in both
groundwater and surface water (Castillo Hernández et al., 2006). However, the spatial distribution of this resource is often mismatched with the need, particularly with respect to tourism development. Over the past decade, this incongruity has become more apparent in the face of growing tourism along the southwest Pacific coast—a region with the most tourism growth and least amount of rainfall.

Nicaragua has emerged as an attractive tourist destination, thanks in part to abundant natural resources, government promotion, and endorsement from satisfied travelers. Babb (2004) and others (Hunt, 2011; McClure, 2014) have detailed the remaking of Nicaragua into a safe and desirable tourist destination. After decades of political and revolutionary turmoil, Nicaragua now offers ‘unspoiled’ natural beauty, tourist-friendly locals, and ample opportunities to buy, rent, or borrow a slice of paradise (Dear, 2013; LaTourrette, 2006; Nichols, 2010).
Indeed, since the mid-1990s, tourism arrivals and receipts have grown at a steady rate from US$50 million in 1995 to over US$400 million in 2013 (Figure 2.2).

Historically, arrivals to Nicaragua have been tourists from other Central American countries or backpacker, budget-minded travellers from North America (INTUR, 2009). This mode of tourism translates to a modest average of US$325 per tourist visit, the lowest in Central America and one-third that of Guatemala and Costa Rica (Vargas et al., 2010). To increase revenue, the government and investors have promoted tourism in a variety of forms and durations. Moreover, in 1999 the Nicaraguan government increased
its commitment to and dependence on the foreign-exchange earnings from tourism by passing Law 306, making tourism an “industry of national interest” (Article 1). This was further codified through a reform bill (Law 495) in 2004 that offered aggressive incentives and benefits to individuals or corporations that generate tourism activities.

This prioritization of tourism on the part of the national government has resulted in increased tourist arrivals, diversity in types of tourism, and accompanying rises in tourism receipts. Perhaps the most pronounced example of the diversification of tourist types is the rise in residential tourism. Matteucci et al. (2008) have documented the increase in second home tourism proliferating along the southwest coast since 2000.
Although these ‘holiday’ homes often lack full time residents with enduring expenditures, they represent a significant injection of revenue into local economies.

Residential tourism in Nicaragua has agglomerated along the southern Pacific coast where population densities are low and weather is more temperate and dry—key ingredients to many looking for retirement or a second home in seaside locations. During the late 1990s, the southwest coast was particularly attractive to surfers searching for empty waves, pristine coastline, and the pace of unhurried life (Klinger, 2014; LaTourrette, 2006). This commencement of tourism opened the door to expanded infrastructure, amenities, and grand schemes for owning a slice of paradise. A burgeoning surf culture now exists along the Pacific coast that supports all level of surfers—foreign and domestically grown. Nicaragua tourism authorities (INTUR) have been quick to recognize this boom and have shaped media campaigns to entice tourists to the southwest Pacific region. Advertisements inside the Managua international airport invite arriving tourists to sample coastal amenities, while major surf competitions, such as the 2012 International Surf Association (ISA) World Masters, 2013 Junior ISA World Championships, and 2015 ISA World Surfing Games have been hosted in an effort to attract more of the international surfing community and build Nicaragua’s reputation as a world-class surfing destination.

Similar to other global tourist destinations, the increase in arrivals and amenities to this area brings a growing demand for provisioning water resources and the risk of over-exploitation. Gössling (2001) and others (Cazcarro et al., 2013; Kent et al., 2002; Rico-Amoros et al., 2009) have provided case studies that demonstrate the imbalance of
water use between locals and tourists—a pattern of demand that is certainly true of southwest Nicaragua.

**Research Area**

Although tourism is experienced in many locations throughout Nicaragua, the southwest coast is heavily marketed and represents a significant revenue opportunity for the economy of Nicaragua as evidenced by the sale of ocean lots in excess of US$400,000 and homes of US$2 million. The trajectory of growth seems problematic given the lack of developed water resources in this region. Playa Gigante offers a case study that typifies much of the southwest coast with respect to tourism growth and deficient water resources.

Located west of Rivas in the municipality of Tola, Playa Gigante is a small coastal community with a population of roughly 550 in an area of 16 km² (Figure 2.3). A small portion of its inhabitants live along a short stretch of beach on the Pacific Ocean, while the remainder are distributed along two stretches of dirt roads connecting the coastal community to a larger municipal road. The community of Playa Gigante (hereafter referred to as Gigante) has a relatively short history and is currently comprised of fisherman, farmers, expatriates, and a few part-time residents from Managua. As recently as the late 1970s, this area was a cattle ranch owned by former Nicaraguan dictator Anastasio Somoza Debayle. In the late 1980s, the land was re-distributed by the Sandinista government to a cooperative of 72 families who began fishing and small-scale farming. Since that time, the land around Gigante has been settled, sold, and bought as various individuals, entrepreneurs, and developers have recognized the abundant natural beauty and wealth of the area.
Tourism Development in Gigante

As the international surf community became aware and interested in the idyllic surfing conditions around Gigante, small surf lodges proliferated and tourism arrivals and expenditures increased. Additionally, interest in buying land and building vacation homes led to the establishment of several gated communities poised exquisitely along prime coastline. These larger gated communities exemplify the residential tourism outlined by Matteucci et al. (2008) and reflect the hard pioneering work of both foreign and Nicaraguan ingenuity, capital, and vision. For the most part, these larger tourist enterprises market themselves as environmentally conscious purveyors of local socio-
economic progress. Undoubtedly this pioneering effort has ‘opened’ up the southwest coast to development aimed at a range of tourism opportunities, local job productions, education initiatives, and health brigades. This opening up of the coastal face of the Pacific, however, has not come without a struggle and conflict over land (Abu-Lughod, 2000; Ferrando, 2007; Morales, 2007). It is also worth noting that most of this development has been carried out with assumptions of sufficient water resources and little to no government oversight or studies on groundwater.

Infrastructure and opportunity have grown in tandem with tourism development in Gigante and have created a ‘pull’ effect, attracting Nicaraguans from other parts of the country. Some migrants have been employed by outsiders, own their own tourism enterprises or have squatted on land to stake a life in fishing or establishing ownership on land that might someday appreciate as the coast is further commoditized. Integrative evaluation of the impact of tourism has yet to be realized due to its nascent presence in this area. Some researchers and small non-governmental organizations (NGOs) are beginning to capture this change through social, economic, or environmental lenses. This research, then, addresses the resource upon which current tourism is predicated—water.

**Research Methods**

This paper draws on data collected during field research from December 2010 to March 2014. There are limited baseline data for this remote research area. Isolated references to water availability in regional-scale reports and generalized geological maps provide limited clues about water resources in the area. Thus, more data were required for rigorous hydrological investigations to speak to the issue of water availability and growing demand of a resource of unknown quantity. A mixed-method approach was used
to gather data on site-specific water availability, use, and conflicts. This included interviews (n=80) with local residents, community leaders, tourists, tourism development managers, and local NGOs; well monitoring (n=70); and geological field mapping. This mixed-method approach was appropriate for getting at the water ‘story’ from both a social and physical perspective. The research was designed to map the distribution of wells, to track changes in groundwater levels, to estimate the water usage of various stakeholders, and to discover perceptions of groundwater level changes with respect to tourism growth and variation in precipitation.

Well monitoring was performed to measure changes in the water table of the provisioning aquifer. This involved locating and tagging each well with GPS (Figure 2.4), recording well elevations relative to sea level, and measuring static water levels (SWL) for both wet and dry seasons from June 2012 to March 2014. A Geographical Information System (GIS) was implemented using ArcGIS 10.2.

Historic rainfall data are limited for this area; however, a 39-year averaged monthly record is available from a National Oceanic and Atmospheric Administration (NOAA) station in Rivas (id: NK78733000690700), 22 km linear distance north of Gigante. A more useful daily precipitation data set was acquired through the generosity of one of the local tourist developments, located nine kilometres from Gigante. This detailed data set extends back to 2009 and provides a helpful correlation and comparison with daily static water levels in local wells. In order to document and analyse the fine scale response of groundwater to precipitation and withdrawal, data loggers were deployed in two wells to monitor water levels, water temperature, and electrical conductivity continuously.
Water Resources: Physical Parameters and Policy Issues

The geology of coastal southwest Nicaragua has direct influence on the quantity of water resources available to its communities and accompanying tourism developments. The area of Gigante is underlain by the Brito geological formation, a sedimentary sequence of sandstones and thinly bedded siltstone and mudstone turbidites up to 2500 m in thickness (Arengi & Hodgson, 2000; Levi et al., 1995). In general, the fine-grain nature of mudrocks (<63 µm) severely constrains groundwater movement since clasts are tightly packed together and little pore space is available for water storage and movement. Aquifers comprised of siltstones and mudstones are typically low yield, unless
accompanied by vertical fractures or horizontal bedding plane separations that allow for more water to be stored and transmitted through the aquifer. The Brito formation underlying Gigante is highly fractured, thus providing secondary porosity for groundwater movement along bedding planes and vertical fractures (Figure 2.5). Although fracture-hosted flow is capable of enhancing water provisioning, the complexity of determining fracture distribution and rates of groundwater flow renders water management a challenging enterprise. Since this area contains no surface water and only two ephemeral streams, groundwater is the only freshwater option.

Figure 2.5. Generalized schematic model showing the role of bedding planes and fractures on groundwater movement in the Brito formation.
Most of the wells in Gigante are hand-dug (artisanal) and extend from 5 to 15 m in depth. These generally produce limited quantities of water (between 0.5 and 5 l/s) and can supply several households. Drilled (perforated) wells are few in number and are owned by larger tourism developments or resident foreigners. These deeper wells (35-260 m) tap into the larger cross-section of the fracture network (Figure 2.6) and typically produce greater volumes (up to 970 l/s), though they are susceptible to saltwater intrusion due to over-extraction.

Figure 2.6. Simplified cross-section showing well and conceptualized coastal hydraulic conditions in the Brito formation.
The rainfall regime of southwest Nicaragua also plays a major role in determining groundwater quantities. It is characterized by a rainy season that runs from May to November, which produces 96% of the annual average of 1476 mm (Figure 2.7). Two sub-watersheds (La Boba and Manzanillo) control the input of recharge for the provisioning aquifer(s) of Gigante (Figure 2.3). Recharge is regulated by precipitation, evapotranspiration, and infiltration rates, the latter being strongly influenced by soil surface and topography. In this case, thin rocky soil cover on sloping hillsides contributes to increased surface run-off and reduces the effectiveness of precipitation to recharge the aquifer(s).

*Figure 2.7.* Average monthly precipitation for the state of Rivas, 1968-2006. Source: INETER data from NOAA station NK78733000690700.
The National Water Law (Law N° 620 of 2007) establishes water as a public good and provides a framework for the state to ensure its role in social and environmental well-being and to protect against over-exploitation. The law empowers the National Water Authority (Autoridad Nacional del Agua, ANA) to manage national water resources and regulate allocation of water rights among users. The law was based on the Dublin principles, which contend that successful water management systems entail meaningful stakeholder participation and some degree of government oversight and support. In part, the ANA’s mandate is to “prepare a water balance for each basin” and “propose management regulations for basins and aquifers” (Republic of Nicaragua, 2007, p. 20). These directives have yet to be implemented for the Manzanillo and La Boba watersheds, rendering any notion of recharge quantities or safe-yield extraction a veritable guess. Thus far in the Gigante area, only a few of the tourism developments have complied with regulatory demands that require property owners to request permission to drill wells. Applications for these permits include technical reports for projected usage and rudimentary environmental impact statements. Novo and Garrido (2010) noted that Law N° 620 has great potential to reach its stated goals, but as of yet has no practical success of solving water conflicts due to the barriers of “transaction costs of inter-institutional coordination, information gathering, property rights protection and enforcement, and strategic costs” (p. v). Although other case studies in Nicaragua successfully demonstrate the intent of national water law policy (meaningful stakeholder participation plus government oversight and support), Gigante and other areas undergoing rapid tourism development along the Pacific coast represent a gap between policy intent and successful water management.
Results

Data collected from the well-inventory show seasonal changes in static water levels (SWL) over the past two years and illustrate the rapid increase in the number of wells over the last 20 years (Figure 8). The proliferation of wells shown in Figure 2.8 gives a sense of the exponential rise in water demand since the mid-1990s. This growth in number of wells means that more ‘straws’ are pulling from the aquifer(s).

![Figure 2.8. Proliferation of wells in Gigante.](image)

Water level monitoring of 70 wells revealed that 73% of the artisanal wells were lower after the 2013 dry season than they were following the 2012 dry season and seven went completely dry for three months or longer during 2013. Although two years of precipitation and water level observations cannot provide sufficient data for long-term
hydrological predictions, the addition of results from semi-structured interviews about water availability and use through time adds depth to the picture of increased water demand and potential conflicts over water availability. Nearly all of the informants interviewed (n=80) believed that precipitation was diminishing and well water levels were progressively declining since 2010. Almost all well owners had a quantitative idea of the water level differences within their wells from dry to wet season and 90% reported that levels from the past two years were less than any other time in memory. Such intimate knowledge of their wells comes from the daily activity of drawing water from their wells using a rope and bucket.

Additional interviews (n=11) revealed the growing use of water from tourism developments. The recent construction of a world-class 18-hole golf course, several boutique hotels, and numerous restaurants means that demand for groundwater will continue to grow. Some of these needs are met through additional perforated wells, while other tourism enterprises are pumping from artisanal public wells. Rapid and sustained extraction of water from Gigante’s public artisanal well by one tourism outfit resulted in the drying of this well since April 2013 and forced neighbouring households to scramble for alternative water sources. A formal complaint was lodged by community members at the municipality mayoral office to contest the excessive extraction of groundwater from a public well. To date, no action has been taken due to the strong political connections of the responsible tourism outfit. Similarly, four households and a primary school reported that their artisanal wells have gone dry since the installation of an adjacent perforated well to provision the golf course of the largest tourism outfit in the Gigante area.
Daily static water levels (SWL) from data loggers in two wells were compared to cumulative daily precipitation values in order to understand aquifer recharge response to rainfall throughout the year (Figure 2.9). The time lag between onset of rains in May and aquifer response (as reflected by increase in SWL after August) was just over three months, demonstrated nearly simultaneously in both wells. (Compare marker P₁ to R₁ and R₂). Conversely, SWL began steadily decreasing a mere three weeks after the terminal rainfall in early November. (Compare marker P₂ to R₃ and R₄). This difference in response time (onset of the rainy season vs. the terminus) suggests that extraction rates exceed recharge rates for the given hydrologic year.

