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A SUSTAINABLE WATER SUPPLY FOR SANTORINI
Creating a Model for Islands of the Aegean Sea

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Abstract

The islands of Santorini, Greece, experience a shortage in sustainable water supply due to an arid climate and tourist economy. Current conditions include saltwater intrusion in groundwater, reliance on imported water for drinking, a lack of widespread seawater desalination, inequitable pricing, and decreasing use of rainwater harvesting. Santorini has a sustainable water supply estimated at just over 1 million m^3/year and an estimated demand of 2.4 million m^3/year, leaving a deficit of 1.4 million m^3/year produce in a sustainable manner. A large implementation of reverse osmosis seawater desalination can provide for Santorini a more sustainable supply. Two scenarios for implementation are presented, both with an additional capacity of 1.8 million m^3/year, installation of storage tanks for backup supply, and a suitable pricing system. The second of these would also use wind energy and an advanced desalination technology that also produces salt to lower environmental impact.

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Finally, I would like to thank my parents, Roger and Mary Jo Duvall. Without their continual support, love, friendship, and especially patience, I never would have accomplished this goal. I hope that through my future work as a planner I can offer to the world the same selfless service that they have always known.

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Chapter 1: Introduction and Problem Statement

Water is the most basic and essential need for all types of life: human, animal, and plant. Without it, humans cannot live more than a few days. Water is essential to the survival of societal and ecological systems, for the success of agriculture and the creation of any other foods, for waste disposal, household sanitation, transportation, firefighting, and industry. Without it, we could not flush toilets, wash clothes, or perform any variety of other daily tasks. Water is the ultimate prerequisite for life and society. Without an ample and sustainable supply of water, no civilization can thrive, expand, or survive.

Santorini is a small complex of five islands in the southern Aegean Sea that is currently experiencing a drastic shortage in its sustainable water supply. The rain season in Santorini, like much of the Aegean and Mediterranean Seas, is very short. The aquifer of Santorini's main island of Thira is heavily stressed and currently experiencing saltwater intrusion, making tap water unfit to drink, and requiring all drinking water to be imported. Santorini has a volcanic past that has provided for it a very unique beauty in both the natural and built environment. This beauty and uniqueness has made Santorini

Figure 1.1: Location of Santorini in the Aegean Sea

Source: Author 2006

Figure 1.2: Islands, municipalities, settlements, and major geologic formations

Source: Author 2006, University of Cincinnati Sustainable Development Group 2005

extremely popular for tourism, which has shaped its development for the better part of the last fifty years, and substantially increased the demand for water.

1.1 Context of the Study

Santorini is the southernmost of the Greek Cycladic island group in the Aegean Sea (Figure 1.1). It is a cycle of five islands (Figure 1.2), the two largest of which, Thira and Thirasia, are inhabited by approximately 14,000 permanent residents. The islands of Nea Kameni and Palea Kameni are active volcanic islands, and the smallest island of Aspronisi is completely uninhabited. The islands have several settlements, the most significant of which being located on Thira. The Municipality of Thira, whose offices are located in the city of Fira, governs most of the island of Thira. The Community of Ia, located in Ia, governs the northern tip of Thira and all of Thirasia.

Many aspects of Santorini have contributed to making the islands unique. Chief among these aspects is the volcanic past of the islands, which shaped the islands into their current form and subsequently shaped future development. Through a series of eruptions, the center of ancient Santorini sunk into the ocean, leaving only the outer ring and the dynamic caldera for which the islands are known (Figure 1.3). These sheer cliffs on the inside of the ring are contrasted by beaches and soft cliffs on the outside. Figure 1.4 illustrates the dynamic terrain of the islands through a series of three dimensional images. The uniqueness of Santorini goes beyond its geologic splendor however. Early inhabitants of the islands developed their settlements by building into the soft volcanic rock (a technique known as yposkafa). Ruins of Venetian castles are located throughout several settlements, while ancient ruins near the town of Akrotiri and on the mountain of Profitis Ilias give evidence of much earlier civilizations. The wines made on Santorini cannot be found anywhere else in the world because of a unique type of grape and the unique methods used to cultivate them.

Figure 1.3: the caldera at Akrotiri

Source: Author 2005

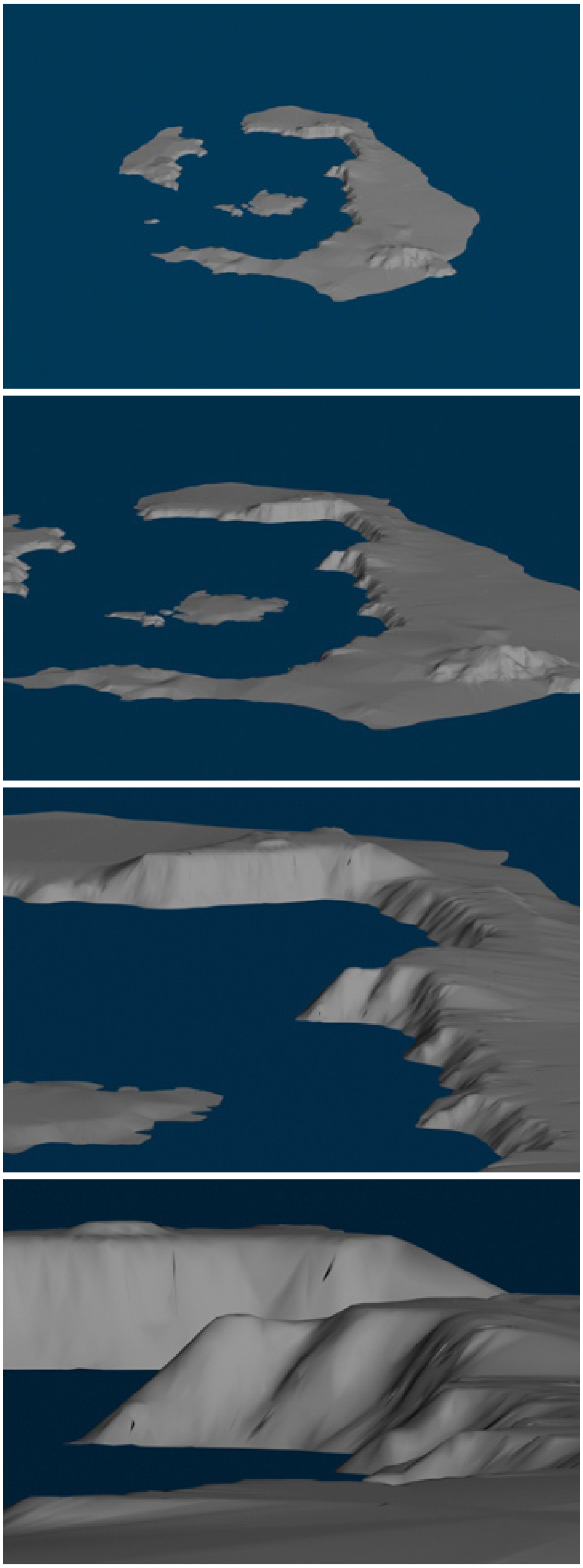
In 1956 a powerful earthquake devastated Santorini, destroying or damaging a majority of the islands' built environment. The earthquake gained worldwide attention for Santorini, giving visibility to the world of Santorini's environmental splendor. This exposure is what boosted tourism on Santorini, and by the early 1970s, tourism was shaping all development forces. This would eventually begin to have an affect on the natural and cultural resources of the island complex.

Santorini is but one of many islands in the Aegean and Mediterranean Seas that experience water shortages brought on by arid climates and heavy tourism. In Spain, Italy, France, and Greece in particular, small islands experience a surge of tourism in the summer that puts additional stress on existing water resources. Only limited seasonal rainfall contributes to the regeneration of the aquifers on these islands, and many of them have yet to adopt wide use of water conservation measures or seawater desalination to provide an ample supply of freshwater.

1.2 Viewpoint of Research and Written Work

All work conducted for this study, including the literature review, research methodology, and formulation of recommendations, is conducted

Figure 1.4: 3D imagery of Santorini's terrain



Source: Author 2006, Center for Electronic Reconstruction of Historic and Archaeological Sites 2005

from the viewpoint of sustainable development. Sustainable development is commonly defined as development that meets the needs of the present without compromising the ability of the future generations to meet their own needs. Sustainable development works for the vitality of social development, economic development, and the natural environment. Therefore, a sustainable water supply for Santorini would meet water demand without limiting the ability of future generations to meet their demand, while enhancing the social, economic, and environmental aspects of the islands. Other factors, such as limiting reliance on outside resources, also come into play. This definition is expanded upon in Chapter 2, where principles of a sustainable water supply are better explained, and examples in Greece, the Middle East, and elsewhere are given.

1.3 Problem Statement

Justification for this study is simple: Santorini desperately needs to formulate a water management system that provides for a sustainable supply of quality freshwater. Water on Santorini fails in terms of both quantity and quality. Tap water does not meet the minimum requirements of the Greek government even for sanitation, let alone for drinking. Groundwater supplies have been exploited far beyond sustainable means, and are at risk of long-term damage. The islands' climate provides very little rainfall to actually recharge this aquifer, and very little rainfall is harvested or stored. All of this is made more severe by the extreme demand that Santorini's seasonal tourism puts on the island during the summer months, during which the number of people on the island will raise to as many as 50,000 on a given day. This puts extreme stress on the water infrastructure of the islands, on finances because of the need to import bottled water, on the agricultural traditions of Santorini, and on the natural environment of the islands.

The current sources of water on Santorini cannot be seen as sustainable. Outside of drinking water, most water used on Santorini is extracted from deep within the main aquifer. However, because it has been welled so intensely and never been given the chance to recharge itself, the aquifer is experiencing saltwater intrusion, making groundwater unsuitable for consumption. However, due to a lack of education about this issue, many permanent residents of Santorini still consume groundwater. Minimal annual precipitation on the islands led to the use of cisterns to capture rainwater for use during the arid summer months. However, the use of these cisterns has dwindled, despite laws that require them in new construction. Many of the existing cisterns have fallen into disrepair. However, even if all cisterns were working properly and used to their full capacity, it would only be enough to cover a very small percentage of Santorini's water needs.

Because of the poor water quality coming from the aquifer, drinking water must be imported to Santorini, mostly from mainland Greece or Crete. This is a stress on the economy as bottled water is much more expensive than fresh tap water would be, and is also a stress on infrastructure and the environment because of the need to transport the water across the Aegean and the trash that is created. The only water suitable for drinking that comes from the island itself is from a small desalination plant that only serves the village of Ia in the north.

All of these problems are exacerbated by the stress that seasonal tourism puts on Santorini. The number of people on the islands rises from about 14,000 to upwards of 50,000 on any given day, but only for a few months a year. This substantially raises the water demand, adding the issue of a major fluctuation that occurs in a very limited period of time. Only a new water management system, involving technologies, management schemes, better infrastructure, and conservation practices, will help to make the water supply of Santorini sustainable.

1.4 Research question and expected outcomes

With the problem of Santorini's water supply stated, and the research viewpoint of sustainable development determined, the following research questions can be stated:

1. How unsustainable is the current water system of Santorini?
2. How can sustainable development principles in water resource management be applied to Santorini?
3. What technologies exist to help implement a more sustainable water supply?

Success stories exist from regions throughout the world: Singapore in Asia, Arizona in the United States, countries in Africa and the Middle East, and on several islands throughout the Mediterranean Sea itself. By examining the field of sustainable water resource management, and how it has been applied in these and other regions, answers for Santorini will begin to emerge. Creating a sustainable water supply for Santorini requires a drastic change to the way water is currently managed and exploited. Seawater desalination is the best solution to produce a water supply that will meet both quality and quantity requirements for residents and visitors alike. An ideal scheme would combine desalination with wastewater reuse, rainwater harvesting, and sustainable use of groundwater resources, in addition to a management system using proper water pricing and metering.

1.5 Objective of the Study

The objective of this study is to formulate recommendations for the island complex of Santorini in regards to its water system. Recommendations will be made only if they can provide a sustainable water management scheme for the islands, which will not deteriorate the social development, economic development, or natural environment of the islands. These recommendations are to provide Santorini with a water scheme that can be seen as a vehicle for future development, not as a hindrance or limitation.

A secondary objective of this study is to provide the most complete profile of Santorini's water supply ever compiled. To date, many reports on water in Santorini are incomplete, politically biased, or incorrect. This study will be as complete as available information will allow it to be, will avoid political bias, and will only provide information that is known to be correct.

1.6 Contents of this Study

The following chapter provides background for the study with a literature review of the field of sustainable water resource management, including its origins and definitions, planning for sustainable water supplies, and case studies in which more sustainable supplies have been accessed or are being sought. After the literature review will be a description of the six steps of the research methodology, from the system inventory to the final formulation of recommendations. A comprehensive analysis of Santorini's current water situation will then be provided, per the outline in the methodology. This will include an analysis of supply and demand, likely future conditions, factors that affect the water supply, and major issues. Following this will be a review of alternative water resources, including desalination, wastewater reuse, and others, to determine which one would be most likely to create a sustainable water supply for Santorini. Next are recommendations for implementation of this technology in two forms: one standard and one that aims to be totally sustainable. The written work will end with other supporting recommendations, suggestions for further research, and conclusions.

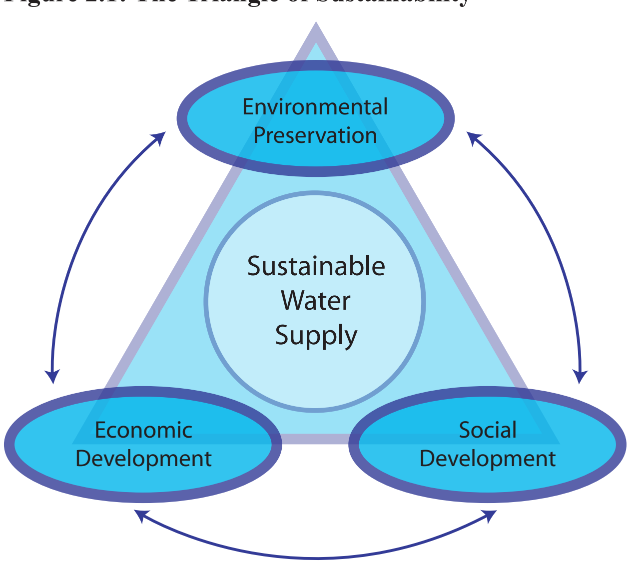
Chapter 2: Sustainable Water Resource Management

If a definition of sustainable development were adapted for a water supply, it would read something like this:

> A sustainable water supply is commonly defined as a water supply that fulfills the water demand of today's generation without limiting the ability of future generations to fulfill their water resource needs.

In 1992, adoption of Agenda 21 by more than 178 governments at the United Nations Conference on Environment and Development made sustainable development the standard of international environmental law (Kenney 2005, 155). It is based on a "triangle" compromised of economic development, social development, and environmental preservation (Figure 2.1). A sustainable water supply must be sensitive to and supportive of each side of this triangle of sustainability. To create a sustainable water supply is to be mindful of how water is related to society, economy, and the environment, and how those aspects are linked. A sustainable water supply is not consumed or polluted at a faster rate than it can be recovered or purified by nature

Figure 2.1: The Triangle of Sustainability



Source: Author 2006

or society. Aquifers are only pumped at rates which natural or manmade recharging processes can support. Sustainable water resources should also be free of unsustainable side-effects, such as trash or shipment pollution. A sustainable water supply is also secure in the wake of a crisis, with either an alternative resource or a backup supply ready.

This chapter offers a review of sustainability as it applies to freshwater supply. The first section emphasizes the need for a sustainable water supply, explaining how economic development, environmental preservation, human health, and social health are all linked to a dependable source of freshwater. Following this is a description of the movement within sustainable development that is concerned with freshwater supply: Integrated Water Resources Management. Next is a short description of planning for sustainable water supplies, followed by brief case studies illustrating how regions have worked toward this goal. Of particular interest are success stories in arid climates or on small islands, as these regions share common water supply issues with Santorini. A final section describes how a heavily tourist economy can affect water resource management.

2.1 The Need for a Sustainable Water Supply

Water is intrinsically linked to all aspects of society, and is a resource that cannot be put at risk. Water is necessary for supporting life, ecosystems, and industry. It is used in household cleaning, agriculture, transportation, and waste disposal. It is used at all levels of society, from the individual to all of society at once, making it a local and global concern. Although exact numbers vary, most agree that of the total amount of water on the Earth, less than 1% is available freshwater, leaving very little of all of the Earth's water to provide for all the needs of 6.5 billion people. Water supply is on the verge of becoming a global crisis because of pollution, aquifer draining, and unnecessary waste. Promoting and implementing water resource management that is sustainable, resilient, and flexible is the only way to alleviate this oncoming crisis.

A sustainable water supply is flexible over both space and time. All reaches of society must have access to this water, and the exploited resources must be able to support demand throughout the year. If the population of a region fluctuates at great numbers throughout the year, the water resource scheme must have the flexibility to handle these changes without negative impacts on society as a whole, the economy, or the environment.

Many factors affect how much water a region will need. The population and its characteristics, such as water-using appliances, use of swimming pools, and landscaping practices, are all important factors. If the economy of an area is heavily industrial or agricultural, that too can require more water in the system. Finally, the structure of water management, including prices and policies, can affect how people use water, particularly in terms of conservation or waste (Malkina-Pykh and Pykh 2003). The more aspects of society that demand water, the more that a sustainable supply is necessary.

Water supplies, like all resource infrastructure, are at the mercy of the environment. The climate of a region is a primary example. Inconsistent or sporadic rainfall, drought, or extreme heat can affect how much water is available, and for how long. Natural disasters can destroy facilities and infrastructure, creating the need for a water network that is ready for almost anything, within a practical financial framework. Also, the aridity of the land, composition of the soil, and amount of vegetative cover all affect the water supply. For a water resource to be sustainable, it must not hinder environmental preservation and protection, as is explained below.

A sustainable water supply is resilient to negative variables that can affect both quantity and quality. Quantity is affected by overexploitation of aquifer groundwater, leaks and problems with infrastructure, and human waste. Pollution coming from many water-dependent activities is the major negative affect on quality. Pesticides and fertilizers used in agriculture can enter either the ground or surface water supplies when it rains. Many pollutants from motor vehicles enter water supplies when runoff on impervious surfaces reaches rivers and streams. Other examples are hazardous chemicals from industry, pollution from poorly managed on-site septic systems, overflowing storm sewers, and thermal pollution (Daniels and Daniels 2003). A lack of proper purification can also be a problem with quality.

2.1.1 Water and the Environment

A region's water supply and the environment have a two-way relationship. Climate, hydrology, and the existence of water bodies greatly influence the means and extent of water collection. The means and extent of water collection therefore have an affect on hydrology, water bodies, and the environment at large. When water is extracted from the natural environment at unsustainable rates, it can damage wetlands, affect stream flow, or displace and harm ecosystems and wildlife, affecting biodiversity (Kenney 2005, 72). Arid regions of the world, such as Santorini, should be especially careful in the exploitation of water resources, as the fragile biodiversity can falter easily in the wake of poor water quantity or quality. Destruction of the hydrological cycle in urban areas can cause urban flooding, water pollution, spring destruction, and the transformation of cities into "heat islands" (Matsushita 2001). Destruction of an aquifer can also cause the land to subside. The 18 million population of Mexico City rely on the underground aquifer as the primary source of drinking water, but over-pumping has caused certain parts of the city to subside up to thirty feet (Fortner 2001).

2.1.2 Water and the Economy

A sustainable water supply is also necessary for the success of economic development. In its simplest importance to economic development, water helps to keep people alive so that they can pursue successful economies. However, the importance of a sustainable water supply to economic development is much deeper than this. In societies where agriculture is a large economic sector, access to sustainable water can mean making a profit or not. In mining economies, water is needed in extracting materials. In power generation and other heavy industry, water is used as a coolant and a medium in which to dispose of waste (Mays 2002). In reverse, a poor or declining water supply will negatively affect an economy. If an area loses its ability to fully support its population, one of two things will happen, either people will leave or water will have to be imported. If people leave, business will die, followed by a further loss of employment. If water has to be imported, the cost burden will find its way to the businesses and individuals of the region. In addition to these economic affects, a lack of water quantity or quality will cause healthcare costs to be incurred by individuals when people face disease or dehydration. (Biswas, Ünver, and Tortajada 2004).

