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Reverse osmosis on a small barrier island: transformations of water, landscape, and vulnerability on Ocracoke Island, NC, USA

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Abstract Globally, modifications to the landscape have drastically transformed social and ecological communities. The implication of global climate change for small islands and small island communities is especially troublesome. Socially, small islands have a limited resource base, deal with varying degrees of insularity, generally have little political power, and have limited economic opportunities. The physical attributes of small islands also increase their vulnerability to global climate change, including limited land area, limited fresh water supplies, and greater distances to resources. The focus of this research project is to document place-specific human–environmental interactions from a political ecology perspective as a means to address local concerns and possible consequences of global environmental change. The place in which these interactions are examined is the barrier island and village of Ocracoke, NC. I focus on the specific historical-geography of land and water management on Ocracoke as a means to examine relationships between local human–environmental interactions and environmental change. I provide an account of technological changes in potable water procurement and the paralleling development of island growth (i.e. people, buildings, tourism). Then, relying on interviews with island residents, I consider how advancements in local water infrastructure, specifically the installation of an additional reverse osmosis unit, are hinged on anticipated future economic development. Lastly the social dimensions of change are discussed with specific focus on the increase in housing density and overburdened septic drainage fields in relation to changing hydrologic processes with an examination of how all of these factors affect local vulnerability.

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Research problem

The manner in which water is used and managed is a major influencing factor of global environmental change (Stocker et al. 2013; Turner et al. 2007). Globally, modifications to the landscape in the form of agriculture, forestry, and other land and water management practices have drastically transformed social and ecological communities (Ojima et al. 1994). The potential harmful consequences of these transformations include altered hydrologic systems, the loss of biodiversity, species extinction, increased pollution, and rising sea levels (Foley et al. 2005), to name a few. Water management practices have also been evidenced to influence people's vulnerability to hazards with initial research focused on examining the mitigation, response, and range of choice associated with hazards (White 1974; Burton et al. 1993). Other interrelated factors are compounding problems of environmental change as a result of water use changes. Such factors include climate change, sea level rise, the nature of hazards, and increased populations in coastal regions. Recent reports from the Intergovernmental Panel on Climate Change (IPCC) indicate that global temperatures are rising, and project that temperatures will continue to rise into the near-future (Stocker et al. 2013). As temperatures rise, the increased melting of global ice sheets will continue to increase the rate of global sea level rise (estimated to rise 0.09–0.88 m by 2100). Also a consequence of climate change, the frequency and severity of climatic events is expected to increase, especially Atlantic Ocean tropical cyclones (Stocker et al. 2013; Mason et al. 2002). These issues are increasingly pressing as human populations in coastal regions continue to grow, especially in the Mid-Atlantic and Southeastern US (Pielke et al. 2008; Rappaport and Sachs 2003; Platt 1991).

The implication of global climate change for small islands and small island communities is especially troublesome. Studies have shown that small islands are disproportionately vulnerable to disasters (Ebi et al. 2006; Pelling and Uitto 2001; Briguglio 1993). Socially, small islands have a limited resource base, deal with varying degrees of insularity, generally have little political power, and have limited economic opportunities (Pelling and Uitto 2001; Royle 2002; Briguglio 1995). The physical attributes of small islands also increase their vulnerability to global climate change, including limited land area, limited fresh water supplies, and greater distances to resources (Pelling and Uitto 2001). Recently, the World Health Organization and the World Meteorological Association have identified small islands as being at the forefront of experiencing the consequences of climate change, especially to intensified tropical cyclones and sea level rise (Ebi et al. 2006).

The focus of this article is to document place-specific—and in this case island-specific—human–water interactions from a political ecology perspective as a means to address local concerns and possible consequences of global environmental change. The place in which these interactions are examined is the barrier island and village of Ocracoke, NC. Ocracoke is located in the Outer Banks region of North Carolina, and is separated from the mainland by thirty miles of the Pamlico Sound (see Figs. 1, 2). The year-round population of the island is approximately 948 (US Census 2012), but as a tourist destination the number of people on the island can swell to 15,000 in the summer months (NC Ferry Division). The island is un-bridged, and only reachable by public ferry or private boat or plane. Roughly ninety percent of the island is part of the Cape Hatteras National Seashore (CAHA) and managed by the National Park Service (NPS). Freshwater for the island is produced from multiple reverse osmosis units using brackish water pumped from the Caste-Hayne aquifer located 620 feet under the surface of the earth. In this article I focus on the specific historical-geography of water management on Ocracoke as a means to examine relationships between local human–water interactions and global environmental change.

In July 2011 the Ocracoke Water and Sanitary District (OWSD) completed construction of an additional reverse osmosis unit that multiplied the supply of freshwater by 50 %. The history of development on Ocracoke is paralleled by continued advancements in water technology and infrastructure since the first reverse osmosis unit was installed in 1978. The brackish water used in the reverse osmosis process is pumped from a 620 foot deep well that draws from the Castle-Hayne aquifer. Lacking a central sewage system, all wastewater is drained into household septic drainage fields. During the last 15 years the OWSD has supplied the village with an annual average of 40–50 million gallons of freshwater. After human-use, the water—which had previously been stored in the Castle-Hayne aquifer for hundreds of thousands of years—enters the local hydrologic system of the island. This human–environmental process has several interrelated relations in regards to landscape change. The prospect of economic development has required additional technological modifications to secure a continued water supply. Additional water supplies have allowed for increased housing density and an increase in the number of tourists the island can support. Growing water use additionally increases the amount of wastewater added to the local hydrologic system via household septic drainage fields. As the near-surface layers of sandy-soil become increasingly saturated the ability of the soils to absorb rainwater and storm-surges decreases. This issue has great ramifications for the future of the island, both in terms of the islands exposure to hazards and the preservation of the islands historic housing character.

Fig. 1 Map of outer banks region in North Carolina. Basemap data from ESRI

I use a qualitative approach to collect and analyze data to address the research questions. Primary data were collected with interviews and participant observation. Secondary data includes the use of quantitative bio-physical and social data, and historical archival sources. Data were collected from June 2011 to June 2012.[1]

[1] This research has been rated exempt by the Institutional Review Board (IRB Protocol No.: 1104006400) through the Arizona State University Office of Research Integrity and Assurance.