*Figure 2.9.* Comparison of precipitation and static water levels in two wells in Gigante.
Examination of geological outcrops and artisanal well lithologies revealed discrete vertical fractures within inter-bedded siltstones and mudstones. Such rocks typically result in low yield aquifers, however the observed fracture networks indicates that groundwater is predominately moved via secondary porosity, rather than pore space. Transmissivity (T) is the rate at which groundwater moves through an aquifer, expressed as distance over the period of a day. Values can be determined through pump tests and provide comparative productivity between wells within an aquifer. In this study, T variations ranging from 9 to 360 m$^2$/d were measured in five deep wells (210-260 m) over a relatively confined area (QUENCA, 2011b). This dramatic range in values underscores the heterogeneity of the geometry of the fracture system and illustrates the complexity involved in quantifying the aquifer and the inherent water management challenges for this area.

**Discussion and Policy Ramifications**

Groundwater resources in Nicaragua are considered assets of the entire nation under the managing responsibility of the state (Law 620). In this sense, they functionally exist as a common property regime. However, groundwater quantities and spatial distribution are largely unknown in the Gigante region due to insufficient data and research. This lack of information is particularly disconcerting in view of the substantial investment being made in various tourism developments (up to US$500 million in one case) and the subsequent need to secure provisioning water resources (see McDonnell, 2008, for an analysis of the value of supportive data and technology to productive water management). Although the state is tasked to manage groundwater, currently there is no implemented means to quantify resources and measure extraction, thus setting up the
potential for a tragedy of the commons. Similar to other countries in Latin America, the national water policies of Nicaragua have compelling aims, lofty intentions and trendy vernacular. They employ an implied ‘integrated’ perspective for water management that is intended to bridge various institutional sectors (social, environmental, and economic), efficiently decentralize responsibility to lower levels of government, and engender local stakeholder participation. However, these broad aims to promote socially, environmentally, and economically responsible water management have fallen short in much of Nicaragua such that effective water management at local scales is often lacking (Novo & Garrido, 2010; OECD, 2012). Unfortunately, wide gaps between national policies and implementation are not unique to Nicaragua (see Biswas, 2008, and Scott & Banister, 2008, for critical examinations of similar shortcomings in Latin America).

In the case of Nicaragua, a grassroots response to this gap has provided some progress and offers hope for improved water management throughout the country, particularly in rural areas. Potable Water and Sanitation Committees (Comités de Agua Potable y Saneamiento, CAPS) are recognized and encouraged by the central government as a way for local stakeholders, through collaboration between government and international donor institutions, to fund and govern local water resources. Active CAPS have historically protested and fought for inclusiveness in state policy and have earned a credible spot at the table within the discourse of water policy and management (Romano, 2012a). Presently, there are thousands of CAPS operating throughout Nicaragua at a variety of levels of success (Kreimann, 2010). As might be expected, any success is ultimately a product of the organizational and leadership strength of the local CAPS (Romano, 2012b).
The gap between national policy and local water management is particularly striking in Gigante. Since none of the water laws are implemented in this rapidly developing region, water resources are at the disposal of anyone with sufficient means (and needs) to extract them. In this sense, Gigante is a bit like the ‘Wild West’ in that almost anything goes with regard to developing tourism and securing the water necessary to support such tourism development. Like other forms of common pool resources, extracted groundwater impacts all other users of the aquifer in the watershed and will invariably lead to unequal apportioning or even conflict under conditions of scarcity. At this stage, with two years of collected data, it appears that the large quantities of water used by tourism-related operations are beginning to impact the total supply. This can be argued quantitatively from the difference in SWL response time between the wet and dry seasons. The aforementioned conflicts between locals and tourism outfits further support this assertion of extraction outpacing recharge. Gigante’s public well adequately supplied residents with cleaning and cooking water for the entire 30-year history of the town. Soon after a tourism outfit began pumping 10,000 litres per day (to clean fishing boats), the well dried up and remains unusable to date. Additionally, residents living near the golf course installed in 2011 reported that once reliable family wells are now perennially dry. Noting that the golf course has a budgeted dry season requirement of 2.5 million liters per day (QUENCA, 2011a), it appears rather likely that high levels of extraction by tourism developments is causing shallow artisanal wells to run dry. This ‘water grabbing’ (Mehta et al., 2012) in the Gigante area has accelerated perceptions of diminishing water quantities and also heightened awareness of the power inequalities between actors. Those
actors with more money and/or political clout can extract water, with impunity, when and where they want.

Local residents of Gigante worry about water security as more of their wells dry or drop to new low water levels. Previously, local users were fewer in number and drew water from large diameter hand-dug wells using a pulley and bucket. Under this regime, groundwater volume (and recharge) was sufficient to meet low levels of use. Tourism growth and increased population in Gigante has resulted in more users and more wells. Additionally, electric pumps are now being used by many locals to draw water from artisanal wells. Although this method decreases the labor required each day to draw water, it subsequently translates to greater withdrawals as local users find additional uses for water (e.g. irrigation of crops). Although most local residents seemed aware of the growing demand for water and limited supply, few informants offered community-wide solutions. When wells are seasonally dry, owners either excavate additional depth from the well (if possible), manually haul water from further distances, or decrease consumption. Typically the burden of excavation falls on the shoulders of men, while hauling water manually on those of women and children.

**Whither tourism?**

Although tourism appears to be eagerly embraced at nearly all levels across Nicaragua, it represents an ideological anomaly for a country still committed to socialistic outcomes and equality. Since the 1979 Sandinista revolution, Nicaragua has moderately held a position in which the state and the economy are (ideologically) meant to serve the majority through a socialist-oriented system. However, in an effort to dislodge its status as the second poorest nation in the western hemisphere, Nicaragua’s
government has embraced neoliberal economic agendas, including the promotion of
tourism. Using tourism as a tool for development is a promising piece of this solution,
however, it is unclear whether this tool will provide sustainable socio-economic
development or merely perpetuate inequality in wealth (Wilson, 2008). It also remains
unclear what impact the tourism agenda will have on the environment—a critical
resource for the country and for tourism development.

It is evident that tourism is already impacting water resources in the Gigante area.
The combination of smaller tourist developments, along with the construction of a water-
intensive golf course, puts increased demands on water for which the supply is not yet
known. Interviews with tourism developers (n=14) revealed that all stakeholders are
wondering if they will have sufficient water resources to maintain their business. This
pressure on groundwater is anticipated to increase given recent advertising for this area of
Nicaragua’s Pacific Coast in prominent international surf, outdoor, golfing, and inflight
magazines. This increased visibility will likely translate to increased tourism visits and an
array of interest in adding more tourism development.

Some collaborative effort has been made in Gigante to tackle the growing issue of
water security through the organization of a chamber of commerce and a CAPS. This is a
promising development in that a CAPS represents a viable link to national policy and
holds strong potential for representative power in legal battles over water. However,
interviews with Gigante CAPS members revealed that they had little knowledge of the
process for presenting claims to the municipality mayoral office or how to solicit and
access outside donor funds. To date, the CAPS in Gigante has not been able to move
from the organization to action phase, leaving a question of its efficacy and ultimately the plight of water security in Gigante.

**Conclusions and Recommendations**

This chapter has reported on a study of the increase in tourism and its implications on water resources in Gigante. Despite the limitations of the local hydrogeological data, it has been possible to identify the increasing demand and diminishing supply of water, and the culpability of tourism development. This area represents a growing epicentre of tourism for Nicaragua and holds potential to successfully demonstrate the efficacy of tourism in the context of economic growth and social and environmental responsibility—useful examples to many other contexts within Latin America.

I have identified several conflicts between local users and tourism outfits and argued that future conflicts will only increase among all stakeholders unless the gap between national water policy and local water management is narrowed. This gap entails both an organisational component for stakeholders and the quantifying of water resources within the complex aquifer(s) to determine a safe yield for groundwater extraction. The mechanism of CAPS has been proven effective in other parts of Nicaragua and represents a very plausible solution for bringing attention to the growing demands of water from tourism within a context of insufficient hydrological data for this area. Without investment in baseline research and subsequent knowledge dissemination, conflict over water is likely to increase. Additionally, a well-informed CAPS can fairly represent all stakeholders and streamline reporting to the National Water Authority (ANA), thereby helping to bring resolution to water access inequalities and over-exploitation of
groundwater through its legislative connection to national water policies aimed at social and environmental protection.

In order to close the gap between national policy and local management, it is recommended that steps be taken to 1) determine aquifer(s) safe yield and 2) strengthen local organisation and capacity. The former is necessary to guide water management so as to avoid undesirable results such as deterioration of ecosystems, contravention of local water rights, saltwater intrusion, and diminishing provision for tourism. Safe yield is distinct from sustainable pumping rate, which is typically calculated as an equivalency of estimated recharge. Rather, safe yield, or sustainability, is based on hydrologic principles of mass balance and should be understood as a dynamic and iterative process that captures the nuances of human and environmental changes over time. Thus, it is necessary to monitor groundwater levels, track land-use changes (affecting infiltration and recharge), and integrate hydrologic dimensions of climate change. A unified monitoring network of key perforated wells should be established in order to facilitate observation of groundwater level changes with respect to recharge and withdrawal. This would require installation of data loggers (for water levels, water temperature, and electrical conductivity) and a central collection system and database. Since fractures represent the principal pathways of groundwater flow in the aquifer(s), it is recommended that fracture network geometry (length, orientation, location, density, aperture, and connectivity) be characterized via appropriate methods (e.g. tracer and packer testing). Tourism developments should take the lead, but contribution should also be made from single well owners. Additionally, monthly water level measurements for all artisanal wells should be collected and added to the proposed central database. This would allow
for transparency and supportive evidence in conflict mediations and would serve to narrow the aforementioned gap between policy and management.

In order to strengthen local organisation and capacity, informational meetings should be convened for the Gigante CAPS in order to link members with others successful CAPS in Nicaragua and to educate members on the process of gaining national recognition and collaboration with potential donor agencies. Additionally, a workshop for sharing best practices on tracking water consumption rates and promoting water conservation would serve to stimulate collaboration amongst all stakeholders, as well as contribute to sustainability and adaptive water management.
CHAPTER 3:  
WATER RESOURCES AND TOURISM DEVELOPMENT ALONG THE WESTERN COAST OF NICARAGUA: A POLITICAL ECOLOGY PERSPECTIVE

Introduction

Peering over the ledge into the dimly lit, hand dug well, my eyes slowly adjusted so that I could see the thirty centimeters of accumulated water at the bottom of the seven-meter deep well. This amounted to a mere 240 liters of freshwater—hardly enough to satisfy the needs of the six houses that depended upon the well. Maria explained to me that it would take three to five days before the well produced another 240 liters that could be pumped and distributed to her relatives.¹ Things have changed in the small coastal community of Playa Gigante (Figure 1). In years past, this well had been more than adequate to meet their needs. Maria and Ernesto have lived in Playa Gigante since the mid-1990s, shortly after a large portion of the area was re-distributed to an agricultural cooperative by the Sandinista government. They had moved here to carve out a new life, supported mainly through fishing and subsistence farming. Ernesto had told me on previous visits that his well would fill completely at the end of each rainy season. “I could reach down into the well with my hand and scoop out water with a bucket.”² This year (2014), the rainy season brought only 60% of the average precipitation. The two

¹ ‘Maria’ here is a pseudonym, as are the other names in this article.

² Personal interview, June 4, 2014. (Author’s translation).
previous years had been below average also. To make matters worse, a local tourism business bought a four-meter by four-meter plot of land within ten meters of his well for the sole purpose of installing a deeper well with a pump. Ernesto told me this was a big reason why his well is now nearly empty.

Earlier that week, Ernesto mentioned he was going to dig his well deeper—something he has never had to do before. When I arrived to help him the next morning at 6:30am, his wife Maria was orchestrating the deepening of the well with her nephew and brother-in-law. She told me Ernesto was still out on his fishing boat with a client. Standing in the dusty, dry yard, listening to the sounds of chicken, pigs, and howler monkeys, I surveyed the situation. A decade of tourism growth had brought significant opportunity for local business, including charter fishing for Ernesto. Although many in the community welcome this economic ‘progress,’ they also speak with growing concern about tourism’s impact on limited water supply. More tourism means more business, but it also means more demand on water—something that is in shorter supply due to prolonged drought in the region. Collectively this means a scramble for water security and subsequent conflict with definite winners and losers.

This chapter explores the relationship between tourism development and local populations in southwest Nicaragua through the lens of freshwater supply. Particular attention is paid to the political and economic institutions in which tourism is embedded, globally and in Nicaragua. Research for this study involved various aspects of the human and physical geography of the study area gathered over five years of intensive field visits to Playa Gigante (2010-2015). Specific research into the water supply issue involved a well inventory, quantitative groundwater measurement, geologic mapping, and in-depth
and multiple informal interviews with stakeholders. This interdisciplinary and multi-method approach was employed to better understand the complex nature and contingency associated with environmental, political, and economic issues.

The chapter is divided into three sections. First, the political ecology of tourism development is outlined at the global and regional level, with particular emphasis on tourism linkages to political agendas and water supply. Second, the causes of water crisis in Playa Gigante are evaluated. Water supply is traced through the limitations of geology and recent climatic variability to growing demand through tourism development and increase in local populations. Water is shown to flow towards power, with a small number of winners capturing most of the rewards and the remaining participants scrambling for resources with little to no hope of water security. Third, the water struggle and its consequences for local populations and tourism developers are outlined. Social power is scrutinized through examples of competition over limited supplies of water, while economic consequences for tourism developers are projected. Implications and recommendations for water management are then offered.

