SUSTAINABLE AQUIFER PRODUCTION ON THE ISLAND OF SAIPAN

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Foreword

I currently work as a project engineer thru the US Public Health Service for the Commonwealth Utilities Corporation (CUC) which is the local utility that provides power, water, and sewer services to the island of Saipan and power and water to the islands of Rota and Tinian. I plan on using data I already have from working with the utility, as well as data that has been collected

by our lab, our regulatory agency, and by the US Geological Survey (USGS) of Saipan to evaluate the aquifer and propose a way to hopefully sustain it for years to come.

Introduction

The sustainability of water resources is a huge concern for most of the world. Planning for water usage and sustainability is especially worrisome for some islands. The amount of water collected on small islands can vary greatly thru the seasons so it is necessary to plan and implement a sustainable goal for the water aquifer. I plan on evaluating the island of Saipan's water infrastructure, aquifers, needs, and long-term goals to provide sustainability to their aquifers.

Islands can vary greatly on the amount of land they contain, the type of land, and the amount of freshwater they contain. Most islands rely on groundwater as their main water source and the sustainability of islands water is heavily dependent on protecting the groundwater lens above the brackish or saltwater underground. Without proper planning and maintenance, the aquifer can be greatly affected by pumping wells inserted into the aquifers.

The island of Saipan is located south of Japan and is the largest of the 14 islands in the Commonwealth of the Northern Mariana Islands(CNMI). Saipan's economy is built around a booming tourism industry. Multiple flights per day arrive from around the south pacific including; Japan, China, Philippines, and Guam. The island of Saipan is also one of the only US territories or cities to not provide 24/7 pressurized water.

For my Sustainability Analysis final paper, I will be focusing on engineering design and operation for sustainability in the utility industry. I will look at the infrastructure on Saipan and the current water resources to come up with a list of problems, goals, and alternatives to allow Saipan to continue to pump fresh groundwater. The main goal will be to protect the freshwater lens that is part of the groundwater system. The small freshwater lens above the salt water layer can be effected greatly by over pumping, which in turn will affect water quality and possibly destroy the water source. Non-sustainable pumping could destroy the aquifer by over pumping our ground water natural resources and it could cost the utility millions of dollars by needing to add treatment processes etc. to fix the water aquifer or treat salt water.

Island Aquifers

The islands aquifers are very different than mainland aquifers due to their close proximity to the ocean. The larger the island the more surface area it has, to capture more freshwater from the rain. But, truly the main force in groundwater is the geology of the island which allows the water to percolate into the aquifer to recharge it, or runoff down to the ocean. Figure 1 below shows the hydrologic cycle as it generally relates to Pacific Islands.