Literature review

Research in political ecology is rooted in examining relationships between land management and human–environmental change. In the seminal text *Land Degradation and Society,* Blaikie and Brookfield (1987, p. 17) reestablished political ecology as a combination of "the concerns of ecology and a broadly defined political economy." These concerns include a focus on decision-making, societal relations with land-based resources, and attention towards the relationships

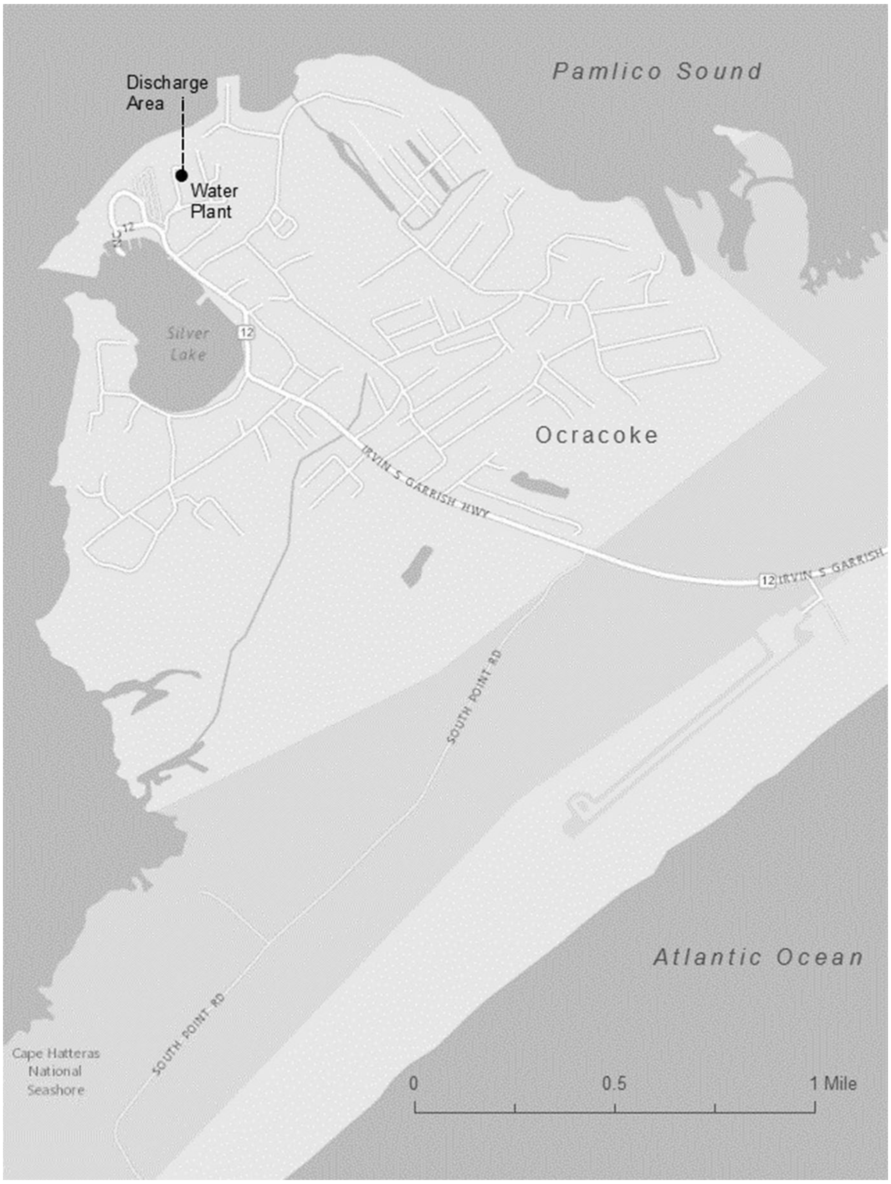

Fig. 2 Map of Ocracoke village. Basemap data from ESRI

amongst the environment, development, and vulnerability (Blaikie and Brookfield 1987). This version of political ecology can trace its academic lineage to research conducted in the fields of cultural ecology and risk-hazards (Turner and Robbins 2008). Risk-hazards research of the mid-1970s emphasized the relationships amongst nature, technology, and society (Burton et al. 1993; White 1974). Through a series of case studies from around the globe risk-hazards research documented that technological advancements towards risk reduction and rapid social change has unintended and often harmful consequences in regards to how people experience and cope with extreme events (Burton et al. 1993; White 1974). Building on the risk-hazards tradition, political ecology—prior to the label—called attention to the failure of previous research to emphasize the social relations of hazards (Hewitt 1983). As Watts (1983, p. 257) stated, “The necessary starting point for any critical elaboration of hazards is one that grounds the relation between nature and society.” Whyte (1986) agrees and continues by stating that "the problem appears not to be only the lack of recognition of the social, economic, cultural, and historical context of vulnerability, but a general failure or unwillingness to put this recognition into practice." Blaikie et al. (1994, a revised edition is cited as Wisner et al. 2004) provide a framework for putting these ideas to practice by conducting community research that examines the combinations of decision-making, access to information, scientific research, resource management, and planning that could reduce risk to hazards. More recent research in political ecology has emulated this framework while striving to incorporate equal attention to social and biophysical conditions and knowledge in assessments of hazards vulnerability (Mustafa 2005; Wisner et al. 2004; Pulwarty and Riebsame 1997).

A sub-field of political ecology, urban political ecology, has concentrated on the relationships between freshwater technologies, the global political economy, and human–environmental change (Swyngedouw 2013; Kaika 2012; Loftus 2007, 2009; Kaika and Swyngedouw 2000; Swyngedouw 1997, 1999). Urban political ecology uses a Marxist perspective to frame the socioenvironmental degradation associated with manipulations to water systems. These manipulations are not only limited to the hydro-engineering feats of canals, dams, irrigation, and desalination technologies, but also includes the deployment of social manipulations of water including privatization and commodification. I draw from and contribute to this literature by examining the implications of physical and social adjustments to the local hydrologic system of Ocracoke Island on local environmental risk regimes and the socioeconomic well-being of the community. My research questions are: (1) how and to what degree does water management on Ocracoke influence environmental conditions and change? (2) What are the implications of changing water management techniques for shifting environmental risk regimes and socioeconomic well-being?

