Conservation, Retain, Reuse and Desalination at Joint Base Pearl Harbor - Hickam

Keith J. Jabbusch
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CONSERVATION, RETAIN, REUSE AND DESALINATION AT JOINT BASE PEARL HARBOR - HICKAM

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CONSERVATION, RETAIN, REUSE AND DESALINATION AT

JOINT BASE PEARL HARBOR - HICKAM

A Master Thesis

Submitted to the Faculty

of

American Public University

by

Keith J. Jabbusch

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Public Administration

May 2016

Honolulu, HI
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DEDICATION

With sincere appreciation and love to my wonderful wife Kelly for her tremendous support and love during my graduate process. Her motivation, encouragement, and patience was vital and a true blessing.
ACKNOWLEDGMENTS

To Dr. Stephen Schwalbe my thesis advisor, I express gratitude in his guidance and support during my capstone process. I’d also like to thank him for his faithful service to our nation.

I also wish to thank the following staff members at American Public University in challenging me to learn, Professor Lisa Saye, Dr. Ron Johnson, Professor Reshowrn Thomas, Professor Collins, Professor Timothy Bagwell, and a special thank you Dr. James Bullen.

To my Brothers and Sisters in the military, thank you for standing the watch.
ABSTRACT OF THE THESIS

DESALINATION AT JOINT BASE PEARL HARBOR - HICKAM

By

Keith Jeffery Jabbusch

American Public University System, April 27, 2016

Charles Town, West Virginia

Stephen Schwalbe, Thesis Advisor

This thesis examines the need for an alternate source of fresh water on Oahu, and the need to reduce the current demand on the Island’s aquifer. The Navy’s investment into next generation reverse osmosis (RO) desalination has proven to reduce annual operating cost by 70 percent, with improved operational time, reduced part failures, and maintenance time, while producing 50 percent more clean water. Joint Base Pearl Harbor- Hickam has the ability to reduce its current requirement from 18 million gallons a day to 3 million gallons per day, by implementing current technologies in desalination from shipboard RO’s and in the use of using high efficient conservation methods. Along with desalination, JBPHH’s ability to retain and re-use run-off water from impermeable surfaces can reduce JBPHH’s daily aquifer withdraw by 85 percent in helping the State of Hawaii Department of Land and Natural Resources Commission on Water Resource Management’s sustainable yield goal of 165 million gallons per day (mgd).
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<td>CNIC</td>
<td>Commander, Navy Installations Command</td>
</tr>
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<td>CNOAVAL</td>
<td>Chief of Naval Operations Availability</td>
</tr>
<tr>
<td>CWRM</td>
<td>State of Hawaii Department of Land and Natural Resources Commission on Water Resource Management</td>
</tr>
<tr>
<td>DS</td>
<td>Direct Service</td>
</tr>
<tr>
<td>DOE</td>
<td>Department of Energy</td>
</tr>
<tr>
<td>DOD</td>
<td>Department of Defense</td>
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<tr>
<td>DODS</td>
<td>Department of Defense Schools</td>
</tr>
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<td>DON</td>
<td>Department of Navy</td>
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<tr>
<td>EESI</td>
<td>Environmental and Energy Study Institute</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
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<tr>
<td>EUWP</td>
<td>Expeditionary Unit Water Purification Generation 2 Plant</td>
</tr>
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<td>FEMA</td>
<td>Federal Emergency Management Agency</td>
</tr>
<tr>
<td>FEMP</td>
<td>Federal Energy Management Program</td>
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<td>FY</td>
<td>Fiscal Year</td>
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<td>HBWS</td>
<td>City and County of Honolulu’s Board of Water Supply</td>
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<td>HECO</td>
<td>Hawaiian Electric Company</td>
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<td>HMP</td>
<td>Hawaii’s Hazard Mitigation Planning</td>
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<td>JBPHH</td>
<td>Joint Base Pearl Harbor-Hickam</td>
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<td>KWHR</td>
<td>KiloWatts Per Hour</td>
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<td>LICH</td>
<td>Landscape Irrigation Council of Hawaii</td>
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<td>LWC</td>
<td>Light Weight Cargo Ship</td>
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<td>MAC</td>
<td>Hawaii Military Affairs Council</td>
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<td>MGD</td>
<td>Million Gallons per Day</td>
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<td>Morale Welfare &amp; Recreation</td>
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<td>MHMP</td>
<td>Multi-Hazard Mitigation Plan</td>
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<td>Naval Facilities Hawaii</td>
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<td>Naval Medicine</td>
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<td>NAVSUP</td>
<td>Naval Supply Fleet Logistics Center Pearl Harbor</td>
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<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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<td>NSRO</td>
<td>Naval Standard Reverse Osmosis</td>
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<td>ONR</td>
<td>Office of Naval Research</td>
</tr>
<tr>
<td>PDO</td>
<td>Pacific Decadal Oscillation</td>
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<td>Pre-Disaster Mitigation</td>
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<td>RO</td>
<td>Reverse Osmosis</td>
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<td>San Diego County Water Authority</td>
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<tr>
<td>UH</td>
<td>University of Hawaii</td>
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<td>USCG</td>
<td>United States Coast Guard</td>
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<td>ZID</td>
<td>Zone of Initial Dilution</td>
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CHAPTER 1 - Water

Life Depends on Fresh Water

Water is the most common compound on Earth and vital to all living organisms. It covers 70 percent of the Earth's surface, and provides a habitat for all aquatic organisms. It is the largest part of all living organisms; the human body consists of 65-70 percent water.

Some 97 percent of the Earth's water is salt water. Of the remaining three percent, just 0.3 percent of that is in the form of surface water, such as lakes, rivers, and streams. The remaining 69 percent is frozen water that is located in polar-regions and is currently unusable. The remaining 30 percent is groundwater found in caverns, crevices within split rocks and aquifers, like what is found in the Hawaiian Islands.

Water has even become a likely investment for those looking to advance in the stock market. According to Balchunas (2014), water is the world’s most precious resource next to air. Over the past century, worldwide water usage has been increasing more than twice the rate of population growth, and this water scarcity is already becoming a source of geopolitical conflicts. Many investors are buying up mutual funds and electronically traded funds that invest in companies which regulate or purify water anticipating that, like oil, water will be the next resource in short supply and high demand.

Among the Hawaiian Islands, the aquifers provide 500 million gallons a day (mgd), which is 99 percent of the fresh water required every day. Oahu’s aquifers are continually replenished with 152 billion gallons of annual rainfall. On average, Oahu is estimated to receive 417 million gallons of daily rainfall. This estimate is taken during
drought a condition that is defined as 37 percent less of a recharge than average conditions, according to Commission on Water Resource Management (CRWM) (State of Hawaii, 2008). In addition to rainfall, the aquifers are supplied by fog drip and irrigation water. Some irrigation water is lost to runoff, and some is stored in the Island’s soil. On Oahu, nearly 80 percent of the water comes from the Ko`olau Mountain Range. The convergence of warm ocean air moving up the forested mountains creates quick cooling and condensing on the slopes, also known as orographic rainfall. The upland forest then captures the water in the form of mist, fog, and rain. This water is then absorbed into the volcanic rock and surrounding environment, creating beautiful waterfalls, streams, and fresh water replenishment of the aquifer.

The Hawaiian Islands are highly dependent upon consistent weather patterns that result in adequate rainfall. However, should those weather patterns be interrupted, island residents and the Hawaiian agriculture and agribusiness way of life will be in jeopardy. In fact, the Marshall Islands (located at the halfway point between Hawaii and Australia) are already experiencing challenges in accessing fresh water (Mellgard, 2016). The State of Hawaii needs a plan in place in the event that draught or rainfall shortages threaten the Islands.

**Water Management**

The Hawaiian Islands are the most isolated chain of Islands in the world, and with a population of over 953,000 on Oahu, fresh water supply is often a topic of concern (Census Bureau, 2015). From its earliest roots, the Hawaiian Island of Oahu thrived due to strict management of water resources. In fact, in ancient times, abuse or mismanagement of water was punishable by death. The land and resources were sacred
and managed by the highest chief or king for the entire population. Strict laws, or kapu, were in place so that agricultural growth could be effectively managed (Ford, 2015). According to the Board of Water Supply (2004), Hawaiians had developed advanced agricultural irrigation systems that resulted in farmlands and nourishment for a thriving population. Even in their earliest days, Hawaii’s inhabitants understood the importance and value of fresh water on an Island surrounded by salt water.

By the 1800s, the Hawaiian Islands were frequented by foreigners who benefitted from the Island’s water supply by filling their ships’ barrels with water (2004), water needed for 19th century crops. That was just the beginning. By 1879, James Campbell used a well driller to explore for an alternate water source. This was the beginning of the aquifer system that still supplies Oahu today. Now, artesian wells fulfill most of Honolulu’s water needs (2004) for daily living and its agricultural needs. The most productive aquifers in Hawaii are made of volcanic rock, which erupted during the initial formation of the Hawaiian Islands. These aquifers are of high quality and value, volcanic rock is a superior form of a natural filter meaning the water filtered through this rock has less minerals than man-made purifiers. In fact, their value in material quality exceeds that which houses the majority of the mainland United States’ water, which often have high sediment deposits, limestone, and can even yield brackish water (Oki, 2005).

**Development of The State Commission on Water Resource Management (CWRM)**

In the early 1900s, Oahu faced resource challenges, such as drought and water shortages. As a result of poor management, the Honolulu Sewer and Water Commission was formed to overcome the Island’s water challenges, and, by the 1950s, the Board of Water Supply was in place to protect the Island’s mountain watershed and forests. The
State Commission on Water Resource Management (CWRM) sets policies and approves water allocations for all water users, including the Board of Water Supply (HBWS), which protects and oversees the Island’s groundwater resources.

**Fresh Water Demands**

Oahu’s average water use is 240 million gallons a day (mgd). (Figure 1.) The Board of Water Supply accounts for 62 percent of Oahu’s water usage (150 mgd). The agriculture, industry, and irrigation accounts for 72 percent (65 mgd). The five branches of the military total 18 percent, (45 mgd). Of which 27 percent (24 mgd) is not provided by HBWS. (See Figure 2 for Military locations on Oahu). Private residents and industry account for the remaining 1 percent (.5 mgd). Sugar and pineapple production has since decreased and is no longer accounting for the 35 percent, (102 mgd) that it previously consumed (Leong, 2015), rather it accounts for less than 7 percent, (16 mgd).

![Board of Water Supply 150 mgd, (2014)](chart1)

![Oahu water use 90 mgd (non Board of Water Supply)](chart2)

Figure 1. Oahu’s Water Usage by Consumer. (HBWS, 2014 and Leong, 2015)
Despite some of the minimal conservation efforts, water usage levels for Oahu have steadily increased with the calculated population growth rate of 4.5 percent according to the U.S. Censes Bureau (2015). (See Table 1) While there is not an immediate sense of urgency surrounding the possibility of water shortages and restrictions on Oahu, it is a question that does weigh on the minds of many Hawaiian residents. Additionally, with water usage worldwide increasing at a rate double the population growth, it is likely that water, as a whole, will also be a scarce resource in Hawaii, specifically, within the next 50 years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Population in thousands</th>
<th>Million gallons daily</th>
<th>Gallons per person daily</th>
<th>Irrigation in Millions of gallons daily</th>
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<td>2010</td>
<td>947</td>
<td>163</td>
<td>172</td>
<td>73</td>
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<td>2005</td>
<td>905</td>
<td>152</td>
<td>169</td>
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<td>2000</td>
<td>876</td>
<td>164</td>
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Table 1 Water Data use for Honolulu County
Oahu’s Future Water Supply

In December 2011, the US Geological Survey (USGS) announced that Hawaii is in a long-term drought, “severe” and even “extreme” in some parts of the State. Chief engineer and manager of the Honolulu Board of Water Supply Clifford Jamile warns that in the case of a draught, Oahu could be in serious trouble (Leone, 2001, 2006). Additionally, University of Hawaii Professor Tom Giambelluca testified to the Board of Land and Natural Resources that while projecting the future of Hawaii’s climate is difficult, the one certainty is that rainfall over the Hawaiian Islands has declined since 1978 (Dunster, 2013). A joint study published by the University of Hawaii at Monoa and the University of Colorado Boulder indicates that trend in declining rainfall will continue as global warming continues (Timm, Takahashi, Giambelluca, Diaz, 2013). Because short-term fluctuations in rainfall do not have a lasting impact on Oahu’s underground aquifer (water supply), adequate resources have not been immediately dedicated to overcoming a potential water shortage in Hawaii. However, should rainfall be jeopardized for a longer period of time due to a weather event like El Nino, an earthquake, draught, or Pacific Decadal Oscillation (PDO), the drawdown and recharge of the aquifers would be impacted, and that would ultimately hurt the Island’s water supply.