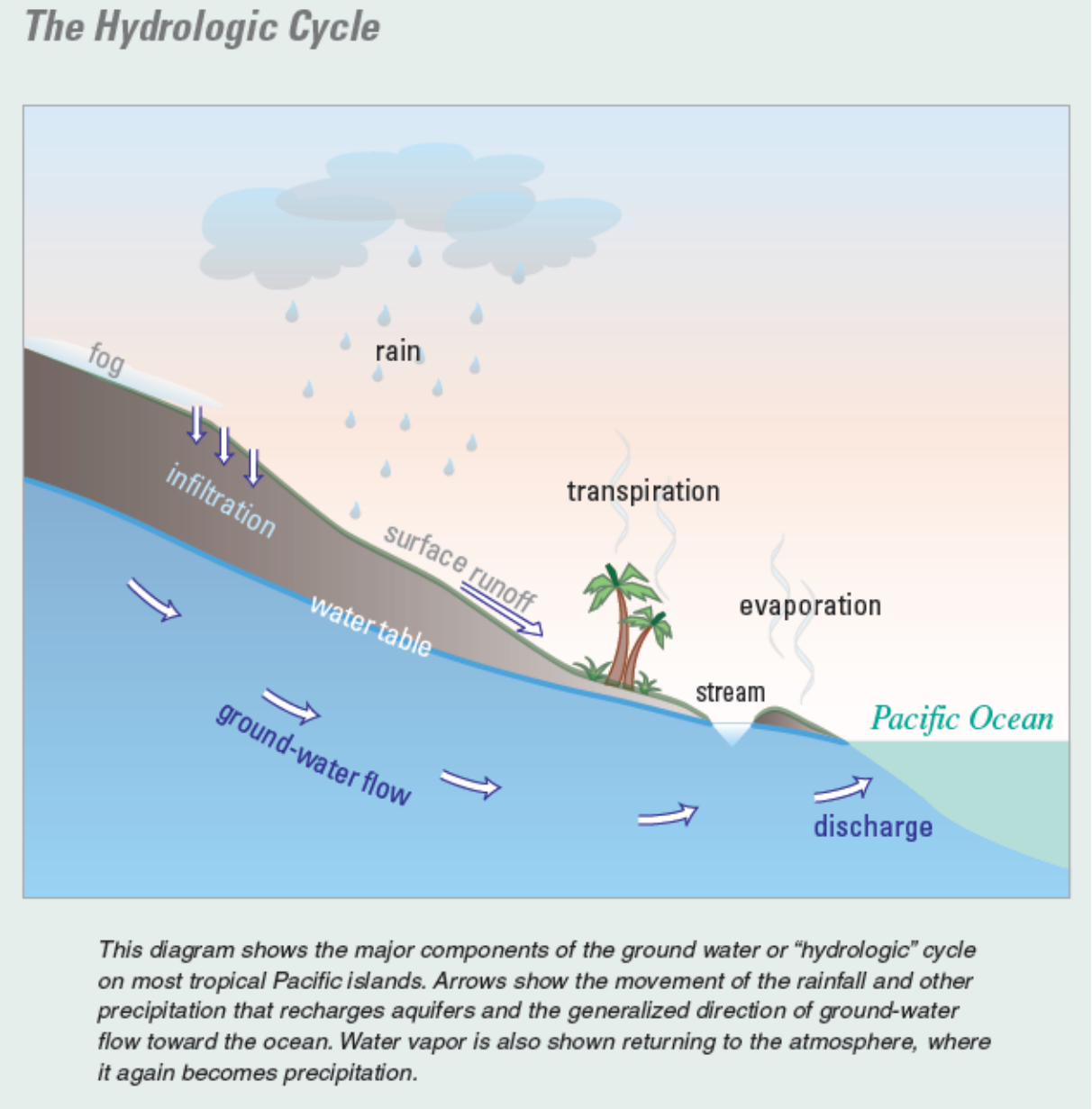

Figure 1 – Pacific Island Hydrologic Cycle (Tribble pg 12)

The island of Saipan's geology is a mixture of volcanic rocks and limestones. "Saipan is a subareal peak on the Mariana island arc and consists of a volcanic core overlain by younger limestones. Limestones and calcareous deposits dominate the surface lithology, comprising about 90 percent of the surface exposures. Volcanic rocks are exposed on the remaining 10 percent of the land surface" (Carruth). Saipan's limestone is very permeable but the volcanic rocks have a very low permeability which doesn't allow much water into capturable locations. Figure 2 show the geology of Saipan in regard to the water table.

