Reports and Commentaries

A hydrogeologic overview and discussion of sources of groundwater pollution on Rapa Nui

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The hydrogeologic conditions and water supply of Rapa Nui have recently become a matter of concern since the island has become more readily accessible by plane. This has increased resident and tourist populations, which has heightened the demand on the island's groundwater supply. Another threat to the future of Rapa Nui is pollution of its freshwater resource. Three possible pollution sources are seawater intrusion, the Orito Landfill, and the lack of a septic waste system. Seawater intrusion is a potential threat for Rapa Nui because the aquifer becomes shallower near the coast and groundwater pumping occurs near the coast. The unlined Orito Landfill sits atop a groundwater divide, increasing the potential for chemical compounds to disperse in various directions. The lack of a centralized septic waste system also poses a growing threat from potential seepage into the groundwater supply. Increased understanding of the hydrogeologic conditions and sources of groundwater pollution need to be a priority for the government of Chile and the municipality of Rapa Nui to help sustain the fresh groundwater supply.

This research focuses on the groundwater conditions in the southeastern part of the island near the town of Hanga Roa, where most residents live and where groundwater is the sole source of potable water. This report attempts to combine general hydrogeologic knowledge with observed data from various sources in order to create a baseline assessment of the current groundwater situation. Current knowledge of groundwater pumping wells and pollution sources needs to be expanded in order to manage the water supply sustainably for future generations. An investment in a hydrologic monitoring program, compatible with improved waste management, would help lead to a safe, reliable drinking water source for the people of Rapa Nui.

La hidrogeología y las fuentes de agua de Rapa Nui se han convertido últimamente en asunto de interés público, pues la isla se ha vuelto más accesible debido a la llegada de vuelos aéreos. Esto ha incrementado la población residente y también la turística, lo cual está aumentando la demanda sobre el suministro de agua subterránea. Otra amenaza en el futuro de Rapa Nui es la polución de las fuentes de agua fresca. Las tres fuentes posibles de polución son intrusión de agua de mar, el vertedero de Orito y la falta de un sistema de residuos séptico. La intrusión de agua de mar es una amenaza potencial para Rapa Nui, pues el acuífero se hace menos profundo cerca de la costa y el bombeo de agua subterránea se produce cerca de la costa. El vertedero de Orito sin capa impermeable se encuentra sobre una divisoria de aguas subterráneas, lo que aumenta el potencial de que los componentes químicos se dispersen en varias direcciones. La falta de un sistema de residuos séptico centralizado plantea una creciente amenaza de posibles filtraciones en el suministro de agua subterránea. Prioritario para el Gobierno de Chile y la Municipalidad de Rapa Nui debería ser una mayor comprensión de las condiciones hidrogeológicas y de polución de las fuentes de agua subterráneas, con el fin de ayudar a mantener fresco este recurso hídrico.

Esta investigación se enfoca en las condiciones de las aguas subterráneas en la parte sureste de la isla, cerca del pueblo de Hanga Roa, en donde vive la mayor parte de los residentes y el agua subterránea es su única fuente de agua potable. Este informe trata de combinar el conocimiento hidrogeológico en general con los datos observados a partir de varias fuentes, con el fin de crear una evaluación inicial de la situación de las aguas subterráneas en la actualidad. Es necesario expandir el actual conocimiento de los pozos de bombeo de agua subterránea y de las fuentes de polución, a fin de que se pueda manejar la sostenibilidad de la fuente de agua para las futuras generaciones. La inversión en un programa de monitoreo hidrológico, compatible con una mejor gestión de los residuos, contribuirán a que la fuente de agua potable sea segura y confiable para los habitantes de Rapa Nui.

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Introduction

Rapa Nui's water supply consists of two small rain-fed lakes in volcanic craters and an aquifer system; there is no permanent surface water network. With its highly permeable volcanic soil, the primary source of freshwater for Rapa Nui is infiltrated precipitation that, over time, has created a lens-shaped aquifer. This makes the water supply very vulnerable, as it is dependent on precipitation rates, which can vary greatly.

With a growing population and increasing tourism, the groundwater supply needs to be adequately understood and managed in order to prevent pollution and depletion of the resource. Little is publicly known about the general state of the aquifer system or the level of contamination associated with overlying landfills and septic waste. This paper will evaluate the water system on Rapa Nui in a hydrogeologic framework, specifically considering the effects of over-pumping leading to seawater intrusion, and how the Orito Landfill and septic waste system could affect the water supplied to the people in the village of Hanga Roa.