Data and methodology

Primary data was collected using semi-formal interviews and long-term participant observation. Interviews were conducted with 54 island residents using a purposeful interview sampling technique (Dey 2003). Interviews were conducted as conversations with a purpose focusing on issues of local history, socioenvironmental change, development, community, and vulnerability. Specific participant observation tasks involved consistent attendance at local political boards and management meetings, volunteering, and on-the-job observing.[2] Data were collected from these events with detailed note-taking in multiple field journals and with a digital audio recorder.

Semi-formal interviews were conducted to solicit people's ideas, opinions, and knowledge about local socioenvironmental issues and conditions. I analyzed the resulting interview transcripts and PO field journal for the following themes: repetitions, indigenous typologies or categories, similarities and differences, missing data, and theory-related material. Recognizing repetitions is one of the most commonly used procedures for identifying themes in qualitative data (Guba 1978; D'Andrade 1991). Ideas of change included a wide-range of topic discussions that were identified and highlighted in the text. Identifying indigenous typologies or categories involves "look[-ing] for local terms that may sound unfamiliar or are used in unfamiliar ways (Ryan and Bernard 2003)." This involved analyzing the texts for phrases or descriptions of socioenvironmental processes that were in unfamiliar terms. The identification of similarities and differences involves a "constant comparison" of all other transcript text that focuses more on the data than theoretical preconceptions (Ryan and Bernard 2003; Glaser 1978; Charmaz 1990; Strauss and Corbin 1990). The procedure for this analysis as explained by Ryan and Bernard (2003, 91), involves asking yourself (the researcher), "How is this text different from the preceding text? And what kinds of things are mentioned in both?" Identifying themes from missing data involves considering what topics are not mentioned (Bogdan and Biklen 1982). This technique is difficult to systematize, but some have tried (Ryan and Bernard 2003, 93):

[2] I attended the meetings of the following organizations: the Ocracoke Civic and Business Association, Hyde County Commissioners Meetings, Ocracoke Planning Advisory board, the Ocracoke Foundation, the Ocracoke Water and Sanitary District, Ocracoke Occupancy Tax Advisory board, the Ocracoke Preservation Society, and the Ocracoke Community Radio board. I volunteered with the National Park Service, the Ocracoke Foundation, and the Ocracoke Preservation Society. I participated in on-the-job shadowing at the Ocracoke water plant.

> This means reading a text over and over. On the first reading, salient themes are clearly visible and can be quickly and readily marked with highlighters. In the next stage, the researcher searches for themes in the data that remain unmarked. This tactic – marking obvious themes early and quickly – forces the search for new and less obvious themes in the second pass.

The missing data approach proved helpful to address questions regarding the lack of mention of changing water infrastructure and its relationship to environmental change and development. Theory-related material involves analyzing transcripts to identify how the data illuminate important theoretical concepts in contemporary geographic-thought, or any other social science (Spradley 1979). This technique requires researchers "to be more sensitive to conditions, action/interactions, and consequences of a phenomenon and to order these conditions and consequences into theories (Ryan and Bernard 2003)." Within my analysis this involved highlighting text that conveyed information about socioenvironmental conditions that pertained to my research questions.

Theme identification approaches were paramount in developing a systematic procedure to analyze interview transcripts and field journals. A critique of transcript analysis often focuses on the lack of transparency regarding why some interview quotes are included in the final product, while others are excluded, and still other projects have a complete absence of respondent quotes (Baxter and Eyles 1997). Including quotes is "important for revealing how meanings are expressed in the respondents' own words rather than the words of the researcher (Baxter and Eyles 1997, 508)." The quotes identified within this article were selected based on the criteria above. Those quotes that best described the identified theme were chosen to provide texture for the case study while advancing the goals of the research. "Best described" quotes were those that succinctly and coherently represented the major thematic categories as identified.

Historical conditions

Historically, seemingly small changes to the water infrastructure change the interface between humans and water. On Ocracoke, the cumulative effect of these changes is a reorganization of local social and biophysical processes. These reorganizations include changes in housing types, housing density, population, surface hydrology, and aquifer characteristics. A map authored by Edward Moseley in 1733 titled "A New and Correct Map of the Province of North Carolina" depicts a point at present day Springer's Point labeled as "Well" (see Fig. 3). In 1733 there were only about a dozen pilots[3] and their families living on the island, but this well was more than likely used primarily for passing sailors and pirates to refill their water supply (Howard 2010). This is the earliest documented evidence of water infrastructure on Ocracoke. The well represented on the Moseley map was probably a wooden plank-lined pit that reached the shallow uncontained aquifer located four to ten feet below the surface (Howard 2010). This uncontained aquifer is referred to colloquially as the fresh water lens. The freshwater lens and rainwater collection served as the primary means of water access for another 244 years.

From the 1700s to the mid-1900s, wells and storage container types went through various phases of development (Howard 2010). Most early wells were wooden barrels stacked on top of each other inside a 5–10 foot hole.[4] The next development in cistern technology consisted of a diverse array of brick built storage containers. These cisterns were round or rectangular, with either a flat wooden top, a brick sealed dome, or a brick flattened top. During the 1950s most cisterns were constructed of large concrete blocks and a reinforced concrete top. This was the last stage of individual household water infrastructure development prior to the installation of the first reverse osmosis unit in 1977.

A 1972 Ocracoke village land use plan was conducted by the East Carolina University Regional Development Institute to analyze how a public water system would impact the development of the village (Mewborn 1972). The plan projected accelerated development if a public water and sewage system were installed; stating (9), "the present limitations of

[3] Pilots of ships would greet incoming commercial vessels and lead them through the dangerous inlet, or assist in the unloading of cargo on small skiffs to transport goods across the Pamlico Sound.

[4] All of the history of cistern advancements information is gathered from Phillip Howard's monthly business newsletter: "Ocracoke Cisterns", The Village Craftsmen Newsletter, October, 2010.