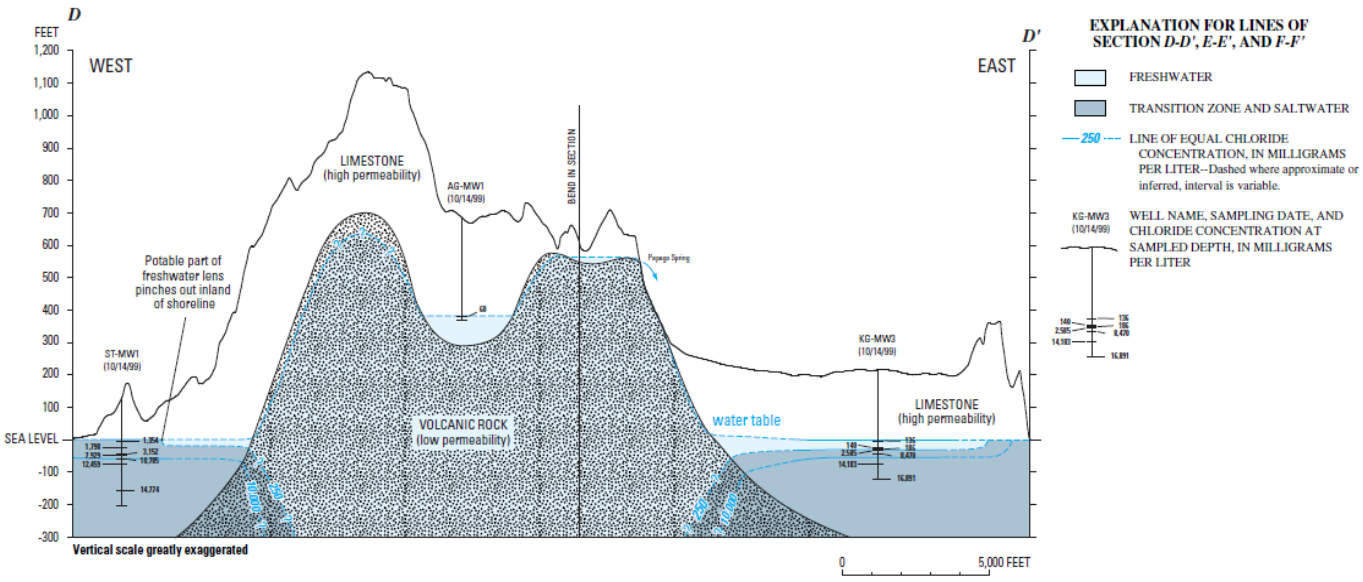

Figure 2 Cross Section of Saipan's Geology (Carruth)

The effects of pumping ground water on islands has 2 effects. One, it creates a drawdown effect on the water table as a direct result of pumping the water out. Two, it creates a saltwater upconing effect which can bring brackish or salt water up into the normal freshwater boundary. Figure 3 shows the effects of ground water withdrawal of the freshwater lens on an island aquifer.