Oahu once considered the construction of a desalination plant, but those plans were put on hold due to the fact that the urgency for water alternatives subsided when aquifer levels were estimated to be adequate for current and future population levels (HBWS, 2016). While Oahu has the natural resources of rainfall and a lush terrain on its side, it also has another interesting resource – the United States Navy, which routinely
uses reverse osmosis processes to desalinate ocean water and provide water for use and consumption upon its ships while at sea. The Navy’s desalination processes can be helpful in two ways: 1) reducing the military’s consumption of Oahu’s water, and, 2) establishing a water supply that can bridge the gap should the Island face a water shortage or natural disaster.

**Oahu’s Fresh Water Lens**

Most of Oahu’s groundwater comes from freshwater lens in volcanic-rock aquifers, which float above the saltwater table. The thickness of a freshwater lens is affected by recharge, withdrawal rates, hydraulic properties of the aquifer system, and distance from the ocean. In the Pearl Harbor area, thick caprock sediments contribute to a large freshwater lens with thicknesses that range from 150–450 feet in coastal areas to 700 feet inland, measured in deep monitoring wells (DMWs) during 2008–2009 (Rotzoll, K., Oki, D.S., El-Kadi, A.I., 2010). See Figure 3 below for details. The freshwater lens is sometimes referred to as a Ghyben-Herzberg lens after Badon Ghyben (1889) and Herzberg (1901). The Ghyben-Herzberg principle states that the altitude of the water table in a freshwater lens is balanced by the buoyancy of the freshwater floating on saltwater and assumes hydrostatic (non-flowing) conditions.
Figure 3. Generalized fresh water lens diagram of groundwater occurrence and movement (arrows) in the Pearl Harbor aquifer. (1) discharge from high-level water bodies to the freshwater lens, (2) downward flow in recharge areas, (3) horizontal flow, (4) upward flow in coastal discharge areas, and (5) discharge through the coastal sediments into the ocean (Tribble, 2008).

**Basic Water Needs**

Natural disasters, such as floods, tsunamis, hurricanes, earthquakes, and terrorist attacks, affect more than 226 million people every year. Some of the most notable areas affected by natural disasters: Philippines, Hong Kong, Taiwan, and many Japanese Islands have recently been impacted by large typhoons. Africa, Haiti, China, and multiple countries in South America have also been impacted by earthquakes, which have destroyed vital infrastructure. The occurrence of these natural disasters has increased each year due to the synergistic effect of climate change. (Langtagne and Clasen, 2009). Developing a guideline for emergency water resources will become even more important as the number of natural disasters continue to increase.
Natural and man-made disasters are the biggest concern for emergency use in secondary sourcing of fresh clean water. Contaminated water and insufficient water for hygiene purposes are related to droughts and disasters. The Red Cross and its partners have defined two standards with the Sphere Project (2011) for water supply usage during emergencies. The first standard involves the quantity of and access to drinkable water, while the second standard regulates water quality. A summary for safe and healthy water consumption is listed with the minimum requirements listed in Table 2. Water for hygiene use is considered a basic water need. Not maintaining proper hygiene during disasters will significantly increase the risk of disease.

| Survival needs: water intake (drinking and food) | 2.5–3 liters per day | Depends on the climate and individual physiology |
| Basic hygiene practices | 2–6 liters per day | Depends on social and cultural norms |
| Basic cooking needs | 3–6 liters per day | Depends on food type and social and cultural norms |
| Total basic water needs | 7.5–15 liters per day | 2-4 gallons per day |

Table 2. Basic survival water needs (Sphere Project, 2011)

**Need for a Water Conservation Plan**

As an island state, Hawaii has limited access to natural fresh water supplies. Competition for fresh water, increasing population and development pressures, the rising awareness of environmental water needs, and the impacts of global climate change require that Hawaii become as efficient as possible in its uses of limited fresh water supplies. In some areas of the State, demand for water is approaching the sustainable limits of supply, and these demands are expected to increase in the future. In order to
sustain and protect our water for future generations, we must strive to be as efficient as possible in all of our water uses.

The Commission on Water Resource Management (CWRM) is the primary steward of the water resources public trust and has broad powers and responsibilities to protect and manage Hawaii’s water resources. This includes the authority and duty to develop plans and programs to conserve water across the State of Hawaii. While various State agencies and municipalities have developed and implemented individual programs to conserve water, there has been a lack of coordination and communication to collaborate those efforts toward a common goal of aquifer sustainment. According to CWRM, Hawaii’s current reachable goal should be an additional 100 million gallons of fresh water per day due to expected Island growth and agriculture requirements (Hawaii, 2008).

CHAPTER 2 - US Navy

Home to United States Navy Middle Pacific Fleet

The Island of Oahu has a unique advantage should such an emergency strike. Oahu is home to the United States Navy Middle Pacific Fleet. This puts Oahu in a unique position to benefit from the reverse osmosis and desalination processes that the Navy has used on its ships since the mid-1980s. This thesis will explore how the Navy can move Joint Base Pearl Harbor - Hickam (JBPHH) into becoming completely independent of Oahu’s Board of Water Supply, thereby alleviating pressure on the Island’s water supply. Additionally, this independent fresh water supply can become a fresh water source should Oahu face an emergency, such as a draught or natural disaster.
Middle Pacific’s Fleets Capabilities

The Navy currently stations 18 submarines, 9 destroyers (DDs), 2 cruisers (CGs), and 2 decommissioned Landing, Helicopter Assault ships, (LHAs) at Pearl Harbor. The subs currently generate 40,000 gallons of usable water each day. The destroyers and cruisers can each generate about 24,000 gallons daily, and the two decommissioned LHAs can each generate 400,000 gallons of usable water per day. That totals about 1.7 million gallons of available clean water daily. And, the potential could be 50 percent greater if the Naval Standard Reverse Osmosis (NSRO) units were to be upgraded to the Expeditionary Unit Water Purification (EUWP) reverse osmosis desalination units and additional decommissioned ships were put to use in this capacity.

Utilizing the NSRO, the surface ships averages 30 gallons per day per Sailor aboard a surface vessel. Utilizing the EUWP, the Navy expects to exceed 50 gallons per day per Sailor, plus increased shipboard usage. The current replacement cost of the EUWP, depending on class of ship and water requirements cost the same as the NSRO units, between three and six million dollars per unit, according to Office of Naval Research (ONR). With the reduced maintenance requirements, extended filter run time between production times, and reduced energy cost of 70 percent, make the EUWP the preferred replacement during a major shipboard overhaul (2009).

Hawaii’s Partnership with the Military

Hawaii has a long history with the U.S. military. As home to the Middle Pacific Fleet, Hawaii is a crucial part of the United States Navy. The Hawaii Military Affairs Council (MAC) hosts an annual partnership meeting as well as monthly meetings. This Council is comprised of Hawaii’s active and retired military, business, and government
leaders. This Council would be a logical initial liaison in assisting the State with an emergency water plan that would require the Navy’s help.

There are two major goals of the Hawaii Military Affairs Council (MAC) that are in line with ensuring that Hawaii’s water supply remains available. One of the major goals of the Hawaii MAC is to act on the State’s behalf in preserving and protecting Hawaii’s crucial role from which the military controls the humanitarian assistance and disaster relief operations throughout the Asia-Pacific region (Kaimuloa, 2016). A second major goal of MAC is in supporting the U.S. military’s strategic headquarters for the Asia-Pacific region’s military operations. In maintaining these interests, the military (to include the U.S. Navy) has a vested interest in the continued health and functionality of the State of Hawaii, which includes valuable natural resources, such as water.

To begin the process of using the Navy’s desalination resources and potentially allocating more resources to the region, Hawaii government officials and the Honolulu Board of Water Supply should initiate discussions with the Hawaii Military Affairs Council.

**MAC’s Success**

The Hawaii Military Affairs Council (MAC) facilitated a first-ever meeting of the Navy Facilities Command and the Public Utilities Commission in December 2014. As a result of this informational session, the Navy was able to share its requirements, goals, and challenges. Being the single largest energy customer on Oahu, the Navy’s interests range from adding significant solar power to its renewable energy portfolio, continuing its demand reduction and efficiency efforts, and serving as a community partner with Hawaiian Electric and Hawaii Gas. The Navy's goal is to lower energy costs and reduce
dependency on fossil fuels. According to MAC Chairman Vic Angoco, it was an “excellent first meeting, with an interest by both parties to continue the discussion for the benefit of all” (Hawaii, 2014).

**Joint Base Pearl Harbor- Hickam Partnership with Oahu**

In addition to Hawaii’s critical stature within the Asia-Pacific region, the U.S. military should be a concerned and logical partner because two of its military bases are among Honolulu’s Water Board of Supply’s top water users. Marine Corps Base Hawaii uses over 59 billion gallons of Oahu drinking water annually, and Fort DeRussy Army Facility uses over 11.6 billion gallons annually (Hao, 2009). Not only can the military provide an alternative water source, but also it can be very influential in implementing effective water conservation programs on its many military bases.

**CHAPTER 3 - Osmosis**

**Process Description of Reverse Osmosis**

Osmosis is a process by which a liquid passes through a thin, porous (semipermeable) membrane that acts as both a filter and a salt barrier. As a filter, the membrane prevents solids entrained in a liquid from passing through it. More important in the osmosis process, the semipermeable membrane acts as a barrier to prevent specific dissolved substances (salts) from passing through it, only allowing freshwater to pass. In a normal osmosis process, when there are two solutions of unequal salt concentration on the two sides of the membrane, then the more dilute solution will tend to pass through the membrane, decreasing the concentration of the saltier solution on the other side. For example, with fresh water on one side of the membrane and seawater on the other, the fresh water will pass through the membrane, making the seawater a weaker (less
concentrated) solution. However, the normal direction of water flow through the membrane during osmosis may be reversed (i.e., reverse osmosis) by pressurizing the seawater solution above its equilibrium point, i.e., above its osmotic pressure. For seawater the osmotic pressure is approximately 350 psig (pounds per square inch gauge). Typically a much higher pressure (650psig to 1000 psig) than the osmotic pressure is needed to efficiently obtain desalted product water (permeate) on the opposite side of the membrane by forcing water from the seawater side through it. The membrane allows the water to pass through while excluding most of the salts, which are then retained on the seawater side as concentrated brine.

The quantity and the salinity of the resulting permeate that passes through the membrane is dependent upon many factors, including temperature, pressure, membrane material, and the composition (salinity) of the salt solution. In the RO process, “product water” is the term applied to the portion of the liquid that passes through the membrane. The terms “permeate” and “product water” are used interchangeably. The term “potable water” refers to RO product water that has been treated with bromine or chlorine and is ready for human consumption.

**Introduction of Reverse Osmosis**

Introduced into the US Navy during the late 1980, Reverse Osmosis (RO) desalination plants quickly converted the standard for the shipboard production of freshwater. RO plants quickly provided significant operational benefits and reduced the operational cost over conventional distillers. Distillers were used on Naval ships for over 150 years. However, RO plants reduced monitoring operations and manpower requirements while significantly reducing operational costs by removing distilled
evaporators and shipboard steam systems. The use of ROs has reduced the need for higher levels of chlorine and bromide chemicals, and reduced maintenance, according to Office of Naval Research Science & Technology. (2009). Unlike distillers that required costly and time-consuming overhauls, overhauling the RO plant requires a simple replacement of modular membrane elements, a process that usually take four man-hours on a 12,000-gpd plant.

RO plants have improved the quality of life for our Sailors. Achieving a higher level of acceptance within the Naval Service, the level of performance from the RO plants, including system operational availability, often exceeds 98 percent, versus 80 percent or less experienced with standard distillers and steam evaporators (ONR).

The 12,000-gpd “Navy Standard” RO (NSRO) desalination plant was designed nearly 30 years ago when the majority of naval operations were conducted in “blue water/deep water.” It continues to be the design basis for reverse osmosis desalination plants on new construction. The NSRO system includes a series of single-use, disposable cartridge filters for removal of suspended solids in the seawater that could foul or plug the RO membranes. In blue water/deep water operations, the current filtration system and cartridge filters routinely last 1,000 hours before needing replacements, and RO elements routinely lasts more than three years before needing cleaning or replacement.