**Political Ecology of Tourism Development**

Global tourism has experienced steady growth and expansion over the past six decades and represents one of the largest economic sectors in the world at a value of US$1.245 billion (UNWTO, 2015). International tourist arrivals grew by 4.7% in 2014, the fifth consecutive year of growth since 2009 (UNWTO, 2015). Like most capitalistic ventures, the long-term success of tourism is dependent upon new markets and opportunities. Within tourism literature, these new markets are described as ‘emerging destinations’ and constitute the highest area of growth across the tourism landscape.
Arrivals to such destinations are expected to increase at a rate of 4.4% between 2010 and 2030—double that of arrivals to ‘advanced economies’ (UNWTO, 2014). Central America continues to grow in popularity as a tourism destination due to cultural attractions, biodiversity, and affordability. To this end, tourism promoters are increasingly pitching enchanting destinations to tourists with an appetite for discovery and interest in less-crowded destinations. Between 1986 and 2013, tourist arrivals and receipts to Central America grew at average annual rates of 9.3% and 14.2% respectively, exceeding the average global rates. Given the current and projected growth of tourism in emerging destinations, it becomes essential to evaluate the environmental, social, and economic dimensions of impacts on receiving destinations.

**Discourse of tourism**

Tourism is best framed within the larger discourse of capitalism given its market functionality and tendency for valuation within narrowly defined cost-benefit analysis. Although the efficacy and impacts of tourism are simultaneously argued and defended (Hunt & Stronza, 2014; Messerli, 2011; Spenceley & Meyer, 2012; Torres & Momsen, 2005; Zapata, Hall, Lindo, & Vanderschaeghe, 2011), there is little doubt that economies and resources in developing countries are often reoriented to serve the needs of tourism and exogenous markets (Britton, 1982). Similar dynamics in Central America can be traced back to the 19th century when production and exchange of commodities such as coffee, beef, and sugar where brokered at the hands of elites who monopolized resources and subjected certain classes of people to marginalization to the benefit of external consumption (Beckman, 2013; Dore, 2006; Gobat, 2005). This outcome fits with Marx and Engels’ (1978) observation of the larger global pretension of capitalism whereby
“[t]he need of a constantly expanding market for its products chases the bourgeoisie over the entire surface of the globe. It must nestle everywhere, settle everywhere, establish connections everywhere” (p. 476). Although this teleology is conceptually easy to consign to tourism, it is no easy task to determine social and economic implications given that capitalistic impacts in developing countries produce markedly different results across space and time. This brings us back to the debate of tourism as a means for improving economies in developing countries. Presently, many countries throughout Latin America export commodities with high social and environmental costs. Extractive industries (e.g., oil, natural gas, mining) are more costly on the environment and actually produce fewer jobs than other sectors. In contrast, tourism offers countries a commodity that creates jobs and does not have to be extracted for value in the traditional sense. However, tourism comes with a high demand for water, which can prove problematic for areas with limited water resources, often the case for popular tourist attractions in coastal and island destinations (Gössling, 2001).

**Tourism and water**

Nicaragua has emerged as an attractive tourism option within Central America and threatens to supplant the tourism hegemony of Costa Rica (Lane, 2015; McClure, 2014). After decades of being off the travel circuit radar due to political upheaval, Nicaragua is catching the eye of many travelers looking for the ‘next big thing.’ In addition to its ‘unspoiled’ natural beauty and low crime rates, tourism benefits from government promotion and endorsement as a means for generating much needed economic activity. However, tourism development is highly dependent upon sufficient quantities and quality of water supplies. Tourists and residents require safe, dependable
supplies of water to meet drinking, cooking, washing, and cleaning needs. Further amounts of water are needed to support tourism related amenities such as swimming pools, golf courses, and landscaping. Stonich (1998) and others (Crase et al., 2010; Deyà Tortella & Tirado, 2011; Gössling et al., 2012; Holden, 2000) have shown that tourists use significantly more water per capita than local users, thus creating the potential for conflict over water and marginalization amongst users. Despite this obvious link between tourism and local water supplies, very little academic research addresses this issue in developing countries. A few exceptions include work by Stonich (1998) in Honduras, Cole (2012) in Bali, Gössling (2001) in Zanzibar, and LaVanchy and Taylor (2015) in Nicaragua. Limited research may be attributable to a lack of available data. Since access to water is fundamental to development and an indicator of progress towards Millennium Development Goals, more research is necessary to fully evaluate the disproportionate water consumption within the growing tourism sector against the aims of policy promoted tourism to contribute towards economic progress in developing countries.

**A Political Ecology Approach**

Political ecology is an analytical framework employed across several disciplines that “focuses on the interplay of diverse socio-political forces, and the relationship of those forces to environmental change” (Bryant, 1992, p. 14). It allows for research on local environments to be understood through the actions of local stakeholders, as well as global political and economic processes. Although originally posited by anthropologist Eric Wolf in a call to integrate understandings of local ecology with larger economic influences, the field of political ecology has grown along five distinct, but often overlapping, narratives: degradation and marginalization, conservation and control,
environmental conflict and exclusion, environmental subjects and identity, and political objects and actors (Robbins, 2012). These theses of political ecology have been employed in various geographical and political contexts by an array of scholars (Blaikie & Brookfield, 1987; Escobar, 1996; Nietschmann, 1973; Perramond, 2010; Rocheleau, Thomas-Slayter, & Wangari, 1996; Watts, 1983) to demonstrate that environmental change is effectively a product of political process.

This chapter is mainly concerned with environmental conflict and exclusion vis-à-vis water resource access and control in a tourism-laden context. In the case of Playa Gigante, insufficient water supply is a differentiated event, that is to say, consequences are not experienced evenly by all stakeholders. However, it is not enough to simply point out the winners and losers in this conflict. As Robbins (2012) argued, “it is essential to understand the degree to which such outcomes are non-incidental, persistent, and repetitive” (p. 87). To this end, this paper treats tourism developers as diverse actors with degrees of agency, rather than a monolithic entity. Some actors are merely capitalizing on economic opportunity, despite social and environmental consequences to locals, while other actors perceive and pursue sustainability as a best course for all. Thus, a combined structure and actor-based analysis is well suited to capture the complexities of this place-based environmental change (Kütting, 2010).

**Research methods**

The research results presented in this chapter draw from multiple field visits from December 2010 to June 2015. A mixed-method approach was used to gather data on site-specific water availability, use, and conflicts. This included in-depth and informal interviews (n=90) with local residents, community leaders, tourists, tourism development
managers, and local NGOs; well monitoring (n=92); and geological field mapping. This mixed-method approach was appropriate for getting at the water ‘story’ from both a socio-cultural and physical perspective. The research was designed to map the distribution of wells, to track changes in groundwater levels, to estimate the water usage of various stakeholders, and to discover perceptions of groundwater level changes with respect to tourism growth and variation in precipitation. The research was confronted by limited baseline data, including conditions that existed before the recent growth of tourism. This made it very difficult to make causal connections between tourism development and aquifer depletion. However, the trend in decreased precipitation (i.e. diminishing aquifer recharge), proliferation of new wells, and increased water consumption via the tourism sector suggests that the growth of tourism is having significant impact.

This chapter uses a political ecology approach to analyze human-environment interactions in Playa Gigante because of the national political agenda to promote tourism (Carroll, 2007) and the unsupported nature of the national water policy. Playa Gigante (hereafter referred to as Gigante) was chosen as a study site because it represents the ‘frontier’ of tourism growth in Nicaragua. Thus, my findings will be of benefit to the stakeholders in Gigante, as well as to those areas that constitute the next ‘wave’ of tourism growth along the southwest coast of Nicaragua.

Tourism development in southwest Nicaragua

Gigante is a small coastal community in the municipality of Tola on the southwest coast of Nicaragua (Figure 3.1). A small portion of its 550 inhabitants live along a short stretch of beach on the Pacific Ocean, while the remainder are distributed along two
stretches of dirt roads connecting the coastal community to a larger municipal road. The community of Gigante has a relatively short history and is currently comprised of fisherman, farmers, expatriates, and a few part-time residents from Managua. As recently as the late 1970s, this area was a cattle ranch owned by former Nicaraguan dictator Anastasio Somoza Debayle.

Figure 3.1. Map of study area in Nicaragua. Cartography: Mary Lee Eggart.
In the late 1980s, the land was confiscated by the Sandinista government and redistributed to a cooperative of 72 families who began fishing and subsistence farming. Since that time, the land around Gigante has been settled, sold, and bought in waves as various individuals, entrepreneurs, and developers have recognized the abundant natural beauty and wealth of the area. This commodification of land was stimulated in part by the interest of surfers from North America and Europe who discovered pristine surfing locations along the coastline. Studies of surf tourism in Costa Rica offer some consideration of how surf tourists contributed to a process of economic growth and accompanying environmental and socio-cultural growing pains (Krause, 2007).

As the international surf community became aware and interested in the idyllic surfing conditions around Gigante, small surf lodges sprang up to accommodate the interest of well-heeled surfers looking for empty waves and the chance for adventure. Over time, news spread about the opportunities for world-class surfing near Gigante and tourism arrivals and expenditures increased. With this growth came the development of a hostel, a few small hotels, and several restaurants. Additionally, interest in buying land and building vacation homes led to the establishment of several gated communities poised exquisitely along prime coastline. These larger gated communities exemplify the residential tourism outlined by Matteucci, Lund-Durlacher, & Beyer (2008) and reflect the hard pioneering work of both foreign and Nicaraguan ingenuity, capital, and vision. For the most part, these larger tourist enterprises market themselves as environmentally conscious purveyors of local socio-economic progress. Undoubtedly this pioneering effort has ‘opened’ up the southwest coast to development aimed at a range of tourism opportunities, local job productions, education initiatives, and health brigades. This
opening up of the coastal face of the Pacific, however, has not come without a struggle and conflict over land (Abu-Lughod, 2000; Ferrando, 2007) and resources (Alvarado & Taylor, 2014; LaVanchy & Taylor, 2015).

**Mass vs. quality**

Numerous studies on the environmental impacts of tourism in developed nations are relevant for emerging tourism destinations where data are often lacking. Several recent papers examined the comparative water demand and consumption of ‘quality’ and ‘mass’ tourism, where quality tourism is characterized by low density, second homes and golf courses, and mass tourism by intensive vertical hotel growth, and high season sun and sand consumption. Hof and Schmitt (2011) and others (Deyà Tortella & Tirado, 2011; Rico-Amoros, Olcina-Cantos, & Sauri, 2009) demonstrated that water consumption patterns are actually higher for low density, quality tourism than mass, or hotel tourism. In part, this is due to the gardens, swimming pools and golf courses that accompany quality tourism. Although tourism is a highly differentiated activity, these findings are significant to the growth of tourism in southwest Nicaragua that is trending towards low-density models. It is worth noting that these types of tourism developments market their ‘quality’ model as more sustainable and environmentally friendly than other forms of tourism, when in fact, little research seems to have been done on their behalf to warrant such claims.

**Construction of nature**

Sign, symbols, and even slogans often give insight into values and perceptions held by certain cultural groups. The global tourism industry has become adept at creating perceptions of certain spaces through the power of marketing (think of the slogan, “what
happens in Vegas…”), which can lead to homogenous understandings and expectations of certain landscapes. Although Nicaragua is known as a land of water and nature, the country is not uniform in its landscape or resources. Despite the fact that the southwest coast receives a modest amount of average annual rainfall, tourism promotion for this region is overtly ‘green’ in its depiction and branding of pristine and verdant landscapes (Figure 3.2). One particular tourism development has heavily marketed “Emerald Coast” as a moniker for this stretch of coastline even though the hills are completely brown during the five-month dry season.

Figure 3.2. Selected examples of ‘green’ marketing for the southwest coast of Nicaragua.

Although this type of branding makes marketing sense in its appeal to tourists, the projection of ‘green’ obscures the reality that this tourism hotspot is centered in an area with crucial precipitation challenges. Website images, magazine advertisements, and billboards singularly portray the wet season version of the landscape, when everything is
green and water friendly. (See Figure 3.3 for a contrast between wet and dry seasons). This projection then creates a fundamental lack of awareness of the hydrological challenges in this area and establishes expectations for green landscapes by visiting tourists. In turn, copious amounts of water (up to 65% of total daily usage) are required by tourism developments to provide tropical and green landscaping for homes and public spaces during the dry season that meet the expectation of owners and visitors. Even further amounts are necessary for water consumptive amenities such as golf courses. The disproportional demand and use of water for the golf course is visually illustrated in Figure 3.3 by the stark difference between the green course and surrounding brown vegetation in the April image. (April is at the end of the dry season, while January is two months after the end of the wet season). This manufactured landscape has an estimated water demand of 1.7 million liters per day in the dry season. This water demand for green landscapes drives up business costs and further underscores the disproportionate water usage by the tourism sector. Despite these common projections of green landscapes and adequate supplies of water, the tide is turning on perception of water availability and sustainability as many tourism operators are forced to alter their business plans in the face of inadequate water supply.
Figure 3.3. Contrast in wet and dry seasons, emphasizing disparity of watered landscapes. Images of April (above) and January (below). Source: Google Earth.
Gigante’s Water Crisis

The sharp rise of tourism in the municipality of Tola in recent years has led to unpredicted pressures on water resources. Tourism developers use varying amounts of water to provide services to customers. Water is used in nearly every facet of service provided to tourists, including cleaning food (restaurants), cleaning boats (fishing charters), laundry service, showers, swimming pools, landscaping, and keeping golf courses green (to name a few). As recently as 2010, a report issued by the Center for Water Resources Investigations, CIRA, noted that tourism was growing in the region, but that plenty of water seemed available (Delgado, Calderón, Flores, & Salvatierra, 2010).

Yet the combined growth of tourism and declining trend in precipitation has led to a reversal of perspective on water availability. In fact, many wells are running dry in Gigante. Midway through the 2015 dry season, 66% of wells were already dry.

Interviews with well owners revealed unprecedented experiences and a growing sense of crisis by local populations and tourism operators. The water crisis conflates a number of human and physical issues, namely rainfall variability, geology, proliferation of wells, and unsupported national water policy. Most people in the region of Tola depend on groundwater to sustain their lives and livelihood since perennial streams are few and in some locations, non-existent. Given this reliance on groundwater, geology and precipitation become controlling factors in the provisioning of water resources for locals and tourism developers, and only those with money and power can overcome these naturally limiting factors.
Rainfall regime

The study area belongs to a portion of Nicaragua considered dry-tropical forest and is characterized by unevenly distributed rainfall and distinct wet and dry seasons. Nearly all of the average rainfall of 1476 mm occurs May to October, with the *canicula* (brief summer drought) breaking the rainy season in July. A portion of the current water crisis in Gigante results from less than average rainfall in four of the past six years (Figure 3.4).