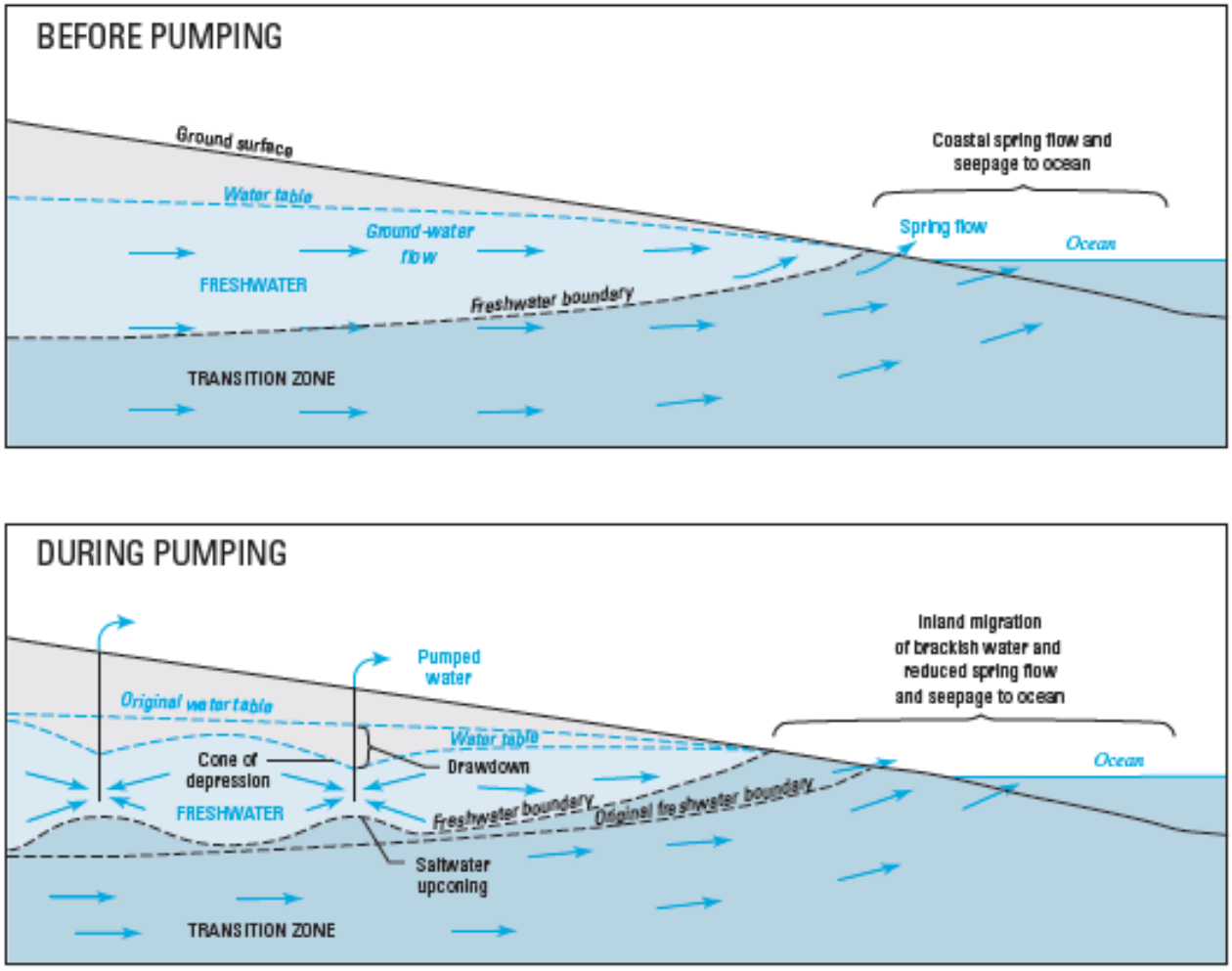

Figure 3 Ground water withdrawal effects (Carruth)

Saipan Water

Saipan currently uses multiple sources of water to provide water to the inhabitants of the island. Saipan has 2 shaft wells, one spring well, and 132 ground water wells to provide the water needs to the people. They currently produce 8.5-10 million gallons per day (MGD) based on current reporting from the Commonwealth Utilities Corporation, CNMI (CUC). Most of the islands wells are directly affected by saltwater up coning and drawdown of the wells. Saipan has 2 perched aquifers (Agag and Capitol Hill wells) that are not effected by saltwater intrusion and they only need to be monitored for drawdown effects. In fact, all of the springs on Saipan are not affected by saltwater intrusion (only 1 active spring).

Saipan receives about 80 in. of rainfall annually and has a distinct wet season (July-Nov.) and dry season (Jan.-May)(Carruth). The rain is the key recharge to all the freshwater on Saipan and water quality is affected greatly during times of drought. When there is extended periods with

little to no rain the groundwater recharge is too slow to keep up with the normal pumping demands and the water quality is negatively affected.

Saipan currently provides 24/7 pressurized water to most of the island but certain regions still do not receive adequate water hours. Some areas only receive 2-4 hours per day which is a huge problem for the people and the utility. As per Bureau of Environmental and Coastal Quality (BECQ) and CUC in April of 2017, 77% of the island received 24/7 water. All other areas ranged from 2-20 hours per day.

The island of Saipan currently has around 50,000- 60,000 people. The most recent census was in 2010 and as per the US census Saipan had 48,220 people. It is hard to state the exact population as the recent influx of people due to all the new drastic development. Many of the resorts on island provide their own water due to CUC not being able to meet the 24-hour demands of the population. Estimated per capital water usage is generally in the 80-100 gallons per person per day. Even with an estimated 60,000 people that would put the need of CUC and Saipan at 6,000,000 gallons per day, which is drastically less than the 8.5 million gallons they currently produce.

Water Losses

Water losses, generally termed as non-revenue water(NRW), are a major concern for most utilities but are of greater concern for islands. Saipan historically loses 50-85% of the water they produce from a variety of factors. The most recent published findings by CUC put them at 59% losses or billing only 41% of the water they produced in July of 2017. This number is a big improvement from even the May 2017 numbers of 64.4% loss.