Navy’s Need for Improved Reverse Osmosis Desalination

As detailed in the CNO SEA POWER 21 and the U.S. Maritime Force's A COOPERATIVE STRATEGY FOR 21ST CENTURY SEAPower (2011, 2013) initiatives, Naval strategic projections anticipate future military engagements, maritime security, operational exercises, humanitarian assistance, and disaster response that are
more likely to occur in littoral and coastal waters. Suspended solids in the seawaters of littoral and coastal areas routinely consist of fine sand or silt, biological micro-solids (bacteria, algae, slimes, etc.) and macro-solids (plankton, krill, etc.), and are often at higher concentrations than in the open ocean (2011). As a result, ship operations in these areas will tax the filtration capability of current RO desalination systems, resulting in more frequent filter replacements. Increased cartridge filter usage rates have been observed on deployments in littoral waters, such as those in the Northern Persian Gulf due to the ships operating RO plants in highly turbid seawaters. With the decreased rate in cartridge filters to sufficiently remove the smaller suspended solids, ships have experienced higher rates of RO membrane element failures. The result is then a decreased amount of desalinized water production. Deployment data and maintenance logs from the littoral operating ships show cartridge filters lasting less than 24 hours, and RO membrane elements requiring replacement in just a few months instead of the expected three to five years before needing replacement. This has created a supply burden on the Navy logistics system and an ever-increasing cost of operation.

**Next Generation Of Reverse Osmosis Desalination Units**

SEA POWER 21 and the Office of Naval Research (ONR) Expeditionary Unit Water Purification (EUWP) Program developed the next generation of reverse osmosis desalination units. The EUWP units have demonstrated the ability to run 70 percent more efficiently and produce 50 percent more water in turbid littoral/coastal waters, harbors and rivers where the quality of seawater is very poor. EUWPs are designed to replace the current 100,000-gallon ROs. Their ability to operate in high salinity seawater for 100 plus days with no operator intervention, reduced power requirements, and
produce more pure water is exactly what the Navy needs for expeditionary, humanitarian, and disaster relief applications (Norham, Varnava, Miller, Heinzel, Peek, 2011/2013).

Currently, the EUWP has been deployed with the US Coast Guard to Loran Station in Port Clarence, Alaska; provided humanitarian and disaster relief in support to Biloxi, Mississippi, following Hurricane Katrina; and, offered drought relief to the Makah Tribe in Neah Bay, Washington (Norham, Varnava, Miller, Heinzel, Peek, 2011/2013).

CHAPTER 4 - Desalinization

Production Cost of Desalinated Water at JBPHH

Hawaiian Electric Company, INC. contracts power distribution to JBPHH as a “Large Power Service” under docket number 2010-0080 for Decision and Order No. 30505; Filed June 29, 2012. This scheduled Direct Service (DS) is charged at:

ENERGY CHARGE - KiloWatt per hour (kWhr) = ¢ per kWhr: 14.9013 ¢/kWhr (HECO, 2012)

According to Technical Manual Description, Operation And Maintenance, Reverse Osmosis Desalination Unit, 12,000-Gpd, Published By Direction Of Commander, Naval Sea Systems Command, the NSRO’s power requirement is 125 amps, 440 volts 3 phase A/C for 55 kWhr. Daily electrical cost to JBPHH operating all NSRO Units verses EUWPs for maxim desalination. (See Appendix 1 for cost analysis, p 68)

One gallons of water from NSRO = $.016392 (1.7 million gpd = $27,866)

One gallons of water from EUWP = $.003278 (2.5 million gpd = $8,195)
Average Desalination Cost per One Thousand Gallons of Fresh Water

Kreamer states recent advances in reverse osmosis membranes are bringing down desalination costs, which now stand at about $0.002 to $0.003 per gallon of potable water produced by which the EUWP falls into this standard at $0.003278. By contrast, average city water in the United States costs about $0.0007 to $0.0057 per gallon (2009). (See Table 3 for a cost comparison between Honolulu Board of Water Supply and the U.S. average as compared to desalination cost).

<table>
<thead>
<tr>
<th>Cost of water production.</th>
<th>HBWS</th>
<th>US Average</th>
<th>NSRO</th>
<th>EUWP</th>
<th>Average Desalination</th>
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<td>Residential</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>First 9,000 gallons or</td>
<td>$4.42</td>
<td>$0.70-$5.70</td>
<td>$16.39</td>
<td>$3.278</td>
<td>$2.00-$3.00</td>
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<tr>
<td>any part thereof</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over 22,000 gallons</td>
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<td>$0.70-$5.70</td>
<td>$16.39</td>
<td>$3.278</td>
<td>$2.00-$3.00</td>
</tr>
<tr>
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<td>$0.70-$5.70</td>
<td>$16.39</td>
<td>$3.278</td>
<td>$2.00-$3.00</td>
</tr>
</tbody>
</table>

Table 3 Cost of fresh water per 1000 gallons (Kreamer, 2009, BWS, 2016)

Lessons Learned from Desalination in Israel and the Middle East

While Hawaii is vastly different from Israel and the Middle East, the Island of Oahu can learn a great deal from a region that survives on the desalination process and has managed to do so for many years. Wali states 150 countries rely on 17,000 desalination plants to produce around 211 billion gallons of potable water daily, of which 50 percent use seawater as their source of primary water supply (Wali, 2014). With growing acceptance and increasing efficiency, Oahu should work now to implement desalination to prepare for a future reduction in water and to conserve current water resources.

Since the 1960s, the Middle East has used thermal desalination, but this process has high-energy demands. As a result, 50 percent of its plants have converted from
thermal desalination to reverse osmosis. A strong testament for using the Navy’s resources for desalination is that the Navy’s standard procedure for desalination is reverse osmosis, which uses less energy. Israel and the Middle East has greater challenges than Hawaii in implementing desalination in a most beneficial manner. The water from the Red Sea and Gulf are higher in salinity than the Pacific Ocean. The Middle East temperatures are higher than Oahu’s average of 77 degrees (USGS, 2016). These challenges make reverse osmosis more difficult in the Middle East. However, the Navy’s standard of reverse osmosis would work well in Hawaii.

Israel has become a world example following their water management program. Following a seven year drought that started in 2005, Israel’s Water Authority built four desalination plants. Israel’s desalination plants now produce 158 billion gallons of water, 70 percent of Israel’s water use. By 2020, these four plants are expected to exceed 200 billion gallons daily (Paulson, 2015).

If a region of the world such as the Israel and the Middle East, which represents over four percent of the world’s population, can sustain itself while only receiving one percent of the world’s renewable water resources, the Island of Oahu can certainly rely upon its partnership with the United States Navy to better conserve water, prepare for emergencies, and bridge the gap of a limited water supply should current rainfall levels and aquifers diminish.

**Marine and Environmental Impact**

Reverse-osmosis desalination plants intake large volumes of water where it is then forced through filters and fine-pored membranes in the process of separating the contaminants and salt to make fresh water. There are some serious environmental
impacts for large scale plants, such as dredging and construction that impacts the local benthic ecosystem located in dredges. The discharge is returned to the source of intake, normally the ocean or harbors in the form of hyper-saline brine. The advantage that Naval ships have over desalination plants is the intake source of water and power requirements. There are two intake sources referred to in the desalination process. Direct intake and indirect intake. Direct intake is sourced directly from the source water either by utilizing deep-water intakes, surface intakes, or by flotation plants. Desalination plants typically utilize indirect intakes. These indirect intakes are located onshore near beaches and or offshore depending on the volume of water needed for production use and the geographical environment of aquifers and thickness of stone and boulders. Further more, not taken into account, “Seawater… is not just water. It is habitat and contains an entire ecosystem of phytoplankton, fishes, and invertebrates” (Gleick, et al., 2013 p 77). The intake volume and current flow of the source water results in impingement and entrainment of the inhabitants. This impingement and entrainment typical involves death of the organism. Impingement usually occurs at the source of direct intake when larger fish and invertebrates are trapped against the screens. Entrainment occurs as smaller fish, larvae, and phytoplankton are sucked past the screens into duplex strainers and into the pump impellers. If the organism makes it through these shipboard removal stages, death will occur at the course and fine filter removal. Any remaining contaminates are then removed at the permeable membrane. The use of bromine and chlorine is suitable for human consumption. Chlorine is also used to prevent corrosion by barnacles and mussels that cause fouling of the service lines. (Mackey et al., 2011).
The environmental impact from desalination plants is relatively unknown. The readily available source of water intakes and marine life impact is taken from conventional coastal plants utilizing seawater as a coolant and for desalination. These plants withdrawal tens to hundreds of million gallons per day. The amount seawater withdrawal via ships intakes will not increase in the Pearl Harbor Basin as the current supply of fire-main provides ample seawater required. Desalination will discharge up to 3.2 million gallons, which is minor compared to coastal plants. Marine life impact will not increase as the withdrawal is taken in a high traffic port, as seen in the steady supply of visiting ships for nearly a century. Reverse osmosis desalination may increase the discharge temperature by 1 degree Celsius of the ambient intake supply. According to NOAA’s temperature tables, the Pearl Harbor Basin, the average temperature is 77 degrees Celsius. The nominal running temperature for the NSRO’s is between 60 and 85 degrees. According to Water Consultants International a one-degree change will have no impact on the biological marine environment (Cooley, Ajami, Heberger, 2013). Ships that utilize evaporation as a source of producing potable water would have a greater impact in the basins temperatures; the discharge is up to ten degrees higher than the ambient supply.

**Brine Disposal at Pearl Harbor**

Further, shipboard desalination units utilize direct seawater intake from the shipboard fire-main. Ships fire-main provides a supply source of seawater which is used in cooling systems and industrial size air-conditioning plants, waste flushing systems and for fire fighting when needed. This water is then returned with zero-waste to the ocean.
Ships discharge brine via overboard discharges located below the waterline of the ship. Direct withdrawal from the ocean produces higher concentrates of hyper-saline brine than plants making water withdrawal located inland. The direct return of brine increases the seawaters salinity levels. Inland desalination plants have the ability to pump brine waste into deep wells, isolated aquifers, and evaporation ponds. Ocean desalination plants have the ability to directly return the brine to the ocean via an estuary or direct injection by diffusion methods.

San Diego County Water Authority (SDCWA) states there are no specific water quality standards regulating concentrate brine discharge. SDCWA permits desalination plants to increase salinity levels up to 10 percent over ambient levels of the zone of initial dilution (ZID). ZID is the permitted location of waste discharge. The Claude “Bud” Lewis Desalination Plant in Carlsbad, CA, currently operates with an indirect intake drawing 110 mgd, producing 50 mgd of fresh water and directly discharges 60 mgd of brine and waste into a lagoon leading to the ocean. Camp Pendleton Desalination Project Phase Three also known as “Ultimate” will withdraw 335 mgd, producing 150 mgd of freshwater, and discharging 185 mgd of concentrate brine and waste. The Naval ships in Pearl Harbor withdraw seawater for fire-main at a rate of 30 mgd. If all ships operating the EUWPs, produced a total of 2.7 mgd of fresh water from the reverse osmosis, with a 40-55 percent desalination process, the ships would produce 3.2 million gallons of concentrated brine and waste. The ships total brine discharge of 3.2 million gallons is diffused by the discharge cycle of 30 million gallons of clean seawater. Currently, the State of Hawaii, Department of Health, Clean Water Branch has no restrictions on brine discharge (Hawaii.gov).
Disposal of Waste

The process of desalination produces two by products; hyper-saline brine and cleaning chemicals used for flushing. Cleaning products are used when needed based off of filter and membrane fouling. The chemical flush is minimal compared with the brine discharge that is produced continuously during the desalination process. The predicted impact to the Pearl Harbor Basin may be elevated salinity levels from the discharge of the ROs. Case study by Dickson, Matoo, Tourek, Sokolova and Beniash show the effects of elevated salinity on physiology marine life had no significant effects on standard metabolic and mechanical properties and moderately reduced mortality in high salinity exposures. Negative effects of low salinity in juvenile marine life were mostly due to the strongly elevated basal energy demand, indicating energy deficiency, that led to reduced growth, elevated mortality and impaired (2013).

During the RO discharge, higher levels of magnesium, boron, calcium, and sulfate have been recorded. These constituents are a natural product found in seawater (Water Consultants International 2006).