This is a call to action. Inadequate water management will pose serious risk for the people and culture of Rapa Nui. This island has a tradition of resilience; consider the tenacity of the Polynesian settlers who first discovered the land, the strength and power reflected in the *moai* statues, and the versatility of the people who created the Rapanui culture. However, no human can survive without water and Rapa Nui has a vulnerable water supply. A serious threat to the island is a polluted groundwater system. This report is seeking to understand the state of Rapa Nui's water supply and elucidate gaps in current management practices. It will hopefully lay groundwork for future data collection and analysis that will lead to changes in waste management and prevent pollution of the island's drinking water supply.

Hydrogeologic Conditions

The volcanic geology of Rapa Nui provides a basic understanding of the hydraulic properties of groundwater in places where data is limited. A surface drainage network is basically non-existent; surface water is limited to a few crater lakes. Due to high porosity of the volcanic rock and a high rate of evapotranspiration, any rainfall quickly infiltrates the soil. After a heavy rain shower, the ground is often perfectly dry within a few hours (Porteous 1981:99). Beneath the land surface, an aquifer system collects the infiltrated rainwater before it discharges into the ocean. Extraction wells located along the coast, including Hanga Roa, capture some of the total supply for human use.

Due to its small size and lack of surface water, a secure fresh groundwater supply is essential for the people of Rapa Nui. Historically, the residents obtained water from the lagoon in the crater of Rano Kao (Montgomery & Associates 2011:14). Recently, groundwater extraction has become the main source of water, with pumping wells installed in the 1960s by La Corporación de Fomento de la Producción (CORFO) [the Chilean Economic Development Agency]. However, concerns of contamination and over-pumping of the water supply are growing as the residential population and tourism increase. In order to properly manage the island's groundwater, it is imperative to have a clear understanding of the availability of the groundwater resource, condition of the pumping wells, and potential sources of anthropogenic contamination.

Availability of the Groundwater Resource

Rapa Nui's climate allows for high rates of precipitation year round, which recharge the groundwater resource. The estimated average annual recharge of the aquifer system is between 3,200 and 4,700 cubic meters per second (Montgomery & Associates 2011:10). Currently, the recharge is significantly greater than the amount of water being extracted from most areas around the island, except near Hanga Roa, where the pumping appears to be exceeding the recharge.

Aquifer Parameters

The main aquifer of Rapa Nui consists of volcanic rock of high permeability zones. Previous studies have estimated hydraulic properties of the aquifer. Hydraulic conductivity is an important measure of aquifers, as it describes the ease with which water flows through the pores of subsurface material. It is estimated that the horizontal hydraulic conductivity (movement parallel to the lava flow) is very high, although it has not been specifically measured (Montgomery & Associates 2011:27). The vertical hydraulic conductivity (movement perpendicular to the lava flow) is much lower, due to the presence of poorly fractured rocks and ash layers from volcanic eruptions. Storage is another important factor of aquifer parameter. Storage is defined as the volume of water present in a given volume of an aquifer (Fetter 2001:100). Basically, storage describes the amount of water that can be held in an aquifer. For the main aquifer of Rapa Nui, it is estimated that the storage varies from 1 to 10 percent, which is reasonable in comparison to other volcanic islands (Montgomery & Associates 2011:27). This ratio describes the average percentage of water released from storage of the aquifer.

Direction of Groundwater Movement

Groundwater movement occurs from areas of recharge to areas of discharge. On Rapa Nui, recharge is mainly produced by precipitation at the higher locations on the island near the volcanoes as it infiltrates into the porous volcanic rock. Discharge occurs into the ocean or through extraction wells.

Many calculations have been done to estimate the amount of precipitation per year; Herrera and Custodio (2008) estimated 325-420 millimeters per year in coastal areas and 720-870 millimeters per year in highlands, which seems to be the most accurate given the two zones of infiltration, coastal and highland. Recharge is defined by the difference between precipitation and evapotranspiration. Therefore, re-charge would be slightly less than precipitation, given the amount of evapotranspiration on the island, which is small.

In an aquifer system that experiences little change in storage, the discharge must be equal to its recharge. As a whole, the island's recharge rates are significantly greater than extraction rates, indicating that a large amount of infiltrating freshwater discharges into the sea.

The direction of groundwater movement can be estimated from the relationship of recharge and discharge and surface topography contours. Figure 1 shows the groundwater flow directions, using the assumption that groundwater movement follows the contours of the surface topography. The general direction of groundwater movement is from the highest points of volcanoes radially outward toward the coastlines.