![Yearly rainfall from 2009-2014. Dashed line represents average yearly rainfall of 1476 mm based on 39 years of data collected by INETER.](image)

*Figure 3.4.* Yearly rainfall from 2009-2014. Dashed line represents average yearly rainfall of 1476 mm based on 39 years of data collected by INETER.
**Geology**

Gigante lies in a watershed underlain by the Brito geological formation, a 2500m thick sedimentary sequence of shales, limestones, sandstones, siltstones, and mudstones, with pockets of volcanic breccias and tuffs (Arengi & Hodgson, 2000). The upper extent is mostly fine-grained sandstone with negligible porosity (<2%).

Thus, groundwater movement in the aquifer is largely controlled by bedding planes and vertical fractures, making well productivity spatially variable and challenging to predict. Rainfall infiltration (i.e. groundwater recharge) is also constrained by the low permeability of surface rocks and material. Most of the wells in Gigante are manually dug and extend from 5 to 15 m below the surface to intersect the water table. These generally produce limited quantities of water (between 0.5 and 5 l/s) and can supply several households. Drilled wells are few in number and are owned by larger tourism developments or resident foreigners. These deeper wells (35-260 m) tap into the larger cross-section of the fracture network and typically produce greater volumes (up to 970 l/s), though they are susceptible to saltwater intrusion due to over-abstraction. Figure 3.5 shows the spatial extent of wells in Gigante. In addition to rainfall and regional geology, anthropogenic factors also play a critical role in water availability.

**Human geography of water crisis**

Gigante’s growth as an attractive tourism destination has led to an increased number of tourism developments and an influx of Nicaraguans from other parts of the country seeking employment, opening businesses, or merely squatting on land to stake a claim in fishing or establishing ownership of land that might someday appreciate as the coast is further commoditized. Collectively, this means an increase in water demand, as
demonstrated by the proliferation of wells since 1990 (Figure 3.6). Boutique hotels, restaurants, and new residences within gated communities continue to spring up in Gigante. Recent interviews with several tourism developers revealed plans to expand operations, which will inevitably lead to further demand for water. These developers are actively looking for ways to improve well productivity and for additional areas to drill new wells.

Figure 3.5. Map of well inventory. Sources: G.T. LaVanchy and Esri base map.
Figure 3.6. Proliferation of wells in Gigante.

The national water law of Nicaragua (Law 620 of 2007) established water as a public good and provided a framework for the state to ensure its role in social and environmental well-being and to protect against over-abstraction. The law empowers the National Water Authority (Autoridad Nacional del Agua, ANA) to manage national water resources and regulate allocation of water rights among users. In part, ANA’s mandate is to “prepare a water balance for each basin” and “propose management regulations for basins and aquifers” (Republic of Nicaragua, 2007, p. 20). These directives have yet to be implemented for any of the nation’s twenty-one water basins, rendering any notion of recharge quantities or safe-yield extractions for tourism development a veritable guess. Without such guiding data, tourism developers are merely poking straws in the ground until they find sufficient quantities of water to suit perceived needs. This uninformed
manner of water abstraction puts tourism developers at risk of failed production, or worse, saltwater intrusion from over pumping. The absence of sustainable water management from the tourism industry then puts local populations at risk as declining water tables fall below their capacity to manually dig wells. Hand dug wells in this area are typically only 15 m deep due to the challenges (material instability, heat, pressure) incurred by excavators. Moreover, any deepening of wells is costly to well owners. During the 2015 dry season, most locals were forced to deepen wells, paying local well diggers US$20 a day for their work.

Returning to the issue of the national water law, Novo and Garrido (2010) noted that Law No 620 has great potential to reach its stated goals, but as of yet has no practical success of solving water conflicts due to the barriers of “transaction costs of inter-institutional coordination, information gathering, property rights protection and enforcement, and strategic costs” (p. v). Thus, Gigante and other areas undergoing rapid tourism development along the Pacific coast represent a gap between policy intent and successful water management.

**Water Struggles and Consequences**

The current water crisis induced by increased demand, decreased supply, and ineffective water laws has very real consequences for both local populations and tourism developers. It can be argued that social stratification occurs in Gigante around water access, regardless of nationality. Those with financial means have power to ‘grab’ water (Mehta, Veldwisch, & Franco, 2012) through larger pumps, deeper wells, or simply freedom to range further from home to meet their water needs. Those without power are
forced to survive on substandard levels by using less, and often brackish water. This imbalance in turn leads to health risks and further disparity.

The term water ‘grabbing’ is suitable to describe the situation taking place in Gigante since groundwater functions as a common property regime and consumption by one individual reduces the amount available for other consumers. Further, groundwater has a non-exclusive quality in that it is impossible, or very costly, to exclude additional users. Given that no water budget or safe-yield has yet been established by ANA for the Gigante area water basin, nothing guides or constrains actors from grabbing water they deem necessary. Several examples are worth noting to illustrate power differential and the marginalization effect of water grabbing.

One of Gigante’s two public wells adequately supplied residents with cleaning and cooking water for the entire 30-year history of the town. Laundry was cleaned at the well and water was drawn and carried by hand to nearby homes. In 2013, a tourism operator began pumping and hauling 10,000 liters per day to clean charter-fishing boats. Within two months the once reliable public well dried up and remains unusable to date. The tourism operator then began pumping from the remaining public well. After several months of similar abstraction, owners of nearby wells reported increased salinity in their family wells from seawater intrusion. Presently, six of these wells are unusable for potable water sources (Figure 3.7).
Returning to the narrative introduced at the beginning of this paper, some forms of water grabbing are more obscure, but just as impactful on water security. The example mentioned in the opening narrative involved a tourism surf lodge that purchased a four-meter by four-meter parcel of land adjacent to historically productive wells in order to secure their water needs. However, they dug deeper and installed a larger pump with no regard or understanding for the impact it might have on the local population in the vicinity. This increased abstraction, coupled with decreased recharge has coincided with the drying of the adjacent well, leaving others to now scramble for water. A similar
scenario unfolded when another small tourism operator purchased a sliver of land (4 m x 10 m) amidst homes and wells and dug a 28-meter artisanal well, largely with the aid of expensive air hammer tools unavailable to locals. Shortly after pumping from the well, adjacent users complained to the tourism developer that their wells were dry. In describing the incident, the developer’s initial (and limited) reaction was merely “I felt like I stole their water.”3 Again, the lack of understanding of groundwater movement by tourism developers and absence of water budgets from ANA creates a scramble for water resources that discriminates against those without power or economic means. As one local put it, “There is no more water anywhere, and the poor people are the ones who suffer.”4

Further to this point, residents living near the golf course installed in 2011 reported that once reliable family wells are now perennially dry. One resident reported that he approached the luxury resort owning the golf course to request that they deliver water to compensate for his dry well. When they refused, he threatened to take the story to a prominent newspaper. This prospect of negative exposure forced the resort to capitulate and now they deliver water to all proximate owners of dry wells. While it is difficult to disentangle the impacts of tourism abstraction from the current drought, the estimated dry season requirement of 1.7 million liters per day for the golf course (QUENCA, 2011a) undoubtedly plays a contributing roll in the drying of artisanal wells. In the eyes of locals, it is THE cause of their dry wells.

3 Personal interview, June 3, 2015.
For tourism developers

The current water crisis has very real consequences for tourism developers also, though the impacts are non-uniform since economic and political power varies among stakeholders. Again, those with less power (politically or economically) are at the mercy of other more powerful actors and often end up in the ‘loser’ category with local populations. This outcome can be seen when small tourism developments, relying on shallow hand dug wells, have been forced to haul water from public sources or drill costly new wells. Some small operations must make do with using brackish water for most of their needs and buying costly delivered water to meet potable demands. Other, larger developments, express growing concerns about encroachment as they watch others scramble for new locations to drill wells. Without proper studies, nothing prevents new users from installing wells that negatively impact adjacent wells. Of greater concern for tourism developers is the issue of saltwater intrusion. Spatially concentrated wells in coastal environments can easily disrupt groundwater flow equilibrium and move the freshwater-saltwater interface. Again, without adequate studies to determine sustainable yields, it is too easy for a few users to over-abstract and negatively effect all other users.

Policy and management implications

Ultimately, much of the water crises hinges on unimplemented national water laws and policy in the face of tourism growth and climate change. The national agenda to promote tourism as a tool for economic growth has resulted in increased tourism growth and concomitant water consumption in geographical areas with little to no understanding of aquifer dynamics and provisioning capacity. This deficiency is the unfortunate outfall of the inability of ANA to produce a comprehensive water plan as mandated by Law 620
in 2007. Ultimately, the blame of the water crisis can be ascribed to this gap between policy and implementation. Most tourism developers have little to no background in water prospecting or management, so are forced to figure it out as they go. One tourism operator went so far as to say, “I’m a businessman, I don’t have the time to deal with this.” Without a proper water budget for individual water basins, tourism developers are not forced to develop an informed water budget for their respective needs.

However, some alleviation to the water crisis is being found via management as the recent drought trend has caused some tourism developers to proactively examine water usage and take steps towards conservation. In part, this has taken the form of small placards and signs in restaurants or hostels to remind tourists to save water. The largest conservation impact has been realized through installing water meters on individual houses in most of the gated communities around Gigante. This strategy has brought much needed realization to homeowners of the amount of water being used (often on landscaping), as well as incentivized the pinpointing and remediation of leaking pipes. Several of the gated communities have implemented tiered tariffs, thereby economically discouraging heavier demands for water. To further decrease their water footprint, one gated community is actively replanting water intensive landscaping with plants that use less water, yet still provide color and variation to the seasonally brown hillsides. Only one development in this study indicated a willingness to invest financial resources for a proper hydrological study to determine the balance between their water demands and aquifer availability.

5 Personal interview, June 3, 2015.
Each of the measures mentioned above are necessary for productive and equitable tourism, yet can often be costly and do not exclude others from disproportionate usage. The larger factor in the water crisis is undoubtedly the role of government and its inability to provide informed support and constraint to water management schemes. Other water scarce global tourism destinations faced with rising consumption have taken steps towards sustainability through various management related schemes and provide helpful examples to follow (Kelly & Williams, 2007). Some of these could be modified or directly implemented in the Gigante area. Cashman and Moore (2012) noted a tradable permit system for hotels in Barbados based on assigned water rights. In such a scheme, caps on total water usage would encourage an increase in efficiency by developers wishing to expand their business. Further credit could be granted to tourism developments implementing water-saving technologies. (These particular schemes and incentives are predicated on the establishment of water budgets for respective water basins). Kent, Newnham, and Essex (2002) asserted the efficacy of a proposed ecotax in the Balearic Islands. A similar tourism tax in Nicaragua could fund education and research on water in collaboration with tourism developers in high growth and under water-resourced areas like the southwest coast.

**Conclusion**

This chapter traced the global growth of tourism to the local context of Gigante, where all users are reliant on groundwater. Declining water tables constitute an important signal that water abstraction is exceeding aquifer(s) capacity. The struggles over water and unequal outcomes are the result of unsustainable tourism development, recent drought, and unsupported water laws and policy.
Several conclusions for tourism developers and policy makers can be drawn from the details of this research. First, tourism is expected to grow at a global level and in emerging destinations such as Nicaragua. Economic challenges facing Nicaragua has led to a prioritizing of tourism to generate jobs and economic growth. This puts Nicaragua into the political economy of tourism, thereby subjecting itself to the demands of global capitalistic markets and normative expectations of tourism. The tourism literature shows that arrivals from ‘developed’ countries use a much larger percentage of water than local users, resulting in a strain on local populations and environments in water scarce settings. It is evident that tourism is already impacting water resources in the Gigante area. This pressure on groundwater is anticipated to increase given recent advertising for this area of Nicaragua’s Pacific Coast in prominent international surf, outdoor, golfing, inflight magazines, and travel sections of newspapers like the New York Times. This increased visibility will likely translate to increased tourism visits and an array of interest in adding more tourism development.

Second, this chapter provides evidence of a water crisis as local consumption has outpaced supply. Tourism driven groundwater abstraction and diminished rainfall in four of the past six years has resulted in lowered groundwater tables and in some cases seawater contamination. Although the national water law requires a water budget for each water basin, none have been completed to date and virtually no technical information exists to inform sustainable abstraction rates.

Finally, this chapter concludes that the gap between national water policy and implementation has opened the door for water ‘grabbing’ by those with power, whereby the poor are marginalized through lack of access, or control of the benefits of water.
When wells run dry, or become contaminated, local populations must walk further to wells with sufficient water supply. This compounding of work for daily water needs inevitably leads to greater cost, or diminished use of water and subsequent potential health risks. Further, accessing reliable sources of groundwater adds considerable stress and expenses for tourism enterprises using deeper and often distant wells to meet their ever-growing demands. The success of these businesses, reliant upon steady water supply, has direct implications on jobs and livelihoods for local populations. Until water budgets are proposed for water basins, poor water management by tourism operators may result in the failure of their operations and simultaneously the creation of a class of losers—the original and less powerful members of this coastal community.
CHAPTER 4
TOURISM AND SUSTAINABLE WATER SUPPLY IN SOUTHWEST NICARAGUA: A HYDROLOGICAL ANALYSIS

Introduction

Water security is increasingly seen as the main global threat in the next decade as water resources face growing pressure from population increase and climate change (Gleick, 2003; Kundzewicz et al., 2008; McKie, 2015). Many aquifers around the world are being depleted of groundwater faster than they are being replenished, often due to agricultural demands. Surface waters are equally implicated. A prime current example of this can be seen in California, USA where sustained periods of drought and inefficient policy and management has led to a major crisis over water in its connection to the agricultural industry. Unprecedented mandatory water restrictions by the state are finding resistance both from individuals and the agriculture community. Somewhat related is the issue of the Colorado River and its inability to live up to a seven state compact for water allotment. Decadal rainfall variability, overestimated water budgets, inadequate management, and booming populations in the Southwest are contributing to a growing crisis over water security (Christensen, Wood, Voisin, Lettenmaier, & Palmer, 2004; Rajagopalan et al., 2009). There simply isn’t enough water in the river to meet expectations. Many similar examples of water conflict can be found across the world, indiscriminate of global status, technology, or economics. In moments of crisis, the
integral, and yet often simplistic role of water to ecological and human survival is revealed.