Mitigate Waste Impact

According to WateRuse Association, desalination plants have added diffusers to promote the mixing and improved dilution of brine waste (2011). A standard navy fire pump runs at 1,100 gpm, 170-180 psig for 1.5 mgd. The advantage for shipboard diffusion is built into our discharge system utilizing the flow rate of 1,100 gpm of the fire pumps and a discharge rate of 4.5 gpm from the NSROs that creates a persistent turbulence through the installed discharge screens for a ratio of 240:1. To achieve
diffusion, the Carlsbad Desalination Plant utilizes the cooling discharge from the Encina Power Station prior to discharging into the lagoon leading to the ocean to reduce high salinity levels (2011).

**Impact on Pearl Harbor**

Ecological research and data would have to be collected, and analyzed for factual impact. Given the details from SDCWA, the 3.2 million gallons a day of brine discharge into the Pearl Harbor basin would have zero impact as compared to the Claude “Bud” Lewis Desalination Plant in Carlsbad, CA that discharges 60 mgd of brine. (Cooley, Ajami, Heberger, 2013). The Pearl Harbor is kept dredged for the continuously flow of visiting ships. The limited vegetation does not promote the growth of marine life. The salinity levels would have to be monitored before and after rainfall. During Oahu’s heavy downpours, the large volumes of runoff rainwater decreases the salinity levels to the point the water visibly looks brackish for 24-48 hours. According to National Oceanic and Atmospheric Administration, the twice daily tide change in the harbor of an average of .5 knots with a one-two foot raise in water depth is essential in flushing the USS Arizona’s crude oil out of the basin (2016). The constant change of salinity levels and lack of vegetation would make the Pearl Harbor Basin ideal for RO desalination production of freshwater utilizing the EUWPs.

According to Cooley, Ajami, and Heberger most of the 17,000 desalinization plants around the world have been built with little concern for the environmental impact. Two desalination plants currently run a continuous monitoring program for evaluating the ecological impact. One location study is the Tampa Bay Desalination Plant in Florida. It
produces 19 mgd of concentrated brine and waste. The plant sits adjacent to the TECO Big Bend Power Station. The power station discharges 1.4 billion gallons a day of cooling water. The desalination plant diverts this cooling into the brine discharge for a mix ratio of 70:1 to prevent high concentrations of brine and raised salinity levels.

The monitoring program was started in 2002, a year prior to plant production. Salinity levels, biological monitoring of the ecological environment is conducted prior to the intakes, discharge, and downstream from the plant for ten years. Utilizing the Shannon Diversity Index, PBS & J has been able to determine that the ecological impact and differences in the environment have been small (Cooley, Ajami, Heberger, 2013).

**Water Rights**

In terms of property rights, desalinated water does not fit into the legal categories that developed for water in the West, most of which is appropriated— that is, water from a limited, natural source that the state allocates to specific users. For example, under an appropriation system, water in a state stream that does not already have a property interest attached to it is considered un-appropriated. Thus, the state can assign this water to a new user. A basic assumption of the prior appropriation system is that water is a limited resource, which leaves decisions about allocating water rights to the state (Waskom, Neibauer, 2014).

**Permitting Requirements**

U.S. land based desalination plants require construction and operation permits to withdrawal seawater and to dispose of brine into the ocean. The required permitting and full analysis is beyond the research of this paper. Currently, the City and County of
Honolulu’s Board of Water Supply has no published requirements concerning the intake and disposal of seawater and brine. MIDPAC ships do follow Environmental Protection Agency and Naval Medicine quality control plans for hazardous waste disposal. Ships are also required to by federal law to abide by the Clean Water Act.

**Navy’s Water Desalination Meets State And Federal Guidelines**

According to the International Desalination Association (2013), desalination is the process of removing dissolved salts from water to create potable water fit for consumption. The Navy meets the requirements of the FEDERAL WATER POLLUTION CONTROL ACT (33 U.S.C. 1251 et seq.) An ACT to provide for water pollution control activities in the Public Health Service of the Federal Security Agency and in the Federal Works Agency, and for other purposes, and TITLE XIV OF THE PUBLIC HEALTH SERVICE ACT SAFETY OF PUBLIC WATER SYSTEMS (SAFE DRINKING WATER ACT)

Naval Ships are required to follow the Naval Medicine (NAVMED) Instruction 6240.1, Standard for Potable Water (See Appendix 4, p 74 for complete references).

**CHAPTER 5 - Water Usage**

**US Navy’s Humanitarian Assistance**

The Navy has demonstrated and continues active roles in supplying water during emergency situations. According to Kreamer (2009), these emergencies have included natural disasters, such as the earthquake in Haiti, the tsunami in Japan, and Hurricane Katrina in the United States. In November of 2013 the Super Typhoon Haiyan/Yolanda landed in the Republic of the Philippines leaving 4.2 million people without basic necessities (Navy, 2013).
Typhoon Haiyan landed on the east coast of Leyte and Samar, destroying everything in its path with sustained winds above 190 mph. The U.S. Navy's only forward-deployed aircraft carrier, USS George Washington (CVN 73), was dispatched and arrived within days of the super typhoons destructive landfall. The Washington steamed off the coast in the Visayas region in support of Operation Damayan. During its time there, the carrier produced 400,000 gallons of fresh water a day. This water was then transported via helicopters to the local hospitals, shelters, and camps for basic human needs (Navy, 2013).

Shortly thereafter, the USS Makin Island (LHD 8) arrived to replace the USS George Washington and its escorts. The USS Makin Island was able to anchor just over one mile off the coast. During this support of Operation Damayan, it was able to produce 100,000 gallons of fresh water a day. The USS Makin Island’s four reverse-osmosis water purification systems each capable of producing 100,000 gallons of fresh water a day were limited in production due to the debris and contamination along the coast of the Philippines. The USS Makin Island made effective use of portable 500-gallon water tanks. The Sailors would load and offload these tanks aboard water landing craft via an open well hull. Each landing craft is capable of transporting 60 tons of supplies or up to 60 pallets of stores and water. Upon U.S. shores during Hurricane Katrina relief, the USS Bataan, USS Tortuga, USS Iwo Jima, and the USS Shreveport provided daily water, medical support, and humanitarian relief supplies along with 20 other naval ships that provided technical assistance and transportation of water and supplies.
While the Navy has only handled the generation of usable water in emergency situations over relatively short periods of time, with some modifications like the installment of the EUWP, these ships would supply more water for longer more sustainable periods of time. This would be helpful in drought scenarios, and it could certainly be relevant to Oahu, which is heavily dependent upon ground water.

Operational impact may be mitigated through the use of decommissioned military ships use of water sourcing for continuous supply. Additionally, significant advances in technology have been extremely effective in decreasing the financial costs associated with desalination, as demonstrated by the Expeditionary Unit Water Purification Generation 2 Plant (EUWP). (See Production Cost of Desalinated Water on page 19). While desalination is a process that occurs regularly in nature (IDA, 2013), the use of these proposed mobile desalination plants must be assessed for its impact on the environment.

**JBPHH Self-Sustaining**

With the assistance of the Island’s second largest industry – the United States military – the Island of Oahu can improve its current water consumption with Joint Base Pearl Harbor - Hickam becoming self-sustaining, thereby eliminating its daily demand of 18 million gallons of water from the Board of Water Supply and the Pearl Harbor Aquifer. Oahu will also benefit from the technology that the Navy is using and developing to generate fresh water faster, 70 percent cheaper, and more effectively. Despite Oahu’s current comfort level regarding water supply, Island population growth, increased demand, and climate change can adversely affect future reserves (Dunster, 2013). University of Hawaii Professor Lukas states that he believes at some point in the
future, the supply of water on Oahu will not be sufficient at a reasonable price due to environmental factors and over usage (Dunster, 2013).

**Joint Base Pearl Harbor- Hickam Water Usage**

All military facilities on Oahu use an estimated 45 million gallons of ground water per day. The four wells for which NAVFAC Hawaii are responsible, pump an average 18 million gallons a day. Of this, 50,000 base consumers use 6 million gallons, and the remaining 12 million gallons are used for irrigation and shipyard work. Naval facilities in Hawaii currently have no additional demand for water resources within JBPHH. The water provided by NAVFAC Hawaii is the only public source of disinfected, fluoridated source of drinking water in the State (NAVFAC, 2015), as the Honolulu Board of Water Supply does not provide additional chemicals like fluoride for cultural reasons.

**JBPHH Storage Supply of Fresh-Water**

NAVFAC Hawaii maintains two 6 million gallon fresh water tanks on Hickam Air Force Base. These tanks are for peak demand of water usage based off of annual computed daily usage (NAVFAC, 2015).

In addition, Pearl Harbor Port Operations maintains a 500,000 gallon fresh water supply barrage used to supply visiting ships to JBPHH. This supply barge is transported via Port Operations tugboats for fresh water distribution. NAVFAC also maintains six 85,000 gallon freshwater transportable water tanks used for engineering plant flushing requirements.
Conservation Today for Water Tomorrow

The Pearl Harbor aquifer is the most important aquifer on the Island of Oahu. It currently supplies approximately 100 million gallons of fresh groundwater per day for public consumption (Oki, 2015). According to Oki (2015), the Honolulu Board of Water Supply and the Hawaii State Commission on Water Resource Management will make future decisions on the production of alternate water sources based upon the long-term sustainability of the Pearl Harbor aquifer.

The advancement in the Navy’s reverse osmosis and desalinization program enhances the recommendation that the Navy’s resources relieve the City and County of Honolulu’s municipality for much of the Navy’s consumption of water from the Pearl Harbor aquifer, as well as utilizing the Navy’s desalination capabilities should Oahu experience a water shortage or disaster.

There are three broad solutions to water shortages. These solutions include water transfer, conservation, and desalination. Water transfer is not realistic for the State of Hawaii as it is comprised of eight islands, and shipping water from one island to another is inefficient. Additionally, the plight of limited water will likely impact all of the islands. While conservation has been suggested, it is unlikely to generate the necessary impact. This thesis focuses on desalination as a major solution to Oahu’s water concerns. Presently, the U.S. Navy’s Pacific Fleet, which is based out of Pearl Harbor on Oahu, can generate approximately 1,700,000 gallons of fresh water per day through the ships’ desalination processes. This would be a considerable contribution in securing the Navy’s water independence and building an emergency water supply for the Island of Oahu.
Much of Oahu’s water was funneled from the Koolau Mountains to the Leeward side for sugar and pineapple farming. The Hawai‘i Supreme Court’s decisions have affirmed a public trust in water and demand adherence to managing the trust. Unfortunately, the current management of water does not take into account the decline in rainfall and base flow that has been observed over the past 60 years (Scheuer, 2012, pp. 4-5). The challenge of climate change is further complicated by the fact that there are increased demands on a declining supply. Resort, commercial, and residential development have increased demand (Scheuer, 2012, p. 6). The population on Oahu is expected to exceed 1.2 million in 2025 at a rate of 4.5 percent a year, which further increases the demand for water (Census.gov 2015).

**Hazard Mitigation Planning and Plan Development Navy & Oahu**

Given real world emergencies and humanitarian support missions around the world, Hazard Mitigation Planning (HMP) and Pre-Disaster Mitigation (PDM) are in the best interest of all residents on Oahu, to include the Middle Pacific Fleet, Joint Base Pearl Harbor- Hickam, and Naval Facilities Hawaii. Beginning November of 2003, Honolulu took its first steps in preparing and planning PDM. With support of State funds, following the guidelines of the Stafford Act for assistance, the Honolulu City and County has been able to access funding from a FEMA approved Enhanced State Hazard Mitigation Grant Program. This FEMA assistance is required to be updated every five years to maintain eligibility for funding.

The development of the Pre-Disaster Hazard Mitigation Plan for Honolulu involves a significant broad-based participation from the Mayor, the City Council,
Department of Emergency Management, and the City & County Department of Planning & Permitting, the Oahu Hazard Mitigation Planning Committee and its public and private partners. Oahu’s State Civil Defense, the Department of Land and Natural Resources, the Department of Transportation, the State Hazard Mitigation Forum, Hawaiian Electric Company (HECO) (electric utility), and federal partners, such as the FEMA Pacific Area Office, NOAA and USGS.