2.1.3 Water and Social Development

From a social perspective, water is necessary for human health, in addition to a number of amenities often related to a higher quality of life. Human health is directly dependent on, and at the mercy of, a sustainable and clean source of freshwater. Humans die within a few days without water. However, an abundance of water that is of low quality can prove to be just as deadly, as water is capable of rapidly spreading disease. This is particularly true in dense urban environments which lack the provisions to purify water or properly dispose of waste. Water can carry minor diseases such as diarrhea or ones as deadly as tuberculosis. Diseases in water are very common in areas that lack proper human waste disposal, causing sewage to mix with the drinking water supply, and leading to a variety of fecal-oral diseases (Kitawaki 2002). Food is also necessary to maintain health, and water is necessary to maintain a food source. Agriculture is the largest user of freshwater worldwide, requiring vast amounts of high-quality water for both crops and livestock. Areas that have a properly managed and sustainable water supply also have a more dependable source of food without depending on outside sources. Irrigation of water coming from a sustainable water supply can help to ensure that the food source is also sustainable. Livestock require a source of water of both quality and quantity in order to pass nutrition onto humans (Biswas, Ünver, and Tortajada 2004, Mays 2002).

Water provides for aesthetic pleasure. The ocean, rivers, and lakes are top vacation and residential locations. Lakes and rivers are also top sources for freshwater. Over-pumping of a reservoir can reduce its size and appeal. Pollution not only damages these locations as freshwater resources, but also takes away their appeal by destroying wildlife, making them unsafe for swimming, or simply destroying their aesthetic quality. Negative affects on the quality of life and the environment can turn right around and affect economic development. These regions where people go for their aesthetic beauty are often parks and recreational areas that attract tourists to a region. If a region cannot provide freshwater because the resource is depleted or polluted, and cannot provide the attractions that it was known for, it will not survive.

A sustainable water supply helps to achieve a higher quality of life for any region. Health is an obvious part of this, but economic development is also necessary. As a region becomes wealthier, it also welcomes better infrastructure, healthcare, education, and transportation. While the existence of a sustainable water supply does not guarantee that a city will have an Ivy League university or perfectly constructed roads, it is one of the key components in a high quality of life. Through realizing how a sustainable water supply affects the economy and the environment, it is easier to see how it not only affects social development and quality of life, but how all three of these aspects of sustainable development interrelate.

2.1.4 Risk of Outside Dependence

Dependence upon an outside source for freshwater supply is not sustainable and can put a society at risk. Factors may change in an area that considers water to be an export economy. These factors may be political, environmental, or social, any of which can cause the supply of water to not reach the location where it is needed.

The functions of a major or minor settlement can quickly shut down in the face of a water crisis. Current trends are also suggesting that outside dependence is continually dangerous. Global warming is affecting the world climate, and increasing the propensity for certain natural disasters (hurricanes). Also, the age of terrorism leaves many things uncertain in terms of cross-border relationships, trade, export economy, crises, and diplomacy.

Matsushita (2001) gives an example elaborating this point. An earthquake struck Japan in 1995, destroying a pipeline that brings water to the city of Kobe from distant Biwa Lake. The pipeline took a month to repair, during which many functions of the city were paralyzed. The city was saved only through a backup well water source. Matsushita continues by saying that regions reliant only on "life lines", or outside water sources, are not strong in the face of disaster or drought. A region should have "life points" within itself from which water is collected.

Outside dependency is seen as a major indicator in determining water resources and supplies. A factor called the "dependency ratio" is given to a region, representing the proportion of water coming from outside an area, and expressed as a percentage (Malkina-Pykh and Pykh 2003). The higher the dependency ratio of a city, state, country, or region, the more likely that area is to face crisis if the supply of water is negatively affected in any way.

2.2 Integrated Water Resources Management

Integrated Water Resources Management (IWRM) is the commonly accepted branch of sustainable development concerned with freshwater supply, and a relevant philosophy to accept when trying to achieve sustainability in a water supply. IWRM consists of four major principles, as outlined by Agenda 21:

- "To promote a dynamic, interactive, iterative and multisectoral approach to water resources management, including the identification and protection of potential sources of freshwater supply, that integrates technological, socio-economic, environmental and human health considerations;
- "To plan for the sustainable and rational utilization, protection, conservation and management of water resources based on community needs and priorities within the framework of national economic development policy;
- "To design, implement and evaluate projects and programmes that are both economically efficient and socially appropriate within clearly defined strategies, based on an approach of full public participation, including that of women, youth, indigenous people, local communities, in water management policy-making and decision-making;
- "To identify and strengthen or develop, as required, in particular in developing countries, the appropriate institutional, legal and financial mechanisms to ensure that water policy and its implementation are a catalyst for sustainable social progress and economic growth" (United Nations Environment Programme 2005).

Working within IWRM demands respect for the three major aspects of sustainable development: environment, economy, and society. It demands full awareness of all available freshwater resources. It recognizes that quality water is a requisite for human health. IWRM also emphasizes planning for water resources and implementation using projects and programs that suit the need for water and the nature of the region.

In the literature, definitions and interpretations of IWRM often reflect the original concepts written in Agenda 21. Thomas and Durham (2003) go beyond these definitions by stating how IWRM is multidimensional, covering four dimensions: time, space, multidisciplinary, and stakeholder. First, and by the definition of sustainable development, IWRM is sustainable through the dimension of time, not harming the rights of future generations. Second, the authors emphasize the need to "think globally" before "acting locally", emphasizing space.

This is to keep in mind the entire watershed, not the individual water consumer, whether that watershed is the entire Mississippi River system or an aquifer on a small island such as Santorini. The third dimension of IWRM is the multidisciplinary dimension, and how it deals with health, legislation, technology, politics, society, history, and culture. Finally, the authors emphasize stakeholders as a final dimension, and urge the involvement of this dimension as early as possible in the water planning process.

2.3 A Better List of Water Resources

Boutkan and Stikker (2004) use IWRM as a basis to expand normal thought on water resources. Their definition of IWRM is not different from that which was already described, in that it emphasizes supply and demand, an organizational framework, stakeholder participation, policies, legislation, and economic instruments. How they differ is that they focus on resources, expanding the traditional list by including alternative water resources: seawater, brackish water, reclaimed wastewater, and harvested rainwater. Seawater and brackish water can be purified by desalination. Reclaimed wastewater can be treated to a variety of qualities and can then be used for non-drinking household uses, irrigation, or even aquifer recharge. Harvested rainwater can be easily purified to drinking quality. By adding these alternative sources, Boutkan and Stikker have created a much larger list of possible sources of freshwater under IWRM:

- Rivers and lakes
- Groundwater aquifers
- Rainwater
- Wastewater
- Seawater and brackish water
- Indirect freshwater (transported)
- New innovative resources (humidity, hydrated water in minerals)

A detailed examination of each of these technologies, along with their potential for large scale implementation in Santorini, is the subject of Chapter 5 of this study.

2.4 Planning for a Sustainable Water Supply

Planning for sustainable water use involves two main strategies: creating and maintaining a reliable long-term supply of high quality water, and managing the demand of that water. An inventory of the current system is a necessary first step, detailing supply and demand, sustainability, the region's dependency ratio, and the water deficit, if it exists. For example, when detailing rainwater as a resource, the quantity, yearly distribution, runoff, and evapo-transpiration are all important factors. If expansion is necessary, each resource should be analyzed based on its future potential. The quality of each resource is also important to document, including where any pollution may come from and the severity of impurity. Projections of demand, supply, and population are also necessary. If there is not currently a water deficit, but there will be in five years when the aquifer goes dry, then action is still needed. Other major planning actions play a part in water resource management. Formulating goals and objectives, rallying the involvement of stakeholders, and educating the public are all necessary actions to take to increase the chances of successful implementation. Like all planning, involvement of water management in all other regional or local planning activities is crucial to its success (Daniels and Daniels 2003, Malkina-Pykh and Pykh 2003, and Mays 2002).

Certain planning tools are available to those involved in water resource management. Zoning ordinances, subdivision regulations, and land use plans in particular can help to guard against sprawl that spreads water resources thin. Building codes, especially involving on-site wastewater reuse and rainwater catchments, are another important tool in implementing the use of alternative water resources. Appropriate water pricing for consumers will help to alleviate individual household and company waste. Regular water audits will ensure that the newly implemented system is doing its job in a sustainable manner so that regular adjustments can be made (Daniels and Daniels 2003, and Jønch-Clausen and Fugl 2001). In areas where large projects are required, such as large desalination plants, government subsidies can be sought to alleviate the burden on the local economy.

Water conservation, or demand management, and reducing waste are all crucial aspects of sustainable water supplies. Leak detection and correction programs are very important, with 5%-10% of all water usage in many networks being leakage. Water saving plumbing devices, among them low-flush toilets and more efficient shower heads, can help to lower water use at the household level. Altering the landscape practices of a region, by changing attitudes, using greywater, or having smaller lot sizes, can also conserve water. Finally, pricing is fundamental to conservation efforts. Metering water at the household level can help to change the attitudes of individual users, as can charging higher rates where there are higher rates of water consumption (Nadakavukaren 2000).

2.5 Water Supply in Arid Climates and Small Islands

In populated regions with an arid climate, water is a very sensitive resource. Rain may only come at certain times of the year, or it may not come at all. In arid regions throughout the world, various techniques have been implemented to ensure a lasting, if not fully sustainable, water supply. Some techniques, such as those seen in Arizona, are primarily focused on conservation and management. Others, such as those in the Mediterranean and Middle East regions, focus on conservation in addition to new sources such as desalination.

2.5.1 Techniques in the Middle East and North Africa

In the Middle East, seawater desalination has become a popular technique to gain access to freshwater in an arid desert climate, fulfilling a large demand in Saudi Arabia, Kuwait, United Arab Emirates, Yemen, and Israel, amongst other countries. Desalination currently supplies nearly 100% of the demand in UAE and Kuwait. In 1992, many desalination plants were built along the coasts of the Red Sea and Persian Gulf, with 80% being multi-stage flash (MSF) and the rest reverse osmosis (RO) plants. By 1997, Saudi Arabia was the world's largest producer of desalinated water. Their 36 desalination plants had a combined capacity of 3,029,513 m^3/day in 1997. In addition, the plants in Saudi Arabia are of various capacities, ranging from 1000 m^3/day to a staggering 798,864 m^3/day. Costs for desalinated water vary throughout the region, but the average is approximately €0.75/m^3. The need for an integrated system is recognized in the Middle East, as most countries in the Arabian Peninsula have also taken advanced steps toward leakage control and increased wastewater reuse. Saudi Arabia has also implemented water tariffs to control waste (Abderrahman 2000). In Israel, about 60% of the total wastewater is used for irrigation (Thomas and Durham 2003).

Specifically within Bahrain in the UAE, desalination is used throughout the island. There are currently many desalination plants located throughout the island. Five of the largest produce a capacity of nearly 320,000 m^3/day. Two of these plants use MSF desalination, two use RO, and one uses evaporation. Some of the water that is desalinated is from the sea, and some is from the ground. Water from desalination is used primarily for agriculture in Bahrain, as desalinated water often has a poor taste. There are systems to make it more favorable for drinking, such as larger secondary desalination or household filters. Some of these systems add to the price of water substantially, often nearing the price of bottled water. Like in Santorini, water infrastructure is weak in Bahrain, with upwards of 30% underground leakage in some areas. Many individuals will splice the piping network so that their meters do not detect all water that they consume. Authorities will often approach these violators as if there were a leakage in their system, so that they do not alarm those breaking the law. Bahrain has a pricing scheme to go along with desalination. At the household level the rate stays the same to a certain limit, but increases substantially above this limit to urge consumers to conserve (Almoayyed 2006).

Desalination has also been used to a successful rate in North African countries, with MSF (48%)

and RO (27%) being the most commonly used technologies. As early as 1995, the combined desalination of Algeria, Egypt, Libya, Morocco, and Tunisia was producing over 1 million m^3 of desalinated water per day, and the rates have steadily increased since. Subsequently, other resources in North Africa, particularly along the coast, have been overexploited. Desalination of seawater, brackish water, and treated wastewaters is seen as a plentiful and technologically viable alternative to help supply the region's domestic, urban, agricultural, industrial, and tourist demands (Abufayed, Elughuel, and Rashed 2002).

2.5.2 Techniques for Islands

Mallorca, a mid-sized island off the coast of Spain, has several similarities to Santorini. It has a hot and dry summer with scarce rainfall, and heavier precipitation during the winter months. Also like Santorini, demand for water is highest during the summer, when both tourism and agriculture are at full capacity. Mallorca has little to no reliable surface water resources, and relies on groundwater for 75% of its freshwater supply. Other measures are being taken to improve the total water supply. First, Mallorca is attempting to make better use of its current water supplies through many familiar techniques (wastewater for irrigation, water meters and audits, pricing measures, reducing loss in the system). Secondly, Mallorca is looking to expand into new resources for water by drilling new bore holes for groundwater and nearly doubling the use of desalination. Mallorca has also recently stopped the importing of water. From 1995-1998, water was being shipped daily from north-eastern Spain, but was stopped in part due to the cost and in part due to political opposition between the regions. Specific efforts of sustainability are also part of the overall water plans of Mallorca. Across the island, architects have been formally presented with the challenge to build progressive and eco-friendly buildings and towns which rely more on storing seasonal floodwater. The government of Calvià, one of the most heavily visited areas of the island, has specifically worked toward conforming to Agenda 21 in terms of water, energy conservation, and waste management (Essex, Kent, and Newnham 2004).

Despite its heavy rainfall, Singapore is stressed for freshwater because of its extremely dense population. The city-state has traditionally relied largely on outside resources, rainwater harvesting, and reservoirs for freshwater. Recent additions have included desalination and more advanced water reclamation techniques. Their rainwater harvesting systems divert water to surface reservoirs for storage to be added to the general water network. Water reuse and recycling is done at the household and community level, with uses varying depending on quality. Desalination has only come into use very recently since the turn of the millennium, and is seen as a supplemental resource, producing approximately 91,000 m^3/day. Desalinated water is treated as a wholesale buyer market, not as a governmental operation. Nowhere is the desire to limit outside dependence more clear than in Singapore. The treaty situation with Malaysia has proven quite complex and often affects pricing, shipment, and quantity. Because of these reasons, Singapore has sought to diversify and limit external sources of water for security purposes (Chuan Goh 2003).

2.5.3 Water Resource Management in Arizona

In 1980, then-governor of Arizona Bruce Babbitt signed the Groundwater Management Act. The act helped to solve legal disputes over groundwater, created programs to reduce overexploitation, and emphasized completion of a canal to bring Colorado River water to central and southern Arizona. The most significant part of the bill, however, was to focus efforts on Active Management Areas (AMA) as individual regions of water supply consideration and protection. The main goal of four of the five AMAs is "safe-yield," attempting to create a balance between annual extraction and natural and artificial recharge. However, the Arizona safe-yield system does not necessarily conform to sustainability, as less is done to account for lowering surface water levels or ground subsistence. A list of water management programs have been set up within each AMA. First, a framework of water rights and responsibilities was formed, including permits for groundwater, wells, environmental impact analyses, and metering of pumping from large wells. Certain programs were set up for managing demand as well, such as a restriction on new agricultural irrigation within the AMA, and mandatory conservation requirements for all water users. All new subdivisions must demonstrate that they can assure a water supply before development begins. Financial and technical assistance is given in the forms of grants and modeling studies, respectively. Within implementation, each AMA must have a water management plan and rule-making procedures. While a sustainable water resource is yet to be achieved in Arizona, it has become clear that it is possible (Jacobs and Holway 2004).

2.5.4 Water Supply in Greek Islands

Because of aridity and limited groundwater resources, water supply is a constant concern for Greek islands. Unfortunately, the literature is extremely limited in terms of implemented actions in Greece. However, there is substantial writing on feasibility studies, proposed solutions, and water resource plans. Kaldellis, Kavadias, and Kondili (2004) list some solutions that have been implemented sporadically, including:

- Surface water resources: reservoirs, better operation, and new dams
- Increased desalination due to decreased cost
- Water transportation from neighboring islands or mainland Greece
- Improvements in water infrastructure to minimize leakage
- Rainwater harvesting: both domestic and public
- Parallel networks for uses that do not require high-quality water: wastewater reuse for irrigation, cleaning, construction works, etc.
- Appropriate pricing policy and demand management

It is also recognized that reservoirs built to harvest rainwater are no longer reliable as a primary resource, due to a 10-20mm/year decrease in precipitation in the Aegean over the last 40 years. To make matters worse, demand is increasing throughout the Aegean. Total water transported by boat to Greek islands (does not include bottled drinking water) increased from 1,300,000 m^3 in 1997 to 2,500,000 m^3 in 2002. As a solution to these problems, Kaldellis et al propose the implementation of a combined wind energy and desalination scheme that would provide both power and water. In addition, reservoirs would be built to hold desalinated water or times of increased demand. Voivantas et al (2003) share the opinion that wind powered desalination should be implemented to supplement declining groundwater supplies. The authors feel that water brought by boat should be a last resort only to meet peak demand, due to high transport costs in the Aegean Sea.

Similar actions are proposed in the Dodekanisa prefecture, east of the Cyclades. Rhodes, one of the largest Greek islands, is currently experiencing a freshwater crisis, specifically in terms of groundwater. The saltwater intrusion front is expanding due to deep drilling and several boreholes within close proximity, specifically in the north of the island. Authority of water is not handled by one agency on Rhodes, but is scattered throughout many agencies and regulations. Manoli, Assimacopoulos, and Karavitis (2004) also express the need that Rhodes needs to change their policy from crisis management to risk management, as the latter will help to prevent the need for the former. Similar to other suggestions for Greek islands, the authors emphasize desalination powered by wind energy, in combination with safe yield exploitation of groundwater supplies and surface storage reservoirs as a sustainable solution to the water supply crisis. Elsewhere in the Dodekanisa prefecture, sustainable measures are proposed to improve water supplies for all of their islands. The island of Kos has decided to build a 5 MW wind park which will cover nearly all energy costs of desalination on the islands of the Dodekanisa prefecture other than Rhodes. Solar desalination was chosen for some of the smaller islands of the prefecture, with RO plants for the larger (Avlonitis et al 2002).

2.6 Tourism and Water Supply

Tourism has dramatic affects on the supply and demand of water in a region, and is a necessary topic for this study due to the dominance of Santorini's economy by travel activity. At the most basic level, tourism brings more people that require water, and their residence is often distributed unevenly throughout the year. In the Mediterranean Sea tourism is extremely heavy during the summer months, when water is at its scarcest. This requires these locations to have a backup water resource to supplement demand during these peak tourist months. Tourism brings a much higher demand for water per capita than permanent residents. 1995 data shows that 15,000 m^3 of water could supply 100 urban families for two years, yet only supply 100 luxury hotel guests for 55 days. Varying reports show that tourists use anywhere from 6-15 times the normal amount of water per day. In addition, tourism development is often focused in coastal zones that are some distance from the primary freshwater sources, requiring extensive piping and shipment. Certain facilities that tourism requires, particularly swimming pools and golf courses, also increase the necessary quantity of freshwater. Some golf courses require over 100,000 m^3 of water each year. A water crisis can be very damaging to a tourist region. For example, in Mallorca in 2000, water shortages, in addition to power outages, created bad press in Germany from returning vacationers (Essex, Kent, and Newnham 2004). A region with an economy relying heavily on tourism must take extra care to ensure that a water source will be of high quality and quantity throughout time and space, and that it will continue to be of high quality and quantity.

2.7 Lessons for Santorini

A great deal of this information offers insight into how to provide Santorini a sustainable water supply. The three tiers of sustainability apply both to the analysis of current resources and to the selection of a better supply. Economic and social factors have been considered during analysis, particularly how they play a part in agriculture and the traditional population of Santorini. Economically, the needs of tourism must be addressed in order for the economy of Santorini to survive. Environmental factors are particularly important to consider in the selection of a new water supply and system, as the geologic instability of the islands creates the necessity for a reserve supply. The "safe yield" of groundwater in Arizona is one example of how the environment has been carefully examined in the application of water management. Furthermore, in both the literature on IWRM and water resources in Singapore and the Greek islands, it is known that overdependence on outside resources can place a region or location at extreme risk.