Figure 1 indicates two groundwater divides shown by the dotted black lines: one flowing from Terevaka to Rano Kao, the second from Terevaka to Poike. This is a conceptual model of groundwater flow based on topography that was not verified via pedestrian survey. A more exact groundwater flow map could be generated if accurate water table heights of wells throughout the island were known.

Hanga Roa Pumping Wells

The water supply for the town of Hanga Roa comes from six pumping wells that are maintained and managed by the municipality, Agricola y Servicios Isla de Pascua (SASIPA) [Agricultural Society and Services of Easter Island, Ltd.]. Almost all the current groundwater extraction of the entire island is performed in the wells located near the southern boundary of the town of Hanga Roa (see Figure 2).

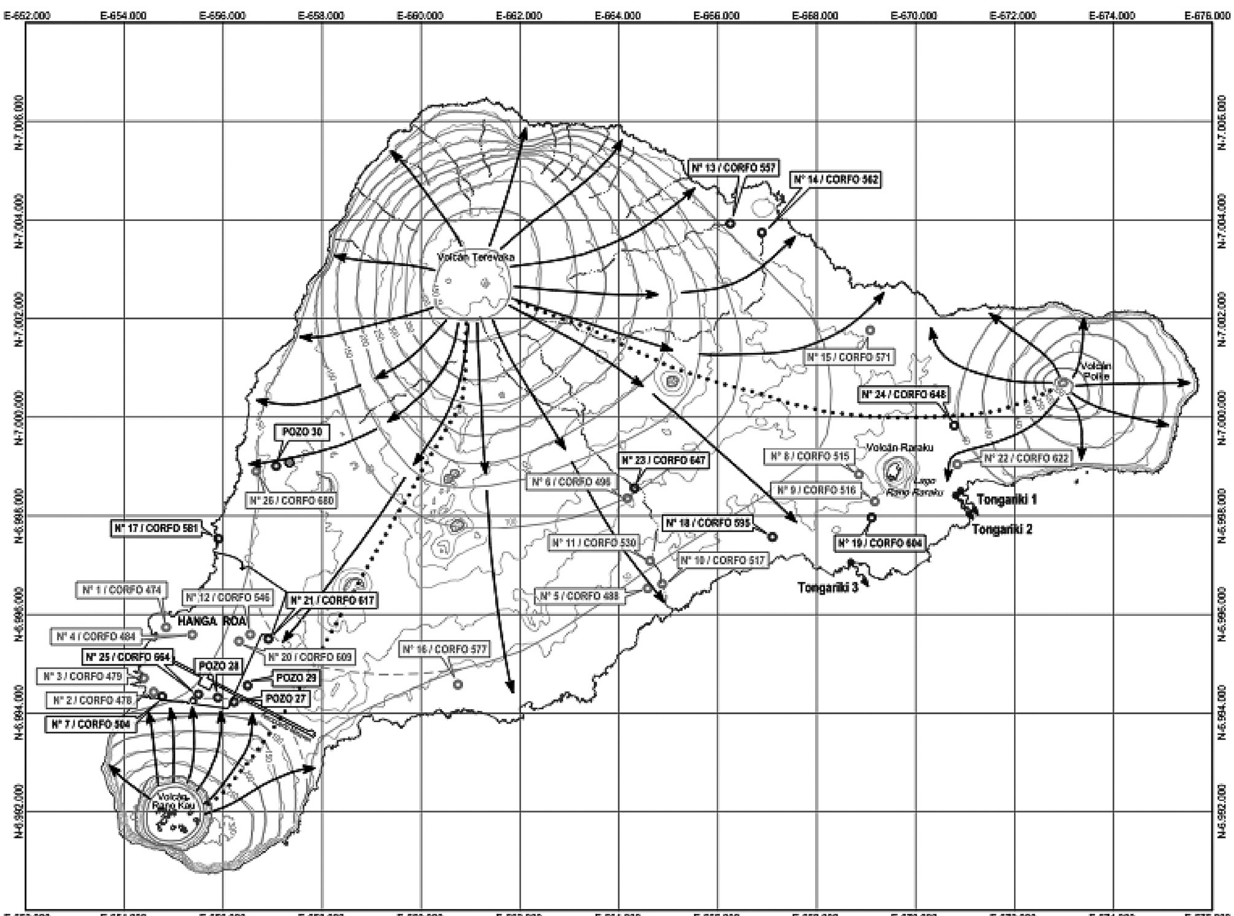

Figure 1. Conceptual map of the direction of groundwater movement, including groundwater divide and surface topography contours (after Montgomery & Associates 2011:Figure 2).