Providing nearly 20 percent of Hawaii’s population, the US military is currently not involved in Oahu’s, nor Hawaii’s Hazard Mitigation Planning (HMP) and Pre-Disaster Mitigation (PDM). Given the experience, trials, tribulations, and success in the Navy providing humanitarian assistance and the needed assistance for restoration with natural disasters, MIDPAC and NAVFAC should be a part of the HMP and PDM requirements.

**Emergency Drinking Water**

Hawaii’s Hazard Mitigation Planning (HMP) and Pre-Disaster Mitigation (PDM) covers a basic Emergency Drinking Water Plan that allocates limited personnel and less than 16 generators that will supply power to pumps for pumping freshwater into a limited number of nearly one million inhabitants of Oahu. Including MIDPAC and NAVFAC into the HMP and PDM increases the survivability and recovery efforts in the event of a disaster. NAVFAC currently maintains six portable, 85,000-gallon fresh-water transportation tanks used for replenishing in-port submarines. Developing a new HMP and PDM to include NAVFAC’s six portable water tanks for immediate delivery and water distribution on predetermined water routes would significantly reduce hardships.
The production of RO desalinated water and the direct delivery of 510,000 gallons a day to predetermined locations, the Navy is capable of exceeding the Red Crosses minimum life sustaining water needs by five-fold.

**Water Distribution Planning**

Reaction to emergency situations is not as efficient or effective as responding to a Pre-Disaster Hazard Mitigation Plan. Developing water system plans and delivery routes to the service locations located in neighborhoods (to include road maps), identifying service connections, required treatments, and the location of the 171 enclosed aboveground reservoirs stationed above residential hills and mountains (Leong, 2014). Including points of contacts with contact information makes for a more effective response. Together, the Honolulu Board of Water Supply with NAVFAC Hawaii, MIDPAC, and Emergency Management Service’s should develop a simple emergency check-sheet to follow with the basic information for a rapid and effective response when responding to emergency situations involving water sourcing.

**Water Sourcing**

Almost imperceptibly, rainfall over the Hawaiian Islands has been declining since 1978, and this trend is likely to continue with global warming through the end of this century, according to a team of scientists at the University of Hawai‘i at Mānoa and the University of Colorado at Boulder (Timm, Takahashi, Giambelluca, Diaz, 2013). The Islands isolation limits their ability to benefit from water management programs such as water transfer, which is the man-made process of transferring water from water source
where the supply is vast to another where the water supply is meager. Water transfer is being used in China and California (Kuo, 2014).

There were plans to build a $40 million desalination plant on the leeward side of Oahu. However, those plans were put on hold because, according to the City and County of Honolulu Board of Water Supply (2015), water conservation efforts extended Oahu’s fresh water supply. According to the Honolulu’s Board of Water Supply, Oahu has decreased daily consumption in fresh water by 10-15 million gallons a day by requiring low-flow toilets for new construction and as replacements as needed over the last two decades. This daily savings has remained even with the increased annual population growth of nearly one percent per year.

CHAPTER 6 - Threats to Water

Island Troubles

Oahu currently has a steady groundwater resource primarily because the mountains cause orographic rainfall. The water tables and water lens are susceptible to even short-term variation in sea level rise and precipitation rates. However, Oahu has other pressures, such as population, that will exacerbate water resource problems associated with climate change and sea level rise. For example, as average temperature increases one degree, the rate of evaporation increases by ten percent.

Invasive plants, trees, and grass species are currently impacting the Island’s absorption of rainwater (See Table 7 for a list of invasive species on Oahu, page 68). Invasive plants tend to have shallow root systems. These shallow roots then choke out native plant species, which typically have deep-planted root systems. As the native plants die, this leads to soil erosion of the upper layers of topsoil. As the soil is removed,
the Islands loses the ability to retain moisture, which leads to greater run-off of rains, therefore less replenishment of the aquifers and faster evaporation (Defenders.org)

**Concerns for the Pearl Harbor Aquifer**

According to the Hawaii State Commission on Water Resource Management (CWRM), the Pearl Harbor aquifer is the most important aquifer on the Island. This aquifer currently supplies 100 million gallons of fresh groundwater designated mostly for public supply. The CWRM is currently concerned with the growth of infrastructure and urban housing development above the aquifer that covers a distance of only 16 square miles with a varied annual rainfall from 19.7 inches to 236 inches. The wide range is due to El Niño and La Niña Pacific Ocean weather patterns. As of today, the aquifer provides a sustainable yield of fresh groundwater. Though there are alarming concerns as some wells on the eastern side of the Pearl Harbor aquifer have shown increases in salinity (Delwyn, 2011).

**Identified Annual Hazards to Oahu Water Infrastructure**

Martin & Chock, Inc. (2013), following the Federal Emergency Management Agency’s outline requirements prepared the State of Hawaii’s “Multi-Hazard Mitigation Plan (MHMP).” Within the MHMP the identified list of hazards are known events that have the potential to impact property, interrupt infrastructure, damage the environment, and create total loss to groundwater wells and Oahu’s freshwater-lens. Table 4 is a breakdown of the estimated annual losses for Oahu.
<table>
<thead>
<tr>
<th>Event</th>
<th>Estimated Annual Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hurricanes</td>
<td>$216 Million / Year</td>
</tr>
<tr>
<td>Tsunamis</td>
<td>$67 Million / Year</td>
</tr>
<tr>
<td>Earthquakes</td>
<td>$21 Million / Year</td>
</tr>
<tr>
<td>Floods</td>
<td>$13 Million / Year</td>
</tr>
<tr>
<td>Debris Flows and Rock Falls</td>
<td>$1 to $5 Million / Year</td>
</tr>
<tr>
<td>Coastal Erosion (sand replenishment)</td>
<td>$2 to $3 Million / Year</td>
</tr>
<tr>
<td>Wildfire</td>
<td>$1 Million / Year</td>
</tr>
<tr>
<td>Dam Failure</td>
<td>Less than $1 Million / Year</td>
</tr>
<tr>
<td>High Surf</td>
<td>Less than $0.5 Million / Year</td>
</tr>
<tr>
<td>HAZMAT</td>
<td>Less than $0.10 Million / Year</td>
</tr>
</tbody>
</table>

Table 4. Relative Hazards and Estimated Annual Losses to the City and County of Honolulu

**Today’s Avoidable Hazard**

Hawaii’s Department of Health states there are 11,000 documented cesspools located on Oahu. Cesspools are drain holes for raw, untreated sewage near buildings containing living quarters of less than 20 people. All 11,000 cesspools impose some form of contamination to the aquifer, fresh-water lens, drinkable water, streams, and even the ocean, according to State Department of Health (Wastewater Branch, 2016). The Department of Health states raw sewage may degrade coral reefs over time, kill the aquatic ecosystem, and sicken humans and wildlife.

An estimated 55 million gallons of raw sewage is pumped into the Islands on a single day (Wastewater Branch, 206). Current demand on water and a declining fresh
water lens, the aquifer is losing its ability to naturally cleanse itself. Steps should be taken to reduce cesspools and minimize raw sewage disposal into the ground. In reducing cesspools, we are reducing the amount of pathogens that cause leptospirosis, hepatitis A, salmonellosis, and gastroenteritis that will impact those who are dependent upon the Island’s fresh water (See Appendix 3 on page 62 for details on Human-Inflicted Contamination).

**Current Contamination of Ground Water**

One gallon of fuel oil contaminates up to one million gallons of water beyond safe drinking levels set by the Environmental Protection Agency (EPA). Urban pesticides used on Oahu are also threatening fresh ground water. Fuel, oil spills and leaks may take years to soak into the aquifer. The impact may not be immediately seen.

The January 2014 Red Hill Fuel Depot spill of nearly 27,000 gallons of Jet Propulsion fuel no. 8 (JP-8) is of major concern for NAVFAC Hawaii and the HBWS. NAVFAC monitors seven sampling stations serving JBPHH on a daily basis for fuel contamination. The estimated lifetime loss of fuel is 1.2 million gallons. (CNIC, 2016).

Schofield Barracks Army Base runs aeration tanks above its wells servicing the base and housing due to above normal levels of pesticides that were used by farming plantations. The aeration enables the pesticide to separate from the ground water prior to being pumped into the water supply for distribution.

NAVFAC’s states the cost to the U.S. Navy is $28.3 million for a granular activated carbon water purification plant for the U.S. Navy Waiawa well shaft. This system was proposed to remove low levels of agri-chemicals for a system with a
maximum pumping capacity of 18 mgd, and includes a testing laboratory. The U.S. Army’s estimated cost for the installed air stripping water purification facility at Schofield Barracks to remove low levels of trichloroethylene for a system with a maximum capacity of 4.3 mgd including capital costs and operations for 30 years is $3.99 million (NAVFAC, 2008).

**Urbanization over Pearl Harbor Aquifer**

Oahu’s fast developing urbanization is above the most plentiful and most important aquifer. The building of homes, shopping centers, driveways, streets, parking lots, and concrete drainage systems and streambeds, automatically increases rainfall runoff. The impermeable surfaces reduce that amount of replenished water into the aquifer. An average 1,000 square foot house or seven parking spots decreases the replenishment of 420 gallons of water for every one inch of rain. Annually 10,000 gallons to 100,000 gallons is lost groundwater to the ocean (Delwyn, 2011).

Development of boat docks and harbors is also a concern. Oahu’s aquifer is protected by silt, sand, stone, and caprock. The groundwater is under constant pressure from our daily 1.8 billion gallons of rainfall. By breaking the caprock, we create a continuous opening under sea level, which opens up an escape for the fresh water and allows the introduction of seawater. Once seawater is introduced into the aquifer, saline levels quickly increase as well as the lens decreases from the lost of pressure.

The implementation of conservation methods and shutdown of sugar plantations is the reason for increased thickness of the fresh water lens (See Table 5). Honolulu
Board of Water Supply also believes a rise in the price of water consumption had a positive impact, by forcing individuals to fix leaks.

Losing nearly 1,000 feet of depth, over the last 100 years, the Commission on Water Resource Management (CWRM) along with the hydrologic planning program manager were commissioned to find a “sustainable yield”. Implementing a plan for a steady withdrawal of ground water, the reduction in permeable ground and the education of Hawaii’s future in water importance.

<table>
<thead>
<tr>
<th>Year</th>
<th>Thickness (ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1878</td>
<td>1,599 (estimated)</td>
</tr>
<tr>
<td>1951</td>
<td>1,025</td>
</tr>
<tr>
<td>2003</td>
<td>615</td>
</tr>
<tr>
<td>2015</td>
<td>677</td>
</tr>
</tbody>
</table>

Table 5. Pearl Harbor’s Fresh Water Lens Thickness

CHAPTER 7 - Possible Courses of Action

Success in California

California’s longest recorded draught has forced the State’s residents into learning to be conservative stakeholders. According to California’s Department of Water Resources, the Southern Coast of 20 million residents currently use 126 gpd per person. In San Francisco, where there is minor irrigation, over six million residences are using 103 gpd per person. Within the Sacramento River region 2.9 million residences average 174 gpd (California Department of Water Resources 2009). Oahu’s daily average is 172
gpd for less than 1 million residence, nearly 70 gallons more than those living in San Francisco with a population six times that of what the HBWS provides for.

**Green Storm-Water Management**

The growing urbanization of Oahu coincides with the increase of impervious surfaces. Apartments, buildings, homes, streets, parking lots, and other paved surfaces prevent the absorption of rainfall reducing the replenishment of the aquifers. Additionally, the urbanized runoff of heavy rains maybe polluted with hazards waste from vehicles and buildings. This polluted runoff goes down the storm drains and collection ditches may have a negative impact on the storm and sewer systems contributing to system overflows that are common in central Honolulu and Kakaako. Utilizing natural systems can often be an effective supplement in helping absorb the runoff while filtering the hazards waste and pollutants.

The State of Hawaii Department of Land and Natural Resources Commission on Water Resource Management will promote the use of green storm water and runoff management techniques and technologies to the City and County of Honolulu’s Board of Water Supply. The HBWS will promote and encourage “Green Management” utilization and techniques for new development and for city and county redevelopment projects.