Water experts contend that more than adequate supplies are available to meet the needs of growing populations, the problem of water scarcity, though real, is actually a spatial and temporal issue and can be remediated through proper management, technology and policy (Oelkers, Hering, & Zhu, 2011). These spatial and temporal dimensions of water resources come to bear in the tourism industry, as typically attractive destinations are often the least endowed with adequate provisions of freshwater, yet are tasked with above-average demands for water. This niche of water demand and supply is the focus of this chapter.

The goal of this chapter is to examine the relationships between tourist demand and water supply in Gigante, Nicaragua and to assess whether the provisioning aquifer serves as a constraint to the sustainability of tourism within this area. Research for this study involved various aspects of the human and physical geography of the study area gathered over five years (2010-2015) of intensive field visits to Gigante (Figure 4.1). Specific research into the water supply issue involved a well inventory (n=92), quantitative groundwater measurement, geologic mapping, and in-depth and multiple informal interviews (n=90) with stakeholders. Data loggers (n=4) were deployed to give continuous data for water level, conductivity, and temperature parameters.

The chapter is divided into five sections. First, the provisioning of freshwater in southwest Nicaragua is outlined, including comparative precipitation regimes, geology, and hydrogeology for the water basin supporting Gigante. After describing the physical factors behind the current supply of water, the evidence of emerging conflict over water
is traced through the growth of tourism and simultaneous onset of drought. Diminished rainfall, unsupported national water policy, and inequitable power dynamics between tourism operators has led to marginalization of certain sectors of society, degraded water supplies, and unsustainable business models for an industry heralded as an economic liberator. Next, the results of an analytic element pumping model is reported, showing the impact of tourism derived pumping regimes on regional hydraulic heads and subsequent contribution to potential seawater intrusion into the coastal aquifer. Lastly, various strategies for conversation and adaptive management are discussed in the context of national water policy and global best practices. Ultimately, equitable and sustainable tourism in southwest Nicaragua hinges on collaborative arrangements between the government, tourism developers, and local community members.
Water in Southwest Nicaragua

According to a water resources assessment by the U.S. Army Corp of Engineers (2001), Nicaragua is considered a water-rich country. This is due, in part, to the abundance of precipitation that falls in the eastern region of the country for nearly nine months of the year and two large rift lakes (Managua and Nicaragua) in the Nicaraguan Depression. Despite overall perceptions of water abundance, spatial and temporal variances in rainfall create distinct regions of water availability across the country (Figure 4.2). Areas with lesser amounts of rainfall are thus hindered in terms of groundwater
recharge, which can then be problematic for those areas reliant upon agricultural or tourism, since both require disproportionate amounts of groundwater.

Key aspects of physical and cultural geography (e.g., precipitation, geology, tourism, and national water laws) contribute to the issue of water supply and demand along the coast of southwest Nicaragua. Since surface water has a limited expression, mostly as ephemeral streams, tourism driven demand for freshwater is met with groundwater reserves. Thus, precipitation and geology serve as moderators of water security for tourism development and local populations.

**Precipitation regime**

As mentioned, climate varies across Nicaragua, with the eastern portion receiving the bulk of rainfall throughout the year. Regional rainfall events are principally controlled by the Inter-tropical convergence zones (ITCZ) of the Atlantic and Eastern Pacific Oceans, the easterly San Andrés jet (12-14°N), the Hadley cell circulation, and land surface-atmosphere interactions (Poveda, Waylen, & Pulwarty, 2006). The latter controlling factor is particularly pronounced via the influence of the northwest-southeast cordillera and Lake Nicaragua on moisture-laden winds from the Caribbean. These, in turn, impact the spatial distribution of rainfall within the country.

The climate of southwest Nicaragua is characterized by continuous warm temperatures and marked seasonality in precipitation (see climate graph for Rivas in Figure 4.2). The Instituto Nicaragüense de Estudios Territoriales (INETER) maintains temperature and precipitation stations throughout Nicaragua. Historical mean precipitation (1968-2006) at Rivas is 1476 mm/year (Figure 4.3) and mean pan evaporation is 1975 mm/year (INETER data set).
Figure 4.2. Summary climate graphs for three locations in Nicaragua. Sources: NOAA data and Alexrk2 (commons.wiki).
The majority of annual average rainfall (nearly 96%) occurs during the monsoon months of May to November, creating a distinct dry season from January through April. Exceptional rainfall in June and October is common (>500 mm/month), contributing to high amounts of runoff and loss of recharge. Only a few areas in the interior highlands receive less rainfall than the Pacific coastal region, making aquifer recharge problematic for the region viewed as the epicenter of a growing tourism industry.

**Geology and hydrology**

The geology of southwest Nicaragua is comprised of several Cretaceous ophiolitic basement rocks overlain by Tertiary sedimentary rocks and Quaternary alluvium (Levi, Kumpulainen, & Darce, 1995). The Brito formation, which influences the hydrology of the Gigante area, is a westward-dipping 2,500 m succession of Eocene age turbidites, shallow marine, and continental deposits (Parsons Corporation, 1972). The top section of the Brito mostly contains interbedded sandstone, greywacke, tuffaceous siltstone, and limestone. Field examinations of outcrops and large diameter wells revealed uniformly
bedded and moderately fractured sandstones, siltstones, and greywacke. Eleven hand samples were analyzed for mineral composition and porosity (Figure 4.4). Quartz constituted the most abundant mineral, followed by plagioclase (these findings are consistent with samples studied by McBirney & Williams, 1965). Matrix porosity values were all reported below 2%, confirming the principal role of fracture permeability in groundwater movement within the aquifer(s). This limitation of groundwater conveyance and the presence of the Rivas anticline to the east prohibits surface water from Lake Nicaragua moving into the Brito formation. Groundwater recharge for the water basin related to the study area (La Boba) is thus restricted due to low matrix porosity and moderately low precipitation rates. These factors and the complexity of well development in fractured medium render groundwater productivity a challenging task for tourism developers with limited understanding, yet exclusive dependence on groundwater abstraction to meet freshwater needs.
Evidence of Emerging Conflict

The southwest portion of Nicaragua has experienced a boom in tourism due to premium coastal access, abundant natural beauty, and increased promotion. Indeed, as a whole, Nicaragua has grown annually in tourism arrivals by 9% since 1994. This
sustained growth can be attributed, in part, to a national agenda (Laws 306 & 495) prioritizing and incentivizing tourism development as a means of promoting economic growth and alleviating poverty (Carroll, 2007). During the early periods of tourism growth, arrivals tended to be backpackers or surfers looking for roads less traveled and satisfied with basic amenities. Subsequent years of tourism growth have followed the classic trajectory of tourism evolution outlined by Butler (1980), whereby expansion of arrivals typology included an increased need and offering of amenities—and proportional demand on natural resources such as water. As a whole, the global tourism sector uses significantly more water per capita than local users (Deyà Tortella & Tirado, 2011; Essex, Kent, & Newnham, 2004; Gajraj, 1981; Holden, 2000; Salem, 1995; Stonich, 1998).

Water is used in nearly every facet of service provided to tourists, including cleaning food (restaurants), cleaning boats (fishing charters), laundry service, showers, swimming pools, landscaping, and keeping golf courses green (to name a few). It is no surprise then that tourism growth in and near Gigante has been accompanied by an increase in freshwater consumption. This provisioning of tourism related amenities places subsequent pressure on area aquifer(s) to provide adequate amounts of groundwater. It is worth noting that increased abstraction of groundwater has also occurred as the result of in-migration of Nicaraguans from other parts of the country looking for employment, business opportunities, or merely the possibility to informally settle land. This increase in local inhabitants can be seen in the proliferation of manually dug (artisanal) wells over the past fifteen years (Figure 4.5).
Figure 4.5. Proliferation of wells in Gigante.

**Diminished supply**

However, below average precipitation in four of the past six years has led to diminished recharge and contributed to declining water tables. The 2014 rainy season was particularly ruinous with a meager yield of 60% of long-term average rainfall (Figure 4.6). Presently, the 2015 rainy season is lagging behind normal rates. An inventory of artisanal wells (n=87) revealed that 42% were dry even after the onset of the 2015 rainy season and another 43% were approaching critical levels (Figure 4.7). These artisanal wells range in depth from 5 to 15 m and produce limited quantities of water (between 0.5 and 5 l/s).
Figure 4.6. Yearly rainfall from 2009-2014. Dashed line represents average yearly rainfall of 1476 mm based on 39 years of data collected by INETER.
Figure 4.7. June 2015 well inventory revealing the relative quantity of water in Gigante wells. Minimum indicates less than 0.5 m remaining; Low indicates less than 1.0 m remaining. Sources: G.T. LaVanchy and Digital Globe imagery.
Data loggers in three drilled wells revealed the longer trend of water table decline in recent years. Figure 4.8 shows a negative change in hydraulic head of 3.5 m (well 202), 5.5 m (well 203), and 3.5 m (well 208) since the terminus of the 2013 rainy season.

![Graph showing daily hydraulic head values for three drilled wells in Gigante.](image)

*Figure 4.8. Daily hydraulic head values for three drilled wells in Gigante.*

These losses are nearly identical to results found in the artisanal well inventory (n=90) for the same period (see Appendix B for complete water level data). Local inhabitants with dry wells have been forced to manually haul water from greater distances, thereby increasing time and energy to meet basic needs. In tandem with these environmental aspects of water insecurity are key cultural dynamics that foment conflict by means of knowledge gaps or social and economic disparities.
Regulatory deficiencies

Tourism has grown in the Gigante area with minimal oversight from regulatory influence or guidance. Boutique hotels, restaurants, and new residences within gated communities have been accompanied by the installation of new wells by tourism developers and expatriates, most of which have been drilled without mandatory permitting required by the National Water Authority (Autoridad Nacional del Agua, ANA). The government agency is tasked to manage national water resources and regulate allocation of water rights among users so that the well-being of society and the environment is protect from over-abstraction. This responsibility is predicated on its mandate to “prepare a water balance for each basin” and “propose management regulations for basins and aquifers” (Republic of Nicaragua, 2007, p. 20). These directives have yet to be implemented for any of the nation’s twenty-one water basins, rendering any notion of recharge quantities or safe-yield extractions for tourism development a veritable guess. Without such guiding data or enforced management regulations, tourism developers are merely poking straws in the ground until they find sufficient quantities of water to suit perceived needs. This uninformed manner of water abstraction puts tourism developers at risk of failed production, or worse, saltwater intrusion from over pumping. The lack of sustainable water management from the tourism industry then puts local populations at risk as declining water tables fall below their capacity to manually dig wells. The residuals of poorly enforced regulations and uninformed groundwater abstractions are evident in selected examples of conflict.
Scramble for water security

In areas where water is scarce, it is said that water can flow uphill towards money—meaning if you have money (or other means), you can get water. Even when the margin of money (i.e., power) might be small, it nevertheless creates inequality with regard to water access and projects hardship upon those without sufficient power. In Gigante, the lack of available water (due to insufficient rainfall and increased abstraction) has led to a scramble for water security and subsequent conflict between users. Conflict over water has arisen between locals, between tourism operators and locals, and between tourism operators. In the absence of enforced water laws, the scramble for water has created physical and economic hardship for many.

As water sources become depleted, several tourism operators in Gigante have secured water needs at the expense of others. One example involved a public well that had adequately supplied residents with cleaning and cooking water for the entire 30-year history of the town. Laundry was cleaned at the well and water was drawn and carried by hand to nearby homes. In 2013, a tourism operator began pumping and hauling 10,000 liters/day to clean charter fishing boats. Within two months the once reliable public well dried up and remains unused to date. The tourism operator then began pumping from the remaining public well until excessive abstraction contaminated nearby private wells through seawater intrusion.

Some forms of water ‘grabbing’ are more obscure than the previous incident. In one case, a tourism surf lodge purchased a four-meter by four-meter parcel of land adjacent to historically productive wells in order to secure their water needs. However, they dug deeper and installed a larger pump with no regard or understanding for the
impact it might have on the local population in the vicinity. This increased abstraction, coupled with decreased precipitation (i.e., diminished recharge), has served to lower the water table, leaving those with dry wells to now scramble for water.

The current water crisis has very real consequences for tourism developers also, though the impacts are non-uniform since economic and political power varies among stakeholders. Again, those with less power (politically or economically) are at the mercy of other more powerful actors and often end up in the ‘loser’ category with local populations. This outcome can be seen when small tourism developments, relying on shallow hand dug wells, have been forced to haul water from public sources or drill costly new wells. Some small operations must make do with using brackish water for most of their needs and buying costly delivered water to meet potable demands. Other, larger developments, express growing concerns about encroachment as they watch others scramble for new locations to drill wells. Without proper studies, nothing prevents new users from installing wells that negatively impact adjacent wells. Of greater concern for tourism developers is the issue of saltwater intrusion. Spatially concentrated wells in coastal environments can easily disrupt groundwater flow equilibrium and move the freshwater-saltwater interface. Again, without adequate studies to determine sustainable yields, it is too easy for a few users to over-abstract and negatively effect all other users. Collectively, these examples underscore the gap between national policy intent and successful water management faced by Gigante and similar areas undergoing rapid tourism development along the Pacific coast.
Hydrologic Modeling

As groundwater consumption grows in the Gigante area, it becomes increasingly important to understand dynamics of regional groundwater flow (e.g., recharge rates, age of groundwater, and the influence of fracture networks on hydraulic conductivities), as well as the location and movement of the freshwater-saltwater interface. Coastal aquifers are highly sensitive to disturbance and require special attention to avoid intrusion of saltwater and contamination through overuse (Kresic, 2007; Todd, 1980). Specialized field studies can yield necessary data for modeling of the aquifer, where forecasted scenarios are simulated and information is provided regarding the lowering of the groundwater table and subsequent influence on shallow wells and seawater intrusion. The latter is especially of concern due to the sensitivity of coastal aquifers to disturbance.