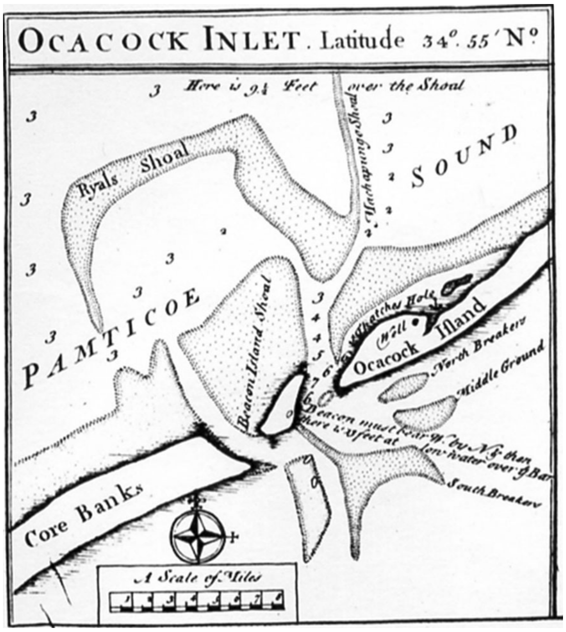

Fig. 3 First map of water infrastructure on Ocracoke Island. Notice the well point symbol on "Ocacock" Island (map from OPS library)

water in the village are retarding the development of permanent residences, as well as commercial service facilities such as motels, restaurants, etc." The plan projected a doubling of motel units by 1980 if a public water system was installed. As of 1972 only 20 % of the available 775 acres of the village were in use. This land in use contained a total of 351 structures, amounting to a density of one structure per 2.2 acres. As of 2008, the ratio of developed land to vacant land had shifted drastically with only 36.7 % of the total village categorized as vacant (CAMA Core Land Use Plan 2008); compared to 79.4 % vacant in 1972. Table 1 illustrates land use change from 1972 to 2008.

The percentages of vacant and used land continue to diverge in a 2025 future land demand forecast (CAMA Core Land Use Plan 2008). There is an anticipated decrease of 28.5 % in vacant land from the 2008 count, and an increase in residential land use by 21.4 %. Thus, if this forecast is accurate, only 27.8 % (196 acres) of the village will be classified as vacant land in 2025. The number of structures on the island increased to 844 housing structures in 2000, and 983 housing structures in 2010 (US Census). The estimated housing density in 2000 was one house per 0.9 acre in 2000, increasing to one house per 0.79 acres in 2010. The number of total structures is actually higher than these counts as these numbers only include housing structures.

Table 1 Land use change

Ocracoke village land use (%)	1972	2008	% Change
Residential	13.4	51.5	(+) 38.1
Vacant	79.4	36.7	(−) 42.7
Commercial	1.8	5.3	(+) 3.5
Office and institutional	0.6	4.7	(+) 4.1

The 1972 plan also warned of the potential pollution risk of increasing housing density and septic system contamination of the shallow uncontained aquifer. The concern over aquifer pollution was in competing interest with the demands of tourist consumption:

> Analysis of the shallow wells points out the fact that they are inadequate as far as capacity is concerned and produce water with higher than normal saline content which, due to its coming from shallow strata, is subject to pollution from septic tanks… the ground water supplies on Ocracoke Island are probably sufficient to provide water to the permanent (winter residents) of Ocracoke; however, they are not sufficient to supply the summer population…. It can be assumed that the development of necessary tourist services and facilities will be curtailed unless the establishment of these needed facilities is given top priority and installed as early as practical. (Mewborn 1972, p. 20)

As the 1972 plan was being researched, efforts were already being made to install a reverse osmosis (RO) unit on Ocracoke, which the plan estimated would be able to accommodate the increase in population and visitors through to the year 2000—five additions were made to the water plant up until the year 2000.

In 1977 the first reverse osmosis unit was installed on Ocracoke on NPS land (via NPS special use permit No. 5:190:14). The plant was funded by a federal rural development grant. The Ocracoke Island Water and Sanitary District (OWSD) operates the water utility plant independently of the county and is the only board on Ocracoke with the power to levy a tax. The supply produced by reverse osmosis necessitated municipal water infrastructure construction. In 1978, for the first time in the history of Ocracoke, water was delivered though underground pipes to 349 island households. The current plant provides water to 1210 buildings. In its first full year of operation (1978) the water plant provided the village with 21.65 million gallons of water; in 2011 the water plant delivered 47.39 million gallons. The increase in demand, driven primarily by increases in tourism, was the impetus for further water plant expansions. The original water plant could produce a daily maximum of 100,000 gallons/day; today it can produce a maximum of 835,200 gallons/day. There have been seven major upgrades and advancements to the reverse osmosis machinery on Ocracoke (1980, 1987, 1993, 1995, 2000, 2003, 2010/2011). The most amount of water supplied in 1 year was in 2002 and subsequent dips are reflective of changes in island visitation.

The additional water supply created via reverse osmosis changed the social conditions of Ocracoke, but also fostered biophysical changes. Reverse osmosis technology alters the molecular character of water by transforming the seawater mixture into the pure elemental compound H_2O. Osmosis describes the movement of a solvent, but not its solute components, through a partially permeable membrane from a space of low solute concentration to a space of high solute concentration, thus equalizing the solute concentration on either side. Reverse osmosis transforms liquids with high solute concentrations into liquids with a low solute concentration that have better potential for human-consumption (Cotruvo et al. 2011).

On Ocracoke the water source for RO treatment comes from the contained Castle Hayne aquifer located approximately 620 feet underground. The Castle Hayne aquifer is an expansive limestone aquifer that stretches from the piedmont region of the Carolinas to the Outer Banks, and longitudinally along the coastal plain from northern South Carolina to New Jersey (USGS Groundwater Atlas). Three deep wells pump brackish water from the limestone aquifer to the plant for RO treatment. There are a total of nine RO units in the Ocracoke plant. Six of the units operate at a processing speed of 60 gallons/min. The three new RO units can operate at a speed of 75 gallons/min. The difference between the speed of this delivery system and rainwater collection across temporal scales is substantial.

Reverse osmosis requires a large amount of electrical power. Ocracoke is the dead-end of a single electric line system that stretches the length of the Outer Banks and is channeled underneath portions of the Pamlico and Albemarle Sounds. If a main power line fails in Kitty Hawk, NC, 90 miles to the North, the power goes out on Ocracoke. This network is extremely susceptible to power failures in the wake of a large storm, as exemplified by the 2 weeks it took to restore power following Hurricane Irene in 2011. The water plant has a gas-powered emergency generator powerful enough to produce 400,000 gallons of water/day. In 2010, on average, each gallon of water delivered by the Ocracoke water plant required 94.9 kWh of energy.[5] In 2013, the second full year of production following the new RO addition, each gallon of water delivered required 103.8 kWh of energy.