**Adopting Effective Programs**

The Pearl Harbor Naval Base can adopt some of the practices implemented by the U.S. Army starting with the Army’s Net Zero Water Program, which has a goal of reducing and conserving water on several of its bases. According to the Army’s Energy
and Water Management Program, a Net Zero Water Installation for the U.S. Army limits the use of freshwater resources and returns water back to the same watershed so that groundwater and surface water resources within that region are not depleted or compromised (in quantity and quality). The Army’s commitment and implementation of Net Zero Energy and Water programs recognizes the scarcity of potable water worldwide, and it knows that continued drawdown of major aquifers is only going to result in significant and long-term future problems. One stage of Net Zero that JBPHH can implement is in harvesting rainwater, recycling discharge for reuse, and desalination of gray water. Utilizing these practices will reduce the Navy’s need for municipal water and reduce Oahu’s overall water consumption of 120 gpd for 50,000 users on JBPHH as compared to HBWS supply of 172 GPD per user (HBWS, 2014).

Additionally, the Navy in Hawaii can impose restrictions on water usage for military families, replace natural grass with synthetic grass or gravel, restrict employee usage, and replace any old, damaged, or leaking pipes. Conservation efforts alone could lead to an average savings of 40 gallons per day per person, based on estimates out of California since restrictions have been imposed there. (See Table 6 for listing of conservation measures on page 56).

Funding is available for President Obama’s “Sustainability” program. On February 9, 2016, President Obama released his $4.15 trillion fiscal year (FY) 2017 federal budget proposal, a 5 percent increase over 2016. In his final budget request, President Obama is seeking to increase funding for his top priorities—including clean energy and climate action. The president has called climate change "one of the greatest challenges of our time," and says his proposed budget includes "new investments to help
the private sector create more jobs faster, lower the cost of clean energy faster, and help clean, renewable power outcompete dirty fuels in every state (EESI, 2016)“.

President Obama is calling for investment into clean energy research and development to double by 2021, from $6.4 billion (in 2016) to $12.8 billion. This would represent an average increase of 15 percent a year, starting with a 20 percent increase in 2017. The funding would support the development of clean, renewable energies such as bioenergy, geothermal, hydrogen, solar, water, and wind, as well as clean-vehicle technologies and energy storage (EESI, 2016).

**Floating Desalination Plant**

The Navy’s decommissioned fleet holds a key in assisting with large-scale desalination. In 2008, the Water Standard Company (WSC) purchased a 48,000 ton vessel. This vessel has been re-commissioned as the H2Ocean I Cristina. Utilizing new reverse osmosis desalination technology, it currently desalinates seawater at 50 mgd. Leaving room for expansion, it is able to add an additional 50 percent production to 75 mgd.

The Cristina is designed to operate on station for 20 years. As a rapid response ship, it is able deploy to 80% of the world's population. Responding to a humanitarian crisis, it is able to remain at anchorage and deploy a flex hose to a receiving station ashore and run at maximum capacity utilizing shipboard power generation. See Figure 4 below for example. The Cristina is also capable of sitting pier side, utilizing a shore power connection for power generation. Giving the shipboard flexibility to relocate on a short notice, it is able to relocate for the most economical location.
With the procurement of a 48,000 ton ship, desalination units and new efficient power generators, and shipyard production cost, WSC with the assistance of the International Desalination Association (IDA) was able to commission the H2Ocean I Cristina for under $145 million (Kreamer, 2009).

Figure 4. WSC’s drawing of a mobile ship used for desalination

The Navy’s untapped resource, utilizing current decommissioned large deck ships, Landing Helicopter Platforms (LPH), Light Weight Cargo (LWC) ships, of which two sit in the mothball fleet of the Pearl Harbor Bay, the U.S. Navy is able to convert these ships into floating desalination plants, each capable of providing drinkable fresh water for cities with a population of under 750,000 people, with a rate of 100 GPD per person for up to 20 years. In conjunction with the fiscal year 2017 budget on “Sustainable Energy, Buildings, Transportation and Climate ” research and development program of $7.7 billion, I propose that JBPHH introduce a conversion plan utilizing the Landing Helicopter Platforms or the Light Weight Cargo ships at an estimated cost of
$145 million, or .002 \times 10^{12}$ of the 2017 Sustainment development program. See recommendations for more details and available Fiscal Year 2016 funding.

Employing the decommissioned Light Weight Cargo Ships that are designed with fluid transportation and holding tanks, instantly reduces conversion cost into a floating desalination plant. The conversion of the LWC’s at the Naval Shipyard Pearl Harbor is a cost benefit for the people of Oahu and the State in both continued job contracts and tax revenue. Stationing just one of these ships in the Pearl Harbor Bay is enough to reduce the Honolulu’s Board of Water Supply demand by over 50 percent for the entire Island. According to the Department of the Navy Fiscal Year 2017 budget, one LHA will be decommissioned at total 3.8 million dollars (Department of the Navy, 2016). The individual cost of releasing inactive ships is held by Naval Sea Command, Inactive Ships On-Site Maintenance Office, Pearl Harbor, HI. Kreamer estimates the cost of $400,000 to $525,000 on annual, five-year storage and maintenance cost on an LHA. (See Appendix 5 for list of Inactive Ships maintained in Pearl Harbor, page 75). Department of Defense Appropriations Act, 2017 will release 18 billion dollars for construction and conversions of US Naval ships till 2021 (Department of the Navy, 2016).

If commissioned as a desalination plant, these ships are not far from responding to any world humanitarian crisis for extended periods of time within one month of deployment. This is with in alignment of the Navy’s global mission and responsibilities (Navy, 2016) and President Obama’s continued environmental sustainment program of $7.7 billion. With Oahu’s population expected to reach 1.2 million by 2025, a rapidly decreasing permeable surface, unstable weather conditions due to increasing temperature, pacific decadal oscillation, and invasive plants, the demand on the Island’s fresh-water
lens is not far from unsustainable levels and brackish intrusion from the sea. It is in the best interest for the U.S. Navy to start a partnership with WSC and start investing in floating desalination plants for the US Navy’s use in supporting their global mission.

CHAPTER 8 - Recommendations

Navy leadership should incorporate the Navy’s “Great Green Fleet” sustainability program with the Army’s “Net Zero”, concept of zero waste in energy, water, and waste for every ship stationed at Pearl Harbor, to include the Joint Base Pearl Harbor - Hickam. According to the Environmental and Energy Study Institute, for each ship that converts to the “Great Green Fleet” program is expected to save $248 million over its lifetime (EESI, 2016). The estimated life savings of the 11 ships in Pearl Harbor is $2.7 billion. The Navy should utilize percentage of its $18 billion dollar budget in conjunction President Obama’s “Sustainment Program” of $7.7 billion to achieve the status of a “Great Green Fleet”. In return, the Navy could provide vital services to the State of Hawaii at a cost savings of 70 percent reduction in electrical requirements in utilizing the Expeditionary Unit Water Purification Generation 2 Plants.

CNIC is responsible for worldwide shore installation support for the United States Navy under the Chief of Naval Operations (CNO). Apart of their responsibility is for the operations and installations on Hawaiian Islands with an operational budget of $6.7 billion in 2014 according to Deloitte Development LLC (2014). In supporting the Department of Defense's pursuit of cost-effective measures in energy performance and reduction in cost of operations, DOD incorporates a three-pillar approach in expanding supply, reducing demand, and adoption of future technologies. The DOD’s Annual Energy Management Report for FY 2014-2015 is $292 million (DOD, 2014).
- Alternative water sources are key to meeting The Great Green Fleet and Net Zero water goals and objectives. On their own, conservative measures typically do not provide enough water reduction. Alternative water projects like containment and reuse are capital intensive, requiring investments in infrastructure upgrades and paradigm shifts in operational practices.

- Economically attractive projects and low-cost operational changes can be leveraged with conservation measures that have poor economics to create life cycle cost-effective project bundles. DON continues to install low flow bathroom fixtures, such as sink aerators, showerheads, toilets, and urinals to reduce potable water intensity in its buildings, low-cost landscape improvements with high-cost irrigation system technology and native landscape conversion. Similar to its energy efficiency and conservation projects, DON pursues water efficiency and conservation projects that provide the greatest return on investment. In many cases, water efficiency improvements are combined with other energy savings projects to maximize economic benefits. Current funding for these efficiency and conservation projects are supported by the Defense Working Capital Fund (DWCF) accounts. Congress appropriated $800 million in FY 2014 to DWCF of which only six percent ($48.3 million) was used water conservation projects (DOD, 2014 page 63). The DON was awarded $300 million of this $800 million. The Navy used the FY 2014 Appropriations for water conservation projects and building retro-commissioning (page 65).

- Distribution system leaks can be a significant source of water loss. A real-time leak-monitoring program called the Department of the Navy’s Advanced Meter Infrastructure (AMI) Program. Coupled to a strategic plan is crucial to target repair versus replacement
of the distribution system. The intended objectives are to capture all leaks and repair 85 percent of all facilities connected to NAVFAC’s water- facilities at installations by FY 2016. The installation of the AMI program falls into the retro-commissioning that is funded under DWCF with a appropriated DON FY 2014 budget of $300 million.

- Public Works and the First Lieutenant's Office re-evaluates JBPHH’s landscape irrigation practices. Adjust the concept of “high visibility” landscape to make water conservation a higher priority in vegetation selection. Decrease watering in low-traffic, high-shaded areas. And, reduce the current daily watering to three or four times a week.

The first major goal is to develop a culture focused on our most important assets, the junior Sailors and officers. Training them today to be efficient and conservative, develops them into the Senior Enlisted Sailors and Admirals who live the Great Green Fleet and Net Zero practice of zero waste. In addition, military parents should teach how our children use water, and the need to implement in conjunction with any technology a conservative solution in sustainment. Without these changes, further reductions in potable water use cannot be realized for future generations.

In part of sustainment, every conservation and security measure should be enforced at the state level down to the counties we live in, neighborhoods we reside, schools we attend, recreational faculties we use (golf courses), and for all irrigational uses, to include the military bases in Hawaii. The currently approved housing devolvement and business complexes above the Pearl Harbor Aquifer should include natural green systems to absorb clean rain water wherever possible. Local vegetation, landscaping, and gardens should be included in designs that promote absorption, filtering,
while preventing runoff to the streets and storm drains. Low-use streets should be made of “Green Streets”. Green streets are typically made of absorbent concrete or a mix of vegetation planters, to include landscaped strips that run adjacent to walkways. Green roof designs is another method of directing rainwater into the ground and away from storm drains is essential in reducing the deep evaporation of ground water. Hawaii’s self-sustainable promotion by 2030 should include green buildings. New technologies allow homes and buildings to be self-sustaining from the grid. They filter their run-off water and produce their own power. In doing so, Green Homes reduce their demand on the aquifer and the need to import fuel for power generation.

The 2015 median price of a single family home on Oahu was $730,000, according to Hawaii Life (Buck, 2015). Kelly Hart, a “Sustainable Architecture” in green homes estimates it cost $20,000 to convert a house into a environmentally friendly home. This does not include the cost of solar panels or solar water heaters, which NAVFAC has already installed and funded by the DON’s Energy Conservation Program (Greenfleet.dodlive.mil). For the DON to continue to fund the Green Fleet, this will cost an average of three percent the value of the 2,400 military family homes.

Extending the local television and radio stations “Public Service Announcements”, which are free, the State will educate all residents of Hawaii, to include the military personal and families, on the concerns of the world water shortages, and what we can do on Oahu today in helping us maintain a healthy sustainable source of fresh water for years to come. Department of Defense Schools (DODS) and public elementary schools will teach the world importance of water and what the children can do to help.
Socially informing residences on where their water usage compares to water restricted communities. In 2013, the Honolulu Board of Water Supply estimated each person on Oahu to include non-metered use is 330 gallons of water per day; metered use is 172 gallons per day. Compare Hawaii’s water usage to those living in Southern California who have an estimated daily water usage of a mere 103-126 gallons.

In 2003, the HBWS raised water rates by 60 percent. This increase did force individuals to fix leaks. The rate increase was a notable success as evidenced by the decrease of 10 million gallons a day of water usage over the proceeding five years. Consider surveying water users what the maximum feasible rate increase is before users will consideration reducing their water usage by being conservative, upgrading appliances to include fixing leaks.

By 2030, Hawaii’s population is expected to be near 1.8 million, of which 1.1 million will live on Oahu, with the highest concentration living above the Pearl Harbor Aquifer. With the increased construction footprint of impermeable surfaces, nearly all rainfall will become runoff water. With less rainwater soaking into the aquifers and every one-degree average temperature increase, Oahu will lose an additional 10% ground water due to evaporation. This is an alarming fact that requires attention today.