The literature on IWRM also lists a more modern and complete list of potential water resources. Several of these resources are already exploited on Santorini to a certain extent. These are further examined in Chapter 5, in which one resource will be selected for a large implementation. The use of several alternative resources is seen in the case studies. Desalination in particular is being used at increased volumes worldwide, and specifically in regions close to Santorini such as North Africa, the Middle East, and other Greek and Mediterranean islands. Much of this is due to constant improvements in technology that are helping to lower the cost. Although rainwater harvesting is a popular resource in many areas, the literature on Greek islands reveals that it is no longer a viable primary resource in the Aegean due to a decrease in precipitation over recent decades. To counter this, multiple authors state that a combined desalination and wind energy scheme would be the best available alternative (Kaldellis, Kavadias, and Kondili 2004, and Voivantas, et al 2003).

Information on planning for water resources has been directly applied to the methodology of this study. An inventory of supply and demand has been conducted, in addition to possibilities for the future if nothing is done and a statement of major issues. Certain management techniques, such as conservation through appropriate pricing, have been strongly considered as well. Much of this will become visible in the following chapter, Research Methodology, when the steps of analysis are outlined in detail.

Chapter 3: Research Methodology

The purpose of this study is twofold. The first goal is to paint the most complete picture possible of the state of Santorini's water supply. This goal has been achieved through Part 1 of the Methodology: Current Situation (Figure 3.1: Research Methodology). The second goal is to conceptually apply or expand one technology within the water network and illustrate how these changes would positively affect the water supply. Part 2 of the Methodology: Improving the Supply is dedicated to this goal.

Within Part 1 includes the first five major steps of the methodology: profile of the current resources, profile of the current demand, calculation of the water deficit, forecast of the future, and statement of major issues. Supplemental information to be included, but not necessarily part of these steps, is a consideration of social issues, a consideration of environmental factors, and economic factors that play a role. Part 1 intends to illustrate the level of sustainability in Santorini's water supply, justify the need for improvement, and create the model upon which the conceptual scenarios in Part 2 will be based.

Within Part 2 are the final four major steps of the methodology: a review of possible alternative resources, selection of one technology, creation of two alternative scenarios for the implementation of that technology, and the expected results of each scenario if they were to be implemented.

It must be noted that much of this study has been conducted with incomplete information. Santorini has never had a comprehensive study done on its water supply and system, and as a result some information may not be in recorded form. It can be assumed that this is among the most complete studies of Santorini's water system ever conducted. Therefore, much of what has been decided was based on educated inferences from the information that does exist. All calculations and assumptions will be explained in full in the Appendix.

Part 1: Current Situation

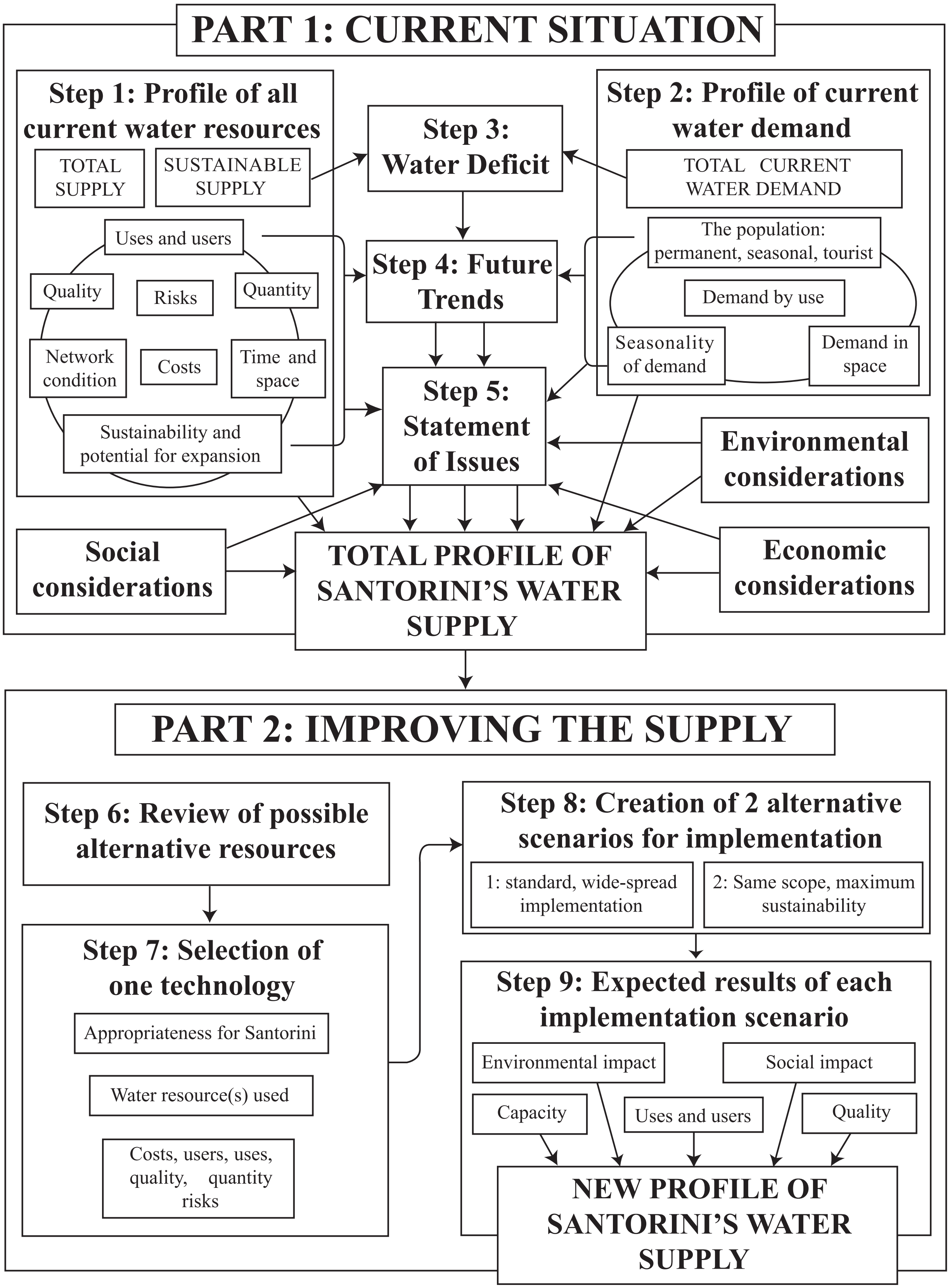
The combination of all steps and information of Part 1 has lead to the first goal of this study: a Total Profile of Santorini's Water Supply. Although there is an order to these steps, execution of Part 1 will depend on constant use of all information, as it all links together to form the complete picture.

Step 1: Profile of All Current Water Resources

In order to understand the entire system, each resource has been analyzed individually. These resources include water pumped from the aquifer, imported, desalinated in Ia, or other such as rainwater or wastewater. Each resource has been analyzed based on quality and the uses that this permits, and quantity (measured by m^3/day or m^3/year, as well as availability throughout the year). Any costs or risks associated with the resource (economic, social, or environmental) have also been analyzed, as well as the condition of each resource's respective water network. This information has been gathered in part from interviews conducted by the University of Cincinnati Sustainable Development Group (UCSDG), from personal experience, and from the few technical reports that do exist. However, exact information on certain resources, such as rainwater harvesting or wastewater reuse, was not entirely available, and required a level of estimation. The main goal of this step was to find out the capacity, sustainability, and potential for expansion that each resource has.

Total supply will be presented in both map and table form. The map will show how each settlement gains access to water, while the table will show more detail on each resource, its costs, quality, and quantity. By compiling information on all resources two total water supplies have been calculated: that which is currently exploited and a sustainable supply. The sustainable supply was what was built on in Part 2 of the Methodology.

Figure 3.1: Research Methodology



Source: Author 2006

Step 2: Profile of Current Water Demand

Demand was based on permanent, seasonal, and tourist population, as well as the special needs of agriculture. Information on the permanent population and agriculture can be gathered from past work of the UCSDG, standards for water consumption, and Greek census data. The special demand of the tourism industry includes the increased water use of tourists based on increased individual consumption, as well as the existence of such amenities as swimming pools. Data on the tourism industry was compiled from interviews conducted with the Santorini Hotel Owners Association, Rental Rooms Owners Association, and other key informants. The total current demand will be analyzed similarly to the total supply, through a series of tables.

Step 3: Water Deficit

Once the sustainable supply and demand were calculated, it was possible to calculate the deficit between demand and sustainable supply. This illustrates the amount of water that needs to be accessed in a sustainable manner to make the total supply of Santorini a sustainable water supply.

Step 4: Expected Future Trends

To the best ability that data allow, future trends have been projected. As expected, this projects the situation to worsen in coming years, helping to justify the need for improvements to the system. Expected trends in supply, demand, and pricing will all be analyzed.

Step 5: Statement of Issues

This step works both backwards and forwards. It works backwards by reanalyzing many aspects of the water supply and demand to find the real issues that are causing water on Santorini to lack sustainability. For example, when reanalyzing water from the aquifer, it was be necessary to describe why the water is not of drinking quality. This step works forwards by creating additional criteria upon which a technology will be selected later in Step 7.

Supplemental Information

Three other groups of information have been gathered that do not necessarily fall into a specific step, but were necessary for the presentation of the total profile. Social, environmental, and economic considerations have all been presented and analyzed, as they are intrinsically linked to the water supply and to hopes for sustainability. Social factors include impacts on culture and stakeholders that are concerned with the water supply. Environmental considerations include anything having to do with Santorini as an unstable area, or possible impacts of alternative resources. Economic considerations include impacts of prices, possible impacts on tourism and agriculture, and costs of resources.

Part 2: Improving the Supply

Part 2 of the Methodology is meant to meet the second goal of this study: providing the conceptual results of implementing new technology for the water supply of Santorini.

Step 6: Review of Possible Alternative Resources

Because this study deals directly with exploiting or enhancing the use of an alternative water resource, those possible resources must be listed. This step analyzed commonly used alternative water resources to weigh their merits in creating a more sustainable water resource for Santorini. They have been reviewed through the lens of Part 1 of this analysis, knowing in advance what is wanted from each resource.

Step 7: Selection of One Technology

With information provided in Part 1, Step 6, the Literature Review, and the past work of others, criteria have been available to analyze each technology. The ultimate criterion is how well the resource can create a sustainable water supply for Santorini by solving the issued presented in Part 1 of the analysis. Economic considerations and the necessary knowledge base of each technology will also be weighed in the decision.

Step 8: Creation of 2 Alternative Scenarios for Implementation

The purpose of this step was to show different options for improving the water network using the technology selected. The first scenario will be meant to implement the technology in a standard sense, which will help to make the water supply of Santorini much more sustainable. The second scenario involves other innovative elements to make implementation and use as sustainable and "green" as possible, in an attempt to eliminate all negative impacts.

Step 9: Expected Results of Each Implementation Scenario

The final step of the study presents conceptual profiles of Santorini's water situation if the different scenarios were implemented. This includes how the technology would affect the environment, the economy (costs of the technology), the overall capacity of the system, and social life on Santorini. Providing conceptual results of implementing the alternate scenarios provides for a clearer vision upon implementation. A supplemental step after this will be to give supporting recommendations, albeit in much less detail, which should accompany the main recommendations of this study.

Chapter 4: Current Profile of Santorini's Water Supply

This chapter provides a comprehensive profile and analysis Santorini's current water supply situation. That is, supply, demand, and their relationship are examined through the lens of sustainable development, and how they affect the social, economic, and environmental aspects of Santorini. The primary data for this stage of the study are interviews conducted by the University of Cincinnati Sustainable Development Group and the author from 2004 to 2006. What technical data does exist, such as consumption and cost reports from the Municipality of Thira, are used as well. Personal and team experiences in Santorini are also a large part of the data. A possible caveat of this stage of the study is the accuracy of data. Some data was generalized, incomplete, or conflicting. A certain amount of reconciliation and judgment was required to come to conclusions. Despite this possible caveat, this study is likely the most complete and accurate profile of Santorini's water supply ever compiled. The Appendix includes full explanations of calculations and data reconciliations that were made.

Water resources are split into seven categories: the Municipality of Thira groundwater network, other groundwater, seawater desalination, imported tank water, imported bottled water, rainwater harvesting, and wastewater reuse. For each water resource, quantity, quality, availability, sustainability, and, perhaps most important to this study, potential for expansion, are presented. A strict use of the term sustainability is used to describe the sustainable portion of Santorini's water supply. The water must come from within Santorini, exploitation involves no substantially negative environmental, social, or economic side affects, and it does not falter over time or in the face of crisis. A total sustainable supply was determined from the above supplies so that it could be compared to demand.

Following the profile of water supply is the profile of demand, based largely upon water that is currently consumed in addition to standard numbers for permanent and tourist populations in Greece. Demand and supply have been compared to calculate a water deficit, followed by likely future trends of supply and demand if the situation continues as is. Following is a brief analysis of other factors that may influence, or be influenced by, the condition of the water supply, such as environmental considerations, stakeholders and other social aspects, and the economy. The chapter ends with a statement of major issues concerning Santorini's water situation.

4.1 Existing Water Resources

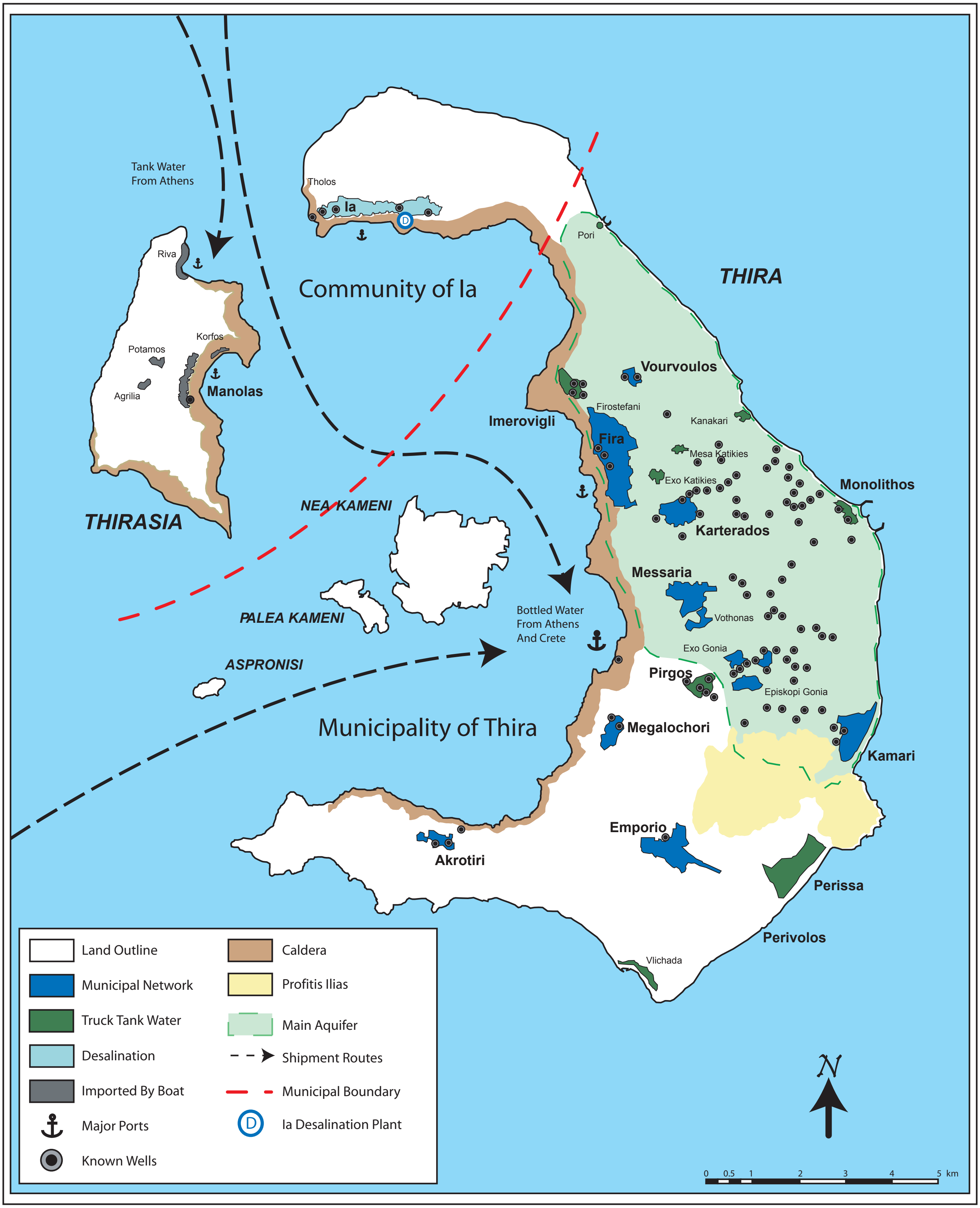
4.1.1 Groundwater Resources

On the island of Thira, groundwater is the primary source of freshwater. The aquifer has a total storage capacity of approximately 100,000,000 m^3, of which 1,300,000 m^3 is extracted annually to supply water to the various villages in the Municipality of Thira. However, this network does not supply water to all of the villages in the municipality, as several have water brought by truck (Karamolengos 2004 and Nomikos 2006). Overall, groundwater on Santorini is of low quality, high cost, and low sustainability.

4.1.1.1 Municipality of Thira Groundwater Network

The Municipality of Thira governs the majority of the island of Thira, minus the area in the north which is governed by the Community of Ia, and is therefore responsible to provide freshwater for its residents. The Municipality runs a connected water network that pumps from deep within Santorini's main exploitable aquifer in the underlying paleodaphic formation (Figure 4.1) (European Commission 1998). However, this network does not supply all settlements or residencies within the Municipality of Thira. Several villages continue to lack infrastructure connection to this network and are forced to have water shipped by truck. The Municipality

Figure 4.1: Water resources across the islands



Source: Argyros 2004, Author 2006, European Commission 1998, Haidakis 2004, Karamolengos 2004, Nomikos 2006, Municipality of Thira 2002, University of Cincinnati Sustainable Development Group 2004

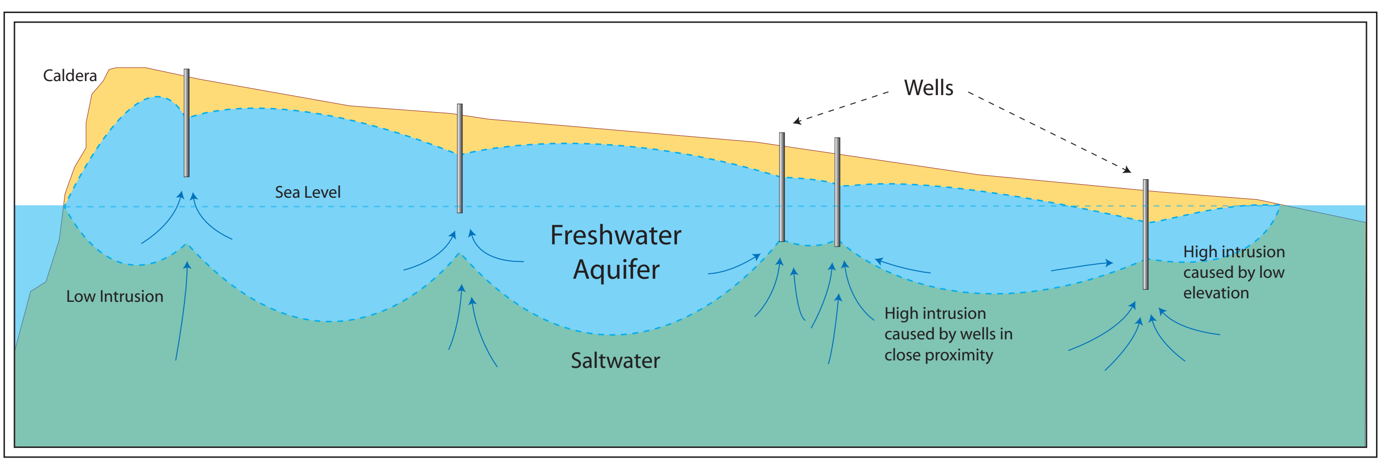
currently supplies piped water to Fira, Firostefani, Vourvoulos, Karterados, Messaria, Vothonas, Exo Gonia, Episkopi Gonia, Megalochori, Kamari, Emporio, and Akrotiri. The Municipality of Thira's groundwater network accounts for 60% of the total water pumped annually from the aquifer, and 60% of the water supplied to the Municipality of Thira (excluding rainwater and imported water) (Karamolengos 2004).