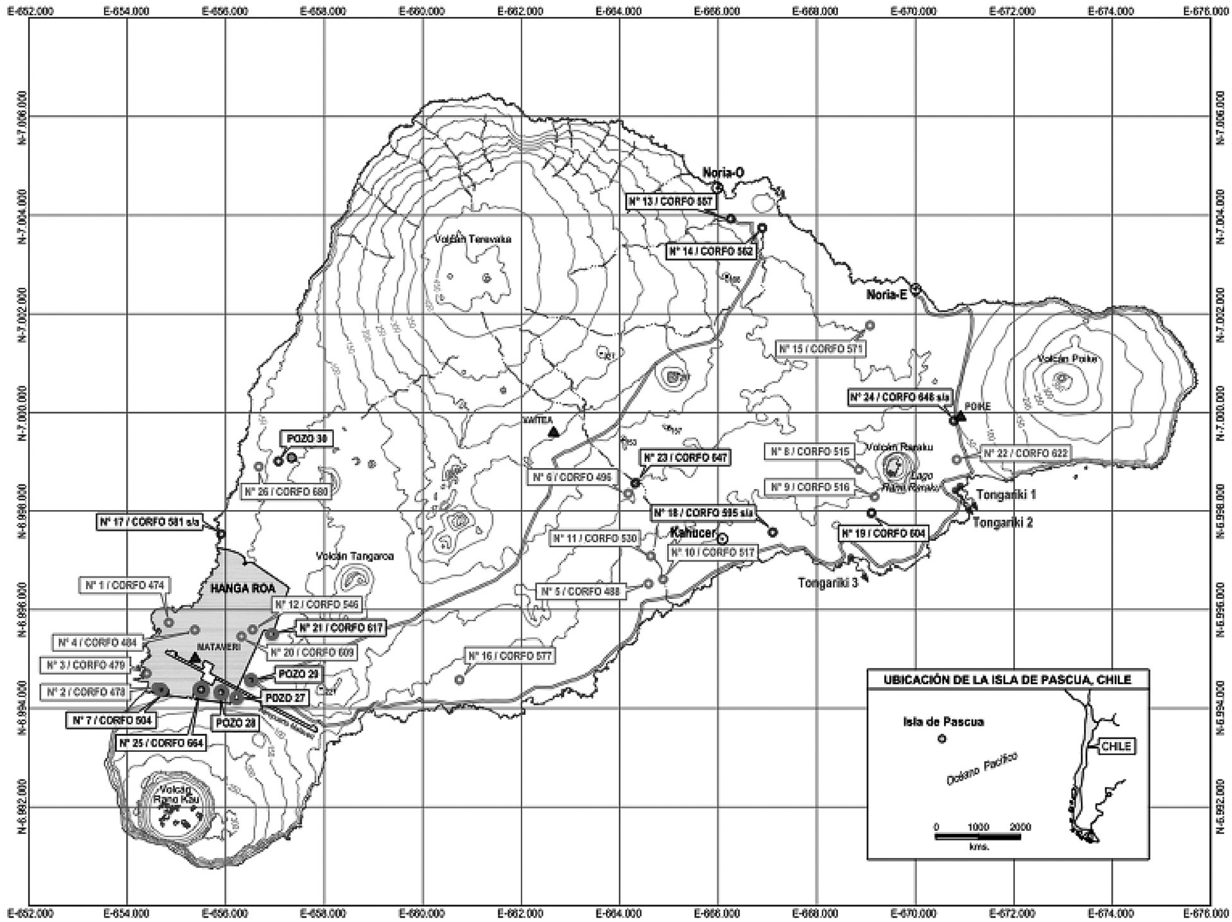

Figure 2. Rapa Nui map showing pumping well locations – wells extracting groundwater for Hanga Roa (N˚7, 21, 25, 27, 28, 29) (after Montgomery & Associates 2011: Figure 1).

Water supply from these six wells is influenced by patterns of groundwater movement and thickness of the freshwater aquifer. The recent state of these wells has been monitored and recorded from 2000-2009 by SASIPA. Overall, these wells provide reliable, good quality water, meaning low concentration of chloride and total dissolved solids (Montgomery & Associates 2011:24). Well #21 was expected to close in 2011 because the concentration of chlorides and total dissolved solids exceeded the permitted standard (Montgomery & Associates 2011:23). This is discussed later in relation to the Orito Landfill.