Given the relative lack of available hydrological data for the study area, an analytic element model (Flowpath II, Waterloo Hydrologic Software) was chosen as a simple, ‘back of the envelope’ approach to understanding the effect of individual pumping wells on the aquifer and proximate wells by providing a continuous solution over the model domain. An analytic element model requires a simplification of the flow system, is two-dimensional, and typically steady state. Like other hydrologic models, it solves the partial differential equation to calculate head as a function of position and time.

The conceptual model of the basin was developed on the basis of surface elevation, static water levels collected during fieldwork, topographic profile measurements collected through Google Earth using the Geocontext profile mapper tool (www.geocontext.org), and a well pump test (QUENCA, 2012). In plan view (Figure 4.9), the model grid consists of 60 columns and 50 rows, further refined (4x) adjacent to
observation and pumping wells. For the flow model, a specified head boundary was
assigned to the Pacific Ocean in the west (0.0 m) and the upper reach of the basin to the
east (20.11 m). The north and south extents were not assigned constant heads.
Hydrological inputs included recharge estimated from annual precipitation and hydraulic
conductivity derived from the pumping test. Operational inputs included pumping rates
from four wells operated by tourism developers. Four scenarios were modeled, (A)
current pumping rates, (B) increase of 50%, (C) increase of 100%, and (D) increase
pumping of 100% and decrease precipitation of 25% (Table 4.1). The model was
calibrated by comparing observed drawdown for a specified well during the pump test to
calculated drawdown for the same well in the current state model. Calculated drawdown
was only 21 cm less than observed drawdown of 4.42 m. (See Appendix C for further
details). The purpose of the model was to simulate several pumping scenarios for a well
operated by the tourism development with the highest water use in the basin in order to
determine influence on other wells and potential contribution to seawater intrusion.
Figure 4.9. Plan view of analytic element model with pumping wells (red), observation wells (green), and head boundaries (red lines).

Table 4.1. Model inputs and scenarios.

<table>
<thead>
<tr>
<th>Component</th>
<th>Scenario A (current state)</th>
<th>Scenario B (increase pumping rates 50%)</th>
<th>Scenario C (increase pumping rates 100%)</th>
<th>Scenario D (increase pumping rates 100%, decrease precipitation 25%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pumping rates (m³/day)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>202</td>
<td>35.77</td>
<td>53.65</td>
<td>71.54</td>
<td>71.54</td>
</tr>
<tr>
<td>203</td>
<td>0.536</td>
<td>0.804</td>
<td>1.072</td>
<td>1.072</td>
</tr>
<tr>
<td>208</td>
<td>13.29</td>
<td>19.93</td>
<td>26.58</td>
<td>26.58</td>
</tr>
<tr>
<td>G_19</td>
<td>381.64</td>
<td>572.46</td>
<td>763.28</td>
<td>763.28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>SWL</th>
<th>Δ h (m)</th>
<th>Δ h (m)</th>
<th>Δ h (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>202</td>
<td>6.5</td>
<td>-0.5</td>
<td>-1</td>
<td>-2.5</td>
</tr>
<tr>
<td>203</td>
<td>13.8</td>
<td>-0.4</td>
<td>-1.8</td>
<td>-2.8</td>
</tr>
<tr>
<td>208</td>
<td>6</td>
<td>-0.5</td>
<td>-0.5</td>
<td>-2</td>
</tr>
<tr>
<td>G_19</td>
<td>16</td>
<td>-4</td>
<td>-8</td>
<td>-10</td>
</tr>
</tbody>
</table>
Model results

Observation of simulated hydraulic heads in the study area was conducted for the pumping well (G_19) and three additional wells closer to the coast (202, 203, & 208) (Table 4.1). An increase of pumping by 50% in all wells (Scenario B) showed slight decrease in head for wells 202, 203, and 208, but a 4 m drop in head for G_19. An increase of pumping by 100% of present rates (Scenario C) showed a similar trend of decline in heads, with well G_19 again demonstrating the highest loss. As expected, the radius of influence from G_19 became more pronounced in Scenario C, as evidenced in Figure 4.10. Collectively these pumping regimes influence the height of the water table within the aquifer(s), which in turn effect water levels in nearby artisanal wells, in addition to the position of the mixing zone of fresh and saline water.
Figure 4.10. Hydraulic head contours for Scenario B (top) and Scenario C (below).

Model implications

The result of the model can be applied to three separate, but related issues: (1) pumping influences on nearby wells, (2) depletion of the aquifer system, and (3) seawater intrusion. Although the model is somewhat limited in that it represents a
snapshot in time, rather than a transient model, it is helpful in its depiction of the changing water table under current and future pumping regimes. Keeping in mind that locals are manually digging wells that only capture the top of the regional water table (≤15 m), even the smallest change can result in limited water supplies, or even drying of wells as the table drops. This scenario is exacerbated under drought conditions, as evidenced over the past three below-average rainy seasons. As previously noted, the change in head for wells 202, 203, and 208 in Scenarios B and C are somewhat negligible with a maximum head loss of 2.9 m (Table 4.1). Under Scenario D, users of adjacent wells would certainly feel the impact. Of greater concern is the pumping influence noted at G_19 for all scenarios. Even under Scenario A (current pumping state), the radius of influence is significant with an 11 m head loss at the well. Figure 4.11 shows the spatial proximity of artisanal wells to G_19. Anecdotally, influence has been corroborated through interviews with well owners in the vicinity of G_19 who reported that once reliable family wells are now perennially dry. Scenarios B, C, and D would undoubtedly widen the sphere of deleterious influence.

**Depletion of the aquifer system**

The drawdown of the water table presented in the various scenarios relates to depletion of the aquifer system—the second issue addressed through the model. In any aquifer system, rates of abstraction must be considered against the concept of sustainable yield. This is often considered to be the long-term balance between annual recharge, annual withdrawal, and demands from the dependent ecosystem (plants, streams, springs, etc.) (Maimone, 2004; Sophocleous, 2000). The question of ‘what is renewable?’ is really the issue at play. Although a value of recharge has yet to be established for the basin, it is
apparent from well data loggers and bi-annual static water level (swl) measurements that the water table is in decline. This indicates that withdrawal rates are out of sync with recharge rates and the system is being depleted. One way of contextualizing withdrawal rates within a system is to calculate the amount of time required for the aquifer to respond and return to a steady state. This value, known as relaxation time, is typically used to evaluate the response of an aquifer to impulsive events such as a flood, but can also be applied to a pumping event and its impact on the aquifer, or individual wells in proximity.

A relaxation time \( T_{RX} \) was calculated using a simple steady solution from Phillips (2009), where \( T_{RX} = \frac{\Phi l_F^2}{2C} \). Here, \( l_F \) is defined as the maximum diffusion distance (divide to discharge), \( \Phi \) as porosity, and \( C \) as transmissivity. A range of values for transmissivity have been measured in La Boba water basin (9.13-359.12 m\(^2\)/day), underscoring the influence of fractures on groundwater movement. Using a geometric mean transmissivity \( C \) of 71.94 m\(^2\)/day and an aquifer path length \( l_F \) of 5 km, the relaxation time \( T_{RX} \) is about 99.9 years. This renders the time scale necessary for the aquifer to recover from a perturbation (such as the withdraw rate expressed in the analytical model) and return to steady state. Disregarding the minimum and maximum transmissivity values from the water basin, an averaged \( C \) can be applied to the equation that results in the relaxation time \( T_{RX} \) of 74.07 years. Both results indicate a substantial amount of time necessary for recovery and underscore the vulnerable nature of the aquifer to unmanaged groundwater withdrawal rates.

A relaxation time can be applied for wells proximate to G_19 (Figure 4.11) to determine the time scale for the groundwater level to return towards its prior configuration. A shorter relaxation time is yielded since the diffusion distance \( l_F \) is taken
as the distance between proximate wells and well G_19 (0.2 km < \( l_F \) < 0.83 km). Relaxation time values range from 58.4 days to 2.75 years for wells 101 to 104.

Figure 4.11. Spatial proximity of local artisanal wells to well G_19.
**Seawater intrusion**

To the point of issue three, seawater intrusion into an aquifer is movement of the interface between freshwater and seawater in coastal aquifers. This happens by natural and anthropogenic forcing, such as precipitation regime changes, groundwater exploitation, and sea level rise. As noted previously, coastal aquifers are much more sensitive to disturbance than inland aquifers, requiring greater diligence to avoid imbalance and depletion. In many cases, a depleted inland aquifer can recover and be of use to ecosystems and human needs, whereas an overdrafted coastal aquifer incurs seawater intrusion and becomes unusable. Knowledge of the aquifer, groundwater abstraction regimes, and principles of hydrostatic equilibrium are necessary to properly manage coastal aquifers.

The interface of saltwater and freshwater is a dynamic mixing zone at the coast where the more dense saline water (pushing inland) is overlain by less dense freshwater (moving towards the coast). The equilibrium of this interface is the result of the hydraulic gradient that exists through precipitation recharge inland (Cheng, 2003). If the hydraulic gradient is altered, through a change in recharge or abstraction rates, the mixing zone will move in response. This movement can alter the supply of freshwater to coastal ecosystems and allow saltwater to move inland, thereby degrading the aquifer.

Assuming isostatic equilibrium, the difference in densities of saltwater and freshwater defines their interface relationship and allows for calculation of the thickness of the freshwater above the interface with saltwater. This correlation is known as the Ghyben-Herzberg relationship:

\[ z = \left[ \frac{\rho_r}{(\rho_s-\rho_f)} \right] h \]
Where $z$ represents the thickness of freshwater between the interface and sea level, $\rho_f$ and $\rho_s$ are the densities of freshwater and saltwater, and $h$ is the thickness of freshwater between sea level and the water table (Figure 4.12). Since freshwater has a density of 1.000 g/cm$^3$ at 20°C and seawater approximately 1.025 g/cm$^3$, the Gyben-Herzberg relations translates to a 40:1 ratio, where every 1 m of freshwater above sea level pushes the seawater interface down 40 m below sea level ($z = 40h$). Although this ratio seems like a nice buffer between the water table and coastal seawater, the ratio equally applies to pumping induced drawdown of the water table, effectively lifting the interface with the same 40:1 relationship. This means that small amounts of drawdown, say 1 m, can bring the interface up dramatically (40 m).

Although geophysical and geochemical investigations are necessary to properly locate the mixing zone, it is possible through simple geometric calculations to determine the spatial effect of pumping regimes (through corresponding head losses) on saltwater intrusion. These results can be used as communication tools to water managers and to conceptually inform further studies.
Integrating model outputs for Scenarios C and D with the Ghyben-Herzberg relation, it is possible to calculate upconing (local rise of the interface) and predict the movement of the mixing zone as tourism abstraction of groundwater continues to grow in Gigante (Figure 4.13). Upconing was calculated for wells 202, 208, and G_19 based on modeled drawdown (Table 4.2). As might be expected, the higher pumping regime of G_19 makes it the most vulnerable well to seawater intrusion.
Figure 4.13. Conceptual model of upconing, illustrating a gradient of densities within the mixing zone. Modified from D. K. Todd (1981: 500).

In Scenario C, when pumping rates were increased twofold, the mixing zone was theoretically brought to within 124 m of sea level. Given the well elevation of 102 m and well depth of 220 m, \( G_{19} \) would incur seawater intrusion under Scenario C. If precipitation were to decrease (Scenario D), intrusion would still occur with only a 75% increase in pumping. Based on model estimates, well 202 and 208 would not incur intrusion, even under the conditions of Scenario D. It must be noted, however, that the model does not include the complexities of fracture porosity, nor additional wells within the aquifer for which data are not known. It is possible that either of these can bring the mixing zone closer to sea level than these models currently indicate. In this sense, the
models underestimate the impact of the specified pumping scenarios and should be used accordingly in water management planning. To this point, daily specific conductivity values in well 208 increased significantly during November 2014 following a below average rainy season output. Figure 4.14 shows a spike from .800 to 30 before stabilizing at 16 mS/cm. Maximum scale for the data logger is 30 mS/cm, so values for well 208 likely exceeded 30 mS/cm. (Seawater is ~55 mS/cm). Although current values are within acceptable rates for drinking, the increased values could be an indication of movement in the mixing zone and should be monitored carefully.

*Table 4.2.* Movement of mixing zone for select wells.

<table>
<thead>
<tr>
<th>G_19</th>
<th>Drawdown (m)</th>
<th>Upconing (m)</th>
<th>Depth below msl to mixing zone (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>524</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario B</td>
<td>4</td>
<td>160</td>
<td>364</td>
</tr>
<tr>
<td>Scenario C</td>
<td>8</td>
<td>320</td>
<td>204</td>
</tr>
<tr>
<td>Scenario D</td>
<td>10</td>
<td>400</td>
<td>124</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>202</th>
<th>Drawdown (m)</th>
<th>Upconing (m)</th>
<th>Depth below msl to mixing zone (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>304</td>
<td></td>
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</tr>
<tr>
<td>Scenario B</td>
<td>0.5</td>
<td>20</td>
<td>284</td>
</tr>
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<td>1</td>
<td>40</td>
<td>264</td>
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<tr>
<td>Scenario D</td>
<td>2.5</td>
<td>100</td>
<td>204</td>
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<table>
<thead>
<tr>
<th>208</th>
<th>Drawdown (m)</th>
<th>Upconing (m)</th>
<th>Depth below msl to mixing zone (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Scenario B</td>
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<td>20</td>
<td>252</td>
</tr>
<tr>
<td>Scenario C</td>
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<td>20</td>
<td>252</td>
</tr>
<tr>
<td>Scenario D</td>
<td>2</td>
<td>80</td>
<td>192</td>
</tr>
</tbody>
</table>
Conclusion and Recommendations

The evidence of declining water tables, examples of conflict among users, and modeled growth scenarios makes clear the current unsustainable nature of tourism in the Gigante area. To the point, tourism developments seem to be operating with a benign sort of recklessness by visioning and running business predicated on specific water needs, without actual knowledge of the hydrological provisioning capacity of the water basin. In their defense, tourism operators are suited for business more than hydrology. Since no water delivery system exists for this rural region, tourism operators are also tasked with securing their water needs in addition to running their businesses.