Prior to entering the RO units, the brackish water is injected with an anti-scalant chemical that works to keep salt and other build-up from accumulating on the RO membranes. Brackish chemically treated water is pumped into the RO units with a 40 horsepower electric motor. The motor pressurizes the water to about 300 psi, pushing the water through a pre-filter that removes large particulates then forcing it through Filmtec BW30-8040 membranes. Each unit of water takes three passes through three tiers of membranes. After RO, the water is treated with 1 ppm of chlorine and 0.3 ppm of zinc orthophosphate. RO does such a good job of stripping the water of mineral solutes that it produces a very soft water. Soft water is corrosive because the weakly bonded hydrogen readily bonds with cations in other materials, causing them to gradually dissolve. The zinc orthophosphate coats any metal pipes, infrastructure, hot-water heaters, etc. to limit corrosion by the soft water. Chlorine is a disinfectant added per the requirements of the state of North Carolina. The water is then pumped up through a standing pipe stack where an aerator blows air into the bottom of the stack. All the air that is blown up from the bottom of the stack releases the hydrogen sulfide smell from the water before it drops down into storage tanks. The plant has a total storage capacity of 550,000 gallons. One elevated tank stores 150,000 gallons and two ground level tanks store 200,000 gallons each. The new water is now ready for distribution. The process results in a 67 % recovery

[5] This number is a simple calculation of water produced divided by water plant energy usage; data from the OSD.

rate for the water pumped through the RO units into the storage tanks. The remaining 33 % of high-saline brackish water is pumped 100 feet away from the shore into the shallow waters (3–4 ft.) of the Pamlico Sound. I asked the water manager if this process impacts the ecology of the sound where the rejected brackish water is pumped back into the sound. He responded:

> No. I do know years back, every now and then, the Marine Fisheries will go around and post signs in certain areas, closed to shell fish. And mostly because of septic drain off. If the, not bacteria but, when the level of bacteria is something in certain areas they will post signs not to eat shell fish. I don't think they've ever had to do it on this area right here where we pump that waste water because that water we actually pump out is a little fresher than the saltwater that's already out there. It's pretty close to what the sound is actually if I remember correctly. (Ted, interviewed 11/12/11)

To clarify what the water manager is saying, the water that is pumped from the deep aquifer does not have as high saline content as the seawater in the sound. Therefore even after the process of reverse osmosis the 33 % rejected brackish water is still lower in saline content than the sound; or what the water manager calls "pretty close." The most recent assessment by the North Carolina Division of Marine Fisheries in 2007 reports that the Ocracoke Sanitary District discharges 0.45 million gallons/day (MGD) into the Pamlico Sound and that the National Pollutant Discharge Elimination System (NPDES) categorizes this output as "minor" (Tar-Pamlico River Basin, Basinwide Assessment Report, Whole Effluent Toxicity Program 2003–2007). The EPA also inspects the OSD every year, consistently designating the surrounding waters as not impaired (EPA Enforcement and Compliance History Online database. Accessed April 2014).

Water, land-use planning, and development

In 1974, North Carolina passed the Coastal Area Management Act (CAMA) which requires coastal counties to take an active part in the management and development of coastal areas. Part of this requirement includes the publication of regular up-to-date land use plans. The most recent Hyde County CAMA Core Land Use Plan was adopted by the county board of commissioners in 2008 (CAMA Core Land Use Plan 2008). The 2008 land use plan projected modest population growth rate of 0.91 % per year through 2030. The predicted low growth rate was based on the limited availability of developable land, the lack of sewer facilities, political resistance, and regulatory restrictions on residential development (CAMA Core Land Use Plan 2008). However, the land use plan did mention that as properties became more valuable, and with continued water system expansions, there would be a gradual increase in residential density through 2030. With the continued water system expansion, the plan also suggested additional zoning restrictions (lot size to structure ratio, structure height, etc.) should be introduced to manage the anticipated development.

Even with the recognition of the continued increase in population and housing density, there are still some quantitative mismatches as to the purpose of the additional water supply. Prior to the 2011 addition the water plant's maximum operating capacity was 534,000 gallons/day. After the 2011 addition the water plant's maximum operation capacity increased to 835,200 gallons/day. The 2008 land use plan anticipated an additional 125 structures built by 2025 which results in a total projected demand of 452,340 gallons/day. It was assumed that the average demand would be skewed by the additional water demand needed in the summer months. Total water use data from the OSD shows that actual water demand in August of 2010 was 8.02 million gallons, or 258,709 gallons/day. The 2008 land use plan forecasted a demand of 393,960 gallons/day in 2010. To clarify, the CAMA land use plan estimated 452,340 gallons/day demand in 2025, and prior to the 2011 water plant upgrade the plant could already operate at 534,000 gallons/day. What will become of the potential additional 382,860 gallons/day (current capacity minus 2025 estimated demand) is yet to be seen, but available water resources acting as a barrier to further development seems unlikely in the near future. To further combat the idea that the village needs additional water supply is the fact that village water use has steadily declined since 2002 (see Fig. 4).

Although the water plant can operate at a maximum of 534,000 gallons/day, its maximum daily output in the busiest summer months is around 350,000

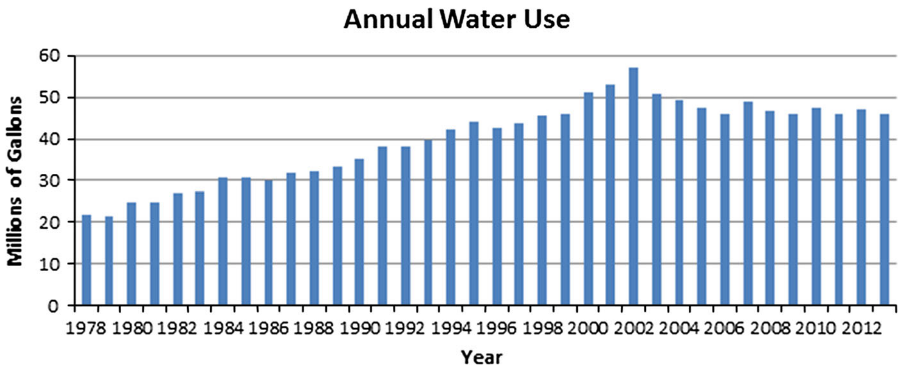

Fig. 4 Annual water produced; data from the OSD

gallons/day. The average cost to produce 1000 gallons is $12.81. The cost of water for customers is based on a tiered pricing structure. A single family residence pays $14.65 for their first 2000 gallons with the price gradually rising per every thousand gallons used after that (e.g. $8.09 per thousand between 2010 and 5000 gallons and gradually reaching $15.48 for every thousand used over 100,010 gallons).