Generally, the conditions of the wells are good, assuming monitoring is consistent and corrosion is kept at a minimum. Observed pumping rates for these wells indicated a significant increase since 2007 by about 10 percent (Montgomery & Associates 2011: Table 4). This has implications for over-pumping of the thin aquifer near the coast and associated effects of seawater intrusion.

Sources of Groundwater Pollution

A major threat to the population of Rapa Nui is contamination of the island's supply of freshwater. Pollution of Rapa Nui's drinking water would be very costly for the island in terms of decreased tourism, health effects, finding alternative sources, or having to pay for water treatment. Just as monitoring the aquifer properties is beneficial, knowledge of potential sources of groundwater pollution should also be better understood and monitored.

Three potential sources of groundwater pollution are seawater intrusion, the Orito Landfill, and untreated sewage from septic systems. As the resident population and tourism has increased, groundwater-pumping rates have increased. In addition, an increasing amount of garbage and raw sewage is being dumped on this small, remote island. Evaluation of the current situation of seawater intrusion, the Orito Landfill, and the septic waste system with regard to the groundwater supply is critical for ensuring a reliable freshwater resource in years to come.

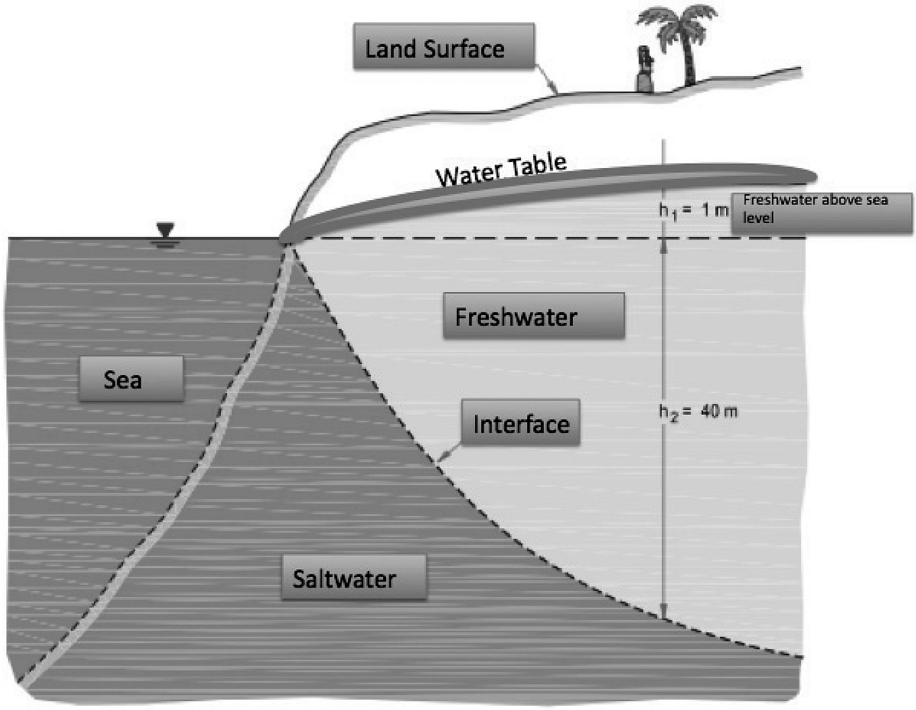

Figure 3. Ghyben-Herzberg principle showing interface between saltwater and freshwater for Rapa Nui (after Montgomery & Associates 2011:Figure 3).