The onset of tourism growth along the southwest coast is characterized by product building, with little apparent forethought on determining how much water was available to sustainably deliver a product. This mindset persists and is observable across multiple scales. One poignant example is the world-class golf course built by a luxury
development looking for an ‘exclusive’ dimension to its branding (Rogers, 2012). To that end, they commissioned a market leading golf course designer to create a distinctive experience for its clientele. Unfortunately, the course followed the style of his portfolio that included renowned venues such as Hawai’i, Fiji, and other water endowed destinations. Keeping a world-class golf course looking world class requires significant amounts of water, which defies principles of sustainability given the hydrological constraints already mentioned for this area. In ironic fashion, the golf course has been predicted to “transform Nicaragua’s Pacific coast—and the country’s image” (Dear, 2013, p. 28). This might indeed be the case for unintended reasons.

At its core, tourism along the southwest coast is unsustainable because of its privileged position of endorsement and promotion by the government to boost the economy, and because of the inability of the government to support its capable national water laws. The former results in a prioritizing of economics over ecology, while the latter allows unchecked tourism to put aquifers at risk of degradation, tourism businesses at risk of failure, and local populations at risk of health and hardship. Similar examples of water conflict have been identified across the border in neighboring Costa Rica, where sixty-five significant water conflicts occurred between 1997 and 2006 in Guanacaste Province (Kuzdas, 2012). Like southwest Nicaragua, northern Costa Rica shares the blessing and burden of booming tourism and constraining hydrological conditions. One might hope that these communities in Guanacaste might offer perspective and insight into Gigante’s plight; however, no enduring solutions have yet to be found for the major contentions centered in Guanacaste, leaving a very real sense of uncertainty for resolution in Gigante.
A traditional response of civilizations to water crisis has tended towards large-scale infrastructure or technology (Gleick, 1998). These responses usually involve major government backing, significant economic investment, and at times prioritizing humans over ecology. Although much progress has been made in recent years to develop rational policies and approaches that generate sustainable water use (Cooley, 2010), the penchant for quick fixes and bailout solutions remains. An example is the growing theme of conversation among tourism developers in southwest Nicaragua on the hope of a water supply pipe from Lake Nicaragua. Although this solution was applied to the desperate water needs of the booming tourism hub of San Juan del Sur, an assessment of its efficacy or transferability has yet to be made.

Returning to Gigante, small measures in the arena of conversation are finding traction. The largest conservation impact has been realized through installing water meters on individual houses in most of the gated communities around Gigante. This strategy has brought much needed realization to homeowners of the amount of water being used (often on landscaping), as well as incentivized the pinpointing and remediation of leaking pipes. Several of the gated communities have implemented tiered tariffs, thereby economically discouraging heavier demands for water. To further decrease their water footprint, one gated community is actively replanting water intensive landscaping with plants that use less water, yet still provide color and variation to the seasonally brown hillsides. Only one development in this study indicated a willingness to invest financial resources for a proper hydrological study to determine the balance between their water demands and aquifer availability.
Each of the measures mentioned above are necessary for productive and equitable tourism, yet can often be costly and do not exclude others from disproportionate usage.

The larger factor in the water crisis is undoubtedly the role of government and its inability to provide informed support and constraint to water management schemes. Without a basin-wide water budget, tourism will likely expand in an un-checked manner. Results of this growth were captured in the pumping model and likely translate to deleterious social, environmental, and economic outcomes. A further point of motivation for the government to act is the forecast of climate change for this region. General circulation models prepared by the Intergovernmental Panel for Climate Change (IPCC AR4, 2007) indicate a long-term decrease in precipitation and increase in temperature for Central America. Specifically, dryer areas will become dryer and rainfall will be more intense and less even. This prediction has serious negative implications on recharge of the basin for Gigante and should further serve as encouragement for legitimate hydrological accounting.

Given the fiscal constraints of government water agencies, tourism developments must take initiative to support the implementation of the National Water Law (306) so that collective objectives can be accomplished. To this end, investment in research, well development, and conservation strategies must be done in a collaborative manner among high-end developers. This involves sharing of data and appropriate levels of transparency. If they take the lead and draw in the mid and small sized developers, sustainability is possible. One possible solution to encouraging and funding such an initiative would be to impose a tourism tax, where arrivals to Nicaragua would be charged a modest fee that, in
turn, could be applied to funding research and supporting government agencies to monitor and provide credible oversight tourism growth.
CHAPTER 5: SUMMARY

The goal of this dissertation has been to speak to the spatial, temporal, and contingent nature of the nexus of groundwater and tourism in southwest Nicaragua. Three themes are embedded in each of the main chapters. First, tourism is growing along the southwest coast of Nicaragua. Given the water demands associated with tourism, this growth in tourism translates to an increase in demand for water, specifically from groundwater. Secondly, freshwater supplies are not keeping pace with the growth of demand. This is in part related to three consecutive years of drought. A larger concern relates to the third theme emphasized in each of the chapters, which is insufficient understanding of the amount of water available in the aquifer to provision both the surrounding ecosystem and tourism related demand. From a hydrologic standpoint, this understanding entails answering the following three question: first, how is groundwater flowing through the system? (i.e., fracture network, corresponding conductivity values, etc.). Secondly, what is the age of the water? This will allow an understanding of how quickly water is cycling through the aquifer, which in turn informs users how to adjust abstraction to achieve a sustainable balance. In other words, is the system being depleted? The third, and related, question is how much recharge is the system receiving? Various methods are available to determine diffuse and focused recharge, but the end goal is to quantify the downward flow of water reaching the water table. Collectively, these themes
were intended to capture the story of water and tourism in within the specific geography of southwest Nicaragua. The theme of available water was addressed in this dissertation, though not to the extent that is should be and could be with more time and funding.

Several caveats are in order. First, there is a noticeable change in reporting as the dissertation developed in tandem with research findings. The number of wells and interviews, and perceptions of the findings were different in 2012 as Chapter Two developed. This chapter was published in an article shortly after. By the time Chapter Four was written, more wells had been added to the inventory, more interviews refined or refuted earlier perspectives, and more data were available to include a rudimentary hydrological model of the aquifer. I hope these points of change and reporting do not take away from the overall flow or substance of narrative.

The second point of qualification regards the analytic element model. Given the limited data, I opted for the simplistic, analytic approach, knowing that it was a ‘back of the envelope’ attempt to determine where tourism-driven water consumption might lead. As any good statistician will admit, it is quite easy for numbers to be maneuvered or attached to agendas. I have tried my best to measure or estimate reasonable inputs for the model without being too extreme or alarmist. I believe this is justified by the nature of the data, as well as the intent to help tourism developers work towards a sustainable future. (Inputs and related rationale are included in Appendix C).

Lastly, this dissertation represents significant progress in evaluating and telling the story of water and tourism in southwest Nicaragua. Little work had been done previously, so the process and output of this work contributes to a baseline that can be
expanded by myself and other interested parties. Much more work can and should be done, though for the moment this will suffice.

One of the things I had hoped to accomplish in this dissertation was to provide a valuation of groundwater as an ecosystem service in the context of southwest Nicaragua. Given the pivotal role of water within tourism services and its subsequent contribution to tourism growth, creating a tangible economic value of water would provide a strong educational and management tool to tourism developers. For a number of reasons this became an unattainable aspect of my dissertation proposal. First, valuation of groundwater requires recognizing and quantifying its total economic value (TEV) in order to determine the net cost and benefits of policies and management schemes (National Research Council, 1997). This total value is conceptually divided into two components—extractive value and *in situ* value. The former accounts for demand from uses such as agriculture or tourism, while the latter captures the value of services rendered through keeping the groundwater in the aquifer. Such services include protection against seawater intrusion, maintenance of ecological habitat and diversity, and many others. As one might expect, valuation of the extractive and *in situ* services of groundwater requires in-depth hydrological and ecological understanding of the region (basin) related to the groundwater source, as well as a market understanding of its value to municipal, industrial, and commercial users. In the case of my study area, very little hydrological data was available at the beginning of my research. Although much data (and knowledge) has been gathered over the past four years in an attempt to characterize the aquifer(s), too little quantitative data are available to fully characterize mass water balance, a key factor in valuation. Additionally, the literature on seasonally dry tropical
forests in Nicaragua is insufficient to inform an evaluation of the relationship between groundwater and the larger ecosystems around Gigante (forests, estuary, etc.).

The second reason a valuation of groundwater was beyond the scope of this study is ultimately related to the lack of data as well. Given the nascent condition of tourism in the area of study, management of water by tourism developers is typically disorganized and undocumented. This serves as a constraint in creating a repository of data that accurately reflects the sum usage of water through tourism and local activity. Several tourism developers have created a tariff system for water within their respective developments. This does discourage water usage and helps the developments to recuperate costs associated with pumping water (electricity). However, this in no way provides a complete valuation of water. Again, because no water budget has been generated, no one really knows how much water is sustainably available. This then prohibits a true understanding of the finite nature of water to southwest coast and the related value of service.
REFERENCES


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Appendix A

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Appendix B

Head values for artisanal wells. (seco denotes a dry well).

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APPENDIX C

Inputs and Rationale for Flowpath II modeling

Image

A Google Earth image was selected and clip to appropriate area size. Then, I brought it into Microsoft Power Point to further edit and save as a .BMP file. This file was imported into Flowpath II and georeferenced with two points that were identified using Google Earth. (In GE preferences, switch to UTM coordinates). The clearest image available was JAN2014.

Well Locations and Pumping Rates

Pumping Wells:

#202 = 35.77 m$^3$/day
#203 = 0.536 m$^3$/day
#208 = 13.29 m$^3$/day
#G_19 = 381.64 m$^3$/day

Observation wells:

#115 head = 10.67m
#152 head = 5.7m
#157 head = 6.19m
#207 head = 0.914m
#212 head = 10.67m
Two “dummy” observation wells were put into the model to stabilize edges without constant head boundaries.

Dummy_1 head = 13.29 m
Dummy_2 head = 17.0 m

**RATIONALE FOR PUMP RATES**

**Redonda - #202**

From Diver data, average pumping 3x per day for 1.75 hours per pumping.

Estimated 30 gpm.

Thus, \[5.25 \text{ hours/day} \times 30 \text{ gal/min} \times 60 \text{ min/hour} = 9450 \text{ gal/day or } 35.77 \text{ m}^3/\text{day}\]

**Taylor/Rufino - #203**

Rufino says they use about 3 tanks (1250L) per week.

Thus, \[3750 \text{ L/week} \times \frac{\text{week}}{7 \text{ day}} = 535.71 \text{ L/day or } 0.53571 \text{ m}^3/\text{day}\]

**Camino Gigante - #208**

From Diver data, average pumping 3x per day for 45 minutes per pumping.

Measured 26 gpm

Thus, \[135 \text{ min/day} \times 26 \text{ gal/min} = 3510 \text{ gal/day or } 13.29 \text{ m}^3/\text{day}\]

**Guacalito - #G_19**

Reported from QUENCA, 0.1393 MMC, or 139,300 m$^3$/year = \[381.64 \text{ m}^3/\text{day}\]
AQUIFER PROPERTIES

Hydraulic Conductivity Distribution

Hydraulic conductivity varies across the study area. Most of the area is underlain by a moderately fractured sedimentary sequence of siltstones, sandstones, and mudstones. A thin layer of alluvium is evidenced in some areas. Given the variability of K from the QUENCA report (0.05 to 1.88 m/day), James Adamson suggested calculating the geometric mean as a point of comparison. A value of 0.28 m/day was used in the model for K since that was the data available from Guacalito well (G_19).

\[
\text{Geometric Mean} = ((X_1)(X_2)(X_3)\ldots\ldots(X_N))^{1/N}
\]

Geometric Mean = \((0.33)(0.05)(1.88)(0.88)(0.28))^{1/5} = \textbf{0.378 m/day}

Maximum = \textbf{1.88 m/day}

Minimum = \textbf{0.05 m/day}

Effective porosity

Porosity is almost exclusively secondary. Effective porosity across the site is assumed to be an average of 21%, based on the arithmetic mean listed for fine sandstone by Argonne National Laboratory (web.ead.anl.gov/resrad/datacoll/porosity.htm).

Or, use plots executed with Jim? Geometric mean of 36.44%

In Flowpath II, effective porosity is mostly representative of storage.
Aquifer Bottom Elevation

Based on a hydrologic study by Guacalito (QUENCA), the aquifer bottom is located at an average elevation of 175.62 m below sea level, dipping gently towards the west. Value entered into the model was -175 m.

Net Groundwater Recharge

The average groundwater recharge is estimated at 6% of average yearly rainfall (1350mm), thus, 81 mm/year. In Scenario D, recharge is estimated as 6% of average yearly rainfall of 1000mm, or 60 mm/year.

Boundary Conditions

- No Inactive Regions
- Constant Head Boundaries*

Ocean: 0.0m, [Water Balance Code: 1]
NE: 20.11m [Water Balance Code: 2]
-No River Boundaries
-No Boundaries to North or South

*For constant head values away from the ocean, James recommended that I plot a gradient from the ocean to known well heads, then project out to extent of study area. Cross-reference with topographic map profile to identify lowest channels, then subtract 20 m. This task was performed using the Geocontext profile mapper tool (www.geocontext.org).
Running the Model

**Scenario A:**

Recharge = 81 mm/year

K = 0.28 m/day  [3.24E-6 m/sec]

Aquifer bottom = -175 m

Effective Porosity = 0.21

Pumping rates:

202 = 35.77 m$^3$/day

203 = 0.536 m$^3$/day

208 = 13.29 m$^3$/day

$G_{19} = 381.64$ m$^3$/day

**Scenario B:**

Recharge = 81 mm/year

K = 0.28 m/day  [3.24E-6 m/sec]

Aquifer bottom = -175 m

Effective Porosity = 0.21

Pumping rates: (50% increase)

202 = 53.65 m$^3$/day

203 = 0.804 m$^3$/day

208 = 19.93 m$^3$/day

$G_{19} = 572.46$ m$^3$/day

**Scenario C:**

Recharge = 81 mm/year
K = 0.28 m/day \ [3.24E-6 \text{ m/sec}]

Aquifer bottom = -175 m

Effective Porosity = 0.21

Pumping rates: (100% increase)

202 = 71.54 m$^3$/day

203 = 1.072 m$^3$/day

208 = 26.58 m$^3$/day

G_{19} = 763.28 m$^3$/day

**Scenario D:**

Recharge = 60 mm/year

K = 0.28 m/day \ [3.24E-6 \text{ m/sec}]

Aquifer bottom = -175 m

Effective Porosity = 0.21

Pumping rates: (100% increase)

202 = 71.54 m$^3$/day

203 = 1.072 m$^3$/day

208 = 26.58 m$^3$/day

G_{19} = 763.28 m$^3$/day

**Calibration of Model**

The model was calibrated using data from a pump test executed for Guacalito (QUENCA) in March 2012. The first step of the test resulted in a drawdown of 4.42 m at
a pump rate of 40 gpm. I ran a test of my model at the same pump rate and observed a
drawdown of 4.21 m. (See figure).