The 2008 land use plan concluded with a summary of key liabilities for the community of Ocracoke. The list of liabilities reflected the paradoxical nature of community concerns. The liabilities listed in order were: "development is out of control (no zoning), lack of privately owned developable land, congestion in peak season, water system needs to be expanded, needs public wastewater collection and treatment system, and needs stormwater runoff system." This list reads as a ping pong match of contradictory concerns. Development is out of control, but there needs to be more land to develop. The village is too congested in the summer, but there needs to be more water services to supply the growing demand. There needs to be wastewater system, and there needs to be stormwater runoff system; these two concerns are also connected because as the oversaturated near surface soils are inundated with extra artificial discharge via septic drainage fields, their ability to absorb rainwater is diminished.

The issue of stormwater runoff is fundamentally connected to local water and land management practices. Research on Hatteras Island to the north has shown that the height of the water table is positively correlated with amounts of runoff (Anderson et al. 2000). There is more runoff because the near surface soils become saturated more quickly when the water table is higher. Recently, standing water on Ocracoke has become an issue of public concern.[6] Depending on the elevation of the property most lots require infill prior to development, as required by CAMA. Infill means that prior to building a house the elevation of the property is raised through the addition of more soil. This has subsequently led to lots being slightly higher in elevation than the nearby roads, which then funnel runoff onto the impermeable asphalt surface.

Residents are concerned with standing water because of the difficulty in traversing the deep puddles, the potential for increased mosquito breeding sites, general public health, and neighborhood aesthetics (The Ocracoke Current: *Rain and Drains* 1/17/14). The inability of this rainwater to be quickly absorbed into the saturated soil can be linked to the additional water added to the local surficial hydrologic system because of the desalination plant. The Castle Hayne aquifer from which the water supply is pumped is a deep contained aquifer. After human-use, the waste water is then redistributed to the near surface uncontained aquifer via septic drainage fields. A preliminary study of the water quality of the harbor (Silver Lake) on Ocracoke by the soil science department at North Carolina State found substantial evidence of fecal contamination from five sample sites of standing water in the village (internal document, 2012). Four of five of these samples tested exceedingly high for *E. coli* counts. The study suggests that the contaminated standing water in the

[6] The Ocracoke Current is Ocracoke's only local online news source: www.ocracokecurrent.com. Recent headlines: *Water, Water Everywhere* (12/5/13), *Rain and Drains* (1/17/14), *Storm Water Task Force Will Meet This Saturday* (1/31/14).

village is a substantial source of contamination in the local harbor.

In 2010, the Ocracoke water plant produced and delivered 47.4 million gallons of water to customers. There is a relationship between adding such a large amount of additional water to the local water table every year and the inability of rainwater to quickly be absorbed into the sand soil. In a phone conversation with the lead engineer of Anlauf Engineering in Kitty Hawk, North Carolina, and consultant to the Ocracoke Stormwater Task Force Committee, he stated that the addition of outside water to the local water table "absolutely" impacts the amount of standing water in the village (phone interview, 02/13/14). Sandy soil generally has a very low infiltration value, meaning that it requires a lot of precipitation before runoff is produced. Over 72 % of the village of Ocracoke is comprised of soil types that have very high permeability rates (Corolla sand, Duckston sand, Newhan fine sand, Newhan-Corolla complex, udorthents) (data form USDA Web Soil Survey). In personal correspondence with Dr. William Anderson, a geologist at Appalachian State University who has researched aquifer characteristics on Hatteras Island, he suggested that the artificial recharge via septic fields would not be enough to significantly raise the water table. He estimates that an artificial recharge of 50 million gallons/year could raise the water table approximately 5–19 cm/year. According to Anderson, this is not enough to significantly influence the absorption of storm surges, but could lead to more standing water at the surface.

Local knowledge and cultural practices

During participant observation tasks I found that discussions of the implications of changes in water infrastructure and management were uncommon. This is not unusual as there are many examples of places and people not concerned with the dynamics of water procurement until it fails to come out of the tap (Kaika 2003; Aguilera-Klink et al. 2000). That water is the limiting factor for development while lacking a widespread popular interest makes this a particularly interesting aspect of local knowledge to examine. Some interview respondents (eight) discussed the relationship between advancements in the local water infrastructure and speculative economic development. Interviewees recounted the story of an off-island real estate partnership consisting of two men, Frank Wardlow and Doward Brugh, that sought to develop two uninhabited sections of the island as housing subdivisions in the early 1970s. Frank Wardlow developed the present day Sound Shores neighborhood, and Doward Brugh developed the Jackson Dunes neighborhood. Wardlow petitioned for federal grants to build a reverse osmosis unit in the early 1970s, and became the first president of the OSD. Three interview participants said that Wardlow and Brugh had a business falling-out prior to the completion of the water plant, so when the water lines were laid in 1977 they were run throughout the historic residential areas of the village (Down Point and Around Creek) and Wardlow's projected subdivision of Sound Shores, but not to Brugh's planned development. In a discussion with Brugh on the phone (2/24/14) he disagreed that it was a "falling-out" and said it was simply a matter of business. Frank Wardlow is now deceased. Brugh's Jackson Dunes would not receive city water until 1985 when homeowners paid the cost for pipeline installment themselves (interview with real estate agent and Jackson Dunes resident, Bonnie 1/12/12).