The 1956 earthquake affected Santorini's water supply in multiple facets. The earthquake destroyed much of the built environment, and Kamari used the opportunity of recovery to improve infrastructure, including building the first village-wide water network on the islands, which later became part of the Thira network. During the tourism boom of the 1970s and 1980s, groundwater replaced rainwater harvesting as the primary water supply on Santorini. Water quality from the aquifer was initially sufficient for consumption, but as demand increased wells were drilled deeper and at greater rates. The result was that by the late 1980s saltwater intrusion had severely affected the quality of groundwater resources (Karamolengos 2004).

Quality degradation comes primarily from saltwater intrusion (Figure 4.2). Other forms of contamination are suspected but undocumented. Chemical tests conducted in November of 2003 in Fira, Messaria, Kamari, Vourvoulos, and Emporio show that throughout the network water does not meet national Greek quality standards for consumption (University of Cincinnati Sustainable Development Group 2004). The level of salinity varies throughout the municipal network, and is dependent upon a number of factors. The level of hydraulic connection with the sea (the ease with which saltwater interchanges with the freshwater aquifer above it) is a major factor. This is often high on Santorini due to aquifers in pyroclastic materials having a more open connection with the sea (European Commission 1998). Figure 4.2 illustrates how elevation, depth of drilling, and proximity of successive wells have all affected the salinity of water extracted from the aquifer. In addition, the aquifer is not given time to recover, as it is over-pumped throughout much of the year.

The quantity of water that is pumped from the aquifer for use in the Municipality of Thira network has risen in recent years. In 2002, the total consumption was 737,533 m^3, a 32% increase from 560,000 m^3 extracted in 2000 (Municipality of Thira 2002). In 2004 it was estimated that consumption had risen again to 780,000 m^3, an additional 6% increase since 2002 (Karamolengos 2004). Consumption varies considerably from village to village based on number of permanent residents and level of tourism activity. The quantity of water consumed, compared to that extracted, is affected by a nearly 25% leakage

Figure 4.2: Cross-section of Santorini showing the nature of saltwater intrusion in the aquifer



Source: Author 2006

rate in the piping network (see the Appendix) (Haidakis 2004).

The cost of water from the Municipality of Thira network is not uniform, but varies throughout the area it covers. In Fira, where tourism and urban life are very active, water is very expensive at €1.47/m^3 in 2002. The price of water in Fira is likely based on a combination of the tourist economy and the high price of property on the caldera. Other villages range from about €0.85/m^3 to €1.00/m^3, with an average cost (not including Fira) of €0.92/m^3. It is not clear why there is a discrepancy between villages, as all water comes from the same network of wells and pipes. The theory that a more active tourist economy would account for a higher cost does not apply consistently, as Kamari is very active with tourism and at only €0.85/m^3 has some of the most affordable water. What is clear is that something, or someone, else is affecting water pricing, and that further research should be conducted to find out the truth about these discrepancies (Municipality of Thira 2002).

In addition to the base cost of water, villages with sewage connection pay an additional €1.50/m^3 (Argyros 2004). For properties with sewage connection, 60% of water consumption is attributed to sewage processing, pushing the price up (Karamolengos 2004). Table 4.1 details costs and consumptions in 2002 within villages covered by the municipal network. Settlements showing no price for sewage do not have that service (Municipality of Thira 2002).

4.1.1.2 Other Aquifer Resources

As stated above, the 780,000 m^3 pumped annually for use in the municipal network only accounts for 60% of the total pumping from the aquifer. The other 40% is pumped by private vendors and transported by truck to the villages within the Municipality of Thira that are not connected to the main piped network: Imerovigli, Monolithos, Pori, Kanakari, Mesa Katikies, Exo Katikies, Pirgos, Vlichada, Perissa, and Perivolos (Figure 4.1). According to Peter Nomikos (2006), there are 30-40 trucks that transport water for these vendors. Because this water is pumped from the same aquifer it has the same quality problems that the Municipality of Thira network does. The connections within these villages were performed by local plumbers, and leakage is up to 25%, similar to the municipal network (Karamolengos 2004). No record exists of whom, if anyone, among these individuals has the authority or

Table 4.1: Cost and consumption in the Municipality of Thira Groundwater Network, 2002

Village	Customers	Total Fee (euros)	Consumption (m^3)	Cost per m^3	Consumption per customer	Sewage per m^3
Akrotiri	155	9,242.32	10,046	€ 0.92	64.81	NA
Emporio	555	25,060.56	29,834	€ 0.84	53.75	€ 1.50
Exo Gonia	236	19,377.48	20,836	€ 0.93	88.29	€ 1.50
Fira	724	274,937.04	187,032	€ 1.47	258.33	€ 1.50
Kamari	1,097	276,618.05	325,433	€ 0.85	296.66	€ 1.50
Karterados	520	60,641.49	62,517	€ 0.97	120.23	€ 1.50
Megalochori	86	4,438.74	5,102	€ 0.87	59.33	NA
Messaria	451	46,573.56	47,044	€ 0.99	104.31	€ 1.50
Vothanos	208	26,985.28	27,536	€ 0.98	132.38	NA
Vourvoulos	273	19,716.17	22,153	€ 0.89	81.15	€ 1.50
Total	4,305	763,590.69	737,533			
Average				0.97	171.32	

Source: Municipality of Thira 2002

legal right to operate in this fashion. In addition, no records exist to tell which villages use more water. This activity accounts for 520,000 m^3, 40% of the total extracted. Cost of transported water to unconnected villages is considerably higher than to those served by the municipal network, due to the cost of transportation by truck. Water is sold in quantities of 8 m^3 for €30.00, or for €3.75/m^3, four times the cost of piped water to some settlements (Haidakis 2004).

4.1.1.3 Sustainability of Groundwater Use

Groundwater, as it is used on Santorini, does not provide a sustainable water supply. Both the increase in groundwater salinity and the need to pump deeper are evidence that the aquifer is currently being pumped at an unsustainable rate. As stated above, aquifer capacity is approximately 100,000,000 m^3 (University of Cincinnati Sustainable Development Group 2004). A 2004 study of Santorini's aquifer conducted by the National Technical University of Athens (NTUA) showed that it had a recharge rate of 1,355,100 m^3/year. Water is currently being pumped at nearly that rate, not allowing the quantity or quality of water in the aquifer to improve. The NTUA study calculated a sustainable yield of 722,135 m^3/year, which is 53.3% of the recharge rate. These numbers are based on a liberal reference recharge rate, and provide for the restoration of groundwater quality and quantity. The authors also warn that this sustainable yield must still be used with caution, and that it should shift with lower rainfall. In years when rainwater is much lower the sustainable yield drops to only 23% of the recharge rate. In the case of the Southern Aegean, rainfall has decreased by approximately 15mm/year over the last 40 years, evidence that a lower sustainable yield may be necessary for Santorini (Kaldellis 2004). However, for the purpose of this study, the suggested sustainable yield of 722,135 m^3/year will be used. In its current condition, and with the continued aridity of the region, it would likely take upwards of 300 years for the aquifer to recharge completely if groundwater use stopped today.

Based on low sustainability and quality, groundwater resources are seen as having no potential for expansion in the future. Making this resource sustainable would require decreased use, repairs to reduce leakage, expansion of distribution to all settlements, and improvements in purification. However, finding ways to purify the water would only solve the problem temporarily, and would encourage further groundwater exploitation. Only through reducing the use of groundwater to the sustainable yield of 722,135 m^3/year will solve these issues for the long term.

4.1.2 Desalination in Ia

The only desalination plant in all of Santorini is located in the village of Ia to the north. Ia, being administratively separate from the Municipality of Thira, is not connected to the southern water network, nor is it served by the private vendors. With existing information, it is evident that the desalination plant only serves Ia itself, and not the smaller villages on Thira that are part of the Community of Ia. Because of this plant, Ia is the only village in Santorini that has drinkable water in its network. Water goes from the plant to the village through the local Ia piping network. No records exist on the condition of Ia's water network, therefore no information on leakage exists.

The desalination plant (Figure 4.3) uses seawater reverse osmosis (RO) desalination to produce freshwater of drinkable quality. It is located 160 meters above sea level, which allows for gravity distribution of the freshwater. The decision to locate it at the top of the caldera, as opposed to the bottom or near the beach, was made after a study revealed that having it at sea level would leave it susceptible to problems with seaweed and damage from winter waves. Desalination in the plant involves four steps: pumping from the sea, sand filtration, microfiltration, and reverse osmosis. Backwash is periodically sent back to the sea to eliminate suspended solids and brine. The plant has a 30% efficiency rate, meaning that for every 100 m^3 taken in it produces a freshwater output of 30 m^3.

Figure 4.3: Ia desalination plan

Source: University of Cincinnati Sustainable Development Group 2004

Figure 4.4: Reverse osmosis unit in the Ia plant

Source: University of Cincinnati Sustainable Development Group 2004

In reverse osmosis desalination, a higher salinity creates a lower efficiency. The waters of the southern Aegean Sea are very saline. The plant has little to no environmental impacts on the sea around Santorini (Pitsikaris 2004).

There are three desalination units in the plant. The first one was installed in 1994 and has an output of 300 m^3/day. The second was installed in 1997 and produces 170 m^3/day, and the third came in 2002 and has an output of 400 m^3/day. All in all the plant has an 870 m^3/day capacity. If the plant was always run at full capacity, it would have an annual yield of 317,550 m^3. However, because of tourism and residential seasonality on Santorini, the plant is not run at full capacity year-round. In the winter only the small desalination unit is used. Adapting full use with the seasonality of tourism (April through October) shows an annual yield of approximately 211,850 m^3 (see the Appendix) (Pitsikaris 2004).

The cost of desalinated water is much higher than for customers of the Municipality of Thira groundwater network. Residents in Ia pay €2.94/m^3 (1,000 Greek drachmas/m^3) for their water, three times the cost for water from the Municipality of Thira network. This cost is due to the high cost of desalination at such a low capacity, in addition to the cost of property in Ia being the highest in all of Greece. These high prices indicate why water is not pumped from the desalination plant to other villages as well, as the added transport cost would make it unaffordable. In addition, the initial cost of building a desalination plant is high, requiring additional income or grants to fund the project (Pitsikaris 2004).

A problem with desalinated seawater is its taste. Although it is purified to a high quality suitable for consumption, it still retains a salty taste that many residents do not drink or cook with. It is unknown whether residents filter the water at the household level to improve the taste, as is done in Bahrain. From team observations during the summer of 2005, it is known that large numbers of people still consume bottled water despite the existence of quality water.

Seawater desalination, as it exists on Santorini, is seen as a moderately sustainable water resource because it comes from within Santorini, provides for high quality water, has minimal environmental impact, and can be seen as a virtually limitless resource. The only factors that lower the sustainability of desalination are cost and taste. High costs are created by the low capacity of Ia's plant. As RO units grow in capacity, the cost of water production per m^3 decreases substantially, and could help to support secondary filtering to improve the taste. Because the overall sustainability of RO seawater desalination actually improves as scale increases, it is seen as a water resource with a very high potential for expansion.

4.1.3 Imported Water: Thirasia

A Greek governmental program exists that requires the government to supply remote islands with water, which Thirasia qualifies for. Evidence shows that nearly all of the water consumed on Thirasia (minus bottled water) comes by tanker boats. It is pumped directly into their water network from boats with capacities of 50-100 m^3 (Nomikos 2006). The condition of Thirasia's water network is unknown, and therefore data on leakage does not exist. This water has a quality suitable for hygiene and drinking. The price of this water to consumers is not known, but is expected to be very low as it is subsidized by a government program. A total of 22,906 m^3 was imported to Thirasia in 2002, and this number has likely stayed stagnant or decreased slightly since due to a lack of heavy tourism and a slight loss of population (Kaldellis 2004).

Water in Thirasia is seen as moderately unsustainable based solely on the fact that it is imported. Although the water is of high quality, low cost, and does not require the residents of Thirasia to over-pump their groundwater resources, complete dependence upon an outside resource is not desirable. In the event of political or environmental crisis disconnecting mainland Greece from Thirasia, the island would be without water. In addition, the boats themselves cause pollution during transport. Therefore, although not the least sustainable water resource currently in use, importing tank water is not seen as an expandable option for an improved water resource for any part of Santorini.

4.1.4 Imported Bottled Water

All throughout Santorini, drinking water is primarily imported bottled water. Even in Thirasia and Ia, where the water is drinkable, it has been observed that bottled water is the primary source. Most of this is imported from mainland Greece or Crete. No records are available detailing exactly how much bottled water is imported to Santorini, however, an estimate of 1,000,000 m^3 imported annually has been calculated (see the Appendix).

The cost of drinking bottled water is very high. The observed was approximately €1.00 for a 1.5 liter bottle at local stores. This price varies depending upon the quantity purchased (cheaper by the case at grocery stores) or where it is bought (more expensive in Fira, for example). No matter the cost, it is much more expensive than the cost of water from the municipality, costing approximately €650/m^3. This is 173 times the cost of tank truck water to unconnected villages in the Municipality of Thira, 221 times the cost of desalinated water in Ia, and 670 times the average cost of tap water for those serviced by the Municipality of Thira network. However, because little other option exists for potable water, both tourists and permanent residents have no choice (University of Cincinnati Sustainable Development Group observations 2005).

Imported bottled water is seen as unsustainable for three reasons. The first reason is its high cost to the individual consumer. The second is that, like imported tank water, it leaves Santorini dependent upon an outside source for a basic and essential resource. Third, and perhaps most significant, it brings with it not only water, but bottles. No recycling exists on Santorini, and no trash is exported. Therefore, all trash is sent to Santorini's non-sanitary landfill. In addition, due to the narrow streets of Santorini, solid waste collection is expensive. Imported bottled water is unsustainable based on multiple environmental, social, and economic reasons, and is seen as having no potential for expansion on Santorini. However, because of trends in Greece, Europe, and the world as a whole, it is assumed that bottled water will continue to be a primary source of drinking water on Santorini. It is the complete dependence upon imported bottled water that is unsustainable and should discontinue.

4.1.5 Rainwater Harvesting

Historically, rainwater was the primary water resource on Santorini and throughout the Aegean. In recent years, however, much of this culture has declined. Nearly all traditional homes on Santorini have at least one cistern, usually below

Figure 4.5: Cistern on Santorini

Source: University of Cincinnati Sustainable Development Group 2004

the structure, with the top of the house acting as a catchment. Often, a home will have two cisterns, with the first being used to catch sediment so that water in the second tank is drinkable. Current building codes require cisterns, and most buildings built in a traditional manner comply with this rule. Where this culture is being lost is in random tourism or private development which does not resemble the eposkifa architectural style that is traditional to Santorini. This type of development is becoming more common, particularly in rural areas between villages (Evelyn Hatzigianakis 2004, Nomikos 2006, University of Cincinnati Sustainable Development Group observations 2005).

The hydrology of the southern Aegean Sea does not allow for a vast amount of rainwater harvesting, but Santorini does experience heavier rainfall during the non-tourist months from November to March, peaking in December and January (University of Cincinnati Sustainable Development Group 2004). The annual volume of rainfall for all of Santorini is approximately 30,000,000 m^3. However, little of this water actually becomes available for harvesting. Evapo-transpiration rates of 65-75% leave only about 9,000,000 m^3 in surface water, of which approximately 1,355,100 m^3 is absorbed into the aquifer, leaving just under 7,700,000 m^3 that is available for harvesting (European Commission 1998 and Mantoglou 2004). However, to collect this water in cisterns, it would require every square meter of surface on the islands to be part of some sort of catchment system. Therefore, the amount of rainwater that is actually harvested on Santorini is extremely lower than this number. For this study, it is estimated that 100,000 m^3/year is harvested and consumed. Many of the cisterns that do exist on Santorini are only currently used to store water from tanker trucks or boats (Nomikos 2006, University of Cincinnati Sustainable Development Group observations 2005). This is not seen as completely negative, as any storage of water on Santorini is positive, but it is a less sustainable resource than rainwater. All of these factors greatly reduce the true quantity of harvested rainwater on Santorini, making the figure of 100,000 m^3/year a reasonable estimate.

Quality of harvested rainwater depends on regular upkeep of the catchment system and the intended use of the harvested water. Surface pollution is a potential problem, but a two cistern system helps to remove much of this pollution during the first rain of the year. On Santorini, water only needs to have its suspended solids removed and a slight chlorination in order for it to be drinkable. If it is used for irrigation, it only needs to be harvested, nothing more. Light but frequent maintenance is the key to quality harvested rainwater. Overall, rainwater is of a much higher quality than the water that is currently being drawn from the aquifer.

Rainwater as a water source can be seen as somewhat sustainable for Santorini. On one hand, it is of high quality, low cost, and there are very few risks associated with it. If anything, it reduces runoff that leads to heavy erosion of Santorini's landscape. On the other hand, the amount that could realistically be harvested is not nearly enough to supply Santorini's tourist population. In addition, much of the cistern infrastructure is falling into disrepair, meaning a full recovery of this system would take a significant amount of time and money. Therefore, it is seen as a very sustainable supplemental water resource. Nonetheless, because of its high quality and current low cost, rainwater harvesting is seen as a water resource with moderate potential for expansion.

4.1.6 Wastewater Reuse

Currently, wastewater reuse is not a prominent water resource on Santorini. It is only used very sparingly in household landscaping and some for agricultural purposes in Kamari and possibly other areas. It is, however, seen as a very sustainable resource that could be expanded on Santorini, particularly for irrigation of crops (Skopelitis 2004). In particular, household reuse of greywater could be a substantial resource for small gardens and landscaping. Larger, more advanced treatment of wastewater could help in the irrigation of Santorini's agricultural base, which currently suffers from a low yield per hectare largely because of a lack of water.

4.1.7 Summary of Water Resources

As can be seen from Table 4.2, the most used water resources on Santorini (groundwater, imported water) are the least sustainable. The most sustainable sources are in need of expansion in order improve Santorini's supply. Currently, the islands have a total water supply of 2,634,756 m^3 and a sustainable supply of much less with 1,034,000 m^3. This number is the sum of water from the desalination plant, rainwater harvesting, and the sustainable yield of the aquifer. This number is what must be built upon, not the total supply, if the water supply of Santorini is to be expanded in a sustainable manner. In addition, Santorini's dependency ratio on outside sources is 39%. In the wake of a crisis that cut off transport, 39% of the water Santorini needs to survive could not be used.

Table 4.2: Summary of existing water resources

Water supply	Yearly Consumption (m^3)	Sustainable Yield (m^3)	Quality	Cost per m^3	Sustainability
Aquifer	1,300,000	722,135	Low	€ 0.84-3.75	Very Low
Desalination	211,850	211,850	Potable	€ 2.94	Moderately High
Imported Tank Water	22,906	0	Potable	Subsidized	Moderately Low
Imported Bottled Water	1,000,000	0	Potable	€ 650.00	Very Low
Rainwater Harvesting	100,000	100,000	Varies per use	very low	High
Wastewater Reuse	Very little	Very little	Varies per use	very low	High
Total	2,634,756	1,033,985			

Source: Argyros 2004, Author 2006, European Commission 1998, Haidakis 2004, Karamolengos 2004, Nomikos 2006, Municipality of Thira 2002, Pitsikaris 2004, University of Cincinnati Sustainable Development Group 2004

4.2 Existing Water Demand

4.2.1 Demand of the Permanent Population

In 2001, Santorini had a permanent population of 13,725 people (Hellenic Republic Ministry of Economy and Finance 2001). Through calculations involving Municipality of Thira consumption, standards of human health, and population statistics, a demand of 31.14 m^3/capita/year (90 L/day) was calculated for all of Santorini (see the Appendix). This in turn gives a demand of 427,443 m^3/year for the entire permanent population (Hellenic Republic Ministry of Economy and Finance 2001, Municipality of Thira 2002).

4.2.2 Demand of the Seasonal Population

In addition to Santorini's permanent population, a significant number of people, approximately 1,876, live there only seasonally to service the tourism industry. It is assumed that they consume the same amount of water that permanent residents do. However, their residence includes only the tourism months of April through October, so their demand would only be 18.17 m^3/capita/year. For a seasonal population of 1,876 there is a total water demand of 34,081.22 m^3/year (Appendix).