**Mixing Zone Movement and Intrusion Possibility**

The downward movement of the aquifer, based on pumping rates, can be
demonstrated through Flowpath model outputs. In separate graphs, I will show the
upward movement of the mixing zone based on the Ghyben-Herzberg relation between
fresh and saline waters, where \( z = 40hf \). (See Table and Figure in Ch. 4).

**Relaxation time**

The time the system takes to recover from a sudden perturbation.

Steady state is interrupted.

\[ T_{RX} = \frac{\Phi \ l_F^2 }{2C} \]

Where, \( l_F \) is the maximum diffusion distance, \( \Phi \) is porosity, and \( C \) is transmissivity.

\[ T_{RX} = \frac{(.21)(5000m)^2} {[(2)(71,94m^2/day)]} = 36,488.74 \text{ days} / 365.242 \text{ days/year} = 99.9 \text{ years} \]

Disregarding the minimum (9.13 m\(^2\)/day) and maximum (359.12 m\(^2\)/day)
transmissivity values, an averaged \( C \) can be used to compute a \( T_{RX} \) of 74 years.

\[ T_{RX} = \frac{(.21)(5000m)^2} {[(2)(97.03 m^2/day)]} = 27,053.49 \text{ days} / 365.242 \text{ days/year} = 74.07 \text{ years} \]
For proximate wells ($0.2\text{km} < x < 0.83\text{km}$), a characteristic $T_{RX}$ for pumping of $G_{19}$ ranges from 58.4 days to 2.75 years.
Appendix D

Elevation measurements:

Initial fieldwork was done with a Brunton V2 Pro Digital altimeter. This instrument was used to measure well elevations necessary for deploying data loggers and calculating groundwater contours. After the first two field surveys, I noticed a discrepancy between measured values for the same location. These differences were further evaluated and I determined the Brunton altimeter was faulty. Subsequently, I used a Paulin Systems surveying micro altimeter (Model M-2), borrowed from the Department of Geography to re-measure all well elevations. These values were crosschecked with position values from a course resolution Digital Elevation Model (DEM).

Water Level Data Loggers:

CTD Divers (from Schlumberger) were used to continuously monitor static water levels. A Baro Diver was used to measure atmospheric pressure for compensation of CTD Divers. Three of the four CTD divers were deployed using an appropriate length data cable; the remaining CTD diver was deployed with a 5mm rope.

Barometric compensation for CTD Divers:

When compensating the data, I used option #3a (Water level with respect to vertical reference datum). See Figure 1 for specifics of compensation options.
Figure 1. Barometric compensation options for Diver data loggers.

Deployment specifications

Well #203 (deployed 25MAR2013)
Cable length used for barometric compensation: $A = 1487.424$ (User defined)
Top of casing: $B = 2042.16$
Installed Data Cable and changed settings (27MAY2014)
Cable length used for barometric compensation: $A = 1935.48$ (User defined)

Well #158 (deployed 11JUN2013; removed DEC2014)
Cable length used for barometric compensation: $A = 1588$cm (User defined)
Top of casing: B = 2804.16cm

Well #208 (deployed 9DEC2013)
Cable length used for barometric compensation: A = 2403cm (User defined)
Top of casing: B = 1189cm
Installed Data Cable and changed settings (26MAY2014)
Cable length used for barometric compensation: A = 2743.2 (User defined)

Well #202 (deployed 24MAR2014)
Cable length used for barometric compensation: A = 1981.2cm (User defined)
Top of casing: B = 1402cm

Well #207 (deployed DEC2014)
Cable length used for barometric compensation: A = 2438.4cm (User defined)
Top of casing: B = 2133.6cm

Precipitation/water levels comparison:
In February 2014 I created a comparison of the precipitation data for 2013 and the static water levels for the two wells with data loggers (#203 & #158). Since the data loggers recorded multiple readings for each day, I chose one reading from each day to plot. For well #158 (manually-dug and in daily use) I chose to preserve the 2:00am reading to avoid human influence. To be consistent, I then chose the available 2:00am reading for well #203 (largely unused/undisturbed). For #208, I chose a reading that reflected the highest level during the 24-hour period. This well has a heavy demand and frequent withdrawal, thus spikes (-) in the water levels. Parties show up on the graph! I tried to filter out these events. For #202, I chose 4:00am as a daily swl reading since Redonda Bay (RB) begins their daily pumping regime at 8:00. This was varied somewhat since levels fluctuated nearly one meter while pump was off, presumably from influence by well #208.
**Adjustments due to Baro:** After working in the field June 2014, I discovered that the Baro diver was malfunctioning. On 21 April 2014, between 9 and 10 pm, the pressure on the Baro diver jumped from a steady 1076cmH20 range to 1150. It pegged at this value continuously. Additionally, temperature values began fluctuating and then dropping to a negative value by 30 May 2014. In order to correctly compensate the CTD divers, I used the Baro diver for daily values up until **21 April 2014**. To compensate later values, I used the RB Baro diver.

**Adjustment to #158:** Since the RB Baro is closer to well #158, I used the Baro for compensation up until 24March2014, when the RB Baro was installed.

**Adjustment to #203:** When I downloaded water level data for DEC2013 to MAR2014, an obvious offset was visible in the trend for #203. Further, it was clear when removing the data logger from the well that the length of the cable had been changed as Rufino installed a pump for irrigation. The general trend of the graph was preserved by compensating 22cm from each of the daily swl from 29JAN2014 onward. This situation occurs in the record again on 22APR2014 (48cm) and 28MAY2014 (94cm). Since cable was installed on 27MAY2014, I then assumed the other offsets were either user error on my part, or tweaking from when Rufino pumped from the well with compressor. An anomaly on 8-12JUN2013 has a gap of measurement. Concurrent with this gap is a rainfall event of 102mm. This event, however, does not seem to warrant a jump of 20cm. To that end, I adjusted the change to match the adjacent trends. (10cm).

Another issue arose after downloading in JUN2015. The CTD had lost its cone and gave erratic readings for 14APR to 20MAY2015. I used a manually measured SWL for 03JUN2015 to manually interpolate the incorrect values.

**Adjustment to #208:** swl readings for well 208 needed several adjustments due to switching to data cable on 23MAY2014, changing Baro station on 21April2014, and offset occurring on 9SEP2014. Average values were determined for changes, then applied to remaining data.
Added 46cm to values between 10DEC2013 and 23MAR2014 to keep consistent.
Added 71cm to values between 10DEC2013 and 27MAY2014
Added 1,343 to values between 8SEP2014 and 24MAR2015 to diminish offset due to equipment failure.

**Weather Stations**

A Davis WeatherVue station was installed at the Rancho Santana (RS) office of desarollo on 24 March 2014. Previous to this, daily precipitation recordings were taken manually. RS gave past records (2009-2013) to me. Some of these records had discrepancies that needed to be resolved (monthly amounts compared to a total of monthly amounts). All final values were compared to the values given for NOAA station in Rivas.

The weather station at RS-desarollo was not functioning properly (user error?) for daily precipitation readings for months of June, July, & August 2014. Thus, it was necessary to extrapolate monthly total to daily averages. For June 2014, I chose to diffuse 18.6mm to six points in the month. I chose to diffuse 67.9mm to twelve points through the month of July (based on spacing of rain events in previous years during July). For August 2014, I needed to diffuse 59mm over the first two-thirds of the month. Again, I followed patterns from 2012 for August. Additionally, values for SEP2014 did not correlate in two different reports from Jose (RS). Daily values added to 133.8, but a monthly value was listed at 233.8. I dispersed 100mm throughout the daily to bring the monthly to 233.8mm.

**Installation of Davis Weather Stations**

**Camino Gigante (DW05)**

Vantage VUE installed June 2014
Lat: 11.4N
Long: 86.1W
Redonda Bay-Nica Tours Office  (DW004)
Vantage VUE installed DEC 2014
Lat: 11.4N
Long: 86.1W

Rancho Santana-La Mohosa  (DW002)
Vantage Pro2 installed DEC 2014
Lat: 11.43N
Long: 86W

Rancho Santana-Main Office  (DW001)
Vantage VUE installed MAR 2014
Lat: 11.5N
Long: 86.1W

Rancho Santana-Los Perros  (DW003)
Vantage VUE installed MAR 2015
Lat: 11.42N
Long: 86.1W

All stations were installed with Weatherlink data logger. Rancho Santana-Main and Rancho Santana-Los Perros recording in 15' increments, all stations in 2-hour increments. See Figure 2 for locations of weather stations.
Figure 2. Locations of Davis weather stations installed within the municipality of Tola. Source: G.T. LaVanchy and Esri base map.
Analyzing Data logger graphs (04March 2015)

Head values were plotted against potential recharge on the same graph. Potential recharge (PR) was defined as precipitation values less ET (values from Guacalito report for each month). The PR produced a graph similar to the daily SWL for well 203; however, it was plotting below the zero mark. Also concerning was the rise of ~3.0m when there was only 1.2m of precipitation. This is roughly a difference of a factor of 10. After speaking with Peter Vaught (retired hydrologist), he suggested that it was due to fractured aquifer. Thus, secondary porosity is 10%.

Geology

Rock samples were collected from various outcrops and manual well excavations. Standard thin sections were generated for four hand specimens, preserving orientation and using (blue epoxy) impregnation to aid in porosity determination. Evaluation of thin sections was done with Prof. Jeff Greenberg (22MAY2014):

Slide 1:

Hand specimen from well #121; exhibited cross bedding and micro channels.
Recrystallized mudstone
Some feldspars, minimal weathering, no carbonates, no porosity (based on lack of blue epoxy), volcanogenic. Mostly zeolites.

Slide 2 (from road cut near #201):
Slide 3 (from well #322):
Slide 4 (from well #108):

1st generation sandstones (zeolites, feldspar, clay, glass)
Sedimentary rock with volcanic parentage
Mix of angular & rounded (volcanogenic), tuffaceous fabric
Immature rock

Additional analysis was done through the QEMSCAN laboratory at Colorado School of Mines. QEMSCAN uses energy dispersive X-ray spectrometers (EDS) for mineral and compound identification. In this process, the electron beam is stepped across samples at a
specified pixel resolution (typically 1 – 40 micrometers), collecting a backscatter electron (BSE) signal and an EDS spectrum. Mineral identification is made on the basis of the BSE value and elemental intensities. A total of ten samples were analyzed for mineral composition and percent porosity. Analyze are summarized in Figures 4 through 13 included at the end of the Appendix.

Geological Surveys:

Only small-scale geologic maps (for structures and hydrogeology) are available for the region of study. These maps are usually 1:50,000 or greater, produced as part of larger studies aimed at natural resource exploration (oil, gas, gold, etc.). As such, each of the maps for the southwest coast lack detailed information necessary for in-depth hydrological analysis of fractured bedrock (see Figure 3 for select example).

Fieldwork allowed me to add additional information such bedding planes and fracture networks. These were measured using a Brunton Geo Transit. This information has been preserved in a GIS and will be of value to future studies after more data has been collected through borehole analysis.

Magnetic Declination (variation) – the angle between magnetic north and truth north. The MD for Tola, Nicaragua (11.4333° N, 85.9333° W) is 0.39° W for 2013-12-06, as computed by the researcher from the International Geomagnetic Reference Field Model, version 11 (1900-2015) from the NOAA website. Declination changes by 0.14° W per year. (www.ngdc.noaa.gov/geomag/declination.shtml)

Water use by Guacalito de la Isla development

Initial data was given to me by Jon Thompson of Guacalito to help me understand the water demand by Guacalito on the aquifer. (Later, the same information was officially given to me after signing a non-disclosure agreement). Although reports indicate a rather large need for the golf course (1,718,081 m³/year), I have adjusted that number to reflect interviews recorded over the past three years. Guacalito has been forced to alter the type of golf course due to a lack of available water to keep the original style in pristine
condition. The modified version of the golf course uses less water, thus I have adjusted the projected number by a reduction of 33% of projected need. This is an estimate since data sharing is not a strength of Guacalito.

**Modeling**

A two-dimensional finite difference model was used to determine groundwater movement and recommend pumping rates to avoid saltwater intrusion. Flowpath II (Franz & Guiguer) is a proprietary piece of code produced by Waterloo Hydrogeologic Software, Waterloo, Ontario, Canada. The governing equation for 2-D, steady-state flow in heterogeneous, saturated, anisotropic, porous media is

\[
\frac{\partial}{\partial x}\left(T_{xx} \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(T_{yy} \frac{\partial h}{\partial y}\right) \pm Q(x, y) = 0
\]

where

- \(T_{xx}\) and \(T_{yy}\) = principal components of transmissivity \((L^2/T)\),
- \(h\) = hydraulic head \((L)\),
- \(Q(x, y)\) = sinks and sources \((L/T)\), and
- \(x\) and \(y\) = Cartesian coordinates.

A Geographic Information System and related maps was carried out with ArcGIS 10.2.2.
Figure 3. Example of small-scale geologic maps available for area of study. 
Source: Parsons Corporation.
Figure 4. QEMSCAN sample 1 indicating mineral composition and porosity.
Figure 5. QEMSCAN sample 2 indicating mineral composition and porosity.
Figure 6. QEMSCAN sample 3 indicating mineral composition and porosity.
Figure 7. QEMSCAN sample 4 indicating mineral composition and porosity.
Figure 8. QEMSCAN sample 5 indicating mineral composition and porosity.
Figure 9. QEMSCAN sample 6 indicating mineral composition and porosity.
Figure 10. QEMSCAN sample 7 indicating mineral composition and porosity.
Figure 11. QEMSCAN sample TS1 indicating mineral composition and porosity.
Figure 12. QEMSCAN sample TS2 indicating mineral composition and porosity.
Figure 13. QEMSCAN sample TS3 indicating mineral composition and porosity.