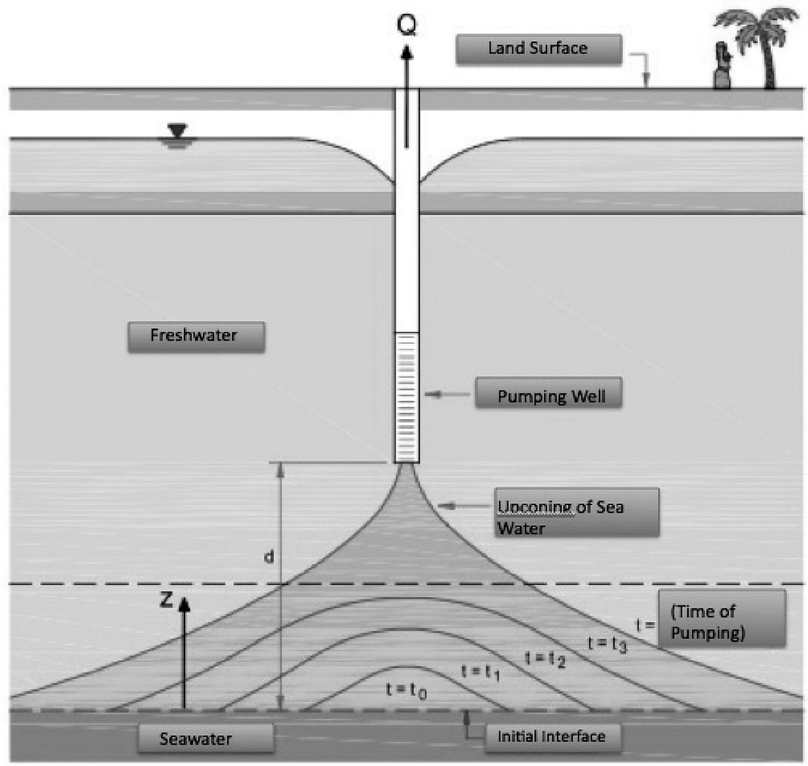

Figure 4. Illustration of seawater intrusion caused by pumping wells over time (after Montgomery & Associates 2011:Figure 5).

Seawater Intrusion

A major concern of freshwater extraction on any island in the world is seawater intrusion. Seawater intrusion is the movement of marine saline water into freshwater aquifers, referred to as "upconing," which is often a result of coastal pumping wells. This is especially dangerous for Rapa Nui, given the location of the Hanga Roa pumping wells.

Within the subsurface volcanic rock, oceanic saltwater exists in a zone beneath the freshwater aquifer. Due to freshwater having a lower density than saltwater, freshwater overlies saltwater (Montgomery & Associates 2011:7). The Ghyben-Herzberg principle describes the relationship between freshwater and saltwater. This principle explains that the depth to which freshwater extends below sea level is approximately 40 times the height of the water table above sea level (Fetter 2001:332). Therefore, if freshwater occurs at 40 meters below sea level, there is one meter of freshwater above sea level (see Figure 3). It is important to note that the interface between freshwater and seawater is usually a mixing zone, not a sharp boundary as suggested in Figure 3.

It is important to know the depth to the base of the fresh groundwater for extraction purposes. If a saltwater zone exists in the aquifer below a pumping well, pumping can cause excessive upconing of saltwater and draw saltwater into the freshwater interface (see Figure 4). Over time, upconing becomes more defined and eventually requires the closure of pumping wells.

On Rapa Nui, the potential for contamination from saltwater upconing due to freshwater pumping is great because many pumping wells are near the coast, especially at Hanga Roa. The aquifer becomes shallower near the coast, increasing the chances for seawater intrusion.

Orito Landfill

Historically, Rapa Nui exported its solid waste to Chile. However, Chile now refuses to accept Rapa Nui's waste, as they fear importing dengue fever from *Aedes aegypti* mosquitoes that typically breed in garbage piles (Campbell 2008:48). The effect of Chile no longer importing Rapa Nui's waste has a direct impact on the local landscape and potential for water pollution.

Figure 5. Location of Orito Landfill in relation to groundwater flow directions and pumping wells for Hanga Roa (based on groundwater flow directions from Montgomery & Associates 2011).

In 1993, the mayor of the island, Alberto Hotus, accepted a proposal to fill a stone quarry with the island's waste (Campbell 2006:67). The location of the Orito Landfill was once an old quarry of red *hani hani* soil (the rock used to make *pukao*, or topknots) that was used to pave the island's roads (Campbell 2008:49). It is a prime location for a landfill, as the quarry provides a natural pit to fill. The rapid growth of this landfill illustrates the increase of human activity on Rapa Nui in recent years.

Effects of Landfill Leachate

Landfill leachate is a liquid formed from precipitation that mixes with liquids already present in the waste and combines with compounds dissolved from solid waste (Fetter 2001:418). Leachate can be compared to coffee, as water that has percolated through the coffee grounds. The volume of leachate produced depends on the amount of precipitation in the area, meaning that landfills in humid climates are more likely to have large volumes of leachate than those in arid climates (Fetter 2001:418). This leachate can move downward into the groundwater, forming a plume that spreads in the direction of the flow of groundwater. Depending on the type of waste in the landfill, leachate that will potentially flow into the drinking water supply are known carcinogenics and mutanogenics such as lead, arsenic, mercury, cadmium, benzene, vinyl chloride, trichloroethylene, chloroform, benzopyrene and/or PCBs (Campbell 2008:49). These chemicals are found in paint products, pesticides, cleaning products and polishes, cosmetics, batteries and used motor oil, all of which can be found on Rapa Nui, especially in more recent times.