Technological infrastructure of pipes and reverse osmosis technologies transform brackish groundwater into "potable, clean, translucent water" laden with powerful cultural and social meanings (Linton 2010). Thus, it is not surprising that in the interview discussions regarding water infrastructure it is inextricable from the costs and merits of development. Compared to access to freshwater, a lack of buildable space was more frequently mentioned in participant observation tasks as the controlling factor of future development. For example, as a volunteer with the Ocracoke Foundation I assisted in producing maps for an affordable housing program and a map that highlighted lots large enough to build a recreation field for a recreation subcommittee. Both of these tasks required attending dozens of meetings where the discussions focused on issues of open space. None of these meetings discussed the potential pressure of an additional water supply on the small amount of open space. The scarcity of freshwater and land on Ocracoke are both capable of being altered by available techno-fixes. In a discussion with a current real estate agent she stated that, "city water is the major cause of development on Ocracoke. You would have no McMansions [large cookie-cutter type houses] on Ocracoke if they had to exist off of groundwater which was disgusting, sulfur-y!” Addressing the issue of limited space for development she fearfully mentioned the potential for wetland infill, “Filling in the marsh land, we’ve got mitigation services. We have options nowadays where all you have to do is pay money and you could fill up to a tenth of an acre.”

Another longtime resident, who can trace his lineage back to one of the original families to settle on Ocracoke, expressed concern over the conflicted relationship between water and sewage systems and the traditional island way of life.

> In a strange way I guess a major threat [to Ocracoke] could be a central sewage system. Which would allow for such density of development. The water system certainly was a major threat to the way of life here. It just changed the whole environment. I mean, the whole social environment. It went from a place where you couldn’t have a hotel that had fifty rooms. You couldn’t build a cistern big enough! (Bert, interviewed 10/11/11)

The water system has undoubtedly supported the increased density of housing on Ocracoke. This increase has some residents concerned with issues of septic field drainage. The 2008 CAMA Core Land Use Plan describes the septic system on Ocracoke as follows:

> …wastewater disposal is provided by privately owned, on-site septic systems of small package systems. Increasingly, traditional septic systems on the Island are being replaced with more sophisticated (and effective) mound systems and low-flow trickling filter systems as the old systems wear out and as properties are sold. …Due to concerns about negative environmental impacts and a significant increase in building density on the Island, the establishment of centralized sewer on Ocracoke Island does not appear to be supported by Island residents at this time. (The Hyde County CAMA Core Land Use Plan 2008)

An example of these possible negative environmental impacts is the housing development of Oyster Creek; a series of fifty-foot wide lots oriented around a finger canal system. When I asked the current water manager what he thought the biggest social or environmental concern for Ocracoke was, he responded:

> The uncontrolled development. One of the things that really just burns me up is some of the things that was done early on by developers when they made these real small buildable lots; like 5000 foot lots. It affects the density of the buildings; we don’t have a central sewer system. You have 50 foot wide lots, like some of the ones in Oyster Creek, you got three lots in a row, you got three houses, you got three septic fields and drain fields right next to each other and then they’re bordered by the canal on both sides. That’s just not common sense. It goes back to the uncontrolled building, a lot of uncontrolled regulations. You have developers doing things that was just not common sense. It was all about the money. (Ted, interviewed 11/12/11)

Without a central sewage system each house is reliant on an individual septic drainage field. The proximity of the series of septic drainage fields has infiltrated the shallow lens of freshwater that rests just below the surface, rendering it unsafe for drinking. The local water table has been inundated with millions of gallons of additional wastewater—the realignment of hydro-social arrangements simultaneously alters the local hydrology. When asked to imagine what future socioenvironmental changes could impact the island, longtime resident and current head NPS ranger on Ocracoke stated:

> As far as other changes that I can see, we’re getting ready to expand the water so we’ll have that. I think one of the worst things that would happen is that if the community ever got, and it might not be in my lifetime, but it might be sometime, that they want a sewage system here. If they do that that’s going to allow people to build closer to each other and it would be more like Nags Head and places like that. (Eric, interviewed 6/24/2011)

A bed and breakfast owner had a similar response

> One of the things that changed Ocracoke most, increased the population, and the tourists, was when the water went in. That was the big thing. And there has been a lot of talk, off and on, about putting a sewage system in, and if that goes in,

Fig. 5 Photo of Oyster Creek: This is the area that the water manager describes in the previous quote. Photo credit: Mark Blecher

> Ocracoke will change irreparably. (Eleanor, interviewed 7/18/2011)

To summarize, a central water system was motivated by economic development, which allowed for an increased housing density and in turn has strained the septic field drainage system. The most recent development in this process is an addition to the available freshwater supply, without contingent changes to human waste management. The increased quantity of water available on Ocracoke directly increased the quantity of consumers. The limiting factor to growth and development is no longer water to satisfy the demand of consumers, but now is a system to mitigate their resultant wastewater. A sufficient supply of water alone does not produce growth. Variables such as housing costs, employment opportunities, desired amounts of isolation, and other issues of political economy influence the number of people on Ocracoke. Water provides for the condition of growth, growth increases system inputs, and then wastewater increases outputs. Without a municipal sewer system wastewater is an externality in this input/output relationship (Fig. 5).

Prior to the most recent upgrade to the water plant, the lack of available water meters served as a disincentive to continued development; household water access hook-ups are referred to as "meters" by local residents. A local inn owner and lifelong resident discussed this transition and speculated on the impacts of the additional water supply:

> We of course grew up drinking cistern water and well points, and then the water system came in the mid-1970s and I think that made a difference in when the real estate boom was hot on the Outer Banks and water meters [hook-ups] were not available here and that made a difference in terms of slow growth. Now that they are available and things are not doing well as far as property selling, it's probably a smart growth way of easing into who needs a water meter. (James, interviewed 11/11/11)

An "impact" is the term used by the local water plant managers to describe the connection of a water meter to the delivery network. One impact can supply a property with a maximum of three bedrooms and two bathrooms. The total fee to connect to the village water system is $5000. The new RO unit went online in the summer of 2011 and created five hundred additional impacts. As of September 2011, one hundred of the new impacts were sold. A year later, in 2012, that number had increased by less than a dozen. As of November 2013, 120 impacts were sold. The decrease in water impacts sales was unexpected by the OSD. The slow rate of impact sales is likely representative of a national decline in housing sales and construction in the wake of the 2009 economic recession; and what James is referring to in the previous quote when he says "thing are not doing well."