4.2.3 Demand of the Tourist Population

Tourism is the dominant sector in Santorini's economy, and is also the largest user of water on the island. Gyzis (2004) has the most recent data on the number of tourists that visit Santorini each year, how they arrived, and how long they stayed. By assuming that visitors to Santorini consume an average of 0.400 m^3/day of water (see the Appendix), a total demand of 1,451,294 m^3/year was calculated (Table 4.3).

4.2.4 Demand of the Agricultural Sector

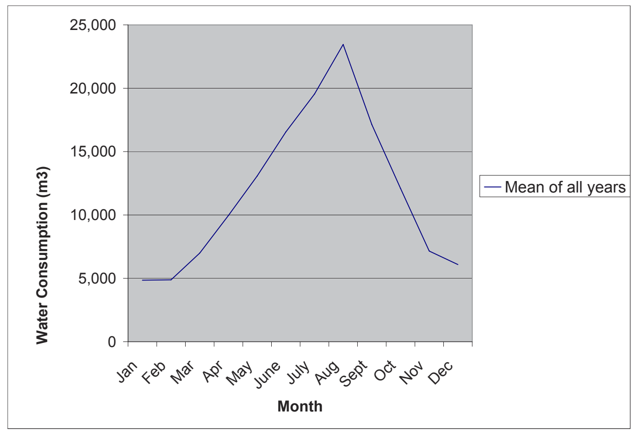
Historically, agriculture, particularly grapes, was the dominant sector in Santorini's economy. With the rise of tourism agriculture has dropped dramatically, but as an industry it still demands upwards of 500,000 m^3/year of water. Like tourism, demand for water in agriculture is seasonal, requiring more during the summer

Table 4.3: Water demand of different types of tourists

Type of Tourist	Number in 2002	Average Stay (days)	Daily Consumption (m^3)	Total Water Demand (m^3)
Charter Flights	170,000	10.00	0.40000	680,000
Normal Flights	81,000	4.00	0.40000	129,600
Ferry	401,000	4.00	0.40000	641,600
Cruise	375,000	0.17	0.00025	94
Total	1,027,000			1,451,294

Source: Gyzis 2004

Figure 4.6: Seasonality of water demand in Fira, 1998-2001



Source: Municipality of Thira 2001

months of June and July (University of Cincinnati Sustainable Development Group 2004).

4.2.5 Seasonality of Demand

Because Santorini's economy relies heavily on a seasonal tourism sector, water demand is extremely seasonal as well. Figure 4.6 shows how water consumption in Fira raises dramatically throughout the year. In 2001, January consumption was very low at 7,670 m^3 for the town, while in August it rose to 27,800 m^3 (Municipality of Thira 2001). This is only personal consumption in an urban area, it does not account for the additional seasonality of agriculture.

4.2.6 Summary of Existing Water Demand

Adding all of these demands together gives a total water demand on Santorini of 2,412,818 m^3/year (Table 4.4), much higher than the sustainable

Table 4.4: Summary of estimated water demand

Water User	Demand Per Year (m^3)	Demand Per Day (m^3)
Permanent Population	427,443	0.09
Seasonal Population	34,081	0.09
Tourism Population	1,451,294	0.400
Agriculture	500,000	NA
Total	2,412,818	NA

Source: Garcia 2003, Gyzis 2004, Hellenic Republic Ministry of Economy and Finance 2001, Municipality of Thira 2001, Municipality of Thira 2002, Nomikos 2006, University of Cincinnati Sustainable Development Group 2004

supply of only 1,000,000 m^3/year. Due to waste and unknown illegal activity, this number may actually be conservative, and planning for water resources should account for this possibility. The majority of demand comes from the tourism sector of Santorini's economy, while agriculture also accounts for a large portion. Seasonality is also a large problem, as much of this water is needed during the summer months for both tourism and heightened agriculture.

4.3 Santorini's Water Deficit

It is the gap between supply and demand that defines the water deficit. Total water demand on Santorini is approximately 2,412,818 m^3/year. Currently, with all resources combined, there is a supply of 2,634,756 m^3/year, which more than accounts for demand. However, only 1,033,985 m^3/year of this supply is seen as sustainable. This leaves a water deficit of 1,378,833 m^3/year that must be made up in order for the water supply of Santorini to be sustainable.

4.4 Expected Future Trends

4.4.1 Expected Decrease of Sustainability

Santorini's groundwater supply is currently diminishing, and continued exploitation at current rates will be worse for the economy and environment over the long term. As drilling becomes deeper and more prevalent, the sustainable yield will not hold at 722,135 m^3/year, but will be lower to allow for a further weakened aquifer to recover. There will also be less available water when those in charge finally decide to limit the amount of groundwater that is pumped from the aquifer to a more sustainable yield. In addition, the cost of water will increase while the quality is decreasing. To make matters worse, there is no indication that other sustainable resources such as desalination will be expanded. If current trends continue it is concluded that the sustainable water resources of Santorini will decline in both quantity and quality in the coming years.

The price of water on Santorini is rising, a trend that is expected to increase. From 2000 to 2002, the average price of water in the Municipality of Thira network increased from €0.82/m^3 to €0.97/m^3. A conservative trend forecast of this cost would see the cost of water increasing to €1.58/m^3 by 2010, a 92% increase over a ten year period, while a slightly less conservative projection would see price increasing by 234% to €1.92/m^3 (see the Appendix) (Municipality of Thira 2002). As the price continues to increase, less of the traditional population will be able to afford high quality water, damaging traditional society on Santorini further.

4.4.2 Trend Forecast of Demand

Detailed data exist on water consumption in Fira from 1998 to 2001. Consumption increased dramatically during each of these four years, from 98,718 m^3 in 1998 to 187,543 m^3 in 2001, a 90% increase (Table 4.5). This is due to an increase in both non-tourism demand and tourism demand, whether by an increase in population or consumption habits. In fact, water demand during the non-tourism months of November through March is growing at a much faster rate than tourism months. While it must be stated that Fira is one of the fastest growing areas of Santorini, and that not all areas are expected to have an increase in demand this dramatic. However, this does reveal, to the best ability that data allows, that the demand will continue to increase in the

Table 4.5: Projection of consumption and demand, Fira

Consumption in Fira (m^3)	Full Year	Tourism: Apr-Oct	Non-Tourism: Nov-Mar
1998	98,718	80,548	18,170
1999	116,750	91,890	24,860
2000	164,100	130,700	33,400
2001	187,543	144,098	43,445
Ave. Change/year	31,382	22,946	8,437
Ave. % Change/year	25%	23%	34%
Total Change	88,825	63,550	25,275
2010 Projected	471,294	352,742	118,552

Source: Municipality of Fira 2001

face of a weakening supply (Municipality of Thira 2001).

4.4.3 A Widening Water Deficit

As the sustainable water decreases and demand increases, the water deficit will widen. Unless sustainability is improved, this will only mean more reliance on outside sources, further destruction of the aquifer, and an overall more unstable and costly water scheme. Eventually, the water crisis of Santorini will become so severe that economic and cultural heritage will be crippled. A lack of access to quality freshwater will damage the tourism industry, and increasing prices will further hurt the traditional villages. In addition, bulk trash from imported bottled water will join destruction of the aquifer as environmental devastation.

4.5 Other Overarching Factors

4.5.1 Economic Factors

A major economic factor is the varying cost of water on Santorini. The more traditional settlements often get shorthanded by this policy. Villages in the Municipality of Fira that are not connected to the water network have to pay €3.75/m^3 of water. Often, these are traditional settlements that do not have much of a tourism economy, and therefore do not have as rich of an economy as villages that are connected to the network. Although no direct evidence exists, it appears that heavier tourism activity has lead to better infrastructure for these villages.

Tourism drives everything on Santorini. It was the reason that much of the traditional population abandoned agriculture. It is also the reason that water is at such a shortage. Developing a new water scheme may involve a large initial investment. Much of this investment should come from the tourism sector, whether through taxes, fines of illegal activity, or developing a more efficient model of tourism.

4.5.2 Social Factors

As explained in the Chapter 2, water is a prerequisite for nearly all aspects of society. Santorini, having a large tourist economy and agricultural base, is especially dependent upon a good water source for survival. This need has made water a popular political topic and issue on the islands. During interviews conducted by the University of Cincinnati Sustainable Development Group, water was often a popular topic, even if it was not the intended basis of the conversation. Officials at the Municipality of Thira (Argyros 2004), the Agricultural Cooperative (Skopelitis 2004), Restaurant Owners' Association (Hatzigianakis 2004), the Director of the Public Power Corporation (Sardelis 2004), the Municipal Company for Water, Sewage and Waste Management of Thira (Karamolengos 2004), and many others were all extremely concerned with water issues on Santorini, as it affects their respective sectors. It will take the involvement and inputs of all stakeholders to not only ensure the development of a detailed water plan, but also to ensure its success.

A secondary effect of the current water situation is damage to cultural heritage. If the theory above holds true that villages with heavier tourism activity gain better infrastructure, then the traditional villages of Santorini may continue to give into tourism not only for money but better services from the local government. Countless residents of the islands have already given up agriculture in order to work in tourism, and evidence suggests that this will continue. Although a dissatisfaction with water infrastructure will not cause this alone, it is one of many ways that these smaller, more traditional villages are falling behind larger settlements such as Kamari, Ia, and Fira.

4.5.3 Environmental Factors

Santorini has an extremely delicate and historically unstable environment. The islands face a volcanic landscape, harsh winds, erosion, an arid climate, and have terrain that is very difficult to build on. All of these factors create the need for a strong and resilient system of resources. Water reserves need to be created so that Santorini is ready for anything from a natural crisis to a spike in tourism. If another earthquake struck the islands, the water network could be damaged, as could the desalination plant. Reserves must be kept, and each system should have the capacity to make up for failures of another.

Expanding rainwater harvesting also brings up certain environmental issues. Because of the slope of Santorini's landscape and impermeability of much of the soil, stormwater runoff and erosion is a major problem. Many seasonal streams run perpendicular down from the caldera and to the beaches, with little opportunity to harvest the water for use or to allow it to recharge the aquifer. Great care must be taken in directing water toward catchments so that rainfall has a more positive affect on Santorini.

4.6 Major Issues Affecting Santorini's Sustainable Water Supply

Current exploitation of groundwater resources is not sustainable

The main aquifers of Santorini are currently being pumped at a rate far beyond what is sustainable. The more drilling takes place, the deeper it has to get, which not only perpetuates the problem but increases the cost of continually lower quality water. Eventually, drilling will be so deep that the line between the freshwater aquifer and the seawater underneath will be gone, and water will not be suitable for any use or affordable for any user.

No potable tap water in the Municipality of Thira

No villages within the Municipality of Thira have tap water that is suitable for consumption. This is largely due to overexploitation of aquifer resources, causing saltwater intrusion. This leaves all residents and tourists dependent on imported, and much more expensive, bottled water.

Water network coverage is very inconsistent over the islands

For being such a small group of islands, Santorini has a large number of water networks. Not even the two municipalities have unified networks to serve their population. As a result, some villages and residences are served by a municipal network, some by private wells, some by imported tank water, and some by illegal vendors (Figure 4.1). In addition, the condition of much of the network is poor, experiencing up to 25% leakage.

Table 4.6: Water pricing in selected settlements

Settlement	Cost/m^3 (2002)
Akrotiri	€ 0.92
Exo Katikies	€ 3.75
Fira	€ 1.47
Ia	€ 2.94
Kamari	€ 0.85
Megalochori	€ 0.87
Perissa	€ 3.75

Source: Municipality of Fira 2002, Pitsikaris 2004

The cost of water varies greatly over the island

Table 4.6 reviews the price of water in selected settlements. Depending on which network a water consumer is services by, as well as where they are, the price of water can vary greatly. It costs as much as €3.75/m^3 and down to below €1.00/m^3. This price discrepancy adds to economic problems that some villages are already facing in the wake of rampant tourism.

Very little water is produced in non-tourism months to supplement demand in the summer

The desalination plant is only run at the capacity necessary for the permanent residents. No effort is made to produce freshwater at a high rate during winter months to provide for a supplemental resource during the tourism months. Also, rainwater harvesting has fallen to a level that cannot be depended on as a supplement for the large influx of summer visitors. No reservoirs exist for major storage of water on the islands.

Santorini is too dependent on outside sources for freshwater

Imported bottled water, supplemental water to Thira, and imported tank water to Thirasia are all unsustainable water resources. Santorini is overly dependent upon these. It is almost completely dependent upon imported bottled water for drinking. Dependence upon outside sources can leave Santorini vulnerable in the wake of a political, environmental, or economic crisis.

Santorini's overall supply to demand relationship is unsustainable

The main water sources on Santorini (groundwater, imported water) are very unsustainable. With a rising demand, this relationship is only expected to get worse. Although enough water is currently supplied to cover demand, much of it is gathered in unsustainable manners. Currently, a water deficit of 1,378,833 m^3/year exists between demand and sustainable water resources. This is more than half of the total demand.

The situation is expected to get worse

No strategic plan exists to connect more villages to a comprehensive water network. No strategic plan exists to expand desalination of seawater throughout the island. No recycling exists to account for the bulk of trash created by consumption of bottled water. The aquifer is being drained at devastating rates that will eventually damage it for a very long time. While all of this is happening, tourism and the permanent population of Santorini are increasing bringing the water demand along. Eventually, the crisis will reach a point when it will become a crippling problem for Santorini if changes are not implemented.

Chapter 5: Alternative Water Resources

Improving Santorini's sustainable water supply requires the implementation or expansion of more sustainable water resources. As mentioned in Chapter 2, a complete list of potential water resources is only created when all potential alternative resources are added to more traditional ones such as surface and groundwater. The list that Boutkan and Stikker (2004) created is repeated below, with the resources currently in use by Santorini in bold:

- Rivers and lakes
- **Groundwater aquifers; no potential for expansion**
- **Rainwater; moderate potential for expansion**
- **Wastewater; high potential for expansion**
- **Seawater and brackish water; high potential for expansion**
- **Indirect freshwater (transported); no potential for expansion**
- New innovative resources (humidity, hydrated water in minerals)

This chapter uses the literature to further examine the three resources with moderate to high potential for expansion on Santorini. One of these alternative water resources, rainwater harvesting, wastewater reuse, or desalination, will be chosen based on its full suitability for Santorini. This is based on cost, necessary knowledge base, and most importantly, the amount of water than can be produced in a sustainable manner.

5.1 Seawater Desalination

Seawater desalination has been a part of human settlements for centuries, and is seen as a virtually limitless source of freshwater. Technological advances in recent decades have made desalination a much more affordable option, and use has thus grown substantially, upwards of 25,000,000 m^3/day worldwide by 2001 (Boutkan and Stikker 2004). Several techniques are available that range from the very simple (freezing, distillation, vapor compression) to the more complex (reverse osmosis, electrodialysis). Each form of desalination has its particular advantages, costs, and disadvantages. The choice of which one to use is based on a combination of the amount of water needed, the finances available, and the technical proficiency of the population that will operate the system. Certain types of desalination are highly compatible with renewable energy sources (RES), increasing sustainability and lowering long-term costs.

Some older forms of desalination are still in use today. Freezing saline water produces freshwater ice. This can then be mechanically separated from the concentrated solution, washed, and melted to get pure water. Energy usage in freeze desalination is primarily in refrigeration. Solar distillation, with stills varying in shape, size, and decline, are also used to desalinate water (Kalogirou 2005). Although these techniques are simple and require little technical knowledge, they do not yield the vast amounts of freshwater that other techniques can, and are therefore not viable to meet Santorini's demands.

5.1.1 Multi-Effect Distillation

Multi-effect distillation (MED) is a form of mass-desalination that has been in use since the mid 19th century. MED is based on transferring heat from steam to either seawater or brine in a series of stages (effects). Seawater is preheated and then sent into an evaporation chamber at a high temperature and high pressure. Steam from this chamber is then sent into a second chamber which has a slightly lower temperature and pressure, and continues in this fashion for anywhere between 8 and 16 effects. Freshwater yields come from the second to last effect. MED may have problems with corrosion (because salt water is highly corrosive) and scaling of oversaturated compounds. The cost of water from MED desalination is €0.83/m^3 to €1.16/m^3 (Van der Bruggen and Vandecasteele 2002).

5.1.2 Multi-Stage Flash

Multi-stage flash (MSF) is another heavily-used form of seawater desalination. This particular form of desalination has been in use since the early 1960s and quickly became the most popular form of desalination for the following few decades. MSF involves a series of flash chambers in which steam is produced from saltwater at continually reducing pressures. As in MED, seawater is preheated in MSF. It is then used as the heat transfer conduit with which to condense the seawater located in the flash chambers. Freshwater is then captured in trays and sent out. The byproduct brine is partially re-circulated in the system to achieve maximum desalination. Major advantages of MSF are its ease of use and reliability. There is also reduced risk of scaling and corrosion than there is in MED, and those affects are less damaging. However, a large disadvantage of MSF in comparison to MED is that it produces less freshwater for the amount of energy that it consumes. Still, the cost of MSF is similar to that of MED, at about €0.83/m^3 to €1.16/m^3 (Van der Bruggen and Vandecasteele 2002).

5.1.3 Reverse Osmosis

Reverse osmosis (RO) was first used to desalinate brackish water in the late 1960s. It is currently in heavy use and is the fastest growing technology for seawater desalination. RO membranes are permeable for pure water but not the dissolved salts of seawater. Separation requires that the water be pumped through at a higher pressure than the osmotic pressure of the water, just above 50 kg/cm^2 for seawater and about 20 kg/cm^2 for brackish water. Pressure this high requires a large amount of energy. Water is typically pretreated for RO, usually involving the removal of suspended solids, and is chlorinated after desalination. A main advantage of RO is its low cost, at only about €0.42/m^3 to €0.58/m^3, half of the cost of MED and MSF. A disadvantage of RO is the sensitivity of the membranes to fouling and to damage by chemicals used in pretreatment. However, more research is currently being dedicated to furthering RO desalination than MED or MSF. A new membrane developed by FilmTec requires 25% less energy consumption and saves the user 4% in cleaning costs due to a better resistance to fouling. In addition, these new membranes have a better water recovery (Van der Bruggen and Vandecasteele 2002).

5.1.4 Electrodialysis

Electrodialysis (ED) is a technologically advanced form of desalination that has emerged recently. An ED plant consists of a feed tank for the storage of seawater, a pump, and an electrodialysis cell (or cells). The cell itself has ion exchange membranes and platinum electrodes. Optimal results from ED come from conditions including high voltage levels, higher salt concentrations (about 30,000 ppm) and lower water pressure. When there is a higher concentration of salts in the water, the less ionic resistance there is resistance from the salt solution to be separated (Mohammadi and Kaviani 2003). However, as salt concentrations increase and the effectiveness of ED increases, so does the cost of the process. Average cost of ED desalination is approximately €0.50/m^3 to €0.80/m^3. ED is actually most economical not for seawater, but for brackish water, and is therefore less suitable to Santorini than RO desalination would be (Van der Bruggen and Vandecasteele 2002).

5.1.5 Environmental Impacts

Environmental impacts of most forms of desalination are minimal. They include the discharge of brine, emissions into the atmosphere, and discharges of other chemicals used in pretreatment. The discharge of brine can affect marine life at different levels based on brine salinity, temperature, and volume. In the Gaza Strip, it has been observed that saline plumes resulting from brine emissions into the sea has changed migration patterns of some fish. Having approximately twice the salinity of seawater, brine is denser, and will sink, harming life on the ocean floor. Emissions into the atmosphere are limited to steam and some emissions from energy production. Other chemicals that may be a risk are biocides used in all techniques, scale-controlling chemicals, chlorines, and anti-foams. More environmentally-friendly products are in development that will provide the same effects in scale-controlling (Van der Bruggen and Vandecasteele 2002).

5.2 Wastewater Reuse

Boutkan and Stikker (2004) also defined wastewater as a potential source of freshwater. The quality of untreated wastewater depends upon its initial use. Likewise, the intended use of wastewater determines the level to which it must be treated. Greywater from laundry and showers requires very little treatment for use in landscaping or other outdoor uses. Wastewater from sewage systems requires a much higher level of treatment. Wastewater treatment also varies in scale, from closed loop household systems for greywater reuse to community- and city-wide sanitation plants.