This is where the JBPHH and the Middle Pacific Fleet currently have the abilities to reduce the demand of fresh water with improved conservation methods such as the Navy’s “Great Green Fleet” and the “Net Zero Program”, zero waste, retain, reuse, and shipboard desalination. The Department of Defense Appropriations Act, 2017, allows for $18.6 billion dollars of shipbuilding, conversions, and major overhauls. As previously
discussed, the cost of replacing a Navy Standard Reverse Osmosis Desalination Plant with a Expeditionary Unit Water Purification Generation 2 Plant cost $3-6 million, with an annual cost savings of up to $44 thousands annually per ship.

The Naval Supply Fleet Logistics Center Pearl Harbor (NAVSUP) has an Environmental Quality Team. This team should fully engage the “Great Green Fleet” and Net Zero water standards ensures that supplies provided to JBPHH like high efficiency showerheads, toilets, and electrical devices meet or exceed current Navy efficiency standards. In 2011, the President issued a challenge—the President’s Performance Contracting Challenge (PPCC)—to the Federal Government to award $2 billion in third-party financed energy efficiency projects. Department of Defense’s (DOD) share of the Phase I goal was $1.2 billion. In 2013, the President extended $2.2 billion through FY 2016, as part of Phase 2. DOD has not fully used the funds, leaving $113 million available for renewable, and conservation programs (DOD, 2014 page 67-69).

The Pacific Fleet Commander should order all non-efficient supplies and items be converted to meet new efficiency standards in accordance with “Great Green Fleet and Net Zero”. This is where Naval Logistics Supply Center will submit a checklist survey to each tenant command requiring them to list the deficiencies with a corrective action plan to replace and fix the deficiencies over the next 24 to 36 months.

Moral Recreation and Welfare runs three golf courses on JBPHH. Morale and Welfare Recreation office would be directed to return the run-off water into the reuse,
detainment ponds located around the golf course. These detainment ponds then should be used first in the watering of the greens and fairways.

JBPHH Public Works is responsible for the maintenance of the base irrigation system. Currently, all irrigation zones run every evening and day, as visible by the daily flooded streets and water spouts along the roads and neighborhoods. Public Works should be required to inspect on a minimum each irrigation zone on a quarterly basis. Each zone should have moisture sensors installed to prevent over watering and to stop or prevent watering when it is raining and limit the number of days in which watering takes place to just three or four days a week, depending on shading and usage.

All of Hickam’s 200 million feet of aircraft maintenance grounds and runways are impermeable to rainwater. The runoff rainwater is diverted into drainage systems that are directed to a processing plant to remove hazardous materials and substances before this water is then flushed into the ocean. What is not cleaned and processed by the treatment plant is directly drained into the ocean.

Given Hickam’s and Honolulu international Airport share more than 200 million square feet of asphalt and concrete runways and maintenance grounds, a conservative effort with the Commission on Water Resource Management (CWRM) should be started in efforts to collect and retain the two to 20 billion gallons of annual rainwater that is returned to the ocean just from the joint airport. Reclaiming this runoff water from the airport could reduce all irrigation needs annually for JBPHH and the Honolulu International Airport, saving up to 20 billion gallons of water. Increasing the current size of holding ponds would help in retaining rainwater for irrigation. This recommendation
falls under the DON’s “Renewable Energy and Water Conservation” projects. In FY 2014 the DON used $43 million of it’s $300 million on renewable and conservation projects.

JBPHH following the above recommendations of “Great Green Fleet and Net Zero” would effectively reduce non-human use of water by 50 percent within three years, from two million gallons a day (or 2.2 billion gallons annually) to three million gallons a day. Other conservation methods for home and business use would reduce usage from 18 – 20 percent, saving 400 million gallons of water annually.

During State emergencies, the Naval ships and submarines become self sufficient in that they are able to provide power and water for up to three consecutive months without having to refuel. (See Appendix 6 for list of Active Ships, page 66). While in port, shipboard water usage runs up to 30 percent usage than what is used at sea. Installing the new Expeditionary Unit Water Purification Generation 2 Plant (EUWP) during major Chief of Naval Operations Availability (CNOAVAL) would produce 50 percent more freshwater in coastal zones and harbors. The ships then would be able to produce 2.5 million gallons a day, or 912 million gallons annually. After shipboard use, the ships are able to provide 620 million gallons annually to JBPHH and the HBWS.

Adding this shipboard water to JBPHH with the recommend conservation improvements, reclaim, and reuse recommendations, in good faith JBPHH would only need 2.7 million gallons a day. This is an 85 percent reduction of water usage taken from the Pearl Harbor Aquifer with an annual savings of 5.6 billion gallons. Using the current pier potable water connections, the ships could reverse the flow of water to provide rather
than receive water. Using the Port Operation tugs, the ships are able to supply water to the water supply barge along with NAVFAC’s portable 85 thousand gallon portable water tanks in the event of an emergency.

CHAPTER 9 - Conclusion

As our natural freshwater resources are decreasing due to population growth, waste and environmental factors such as droughts and raising temperatures, the increased acceptance of seawater desalination has become a sustainable way of life. Oahu single source of freshwater comes from the underground aquifers.

Oahu’s aquifers have recorded of depth lost of over 1,000 feet. Salinity levels have increased near the outer banks of the aquifers. The looming threat of contamination by the US Navy’s fuel leaks are all reasons why the Joint Base Pearl Harbor- Hickam should support Oahu by reducing the daily demand of fresh groundwater by employing the Middle Pacific Fleet in producing desalinated water.

The Hawaiian Chamber of Commerce and the Military Affairs Council should propose the US Navy and the Pacific Fleet Commander review the capabilities of NAVFAC, and Middle Pacific Fleets abilities for reverse osmosis desalination and water delivery to Oahu residence in an emergency situation. Coordination in conjunction with State of Hawaii Department of Land and Natural Resources Commission on Water Resource Management, Federal Emergency Management Agency, and City and County of Honolulu’s Board of Water Supply in strengthen Hawaii’s Hazard Mitigation Plan.

The Navy’s Red Hill fuel storage fuel tanks is estimated to have lost over 1.2 million gallons just 100 feet a top of a major aquifer that provides 10 percent of the
islands daily water needs. If the fuel makes contact, the total lost of the aquifer is expected (CNIC, 2016). CINC and NAVFAC state there is no resolution in removing the fuel from under the storage tanks. The Navy should conduct a risk analysis to see if maintaining the 250 million gallon tanks are environmentally worth the risk of aquifer contamination verse providing a full time commercial oil tanker stationed in Pearl Harbor.

In response to the Red Hill fuel spill, the Office of Chief of Naval Operations (CNO) should consider employing Water Standard Company’s concept of converting decommissioned ships into floating desalination plants not only as a possible response to the water supply lost, but in lines to eliminate JBPHH’s 18 million gallons a day and reduce the Island’s withdrawal by an additional 30 to 57 million gallons a day. This would greatly help the CWRM and HBWS in sustaining the aquifers. According to Kreamer, the US Navy spends 1.5 to 2.1 million dollars on inactivation cost for amphibious warfare ships and $400,000 to $525,000 on annual, five-year storage and maintenance contracts. DOD has a LPH scheduled for decommissioning in FY 2017 at a cost of $3.8 million along with the President’s Performance Contracting Challenge on Renewable Water. DODs share of $2.2 billion in FY 2013, $113 million is waiting to be spent as of FY 2016. In suggestion, the CNO should redirect these funds into converting decommissioned ship into a floating desalination plants (2008) to benefit the Navy’s mission and to assist Oahu in the time of State emergencies.

By leveraging their strong military relationships, Oahu public administrators have the ability to save significant amounts of water annually. Mandating conservation efforts and the implementation of desalination from the Naval ships currently stationed in Pearl
Harbor, MIDPAC in conjunction with HBWS could prepare now for the inevitable shortage of rainfall that is likely to continue should global warming continue on its current track (USGS, 2011). Oahu government officials and the Board of Water Supply should start these conversations with the US Navy now. The tools are there; it is simply a matter of urgency and implementation.

| - Military installations | Install Meters at Users/Buildings | Install meters at users/buildings is a best practice to prioritize on-base military users and/or buildings to install water use meters to better track water usage. | - Work with military installations to adopt a metering policy that all retail (e.g., residences, restaurants, vehicle wash areas, recreational facilities) water uses on the installation is metered, to the maximum extent possible. |
| - Housing | - MWR (report to CWRM) | Information and Education Programs | Information and education programs are the preparation and dissemination of materials about water conservation and efficiency and reducing water waste and loss. | - Promote and make available water conservation messages and other water conservation educational materials to military installations. |
| - Military installations | Distribution System Audits, Leak | The identification and reduction of leaks and other water losses and performing an audit according to industry standards. | - Work with military installations that are self supplied to develop a policy requiring that the military water supplier complete an annual water loss program. - Requirement to report on progress annually. - Incentives could also be used to reward the reduction of leaks and other water losses. |
| - Housing | - MWR (report to CWRM) | Water Efficient Fixtures | The use of more water efficient fixtures in new buildings, and the retrofitting of equipment into existing buildings to reduce water use. | - Work with military installations to develop a policy specifying the use of water efficient fixtures. - Requirement to reduce water use intensity by 20% according to federal requirement. - Implement LEED for new buildings according to the LEED program. |
| - Military installations  
| - Housing  
| - MWR  
| (report to CWRM) | Look for Opportunities to Reuse or Recycle Water; Alternate Water Sources | The practice of identifying opportunities to reuse or recycle water, or use alternate water sources for the original purpose. | - Assist military installations in identifying available alternative water supplies such as reclaimed water for non-potable uses such as landscape irrigation.  
- Assist in determining feasibility and cost payback. |
| - Military installations  
| - Housing  
| - MWR | Water-Efficient Landscaping | Water efficient landscaping is the use of landscaping practices that reduce irrigation water requirements. | - Work with military installations to encourage the adoption of the model ordinance/policy for landscape and irrigation design, and encourage the requirement for the use of certified irrigation professionals. |
| - Military installations  
| - Housing  
| - MWR  
| - CWRM (assist in developing standard audit process) | Water-Efficient Irrigation | Water efficient irrigation is the assessment and replacement of automatic irrigation components with more water-efficient technologies. | - Work with the military to identify and establish demonstration and research projects to show the application of efficient irrigation technologies and document water savings.  
- Work with military leadership and CWRM to revise performance maintenance contracts for landscape management to follow the irrigation and landscape guidelines developed by the LICH and eliminate the “keep it green” payment incentive. |
| - Military installations | Cooling Tower Management | Cooling tower management is the proactive maintenance and management of cooling towers to reduce leaks and water use. | - Work with the military to evaluate water use and efficiency options that are available to reduce and/reuse/alternate sources to offset current cooling tower water use.  
- Options may include: requirement to perform |
regular maintenance; submit reports to prevent/repair leaks and evaluate increasing the cycles of concentration; and require a minimum cycle of concentration be set for all cooling towers

| - Military installations  
- Housing  
- MWR | Use a Bucket and Hose with Spray Nozzle When Washing Vehicles | Promote the use of spray nozzles on hoses when washing vehicles, to prevent wasted water when not initially wetting or rinsing the vehicle during the wash process. | - Military installations will make it policy to require and provide spray nozzles to all vehicle washing locations.  
- Distribution of educational materials describing the benefits of using spray nozzles when washing vehicles. |
| - Military installations  
- Housing | Maintenance and Inspection Program to Repair Clogged Line/Valves/ Meters and Check All Valves, Pressure Reducing Valves, and Meters in the Water System | Maintenance on the water system to prevent leaks and interruptions in operation. | - Assist military installations with the development of a preventive maintenance program that can be used on all facilities in Hawaii. |
Table 7. Invasive Species in Hawaii (Defenders.Org)