Older island residents have described tourism-based development as something eroding the traditional character of Ocracoke, while simultaneously recognizing the importance of tourism on their children and grandchildren's ability to make a livelihood on the island. However, for other residents their livelihoods are dependent on development to strengthen the tourist economy, as the follow interview response elucidates:

> A long, long, time ago people wanted to hold real estate agents accountable for why the property values are doing this [going up]…because the bottom line is if you were born and raised here, never sold off your big tracts of land, there wouldn't be any development. You sold it off so you could make money, so when you refuse to sell a house on the harbor… A House on the harbor sold for $150,000 and we thought that was the most money we had ever heard of, well 2, 3, 4, years later a bed and breakfast goes on the marker for sale for $350,000 because the seller refused to except anything les. So when you refuse to accept anything less you automatically take the bar and push it and it stays up there until you have an economy crash like we just went through; that's what this bubble is all about. And I'm in the business so if people want to continue to sell their property and the water is there for them to develop the property then I think it's just logically going to happen. (Bonnie, real estate agent, interviewed 1/12/12)

The current state of the economy is referenced for the slow rate of water hook-up purchases. Residents also cited the lack of physical space to build acts a limiting factor to continued development. For example, while discussing the possible changes that a septic system would bring to the village, Gabe, a bed and breakfast owner stated:

> To the extent that it can. Ocracoke as you know is hemmed in, and cannot expand. I guess there is no annexation potential at all for the Ocracoke village versus the Park Service. It's probably too late [to install a central septic system], at this point we may be beyond the local level of totally reversing the existing current system for a small gain. There really isn't that much available developable space within the confines of Ocracoke anymore. (Gabe, interviewed 7/18/2011)

Even with the slow start to water hook up sales, the OSWD foresees the need for future upgrades to the plant based on the history of past upgrades. According to the water manager at the Ocracoke Water Plant, "development took off for the next 20 years" following the installation of the first system. During a tour of the water plant the manager discussed the opening of the plant in 1977:

> It was already under capacity by the time it went online. Every summer was a struggle, we didn't have an emergency generator, every time it broke down it was a fiasco. Then we added this (points to RO cabinet) part of the plant in the mid-1980s. We added this section (points to another RO cabinet) of the plant and put on the extra RO that upped our capacity. Ted, interviewed 11/12/11

After each advancement in the water plant's filtration capacity another round of improvements were already in the discussion phase according to the water manager. In an interview he expressed that throughout the history of the water plant—which he has worked at since it opened—he has had a continual concern of the water plant not being able to produce enough water to meet the demand. A nuance in the idea of having an adequate water supply is the fact that village water-use as steadily declined since 2002 (see Fig. 4).

Discussion

The manner in which water is used and managed on Ocracoke has transformed local social and biophysical processes. The implications of these transformations include altered hydrologic systems, increased population and housing density, potential septic-related hazards, and changes in storm surge absorption dynamics. The uncontained near surface aquifer was capable of supplying the small population of the island with ample freshwater, and the density of the island was so sparse that septic contamination was not a major issue. Since the installation of a public water system in 1977 the OSD has pumped an average of 39 million gallons of water from the contained Castle Hayne aquifer every year. This has created a reorganization of local surface hydrology and near-surface groundwater dynamics. The water drawn from the deep contained aquifer is released into the local near surface uncontained aquifer via septic drainage fields.

The amount of wastewater is also steadily increasing as the additional water supply produced via reverse osmosis has allowed for more people to visit and reside on the island. The continuous release of wastewater into the uncontained aquifer has resulted in its contamination. Water from the uncontained aquifer is now only used by residents to water plants. The production of a surplus water supply has enabled the current tourism based economy that a majority of residents rely on for their livelihoods. Although contaminated, a substantial increase of any water into a near-surface uncontained aquifer of a barrier island raises the elevation of the local water table (Anderson et al. 2000).

The changing environmental conditions noted above play a crucial part in shifting environmental risk regimes. Research (Anderson et al. 2000; Masterson et al. 2014) on uncontained near surface aquifers on barrier islands (Hatteras Island, NC and Assateauge Island, MD) shows that elevated water tables produce more runoff, thus increasing the risk of flooding by storm surges. This risk is compounded by the fact that the increase height of the water table on Ocracoke consists of wastewater, thus setting the scene for a post-hurricane toxic flood hazard. Some residents of Ocracoke are concerned with issues of septic drainage, but how to address these issues is not clear. In the portions of interviews shared in this article it is clear that residents fear a central sewage system would alter the character of the island. Much like the central water system, the central sewage system would allow for an increase in housing density. The Ocracoke water manager has explained that the current septic system is already leaking into canals and posing problems when lots are too small and too close to each other. The intertwined social and biophysical conditions associated with water procurement on Ocracoke have absolutely altered local environmental risk regimes.

The dependence on continued tourism-based economic development on Ocracoke remains a root cause of the potential disastrous impact a hazard could have on local livelihoods and socioeconomic well-being. The ability of a population to maintain livelihoods becomes increasingly difficult when it is dependent on an unreliable tourism economy. The dependence on a mono-economy coupled with the fragile resource base of a small island make Ocracoke extremely susceptible to anything that disrupts either one of those social or environmental regimes. On Ocracoke, these fragilities include the pressures of freshwater access and freshwater allocation. In the terminology of Wisner et al.'s (2004) pressure and release model, these root causes, dynamic pressures, and unsafe conditions when interfaced with a hazard produce disastrous consequences for the local socioeconomic well-being, such as a breakdown to lifeline infrastructures (electricity access, transportation routes) or sewage seepage.

The dynamic pressures identified in this article include the increased production of freshwater and a continued increase in housing and population density. The limited land area of the village compounds these issues, and can be categorized as an unsafe condition. Unsafe conditions are the form in which the vulnerability of people is expressed (Wisner et al. 2004: 55). Wisner et al. (2004) use the analogy of a nutcracker to demonstrate the concept of the "pressure and release model." The progression of vulnerability, when interfaced with hazardous conditions produces so much pressure on a place that the "cracking" of the nutcracker is analogous to the production of disastrous conditions. These disastrous conditions are seemingly dormant within a place, but become magnified through the converging pressure of the progression of vulnerability and the physical hazard. In terms of water management on Ocracoke the pressures of limited open space, increased freshwater production, and increased housing and population density take the form of increased standing water and a contaminated near surface aquifer. When these factors in the progression of vulnerability interface with the hazardous conditions of a hurricane the potential disaster includes the ruination of the current septic system. The hazards of rapid coastal erosion and storm surge flooding have the ability to completely undermine the near surface septic drainage fields.

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