Treatment of wastewater is divided amongst biological, physical, and chemical treatments, all with their respective results and places in the order of treatment. Biological treatments include treatment ponds and lagoons. Biological treatment is generally reserved for sewage and industrial wastewater. Physical treatment includes thermal treatment, use of UV radiation, sand filtration, and screens, as well as moringa oleifera seeds, an effective coagulant when crushed. Chemical treatments include treating with aluminum sulphate, calcium hypochlorite, chlorine, or ion exchange (Heeks 1995, Kunst, Kruse, and Brumester 2002, and Malkina-Pykh and Pykh 2003).

Treated wastewater can be used for any number of things. Its use ultimately depends on the level of treatment. Greywater can be used for landscaping and other outdoor uses after suspended solids are removed. Wastewater treated to a certain level of purity can be used for irrigation, a practice which is actually quite common. In Almeria in southern Spain, 32,000 m^3 of wastewater are used for irrigation per day after the water is treated by sand filtration. The water is cheap and it benefits agriculture in the region (Thomas and Durham 2003). Wastewater with little or no treatment can be used in other fashions. In Saudi Arabia, ablution and shower wastewater is often used in toilet flushing (Abderrahman 2000). Wastewaters with little or no treatment can also be reused in industry as coolants or to transport industrial wastes, depending on the chemical contents of the wastes being transported.

Wastewater is also be used to recharge aquifers. For aquifers to recharge naturally, it takes 300 years for depths up to ½ mile, and 4600 years for "fossil water" at depths below ½ mile (Daniels and Daniels 2003). In Mexico City, it has been suggested that highly treated wastewater be injected back into the aquifer. A plant that provides eight to ten cubic meters of water a second would stabilize the aquifer for ten to fifteen years (Fortner 2001). In southern California, a project called the Groundwater Replenishment System (GRWS) was recently implemented to help recharge aquifers in the area and to handle waste in a more sustainable manner. The GWRS recharges aquifers by using highly treated wastewater that was once discharged to the ocean and returning to the aquifers through injection wells or percolation ponds (Durham, Rinck-Pfeiffer, and Guendert 2002).

5.3 Rainwater Harvesting

Rainwater harvesting has been common since Roman times. A catchment system has six basic components: the roof or catchment area, gutters and downspouts, catchment surface washers, a storage tank, the piping system, and water treatment. The first wash of a rainfall brings sediment and dirt from the catchment area. Downspouts in the water system can be placed to divert this first wash and thereby free the water in the storage tank of this pollution. If the water is to be used for washing clothes or cars, or for landscaping, no more purification is necessary. If the water is to be potable, it also requires disinfection by chlorination, sand filtration, or boiling. Rainwater systems are most successful when they are simple in terms of operation and maintenance (Heeks 1995, and Kunst, Kruse, and Brumester 2002).

There are numerous benefits to harvesting and using rainwater. First of all, rainwater is the softest water available, as it has not collected minerals from the ground. Hence, it is the least corrosive and damaging to pipes, appliances, and storage tanks. The cost of rainwater harvesting is negligible. After the investment of building the simple catchment, the only cost is a bit of time required to maintain the system. By retaining rainwater at the point that it reaches the surface, it prevents it from possibly transferring pollutants to large water bodies. In addition, by requiring rainwater catchment systems in building codes and having it be a part of the whole water system, it raises the awareness in a population that water needs to be conserved (Kunst, Kruse, and Brumester 2002).

Rainwater harvesting does have its disadvantages. It is completely dependent upon the amount of precipitation, and because of this, complete reliance can mean water crisis in the time of drought. Secondly, household rainwater catchment systems depend upon the upkeep of the individual homeowner. Failing to maintain a catchment renders them useless, as many on Santorini have become. It is usually seen as a supplemental resource, particularly in more arid climates, and not as a primary supply.

5.4 Sustainable Benefits of Alternative Water Resources

Thomas and Durham (2003) have outlined some sustainable benefits of using alternative water resources. First and foremost, they are additional sources of water to help fulfill the needs of the population. By reusing wastewater, it reduces the cost of discharging that wastewater, both economically and environmentally. Reuse and desalination often cost less than groundwater or imported water, particularly in remote regions that need the alternative sources the most. The dependence on outside sources is reduced when more water is provided from within the boarders of the region or country. Staying informed and up to date with technology can ensure the lowest cost production of treated and desalinated water. Finally, using these techniques can increase socio-economic activities of a region by creating new jobs, improving agriculture, making tourism more stable, and simply improving possibilities for local development.

5.5 Selection of an Alternative Water Resource

In review, Santorini has the following issues to resolve in respect to water supply:

- Overexploitation of groundwater resources
- A lack of drinkable tap water in the Municipality of Thira
- Inconsistent network coverage
- Large variances in water cost
- Very little storage of water created in non-tourism months
- Overdependence on outside resources
- Large water deficit of 1,378,833 m^3/year
- The situation is worsening

Resolving this issue will require a large scale addition to the local water resources on Santorini. The option that will solve the most of these issues in the most affordable and sustainable manner is seawater desalination. It will take the burden off of the groundwater resources so that a more sustainable yield of the aquifer can be exploited. Desalination will help to provide drinkable water to more areas of the islands. Having a unified scheme for each municipality will help to ensure more consistent pricing by removing private, and often illegal, vendors from the picture. Desalination can be run year-round, and combined with a few storage facilities, can help to supplement additional demand during the heightened tourist season. Although it is assumed that many people will still choose to drink bottled water, having desalinated water available will remove the total dependence on outside sources. Finally, a large desalination scheme will, by providing more high quality water and taking stress off of the aquifer, reverse many of the aspects that are currently making the situation worse. It can be built at a large scale to accommodate for more demand, and at larger capacities it is more affordable. The main things

Table 5.1: Summary of desalination technologies

	Cost per m^3	Energy consumption	Best suited to	Advantages	Weaknesses
Multi-Effect Distillation	€0.83-€1.16/m^3	2-4 kWh/m^3	Seawater or Brackish Water	Low energy consumption	Heavy corrosion and scaling
Multi-Stage Flash	€0.83-€1.16/m^3	3-6 kWh/m^3	Seawater or Brackish Water	Light maintenance	Light corrosion and scaling
Reverse Osmosis	€0.41-€0.58/m^3	6 kWh/m^3	Seawater	Much more R&D; new membranes; knowledge base on Santorini	Sensitivity of RO membranes
Electrodialysis	€0.50-€0.80/m^3	15 kWh/m^3	Brackish Water	More effective at high salinity	Cost increases with effectiveness

Source: California Coastal Commission 1991, Mohammadi and Kaviani 2003, and Van der Bruggen and Vandecasteele 2002

that hold rainwater harvesting and wastewater reuse back in this instance is that Santorini needs a large, regional solution, and those are best fit for supplemental supplies at a domestic level.

The only issue above that a large desalination implementation would not immediately start to resolve is incomplete network coverage. This is a step that should be taken soon in the future no matter the steps taken to improve the water supply on Santorini. Expanding the network would only improve the effects of a large desalination scheme.

Of the different technologies used for seawater desalination, reverse osmosis is the one most fit for Santorini. Table 5.1 looks at each of these four desalination technologies across five categories, in which RO has the clear advantage in three (dark boxes). It is by far the most affordable at only €0.41/m^3 to €0.58/m^3. Many factors can affect the price of desalinated water, such as energy use, plant capacity, maintenance, staff size, and machine component replacement. RO finds the best balance of the cost of these factors to achieve the lowest price. Although it consumes more energy than MED and MSF, this does not affect the final price, and it is still much more energy efficient than ED. By design RO is specialized in desalinating seawater. In addition, much more research and development is currently being dedicated to RO. New, more resilient and efficient membranes are being developed, which will likely give RO the least weaknesses as a technology. A final and obvious reason that RO is the right choice is that there is already a three unit RO desalination plant installed at Ia. With technical expertise already in place on the islands, it will make training and transitioning much easier.

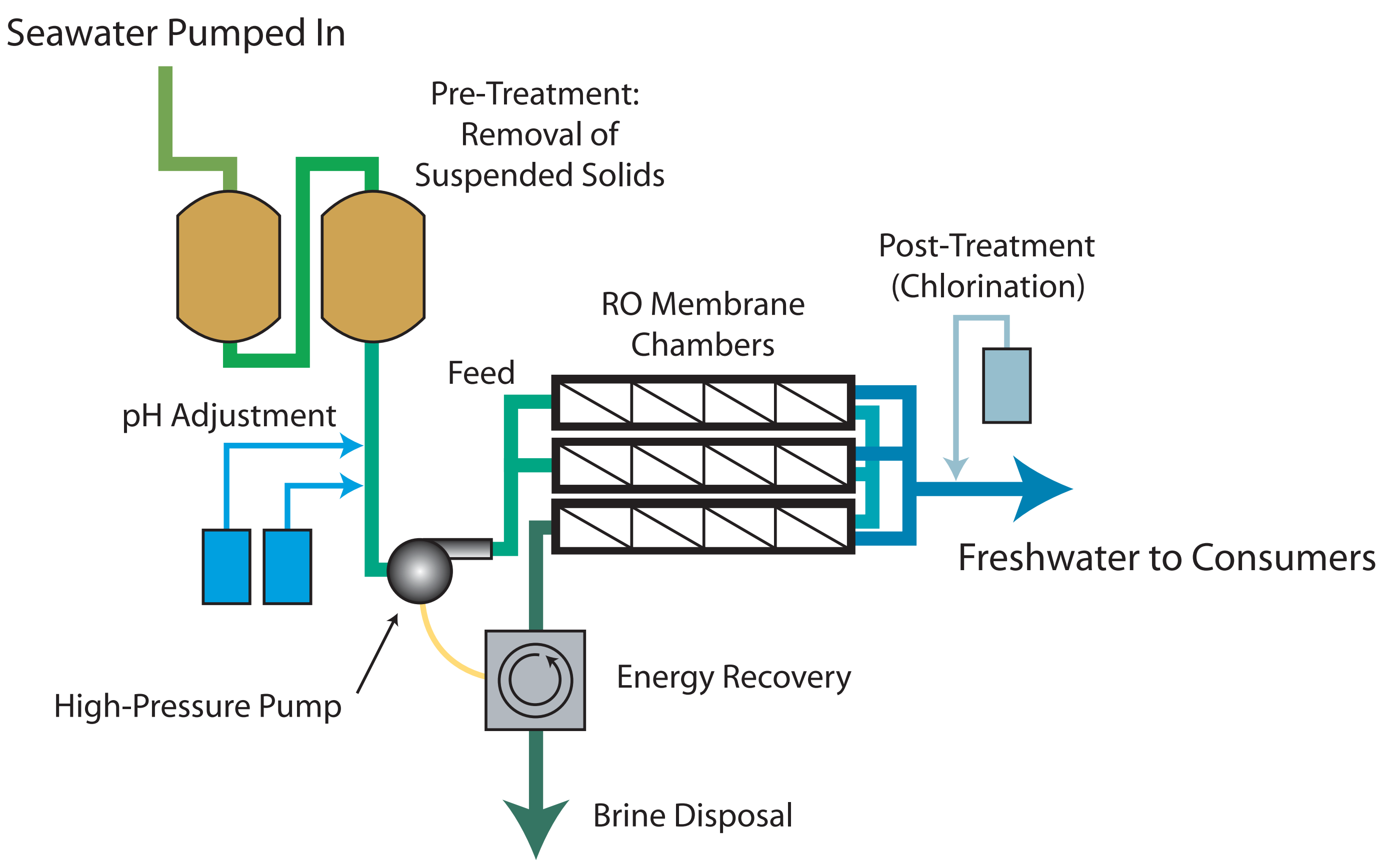
Chapter 6: Alternate Scenarios for Reverse Osmosis Seawater Desalination

Two scenarios are presented for the implementation of a widespread seawater desalination scheme on Santorini. Both scenarios are of the same capacity, location, and water quality. The difference will be in their level of overall sustainability. While both aim to improve the sustainability of water resources on the islands, the second is designed for a much higher level of sustainability. It utilizes renewable energy resources, has all possible energy recovery options, and produces salt as a second product to reduce the amount of brine effluent. This chapter describes each option and the differences between them. For each, expected impacts on social development, economic development, and the environment will be stated.

6.1 Assumptions

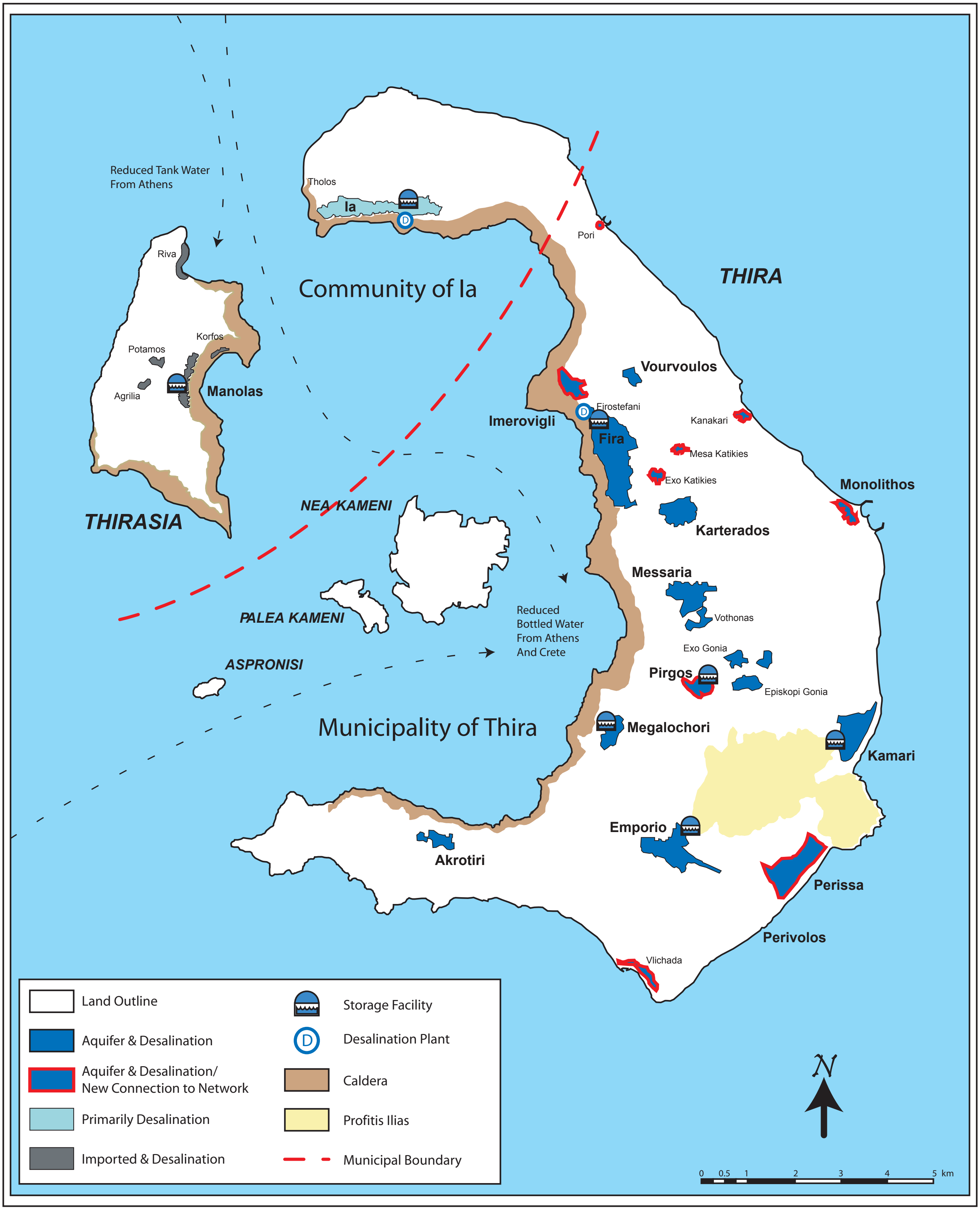
Certain assumptions accommodate the implementation scenarios and recommendations. First, it is assumed that the permanent, seasonal, and tourist populations of Santorini will continue to grow for at least the foreseeable future, and that water demand will grow accordingly. Second, it is assumed that agricultural activity will remain constant for the near future, but will once again rise in volume in the long-term (10-20 years) future, based on the need for secondary economic sectors on Santorini and wine production as the most viable option. This will also raise demand. It is assumed that the two municipalities will still aim to provide water only to their governed area, meaning that a split scheme is necessary. Next,

Figure 6.1: Reverse osmosis desalination



Source: Author 2006

Figure 6.2: Recommendations of desalination plants, storage tanks and settlement resources



Source: Author 2006

it is assumed that imported water to Thirasia will not halt altogether in the wake of a better water resource, as this is a government program and is therefore economically viable. Finally, it is assumed that bottled water will continue to be imported to Santorini in middle to large volumes, based on the general preference for it throughout Greece and Europe as a whole. These five assumptions have been incorporated into the volume and scope of the following two implementation scenarios, as well as the supporting recommendations that will follow in Chapter 7.

6.2 Scenario 1: Reverse Osmosis, Storage, and Pricing

This scenario involves the installation of three RO desalination units to accompany a sustainable groundwater yield, existing desalination in Ia and other supplemental resources to vastly expand Santorini's sustainable water supply. These will be standard RO units that are currently being used and expanded worldwide (Figure 6.1). New storage tanks should also be built in strategic locations to offer backup supplies in times of increased demand. Figure 6.2 reveals the locations of the plants, the new water resources for each settlement, and the locations of the storage tanks. Fira will receive two units while Ia will receive one to add to the existing three. Having multiple units in each location helps to ensure continued freshwater production should one of the units fail, while improving the supply of both municipalities supports the assumption that they will continue to seek resources separately. A management element to this scenario is creating a suitable pricing system.

6.2.1 Plant and Storage Tank Locations

The unit in Ia should be located at the same location as the existing plant in Ia, preferably in the same building if expansion is possible. This will allow for easier installation into the current piping network of Ia. In Fira, the two units should be placed in a plant located just to the north of Fira, between Fira and Imerovigli, where room for construction exists and the elevation is high to allow for maximum gravitational distribution.

These tanks should be located in or near several of the islands' settlements located at a higher elevation, so that standard gravitational distribution can be used (Figure 6.2). To help preserve cultural heritage, all of these tanks should be constructed using traditional building materials and techniques so that they blend in perfectly with the picturesque built landscape of Santorini. For example, a tank would be located in the northern part of Emporio, on the slopes of Mt. Profitis Ilias, so that gravity could take water reserves to Emporio, Perissa, Perivolos, and Vlichada. Each tank is to be used as a water reserve for multiple settlements. In addition, desalinated water should be taken from Ia to a tank in Manolas in Thirasia to provide a backup supply there.

6.2.2 System Capacity

Desalination units are usually described in their output per day, not per year. For example, the three existing units in Ia individually produce 400 m^3/day, 170 m^3/day, and 300 m^3/day. Therefore, to calculate how much water needs to be produced by the new units, the water deficit is changed to m^3/day. The current water deficit of 1,378,833 m^3/year is equivalent to 3,778 m^3/day. Assuming that demand will grow, the total capacity of the new desalination scheme should be higher than this number. A total capacity of 5,000 m^3/day is recommended to eliminate the water deficit and accommodate growth. Though this may not account for the supply on a given day during the summer, it allows for the production of a reserve that can be stored and used at this time. The Community of Ia, already having a three-unit desalination plant with a combined capacity of 870 m^3/day, and having a much lower population and tourist demand, will only have a 1,000 m^3/day upgrade. The other 4,000 m^3/day will be produced in and for the Municipality of Thira, in two units of 2,000 m^3/day each. The new sustainable water supply would be 2,858,985 m^3/year, much higher than the current total demand of 2,412,818 m^3/year. Although it is unknown whether this much freshwater will be necessary, this is only a total capacity, and desalination units do not have to run at full capacity every day of the year. In addition, having this total capacity gives Santorini the option of exporting water to nearby islands such as Ios and Anafi as a supplemental economic sector.

6.2.3 Capital Investment Costs

Desalination units producing less than 5,000 m^3 have a capital investment cost of €1275/m^3/day. At 1000 m^3/day, the capital investment in Ia would be €1,275,000 and €5,100,000 in Fira. Therefore, the total capital investment for desalination units is €6,375,000.