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Origin</th>
<th>Extent</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miconia</td>
<td>Shrub/ Tree</td>
<td>Central America; introduced as an ornamental in 1960s</td>
<td>Infests over 11,000 acres of Hawaii, Oahu, Maui and Kauai</td>
<td>Miconia forms dense thickets that block sunlight and kills other plants; has shallow roots so infested areas become very erosion-prone.</td>
</tr>
<tr>
<td>Fountain grass</td>
<td>Grass</td>
<td>Northern Africa; introduced in 1914 to HI as an ornamental grass</td>
<td>Found on Kauai, Oahu, Lanai, and Hawaii</td>
<td>Highly aggressive, fire-adapted colonizer that readily outcompetes native plants and reestablishes after burning; alters natural fire regime</td>
</tr>
<tr>
<td>Fire tree</td>
<td>Shrub/ Small Tree</td>
<td>Azores, Madeira, and the Canary Islands; introduced in the late 1800s as an ornamental or for firewood</td>
<td>Occurs on nearly all of the major Hawaiian islands, covering more than 100,000 acres</td>
<td>Poses a serious threat to native plants on young volcanic sites, lowland forests, and shrublands, where it forms dense monocultural stands.</td>
</tr>
<tr>
<td>Strawberry Guava</td>
<td>Shrub/ Small Tree</td>
<td>Originally introduced in the early 1800s for its edible fruit, it escaped cultivation</td>
<td>Occurs on all six of the largest Hawaiian islands</td>
<td>Poses major threat to Hawaii’s rare endemic flora and fauna, forming shade-casting thickets with dense mats of surface feeder roots</td>
</tr>
<tr>
<td>Feral Pig</td>
<td>Mammal</td>
<td>Europe; hybridized with smaller pig brought over by the Polynesians</td>
<td>Throughout Hawaii</td>
<td>Crushes and rips up plants, damages root systems and causes soil erosion; wallowing action promotes mosquitos (human and bird threat)</td>
</tr>
<tr>
<td>Yellow Himalayan Raspberry</td>
<td>Shrub</td>
<td>South Asia; introduced around 1960 for its edible fruit</td>
<td>Most wet forest habitats in HI between 2,000- 5,000 ft</td>
<td>Forms impenetrable thickets, threatening native lowland wet forests and displacing native Hawaiian plant species</td>
</tr>
</tbody>
</table>
Appendix 1

Cost Analysis in NSRO Production verses EUWP Production

Hawaiian Electric Company, INC. contracts power distribution to JBPHH as a “Large Power Service” under docket number 2010-0080 for Decision and Order No. 30505; Filed June 29, 2012. This scheduled Direct Service (DS) is charged at:

ENERGY CHARGE - KiloWatt per hour (kWhr) =

¢ per kWhr: 14.9013 ¢/kWhr (HECO, 2012)

According to Technical Manual Description, Operation And Maintenance, Reverse Osmosis Desalination Unit, 12,000-Gpd, Published By Direction Of Commander, Naval Sea Systems Command, the NSRO’s power requirement is 125 amps, 440 volts 3 phase A/C for 55 kWhr.

125 amps x 440 vac = 55,000 watts (55kWhr)

55kWhr x 14.9013¢/kWhr = $8.195715 hr x 24 hrs = $196.70 per day

2 NSROs x $196.70 per day = $393.40

According to ONR, the EUWP are 70 percent more electrically efficient (2009).

16,500 watts or 16.5kWhr

16.5kWhr x 14.9013¢/kWhr = $2.4587145 hr x 24hrs = $59.01

2 EUWPs x $59.01 per day = $118.02

One gallons of water from NSRO = $.016392 (1.7 million gpd = $27,866)

One gallons of water from EUWP = $.003278 (2.5 million gpd = $8,195)
Appendix 2

Water Scarcity Impacts Every Continent

According to the United Nations, half of the world’s population will be living in a water stressed environment within the next 15 years. Nearly 1 billion people currently fight shortages on a daily basis. With rising global temperatures, there has been a rise in wildfires. The destruction of forest has created a domino effect in lost topsoil, increased evaporation rates due to warming of direct sunlight. The increase of wildfires has increased the rate of carbon released into the atmosphere. The fewer trees are then not available for direct carbon removal from the atmosphere. The cultural demand for meat, cattle grazing and feed are also significant factors in world warming.

Current droughts have destroyed vital crops across 12 provinces in China, a decade of massive crop losses in Australia, Madagascar and Argentina. On the continental level, Africa, North and South America, Europe, and large portions of Asia currently live in drought regions. Aquifers below Bangkok, Delhi and Beijing are beyond critical levels, and are expected to be depleted within the decade. Some of the largest rivers are feeling the impact. Currently below normal levels with high levels of salinity, examples to include the Ganges, Jordan, Nile and Yangtze rivers (York, Foster, 2005). The Hawaiian Island of Oahu could be at risk for a fresh water shortage in as little as seven years. Action must take place now to secure fresh water resources in the event rainfall levels diminish due to climate change. More research needs to be done to assess the impact of climate change on the aquifers, which are responsible for maintaining Oahu’s water supply.
Appendix 3

Human-Inflicted Contamination

Any human caused event that creates a water management emergency to include but not limited to the following according to FEMA: chemical spills, construction accidents, cyber-attacks in infrastructure controls, vandalism, terrorism, and neglect of maintenance and infrastructure on the water infrastructure.

Construction accidents: Construction accidents may create a routine operating emergency. Common accidents are cracked and damaged to main waterlines that result in a lost of pressure at pumping station, create serious backflow at user ends causing contamination as well as creating contamination at the construction site. As a requirement, construction sites are required to notify utilities of pending construction within public service lines in the preparation of a timely response to accidents.

Vandalism: Considered a spur of the moment, act of opportunity utilizing materials at hand. Vandalism is typically minor damage such as destruction of equipment, facilities, and defacing of property. Preventing and or reducing vandalism can be achieved with basic security measurements. Increased lighting, security fencing, and locking of all spaces.

Terrorism: Acts of terrorism are defined by the Code of Federal Regulations as “the unlawful use of force and violence against persons or property to intimidate or coerce a government, the civilian population, or any segment thereof, in the furtherance of political or social objectives.” There are many potential threats to drinking water systems,
including physical destruction of infrastructure, chemical, biological or radiological contamination as well as other physical types of damage to infrastructure and HBWS systems. Threats of, or contamination using chemical, biological or radiological agents are a major concern for every public water supply system. (HBWS).

System neglect: deferred maintenance, cost saving measures has become a major cause of emergencies. With aging water plants, piping systems and waste treatment faculties, the threat of failure and contamination has increased. Example the Flint Michigan Board of Water Supply. To reduce cost they seized pumping from Lake Michigan to a source of water that was closer called the Flint River. The natural contents of the Flint River water created a reaction within the water pipes that with-drawls lead from the waterlines creating life altering medical conditions for the local population.

Cross Connections: Cross connections is the physical connection of two lines that allow any substance like liquid, gases, or solids to contaminate in the process of back-flowing.

Back-flow conditions: Backflow is simply to reverse flow of liquid or other substances into a supply line. All serviceable water connections in Hawaii are required to have a back-flow valve. Backflow valves are also installed on the pier connections at JBPHH. These valves would have to be regulated to allow ships to pump drinkable water into the water supply system.

Hazardous Materials: Chemicals, biological or radiological agent are routinely transported. These materials will directly harm the environment and humans. Accidents
can happen anytime. While the activities with the above items are minimal in Hawaii, they also occur naturally

Sewage Spills: Sewage spills occur routinely in Oahu during heavy downpours. The common flashfloods on Oahu due to the natural landscape inundates the storm drains and the sewage processing plant. The sewage is typically dumped into the Honolulu area creating typical closures of Magic Island and the Waikiki Beach.
### Appendix 4


<table>
<thead>
<tr>
<th>Naval Title</th>
<th>Publication Reference Number</th>
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<tbody>
<tr>
<td>Inspections, Test Records and Reports</td>
<td>NSTM Chapter 090</td>
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<tr>
<td>Boiler Water/Feed water</td>
<td>NSTM Chapter 020</td>
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<tr>
<td>Piping Systems</td>
<td>NSTM Chapter 505</td>
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<td>Distilling Plants Low Pressure</td>
<td>NSTM Chapter 9580</td>
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<tr>
<td>Submerged Tube Steam Plants Preservation of Ships</td>
<td>NSTM Chapter 631 (Vol 2)</td>
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<tr>
<td>In Service- Surface Preparation and Painting</td>
<td>NSTM Chapter 670</td>
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<tr>
<td>Stowage, Handling, and Disposal of Hazardous General Use Consumables</td>
<td>NAVMED P-5010-5</td>
</tr>
<tr>
<td>Manual of Naval Preventive Medicine – Water Supply Ashore</td>
<td>NAVMED P-5010-6</td>
</tr>
<tr>
<td>Manual of Preventive Medicine – Water Supply Afloat Standards for Potable Water</td>
<td>NAVMED INST 6240.1</td>
</tr>
</tbody>
</table>
Appendix 5

NAVSEA Inactive Ships On-Site Maintenance Office, Pearl Harbor, Hi

Total Number of Hulls: 15

<table>
<thead>
<tr>
<th>Class</th>
<th>Hull</th>
<th>Name</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFG 7</td>
<td>FFG 37</td>
<td>CROMMELIN</td>
<td>STRICKEN*</td>
</tr>
<tr>
<td>FFG 7</td>
<td>FFG 38</td>
<td>CURTS</td>
<td>STRICKEN</td>
</tr>
<tr>
<td>FFG 7</td>
<td>FFG 41</td>
<td>MCCLUSKY</td>
<td>STRICKEN</td>
</tr>
<tr>
<td>FFG 7</td>
<td>FFG 43</td>
<td>THACH</td>
<td>STRICKEN</td>
</tr>
<tr>
<td>FFG 7</td>
<td>FFG 46</td>
<td>RENTZ</td>
<td>STRICKEN</td>
</tr>
<tr>
<td>FFG 7</td>
<td>FFG 48</td>
<td>VANDEGRIFT</td>
<td>STRICKEN</td>
</tr>
<tr>
<td>FFG 7</td>
<td>FFG 51</td>
<td>GARY</td>
<td>STRICKEN</td>
</tr>
<tr>
<td>LHA 1</td>
<td>LHA 1</td>
<td>TARAWA</td>
<td>INACTIVE**</td>
</tr>
<tr>
<td>LHA 1</td>
<td>LHA 5</td>
<td>PELELIU</td>
<td>INACTIVE</td>
</tr>
<tr>
<td>LKA 113</td>
<td>LKA 114</td>
<td>DURHAM</td>
<td>STRICKEN</td>
</tr>
<tr>
<td>LKA 113</td>
<td>LKA 116</td>
<td>ST LOUIS</td>
<td>STRICKEN</td>
</tr>
<tr>
<td>LPD 4</td>
<td>LPD 7</td>
<td>CLEVELAND</td>
<td>INACTIVE</td>
</tr>
<tr>
<td>LPD 4</td>
<td>LPD 9</td>
<td>DENVER</td>
<td>INACTIVE</td>
</tr>
<tr>
<td>LPD 4</td>
<td>LPD 10</td>
<td>JUNEAU</td>
<td>INACTIVE</td>
</tr>
<tr>
<td>LST 1179</td>
<td>LST 1191</td>
<td>RACINE</td>
<td>STRICKEN</td>
</tr>
</tbody>
</table>

*Stricken: ready for disposal  
**Inactive: available for recommissioning/spare parts

http://www.nvr.navy.mil/nvrships/s_13X2.htm
Appendix 6

Surface ships presently homeported in Pearl Harbor
Arleigh Burke-class destroyers = 9 destroyers
   USS John Paul Jones (DDG-53)
   USS Paul Hamilton (DDG-60)
   USS Hopper (DDG-70)
   USS O’Kane (DDG-77)
   USS Preble (DDG-88)
   USS Chafee (DDG-90)
   USS Chung-Hoon (DDG-93)
   USS Halsey (DDG-97)
   USS Michael Murphy (DDG-112)
Ticonderoga-class cruisers = 2 cruisers
   USS Chosin (CG-65)
   USS Port Royal (CG-73)

Submarines presently homeported in Pearl Harbor
Los Angeles-class submarines = 14
   USS Bremerton (SSN-698)
   USS Jacksonville (SSN-699)
   USS Houston (SSN-713)
   USS Buffalo (SSN-715)[10]
   USS Olympia (SSN-717)
   USS Louisville (SSN-724)
   USS Jefferson City (SSN-759)
   USS Columbus (SSN-762)
   USS Santa Fe (SSN-763)
   USS Charlotte (SSN-766)
   USS Tucson (SSN-770)
   USS Columbia (SSN-771)
   USS Greeneville (SSN-772)
   USS Cheyenne (SSN-773)
Virginia-class submarines = 4
   USS Hawaii (SSN-776)
   USS North Carolina (SSN-777)
   USS Texas (SSN-775)[11]
   USS Mississippi (SSN-782)
Figure 5. Pearl Harbor basin study area, which is the grey-hatched area (Pearl Harbor Aquifer, Chapter 5)
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