Effects of the Orito Landfill on Groundwater

The location of the Orito Landfill appears to be near a groundwater divide, as shown in Figure 5. Hydrogeologically, a groundwater divide indicates distinct water flow regions within the aquifer. Groundwater will flow away from a divide, at times in opposite directions. The implications of the Orito Landfill being on the groundwater divide means that if chemical compounds enter the groundwater, the contaminant transport could span a much larger physical area than if it were not on the divide. The location of the landfill also indicates that the groundwater flows from the landfill towards the town of Hanga Roa (see Figure 5). A plume of leachate would migrate in the direction of Hanga Roa and its supply wells, although the concentration of leachate would decrease as it moved further from the original source.

Pumping Well #21 is the closest well to the landfill. As previously mentioned, this well was expected to close in 2011, due to high concentration of chlorides and total dissolved solids (Montgomery & Associates 2011:23). This pollution could be due to seawater intrusion or chemical components from the landfill. This indicates a possibility that the chemicals from the Orito Landfill are already interacting with the groundwater supply.

In the last few years, major advances in waste management have been made on Rapa Nui. Beginning in 2004, International Help Fund Australia, led by Petra Campbell, initiated waste management programs on the island. Ms. Campbell, now CEO of Pacific Aid Australia, worked with the municipality and representatives from Tahiti and the Ministry of Health of Chile to propose practical and immediate solutions for waste management in order to protect Rapa Nui's drinking water supply (Campbell 2006:67). In September 2011, the municipality opened the island's first recycling center, next to the Orito Landfill (Riviera 2011). There is also work on controlling what is placed in the landfill, including placing a perimeter fence and characterizing the waste received at the landfill to establish appropriate handling conditions for the waste processing (Riviera 2011).

Progress is on the horizon; however, without proper lining of the landfill there is nothing preventing contaminants from interacting with and migrating into groundwater. Monitoring wells need to be drilled on either side of the groundwater divide and hydraulic downgradient near the Orito Landfill to determine the quality of the water and contamination from the leachates (Montgomery & Associates 2011:44).

For future waste management, lined landfills would help minimize groundwater contamination. Now is the time to investigate possible contamination, before it becomes part of the groundwater and affects the people of Hanga Roa.

Untreated Human Waste

The release of raw, untreated sewage to the environment of Rapa Nui presents another source of groundwater pollution. Aside from a few hotels with septic systems, approximately 95% of the toilets on the island are pit latrines (Campbell 2008:49). Generally, the disposal of sewage into the subsurface environment is a major factor contributing to incidences of waterborne diseases from bacteria and viruses living in the anaerobic wastes (Campbell 2008:49).

In 2005, the construction of new homes on the island included a prohibition on pit latrines and a US$2,000 subsidy was provided for installing individual septic tanks in these houses (Campbell 2006:70). However, once the septic tanks are full, there is currently no treatment process (C. Reams, pers. comm. 2013). As of 2006, the septic tanks from a few individual homes were collected by one private operator and were being dumped, untreated, into the environment (Campbell 2006:70).

While the installation of individual septic tanks is a step in the right direction, septic tanks can seep waste into the groundwater. One of the most important factors that influence the development of groundwater contamination from septic tanks is the density of septic tank systems in the area (Fetter 2001:416). Septic tanks are most likely to contribute to groundwater contamination in areas where there is a high density of homes with septic tanks, the soil is extremely permeable (such as volcanic basalt), or the water table is within a few feet of the land surface (Fetter 2001:418). These three conditions are present for Rapa Nui. The aquifer near ‘Anakena Beach has been closed due to contamination from the pit latrines there (Campbell 2006:69). Although there is still more to learn about how the aquifers are connected on the island, Rapa Nui cannot afford to pollute more of its groundwater.

Discussion

The volcanic subsurface of Rapa Nui contains the only source of potable water for the growing population. The aquifer system is dependant on infiltration of precipitation, making the island’s water supply very vulnerable. Extraction wells along the coast pose a threat for seawater intrusion, as the aquifer becomes shallower near the coast. The Ghyben-Herzberg principle can help indicate the depth of seawater to avoid seawater intrusion. This requires monitoring and knowledge of the current well-pumping behaviors. Almost all the water for Hanga Roa comes from wells located on the boundaries of the town. Currently, they provide adequate water, with the exception of Well #21, which was expected to close in 2011. Well #21 should be used as an indicator well, and be a source of motivation for the population of Rapa Nui to understand the conditions that caused it to be shut down. The report that Well #21 had high chlorides and total dissolved solids indicates impacts from seawater intrusion, the Orito Landfill, or both sources. The extent of seawater intrusion needs to be quantified for continuation of nearby pumping wells. The Orito Landfill and lack of adequate sewerage are likely to be polluting the island’s water supply.