6.2.4 A Suitable Pricing System

A suitable water pricing system, as outlined by Nadakavukaren (2000), is needed for several reasons. Primarily, the cost of water should not be a burden to the smaller, more traditional villages, many of which are not connected to the main water networks and therefore pay higher rates. Secondly, permanent residents should not have to pay the same amount for water that tourists do. A suitable pricing scheme for Santorini would meter at the household level, and charge higher rates for higher consumption (usually by hotel or restaurant owners). This would not only place a lower price on permanent residents (in the standard RO price range of €0.42/m^3 to €0.58/m^3), but would help to educate and encourage water conservation among the permanent population. Finally, exceptions may need to be made to these rules, such as a water subsidy for agriculture. If consumers choose to waste desalinated water despite this pricing system, a fee program may need to be set up.

This pricing system will do nothing without enforcement. Evidence exists that many consumers in the Municipality of Thira are delinquent on their water payments, an activity that must be changed. A fee system should be part of the general pricing system to further reprimand those who wish to waste or steal water. However, this fee system would also need enforcement.

6.2.5 Operation, Maintenance, and Staff

Maintenance of a RO unit involves daily monitoring and preventative maintenance through instrument calibration, pump adjustment, leak detection and repair, and scheduled structural repair of the system. Membrane fouling is the main operational concern, requiring each membrane to be cleaned approximately every 4 months. A trained engineering staff is required for the operation, maintenance, and monitoring of these RO units. The 1000 m^3/day unit in Ia will require hiring two trained engineers, while the total 4000 m^3/day plant in Fira will require a six member staff (United Nations Environment Programme 1997).

Table 6.1 summarizes the capacities, cost, and change in total sustainable yield of Santorini's water supply upon implementation of this scenario.

Table 6.1: Capacity, cost, and energy use of scenario 1

	New Ia Unit	Thira Unit 1	Thira Unit 2	Total
Daily Capacity (m^3)	1,000	2,000	2,000	5,000
Yearly Capacity (m^3)	365,000	730,000	730,000	1,825,000
New Sustainable Yield (m^3)				2,858,985
Energy Consumption (kWh/day)	6,000	12,000	12,000	30,000
Capital Investment Cost	€ 1,275,000.00	€ 2,550,000.00	€ 2,550,000.00	€ 6,375,000.00
Base Cost to Consumers	€0.41-€0.58/m^3	€0.41-€0.58/m^3	€0.41-€0.58/m^3	
Engineering Staff (Persons)	2	3	3	8

Source: Author 2006, California Coastal Commission 1991, United Nations Environment Programme 1997, and Van der Bruggen and Vandecasteele 2002

6.2.6 Impacts on the Environment

Installing more RO desalination units on Santorini has a few environmental impacts, both positive and negative. One major impact is positive, as producing this much freshwater by more sustainable means will allow the aquifer to recharge, so that it can once again be a viable freshwater resource alongside desalination. This could not come at a more crucial time, as the aquifer is reaching a point when it could be damaged for a very long period if something does not change.

There are two negative impacts of additional RO desalination. Brine is the byproduct of desalination and must be discharged back into the sea. To minimize impact, it should be discharged in an area that has constant and somewhat strong currents, to ensure that the heavily saline solution distributes well throughout the water. This is especially true in Santorini's lagoon because it is a partially enclosed body of water. Also, increased desalination capacity requires additional energy, which would come from Santorini's fossil fuel power plant.

6.2.7 Impacts on the Economy

Implementing a full-scale desalination scheme should slow the inflation of water prices on Santorini for a few reasons. Prices have recently risen primarily due to increased costs of pumping and importing, something that heavier use of desalination could help to alleviate. The cost of RO desalination is decreasing worldwide. The standard price of €0.42/m^3 to €0.58/m^3 accounts for everyday operation and maintenance, in addition to capital investment costs spread out over time. Due to the large overhead cost of these desalination units, a true price would likely be on the upper end of this range. Also, by allowing the aquifer to replenish, it would help to lower groundwater prices over the long term by setting pumping at reduced depths.

This scenario would lower the burden of water costs to permanent residents. Current prices being higher in Ia is likely due to the low output of the desalination units in place. The smallest of the proposed desalination units is more than twice the size of the largest one currently in use. Because RO desalination reduces in price with the capacity of the unit, the price of water in the proposed scheme would be lower and close to the standard prices. In addition, a system with a higher capacity would make it easier to standardize water prices throughout the islands, or at least within each municipality. This would ensure that none of the smaller, more traditional villages are being crippled by their water prices. However, those wishing to consume the desalinated water may have to pay more if they want to eliminate the stale taste with household filtering systems. This price would likely still be much lower than high volumes of imported bottled water.

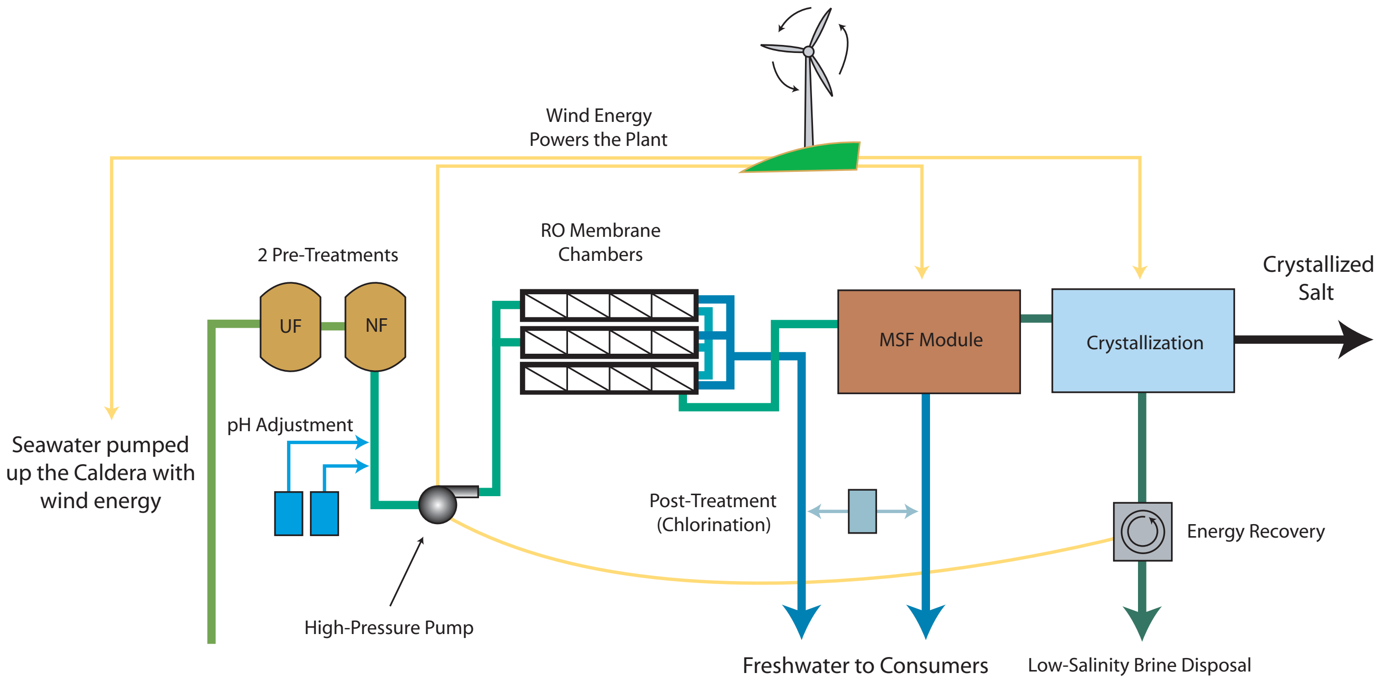
Just having an improved water supply, no matter how it is created, will improve many of the economic activities on Santorini. In recent years, water has increasingly been more of a burden than a resource to tourism and agriculture. Swimming pools have tasted salty, bottled water has cost too much, and agriculture has suffered. Increased quality freshwater will allow wine grapes and other crops to be grown at a higher capacity per land unit than they currently are. Overall, having water as a dependable resource, not a burden, will be one less thing for the economy of Santorini to have to worry about.

6.2.8 Impacts on Social Development

The social impacts of a sustainable water supply often run parallel to the economic benefits. The ability to farm at more productive capacities may turn agriculture back into an economically viable career outside of tourism, allowing residents to return to this traditional line of work. The suitable pricing system will not burden smaller villages despite a lack of mass tourism. Like the impacts on the economy, an improved water supply can be seen as shifting from a burden to a dependable resource in social terms as well.

This scenario also offers a sense of security. By both increasing the capacity of Santorini's water supply and creating a means to store more water, it lowers the possibility of a water crisis

Figure 6.3: Innovative reverse osmosis technology using wind energy, multi-stage flash, and crystallization to produce freshwater and salt



Source: Author 2006 and Turek 2002

which would not only affect social development, but the economy and environment as well.

6.3 Scenario 2: Using Wind and Producing Salt

This second scenario is nearly identical to the first with two major distinctions: it uses renewable energy sources (RES) to power the desalination units and produces salt as a secondary commodity (Figure 6.3). This is done in order to make desalination a self-sufficient operation from an energy perspective, to lower the environmental impact by reducing the salinity of the brine effluent, and to create a second profitable product in salt. Other than these factors, the parameters of the scenarios are the same. The Municipality of Thira is still to receive two desalination units with a combined capacity of 4,000 m^3/day, and Ia is still to receive one additional unit with a capacity of 1,000 m^3/day. A suitable pricing system still applies here as well, as does the installation of storage tanks.

6.3.1 Application of Wind Energy

Water is not the only resource that Santorini, and many other Aegean islands, has a continuing shortage of. Energy is also a problem. All energy on Santorini is produced in a power plant that burns imported fuel. The cost of energy from this power plant is approximately €0.03/kWh (University of Cincinnati Sustainable Development Group 2004). Environmental costs of this energy resource are particularly damaging through air pollution and the stress of infrastructure. Wind energy is the most viable alternative energy resource. The Aegean Sea is known for its strong winds that can be harnessed as a renewable energy source. Santorini itself has an annual mean wind speed of 7.5 m/s at a height of 30 m (Kaldellis, Vlachou, and Kavadias 2004). In recent years, an effort has been made to build and operate desalination plants that run on RES, and wind energy is the most common choice in areas with strong and consistent winds. As seen in Chapter 2, multiple sources in the literature recommend desalination along with wind RES as the most viable solution (Kaldellis, Kavadias, and Kondili 2004, and Voivantas, et al 2003).

This study recommends that wind energy be used to completely replace the use of imported fuels. Costs are presented for enough energy to power this desalination scheme and also for the whole island (Table 6.2). The 5,000 m^3/day desalination system would require an annual energy amount of 10,950,000 kWh, or a wind energy system with an approximate capacity of 1,250 kW. An extra capacity of 50% was added in order to allow for days with slower winds, making the necessary capacity for the wind turbines 1,875 kW. At the standard industry price of €1,000/kW of capacity, this costs €1,875,000. Added to the cost of the desalination plants, this raises the total capital investment of this scenario to approximately €8,258,000. The standard cost of wind energy to the consumer is the same as current energy costs on Santorini, at approximately €0.03/kWh. However, the price of fossil fuels for energy production will likely increase in the coming years, while the costs of harnessing wind energy are constantly becoming more affordable (The Economics of Wind Power 2005). In addition, removing nearly all environmental affects makes wind energy an obvious replacement.

If it is decided that wind energy should replace the current power plant, this will require a much larger capital investment. The estimated power requirement for all of Santorini is 27,000 kW, or 28,875 kW when added to the requirements of these new desalination units. The total cost to produce wind energy for all of Santorini along with the new desalination scheme would be €35,250,000. The total capacity could even be made much larger as to create enough energy to export. A recommendation in *Plan for the Future of Santorini* proposed ten 36,000 kW wind turbines to not only power all of Santorini but also provide enough energy to sell to neighboring islands (University of Cincinnati Sustainable Development Group 2005).

Many companies manufacture and sell wind turbines of several sizes and capacities. They can be designed for use on land or to be placed in the ocean. General Electric is a world

Table 6.2: Capacity, cost, and energy use of scenario 2

	New Ia Unit	Thira Unit 1	Thira Unit 2	Total
Daily Capacity (m^3)	1,000	2,000	2,000	5,000
Yearly Capacity (m^3)	365,000	730,000	730,000	1,825,000
New Sustainable Yield (m^3)				2,858,985
Energy Consumption (kWh/day)	6,000	12,000	12,000	30,000
Energy Consumption (kWh/year)	2,190,000	4,380,000	4,380,000	10,950,000
Capital Investment Cost	€ 1,275,000.00	€ 2,550,000.00	€ 2,550,000.00	€ 6,375,000.00
Base Cost to Consumers	€ 0.42/m^3	€ 0.42/m^3	€ 0.42/m^3	
Engineering Staff (Persons)	2	3	3	8
Power Production Required (kW)	375	750	750	1,875
Existing Power Requirement on Santorini (kW)				27,000
Total Required Power (kW)				28,875
Capital cost of Wind Energy (only desalination)	€ 375,000	€ 750,000	€ 750,000	€ 1,875,000
Capital cost of Wind Energy (all of Santorini)				€ 28,875,000
Total Capital Investment Cost (only desalination)				€ 8,250,000
Total Capital Investment Cost (all energy)				€ 35,250,000

Source: American Wind Energy Association 2000, Author 2006, California Coastal Commission 1991, The Economics of Wind Power 2005, United Nations Environment Programme 1997, and Van der Bruggen and Vandecasteele 2002

Figure 6.4: Standard wind turbine

Source: General Electric 2005

Figure 6.5: New TMA turbine

Source: TMA Global Wind Energies 2006

leader in wind energy (Figure 3.6). They have installed wind parks throughout the United States on land, and throughout the world off shore as well (General Electric 2005). However, these towers are of massive size (100 m) and would disrupt much of the visual beauty of Santorini if not placed in an out of view location (General Electric 2005). Standard wind turbines often render complaints about noise and the harming of wildlife. TMA Global Wind Energy Systems is currently developing new types of vertical axis wind turbines (Figure 6.4) that are free of virtually all of the problems from the standard models. Because of their design, they do not inflict damage to wildlife and operate with much less noise. They are also much smaller, varying in size according to their energy output, but standard sizes are as small as 10 m in height with rotors 3-4 m in diameter. The choice of which wind turbines to use depends on whether wind energy will only be used for desalination, or if it will be used to replace the current fuel power plant. If so, a less populated site (such as Thirasia) may be used to place several wind turbines for all power needs, including desalination. If this is not the case, the less obtrusive TMA turbines should be the choice for on-site power.

6.3.2 Salt Production

An extremely progressive and sustainable form of seawater desalination would see RO combined with two pretreatments, MSF desalination, and crystallization to produce both freshwater and salt. Turek (2002) has researched and developed the UF-NF-RO-MSF-Crystallization method for this (UF is ultra-filtration and NF is nano-filtration, two types of pretreatment). If produced salt will sell for €30/t, then the cost of water is only €0.40/m^3. This is a 45% decrease from the €0.58/m^3 high end cost of the first scenario. Even if no change in price occurs, the environmental benefit of this technology by reducing the brine salinity makes it desirable.

6.3.3 Impacts of Scenario 2

The impacts of Scenario 2 would be largely similar to the first with a few major differences. First, using wind energy would be both a great economic and environmental benefit. Santorini's already stressed power grid, running only on fossil fuels, would not have to power the demanding desalination units. Completely replacing this energy resource would have additional environmental and sustainable benefits.

Secondly, the creation of salt would both lower environmental impact and provide economic benefit. Santorini would no longer need to import salt. Although it seems minor, it may also provide a small export economy. The more complex plant that this would require would also provide more employment. Removing much of the salt from the desalination plant effluent also minimizes the already small environmental harm that RO desalination can create. In addition, this method actually lowers the price of desalinated water, if only by a few cents.

From a social perspective, using such a progressive and sustainable system will create further awareness in both the residents and visitors to Santorini about sustainable development. Successfully using wind energy, particularly that with the new TMA turbines, may create awareness and acceptance that a wider use of wind energy on Santorini could be beneficial, which in turn would have environmental benefits as well.

6.4 Comparing the Scenarios

Each of the two scenarios has its advantages and disadvantages when compared to the other. The first, "Reverse Osmosis, Storage, and Pricing," produces enough water to eliminate the water deficit, relieve the groundwater aquifer of stress, and render the water supply of Santorini nearly completely sustainable. It increases the total sustainable water supply to over 2,800,000 m^3/year, 4,000,000 m^3 more than the current demand. However, the second scenario, "Using Wind and Producing Salt," affects the sustainable supply in the exact same manner while also crystallizing salt as a second product and using wind energy to power the process. This scenario could also start, or be a part of, a major installation of wind energy on Santorini. The problems left by the first scenario, brine effluent and the use of the fuel power plant, are eliminated almost completely by the second.

Although it would seem that the second scenario is the clear choice, one thing stands in its way: capital investment. At €8,250,000, the overhead cost is 33% higher than that of "Reverse Osmosis, Storage, and Pricing". While the long term benefits are easy to see, this may not be enough to persuade the government or private investors to put up the extra money at the beginning. It is the recommendation of this study to find the funding, as this scenario will not only solve problems that have to do with water, but also, at the very least, start movement towards a more renewable energy resource as well. However, if this much funding cannot be generated immediately, using the first scenario is still a monumental step in the right direction in making water resources on Santorini much more sustainable.

Chapter 7: Other Recommendations, Further Research, and Conclusions

The wide use of an RO desalination system, or even the more advanced salt-producing system, should not come alone when seeking a more sustainable water supply on Santorini. The following are recommendations that accompany the main proposal of a desalination scheme.

7.1 Other Recommendations

7.1.1 Use All Existing Storage Tanks and Cisterns

A number of storage tanks, as part of cisterns or not, already exist on Santorini. Some are used for collecting rainwater and some are used to store groundwater. No matter what they are used for, all that are in existence should be used. This ensures some backup supply now, before any large implementation can be carried out. Once a new scheme has been installed, as many as possible should be used for rainwater collection.

7.1.2 Advance Rainwater Harvesting Techniques

Rainwater harvesting should be advanced on Santorini for three reasons. First, the island is arid and all possible water resources should be exploited to the fullest sustainable extent. Second, erosion is a serious issue, and the more that runoff can be controlled, channeled, and collected, the less of a problem it will be. Last, the more rain that can be diverted not to the ocean but to scattered temporary pools on the island, the more of that will end up recharging the aquifer.

7.1.3 Advance Wastewater Reuse Techniques

Wastewater reuse is another technique that can help now, in the time before a larger solution is presented. It can easily be used at the domestic level for gardening and agriculture, with minimal purification in some cases. In addition, there may be possibilities of aquifer recharge through percolation ponds, but Santorini may be too small and the value of land too high for this. Wastewater reuse should continue to be emphasized in the event of a larger solution. It can always offer a sustainable and very affordable water resource for certain uses at the household level.

7.1.4 Expand Water Infrastructure to All Settlements

Planning should commence immediately to expand infrastructure to settlements that are not currently connected to the municipal network, and to as many locations in between. This will help to ensure fair pricing for more of the island, and get more water to agricultural areas so that they do not have to pump illegally from the aquifer.

7.1.5 Implement Land Use Plan Set Forth in Plan for the Future of Santorini

Implementing the regional land use plan described in *The Future of Santorini* (University of Cincinnati Sustainable Development Group 2005) will help to control island-wide sprawl. This will in turn help to lower the amount of new infrastructure that needs to be built throughout the rural areas of Thira and Thirasia. This will also help in the implementation of a more suitable pricing system, as it will lower the overhead costs of these recommendations.

7.1.6 Educate the Public About Santorini's Water Issues

Many permanent residents on Santorini drink water from the aquifer, not knowing that it is unfit for consumption. Many more pump locally and illegally from the aquifer, not knowing, or caring, that it is causing long term damage. Environmental education for the public should be organized to help the permanent population of Santorini know about these issues. This will not only help to ensure safety and health, but may garner support for a wider solution to the problem. It may also convince many of them to repair and resume use of their rainwater cisterns.

7.2 Further research

Although this study provides the most detailed and thorough study of water on Santorini available, there is still much that needs to known. The following suggestions for further research will not only help to realize the recommendations stated within this work, but will help to sustain water resources throughout the future.

7.2.1 Conduct a Detailed Study of Rainwater Harvesting on Santorini

This study has revealed that rainwater harvesting is not used to nearly the extent that it could on Santorini, even without the addition of new infrastructure. However, details are unclear. Very little information exists on the number of cisterns that exist, their storage volume, or their current use. Future research should document cisterns and keep a constant record of their use, as to be part of an overall water resources inventory.

Directing rainwater to cisterns through channels also needs to be studied. The built nature of many of Santorini's settlements is mean to direct water to cisterns, but the extent to which this is successful is also unclear. This will require an engineering level of research, possibly creating a model of water channels on Santorini to optimize rainwater harvesting.

7.2.2 Conduct a Detailed Study of Imported Bottled Water and its Affects

The section dedicated to imported bottled water was one of the most difficult to compile due to a lack of information. Very little information was readily available on the quantity of bottled water that is shipped to Santorini. Like information on rainwater harvesting, this is a resource that must have a constant record to be part of a better water resources inventory.

In addition to being part of an inventory, the environmental affects of this water should be measured. Santorini does not ship out trash to other locations, and the existing landfill located south of Fira on the caldera is not a sanitary one. Knowing the quantity that is imported will give better insight into the volume of trash. Also, the environmental affects of this plastic trash must be measured so that steps can be taken to mitigate them. Just as brine is seen as a by-product of desalination that must be disposed of in the most sustainable manner possible, these bottles are the by-product of importing bottled water, and therefore must also be disposed of in a sustainable manner.

7.2.3 Find the Most Suitable Location to Deposit Brine Effluent

Even with desalination that produces salt as a secondary product, the environmental affect of brine discharge exists. On Santorini, the nearly enclosed lagoon presents the possible risk of brine becoming localized within. Therefore, research should be conducted to find the least obtrusive locations to dispose of brine. This will likely be in a location with more constant flows so that brine can better disperse within the seawater, and obviously away from where feedwater is taken into the desalination plants.

7.2.4 How to Improve the Taste of Desalinated Water in an Affordable Manner

The literature is unclear, possibly intentionally, on the stale taste of desalinated water. It has therefore been difficult to determine the best, and most affordable, technique to improve the taste and make it more appealing for consumption. Further research should be conducted on locations that use desalination for drinking water to understand their techniques.

7.2.5 Finding the Best Location for Wind Turbines

If traditional wind turbines of the General Electric model are used, they will need to be placed in a less populated place where they will not visibly damage the beauty of Santorini. If the new smaller units are too be used, they can be located with the desalination plants. The answer to this question is unclear, and will need to be researched. Public opinion on wind turbines is also important, particularly from the aesthetic perspective.

7.2.6 Find Detailed Examples of Suitable Pricing Systems

A major aspect of these recommendations is the pricing system. This is the major tool to ensure conservation and create a dialog amongst consumers. Finding examples of how these pricing systems have been used elsewhere, how they have worked, and how they have been enforced will help to ensure that Santorini's system will have equally positive results. Some of this research can also be made public to garner support for such a system.

7.2.7 Conduct Research on Water Demands of Surrounding Islands

Santorini could be a major producer of freshwater for other islands of the area. If it is found that islands such as Ios, Paros, and Anafi are also having problems with their water resources, Santorini could choose to expand desalination to levels so that they can export to other islands. The demand for this type of export activity, and subsequently the feasibility, must be determined. For example, if the price of water from Santorini is not considerably less expensive, then it can not be expected that these islands would change their resources.

7.2.8 Find Funding for the Most Sustainable Investment Possible

As explained in Chapter 6, the second implementation scenario, "Using Wind and Producing Salt," lowers the cost of water to consumers, produces a second profitable product in salt, and drastically reduces environmental impact. However, it also increases the capital investment by 33%. Any possible outside sources of funding should be sought out to help pay for this scenario. In the United States, there is a tax incentive for the use of wind energy. Similar incentives or grants may exist from the European Union or the Greek Government. In addition, the tourism industry on Santorini could be sought out to provide funding through special taxes. The suitable pricing scheme could also be formulated to help cover costs at the beginning with the plan to lower costs after a short period.

7.2.9 Research Why Recommendations Such as These Have Not Yet Been Implemented

A final suggestion for future research is to seek out reasons why this type of water supply has not yet been implemented. If what is recommended in this study truly is the necessary and sustainable solution for Santorini, why does it not already exist? Many things may have played a part over the years. There may be an economic agreement with the bottled water industry to purchase so much in a year. There may be public opposition to desalination or wind energy. Political ties may be preventing the Greek islands from halting the use of fossil fuel energy. Another possibility is that the overhead funding could simply not exist, or that the necessary parties (tourism industry) are not willing to invest on their own. Perhaps the administration of Santorini is understaffed and has simply not had the time to get around to the detailed research necessary for such a project. All of this is of course hypothetical, but something has indeed led to the situation becoming as bad as it currently is, and identifying this barrier will help to solve the problem.

7.3 Conclusions

Santorini is one of the world's most unique landscapes. The natural environment, built environment, history, and culture combine to create something that must be preserved. Sustainable resources are a large part of a sustainable landscape. This study has revealed that the sustainable water supply to Santorini is even less than expected. Groundwater resources are near the point of long-lasting damage. Desalinated water is in small supply and only to one village. Nearly all of the islands' drinking water supply is imported bottled water which costs far too much in comparison to quality tap water, which the islands have nearly none of. Pricing of water is as inconsistent and sporadic as the extension of infrastructure is. Sustainability in the water supply is low to the point that a lasting water crisis, such as a lack of shipments, would be catastrophic to agriculture, tourism, and the permanent population. Fixing this problem must commence immediately to begin to reverse the damage.

From the results of this study, it is believed that a large reverse osmosis desalination scheme is the best possible solution. Splitting the capacity between the Municipality of Thira and the Community of Ia would support both governmental areas. A combined total output of 5,000 m^3/day will render the total water supply sustainable, taking stress off of groundwater resources, allowing the aquifer to recharge, and lower island-wide dependence upon imported water. Splitting capacity between three individual units helps to ensure supply in the case of partial system failure, as does the proposed network of storage tanks. Further security can be created by exploiting rainwater harvesting and wastewater reuse to their highest sustainable capacity.

As a final note, it is the challenge of this study to implement these recommendations. Because water resources are such a substantial issue for all Greek islands, a highly advanced system to produce a sustainable supply can help to create a model to be used throughout the Aegean. Several studies have been conducted for other islands of the Aegean to improve water resources with similar techniques. Although certain techniques and alternative resources are used throughout the Aegean, none of these studies has led to a true model of sustainable water use. Santorini is poised to be this model. A highly progressive system combining reverse osmosis desalination with wind energy and salt production would not only create publicity in Greece but globally, and could make Santorini a worldwide model of sustainable water resource management.

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Appendix: Explanation of Calculations and Use of Data

This Appendix explains fully the calculations that were made in Chapter 4, as well as any data reconciliations that were made and the primary data sources. The format of the Appendix follows the same order as that chapter, only omitting sections that required no additional explanation.

4.1 Existing Water Resources

4.1.1 Groundwater Resources

Numbers for groundwater resources were largely derived from a 2004 interview with Michalis Karamolengos, President of Kamari and of ΔΕΥΑΚΘ, the Municipal Company for Water, Sewage and Waste Management of Thira. Data of actual water consumption within the Municipality of Thira network were also available. Karamolengos stated that 780,000 m^3 is supplied annually by the municipality, and accounts for 60% of the exploited groundwater. Official data states that in 2002, 737,533 m^3 was consumed in the Thira network (Municipality of Thira 2002). Although both sets of data were used, Karamolengos' numbers were used for broader calculations, based on currency and minimal variation from older official data. 780,000 m^3 being 60% of the total annual groundwater used reveals the amount of 1,300,000 m^3/year withdrawn from aquifer resources. The Karamolengos interview and municipal data were also the main data resources for analyzing the Municipality of Thira network. Data from the Municipality allowed for some knowledge of how consumption has increased, albeit only over a three year period.

The relationship between extracted groundwater, consumed groundwater, and system leakage is not completely clear. For the purpose of this study, household consumption rates were used as the supply. It is not known if each customer is metered at the household level, or if metering is measured at the source, therefore, it cannot be fully determined if the 25% leakage rate means that an additional 25% on top of 1,300,000 m^3 is actually extracted. However, it is not entirely necessary to know this for this study. The argument for a better water scheme is supported very well by the total of 1,300,000 m^3. A higher number would support the argument more, but it is quite strong as it is. Therefore, the decision was made to stay conservative without losing effectiveness or credibility.

Water is not only extracted from the aquifer within settlements and for settlements. As can be seen in Figure 4.1, a large number of wells exist throughout the islands rural areas. Some of this activity is illegal. In addition, groundwater is extracted in Ia, albeit from a different aquifer. The quantities of these extractions are unknown, and were left out of total supply for much the same reason that the leakage amount was left out. This does not harm the value of the argument, and actually helps the overall credibility of the study.

The time period of 300 years for aquifer recharge is based on the literature. Daniels and Daniels (2003) stated that for aquifer depths up to ½ mile, recharge can take up to 300 years. Although Santorini's aquifer is by no means devoid of freshwater, this number was used based on the aridity of the region.

4.1.2 Desalination in Ia

Much of the data on Ia's desalination plant came from a 2004 interview with Manolis Pitsikaris, a representative from the plant. Additional information was provided by a 2006 interview with Peter Nomikos Jr., son of Peter Nomikos who designed at least one of the three desalination units in the plant.

To calculate the annual yield of Ia's desalination plant, it was necessary to calculate different operation capacities for the tourism and non-tourism months. Although it is not assumed that operation goes straight from the small unit to all three overnight from March 31 to April 1, data does not exist to make an exact calculation. As it is, this system provides for a very reliable figure

Table A.1: Calculation of annual seawater desalination ouput

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Days	31	28	31	30	31	30	31	31	30	31	30	31	
m^3/day	170	170	170	870	870	870	870	870	870	870	170	170	
m^3/month	5,270	4,760	5,270	26,100	26,970	26,100	26,970	26,970	26,100	26,970	5,100	5,270	211,850

Source: Pitsikaris 2004

for the annual amount of desalinated water. Table A.1 gives a breakdown of how this was done.

4.1.3 Imported Water: Thirasia

Varying information exists on the quantity of water that is shipped to Thirasia each year. Kaldellis (2004) has official data for several remote Greek islands, and reported that Thirasia imported 24,211 m^3 in 2001 and 22,906 m^3 in 2002. However, in 2004 the President of Ia, Georgios Chalaris, reports that Thirasia is only receiving 1,330 m^3 of water every two months, for an annual total of 7,980 m^3. Although the population and water demand of Thirasia have decreased over the past decade, this level of decrease over only a two year period is unlikely. Therefore the 2002 number of 22,906 m^3 was used for this study.

4.1.4 Imported Bottled Water

Because no data were available on the volume of bottled water imported to Santorini, another method had to be used to formulate an estimate. In many cases in this study, it has been assumed that consumption = demand. With this in mind, the volume of imported bottled water was calculated as the amount left when all other consumption was subtracted from the total demand. Total demand ended up being 2,412,818. Consumption, minus bottled water, was 1,634,756. The difference was 778,062, which was rounded up to 1,000,000 to account for human waste.

4.2 Existing Water Demand

Water demand on Santorini is generated primarily from three categories: permanent residents, tourism, and agriculture. Other sectors also demand water, such as mining and heavy industry. However, data on their water demand is not available. In addition, certain customers of the Municipality of Thira network are likely some of these industries. Therefore, additional demand for these secondary consumers has not been calculated.

4.2.1 Demand of the Permanent Population

The demand of the permanent population was calculated using both Greek statistical data and recent water consumption in the Municipality of Thira. A sample had to be acquired from this data that could represent the entire permanent population of Santorini. 2002 data was used for this, based on the fact that the 2001 data appeared to have faults. The data for water consumption in the Municipality was used, minus the data for Fira and Kamari. Both of these settlements were very high-end outliers in consumption per customer. This is likely based on their roles as resorts, and many of the customers are likely hotels that have swimming pools and tourists using much more water. This remaining data had 2,484 customers and a consumption of 225,068 m^3. In this data, each “customer” is actually a household. Therefore, the total number of “customers” had to be multiplied by the average household size (2.98 people per household in the Municipality of Thira), which was gathered from 2001 census data, to come to an average consumption of 30.41 m^3/capita/year. However, this does not account for drinking water. People are recommended to drink 2 liters of water per day (0.73 m^3) to combine with food liquids to rehydrate the body, increasing demand to 31.41 m^3/capita/year. The combined populations of the Community of Ia and Municipality of Thira (13,725) were most recently available from the 2001 Greek census. By multiplying this population by the above per capita consumption, a total demand of 417,423.42 m^3 was calculated for the permanent population.

4.2.2 Demand of the Seasonal Population

Calculating demand for the seasonal population was a bit more difficult. Very few dependable numbers exist on exactly how many new people come to work on Santorini and how many already live there but just work there seasonally. It is estimated that 6,800 people work during the tourism months and 4,000 work during the non-tourism months. In addition, 67% of the 6,800 are non-Greeks. However, many of the permanent population of Santorini are non-Greeks (2,051 in 2001) so a simple percentage cannot be sufficient. To calculate the seasonal population, 67% of the difference between 4,000 and 6,800 was used, for a seasonal population of 1,876. Because they only live on Santorini for 58% of the year (April through October), only 58% of the permanent population demand (18.17 m^3/capita/year) is needed. A total demand for the seasonal population was calculated then at 34,081.22 m^3/year (University of Cincinnati Sustainable Development Group 2004).

4.2.3 Demand of the Tourist Population

Tourists consume far more water than permanent residents. Garcia (2003) has estimated that tourists use 575.8 L/day in Mallorca, Spain. Other Mediterranean locations that rely on tourism have similar numbers in water consumption for tourist use. Because Santorini has less landscaping and no golf courses, the number of 400 L/tourist/day (0.400 m^3/tourist/day) consumed was used for this study, much higher than the 90 L/capita/day consumed by the permanent population.

Of all data gathered on Santorini, numbers dealing with the tourism sector of the economy show the most variation. Although varying totals exist, it is estimated that over 1 million, and as many as 1.5 million people visit Santorini each year (Nomikos 2006). Gyzis (2004) provided detailed numbers for tourists who arrive on Santorini by four different methods: charter flights, normal domestic flights, ferry, or cruise ships. Because these data are the most reliable and recent, they were used for this study.

Cruise tourists cannot be expected to consume as much water for the time that they are on the island. They have much less reason. They have no hotel rooms, will no swim in swimming pools, and many of them will not even eat on the island. Therefore, the only water they are sure to consume is drinking water and possibly the water used in flushing toilets. Humans need to consume 1-3 liters of water daily to maintain health. It is unlikely that cruise tourists will consume more than they would be biologically required to in those 4 hours, and many of them may have brought water from the ship. Therefore their daily water use on Santorini is estimated at only 0.25 liters. Using this quantity for cruise tourists and 400 L/day (.4 m^3/day) for all others, a total tourism demand was calculated, as seen in Table A.2.

Table A.2: Water demand of different types of tourists

Type of Tourist	Number in 2002	Average Stay (days)	Daily Consumption (m^3)	Total Water Demand (m^3)
Charter Flights	170,000	10.00	0.40000	680,000
Normal Flights	81,000	4.00	0.40000	129,600
Ferry	401,000	4.00	0.40000	641,600
Cruise	375,000	0.17	0.00025	94
Total	1,027,000			1,451,294

Source: Gyzis 2004

4.4 Expected Future Trends

4.4.1 Expected Decrease of Sustainability

To perform a trend forecast on water costs in the Municipality of Thira, the linear, geometric, and parabolic models were used. The data were deemed too limited to attempt any of the more complex models, such as the modified exponential or Gompertz. The linear model produced the most conservative result, with average water cost being €1.58/m^3 in 2010. The geometric was slightly more liberal at €1.92/m^3. The results of the parabolic model were extremely high at €4.58/m^3 and have been largely thrown out. The results of the linear and geometrci models can be seen below in tables A.3, A.4, and A.5.

Table A.3: Projection of water price in the Municipality of Thira, Linear Model

Year	Y	X	XY	X^2	Y_c
2000	0.82	-1	-0.82	1	0.80
2001	0.86	0	0.00	0	0.88
2002	0.97	1	0.97	1	0.96
2003		2			1.04
2004		3			1.11
2005		4			1.19
2006		5			1.27
2007		6			1.35
2008		7			1.42
2009		8			1.50
2010		9			1.58
Total	2.64	0	0.15	2	

Y= Actual Water Price per m^3 (Euros)

Y_c= Projected Water Price per m^3 (Euros)

Source: Municipality of Thira 2002

Table A.4: Projection of water price in the Municipality of Thira, Geometric Model

Year	Y	log Y	X	X(log Y)	X^2	log Y_c	Y_c
2000	0.82	-0.08822	-1	0.088223	1	-0.09	0.81
2001	0.86	-0.0674	0	0	0	-0.06	0.88
2002	0.97	-0.01278	1	-0.01278	1	-0.02	0.96
2003			2			0.02	1.05
2004			3			0.06	1.14
2005			4			0.09	1.24
2006			5			0.13	1.36
2007			6			0.17	1.48
2008			7			0.21	1.61
2009			8			0.25	1.76
2010			9			0.28	1.92
Total		-0.16841		0.075442	2		

Y= Actual Water Price per m^3 (Euros)

Y_c= Projected Water Price per m^3 (Euros)

Source: Municipality of Thira 2002

Table A.5: Projection of consumption and demand, Fira

Consumption in Fira (m^3)	Full Year	Tourism: Apr-Oct	Non-Tourism: Nov-Mar
1998	98,718	80,548	18,170
1999	116,750	91,890	24,860
2000	164,100	130,700	33,400
2001	187,543	144,098	43,445
Ave. Change/year	31,382	22,946	8,437
Ave. % Change/year	25%	23%	34%
Total Change	88,825	63,550	25,275
2010 Projected	471,294	352,742	118,552

Source: Municipality of Fira 2001

4.4.2 Trend Forecast of Demand

In projecting the future demand in Fira, the linear, geometric, and parabolic models were used. Once again based on the limit of data, the more complex models were not used. Each model was used for the full year, and subsequently for the tourism months and non-tourism months as different data sets. The results of both the geometric and parabolic were very high, and obviously the result of limited data. Therefore, only the linear model was used, the results of which were shocking. These are the numbers that appear in Table 4.5.

Glossary

Aquifer: an underground layer of water-bearing permeable rock, or unconsolidated materials from which groundwater can be usefully extracted (Wikipedia.com 2006).

Brackish water: water with a higher salinity than freshwater, but a lower salinity than seawater.

Brine: water saturated with or containing large amounts of salt, especially sodium chloride (Dictionary.com 2006). In desalination, brine is the environmentally hazardous effluent.

Brown water: wastewater that comes from sewage systems.

Caldera: a volcanic feature formed by the collapse of a volcano into itself (Wikipedia.com 2006).

Dependency Ratio: the percent that a region is dependent upon outside resources for its water supply. The higher the number, the more dependent the region is.

Desalination: the act of removing salts from seawater or brackish water as to render the water suitable for human consumption and household use.

Eposkifa: the building technique unique to Santorini. It involves building into hillsides in a cave-like fashion. This technique has also lead to settlements being used as large rainwater catchments, as many households will be built upon each other like tiers.

Evapo-transpiration: the act of water evaporating into the atmosphere from the surface.

Grey water: wastewater that comes from low impact household use such as laundry and dishwashing.

Hydraulic connection: in this study, hydraulic connection refers to the exchange between freshwater and seawater at the base of the underground aquifer. Greater hydraulic connection means higher risk of seawater intrusion.

Microfiltration: a process which removes contaminants from fluid or gas by passage through a microporous membrane. It is increasingly used in drinking water treatment to remove pathogens and other contaminants (Wikipedia.com 2006).

Permeability: the rate of flow by a liquid or gas through a porous material; specifically the rate by which surface water permeates into a groundwater aquifer.

Pyroclastic: composed chiefly of rock fragments of volcanic origin (Dictionary.com 2006).

Subsiding: the act of land weakening and sinking as it experiences structural damage; known to happen in areas of over-exploited groundwater aquifers.

Suspended solids: particulates that must be removed from feedwater prior to pre-treatment or desalination; must also be removed from initial rainwater harvests when they are picked up from catchment surfaces.

Sustainable Development: development that meets the needs of the present without compromising the ability of the future generations to meet their own needs.

Water deficit: the deficit between total water demand and water supply; specifically the deficit between demand and sustainable supply.