However, Rapa Nui lacks funding for major civil projects, which presents a major obstacle. The Chilean base budget for Rapa Nui is US$7 million, used to cover everything on the island that is not earned by islanders from tourism (Campbell 2006:70). The island can apply for funding from Chile; however, these funds are not nearly enough to create a groundwater-monitoring program or sustainable waste management program. Most interestingly, Rapa Nui does not qualify for international funding from development aid organizations because it is not independent. By international standards, Rapa Nui would be considered ‘developing.’ Because it is a territory of Chile, which is ranked as having a Human Development Index of 40 (UNDP 2013), however, Rapa Nui is too developed, by association, to qualify for aid where independence is not a factor (Campbell 2006:70). The Human Development Index measures development through life expectancy, educational attainment, and income, rather than only economic development.

Chile benefits economically from owning Rapa Nui. Commercial profit is gained through tourism; therefore, Chile is already invested in making the island accessible for tourists by providing airplanes, hotels, vehicles, food, and water for visitors. Thus, the Government of Chile needs to recognize the necessity for additional investments of improved water and waste management infrastructure and programs to ensure the future of the island. Otherwise, an independent Rapa Nui would manage its water and waste to reflect the values of environmental stewards that the people of Rapa Nui represent.

Recommendations

The following recommendations are possible immediate actions, requiring little investment, but have the potential to produce significant changes:

- Implement rainwater catchment structures in individual households. Basic water filters can be installed with a rainwater catchment system for drinking water. (USD$100 for 50-gallon catchment barrel, USD$500-1000, for a rooftop rainwater catchment system).
- Create a financial fund specifically for environmental projects. In conjunction with eco-hotels, Hotel Hangaroa and Explora Rapa Nui, add an “environmental fee” to room rates to be used for environmental projects around the island; such as groundwater well covers, water storage tanks, landfill liners, and wastewater treatment.
- Encourage voluntary donations from tourists for the environmental sustainability of Rapa Nui. “Friends of Easter Island” could be a social network group that provides a forum for tourists who have been to Rapa Nui to donate after they have left the island. “Friends of Easter Island” can also provide discussions of experiences while staying updated on events or progress of the environmental projects.
- Educate children and adults about the importance of clean water and waste management, and educate about the impacts of landfills and over-pumping

groundwater. Instill waste reduction practices, including recycling and composting of organic material in homes and at hotels.
- Bring water management into public knowledge and include the public in future decisions.
- Create temporary storage units for potable water to draw upon during times of high demand. This would allow for pumping of the wells to continue at a lower steady rate rather than operating at high rates when the demand is high, which tends to exacerbate seawater intrusion.
- Extraction of groundwater should reflect precipitation events because being dependent on rainfall for the only water source makes it highly variable and unpredictable.
- Protect the groundwater wells by placing covers on the top and require permits to enter the area near the well fields.

The following recommendations are intended to help Rapa Nui progress towards a long-term sustainable management of its groundwater resource:

Groundwater Monitoring
- Obtain more information on existing wells in order to input this information into a hydrogeologic numerical model, and begin to make it as accurate as possible for predicting future scenarios.
- Implement a groundwater-monitoring program with monitoring wells located at key locations throughout the island to maintain constant understanding of the state of the aquifer system.
- Perform aquifer-pumping tests to better characterize aquifer properties.
- Routinely measure well pumping rates in Hanga Roa's supply wells and measure water levels and water quality in both the supply wells and all monitoring wells that are installed.
- Possibly abandon use of wells nearest to the coast and operate wells further inland to minimize seawater intrusion, as is already seen in Well #21.

Waste Management
- Identify sources of groundwater pollution to the Hanga Roa supply wells and take action to reduce the threat of pollution sources.
- Shut down and remediate the Orito Landfill. Open a new landfill that has a leachate liner and a system to collect and treat the leachate.
- Create a septic tank maintenance program with treatment of extracted sewage.
- Install a proper communal septic waste system with composting toilets on the outskirts of Hanga Roa.

These recommendations require communication and cooperation among people of public authority, including Chilean and Rapanui groups. Information sharing and gathering needs to be integrated between these entities to ultimately determine how the island's water supply is managed and maintained, ultimately for the health and happiness of future generations.

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