The main question is, where are these water losses coming from? It is very hard to pinpoint the exact culprit and really there isn't one major item that causes the NRW percentage to be so high. It basically comes down to a combination of factors. The main water loss issues will be highlighted and insight will be given to try and correct or reduce the losses broken down in the next sections. The less water lost the less water will need to be pumped.

Leaks

Leaks cause any utility to lose water and are generally just a part of life for many utilities. Saipan continually has leaks due to old infrastructure, improper bedding of pipe, and issues related to pressurizing and depressurizing mains. Many leaks surface and repair crews deploy and fix as many as possible throughout the days, weeks, months and years, but there also are subsurface leaks that go to a cavern in the limestone or out to sea through the sand. CUC currently has a full time leak detection program and full time repair crew that continually try and make improvements to the leak issue of the NRW problem.

The future goal of leaks is to continually track down and repair leaks. The CUC team currently does a good job of getting to most leaks but some are hard to find or repair. The other goal will be to leave the water on 24/7 everywhere. This will eliminate air in the system and possible water hammer affects. Continually updating old infrastructure is another large goal of the utility and their ongoing partnership

with funding agencies of the Environmental Protection Agency (EPA), the Department of Interior (DOI), and the Economic Development Administration(EDA).

Theft of Services

The 2nd item of concern is theft of services. Customers can bypass water meters or illegally tamper with pipelines and connect their water line without a meter. Theft of services happens all over and CUC does try and prevent theft of services and reduce the amount of water lines that have been tampered with. CUC has found many large farms which incorporate drip irrigation to have tampered with meters or illegally connected to CUC water mains.

The future goal for theft of services is to eliminate this issue all together. Issuing fines and enforcing other deterrents will drastically improve the ability of CUC to eliminate theft of services and improve the sustainability of the water system. Each theft elimination is one step closer to lower NRW and fines or jail time will deter many customers from even attempting to steal additional services in the future.

Metering

CUC has continually tried to accomplish metering the entire island and has nearly reached the goal. The main issue with metering is the failure rates of meters has been excessively high, creating a system where it is hard to bill and track usage accordingly. CUC Saipan has replaced thousands of meters since the early 2000's and continues to see failures with new and improved meter models that come out. This creates issues where customers are given estimated billing and water operators are tasked with removing and replacing meters when other O&M items are needed.

Metering 100% of customers on a continual basis is the goal of every utility that bills its customers. Reading them and creating a proper water audit are directly dependent on metering customers. CUC needs to continue to work on their metering system to ensure revenues are up to operate and maintain the system for years to come.

Unbilled Authorized Consumption

Unbilled authorized consumption is another item utilities need to evaluate on a month to month basis. Unbilled authorized consumption is usage by unbilled metered consumption or unbilled unmetered consumption. An example of unbilled authorized consumption is a fire fighter connecting to a hydrant and fighting a fire, or a flushing program done by a utility. Saipan has a combination of many unbilled authorized consumption issues including the following:

1. Farm taps – taps that allow farmers to take treated or untreated water to use for farm usage only in areas with no pressurized water.
2. Fire Department usage – Firefighting or training exercises done by the fire department that is not ran through a water meter.
3. Construction usage – Known usage of construction companies completing projects under agreements with CUC (most of the time they are given a metered hydrant)

4. Unbilled unmetered consumption – When meters are not installed yet or customers have un-working meter that is authorized usage but unable to account the actual usage. This could be due to a meter failure, or the customer has applied for a meter it just hasn't been installed yet.
5. Flushing program – When operator's flush lines for maintenance or recent repair reasons.

All unmetered and unbilled consumption adds to the NRW problem. Most utilities should track and document this usage to help reduce the NRW that is unaccounted for. Accounted for water is better than direct system losses as theft, leaks, etc., which is considered unaccounted for.

In summarizing the water loss portion it is extremely critical of any utility to sustain the aquifers. Reducing the water losses directly impacts the amount of water needed to provide services to the customers and hopefully reduce pumping rates. CUC, as many utilities, has major issues with NRW and all aspects of NRW come into play nearly equally when it comes to system losses. The goal of most utilities is to get below 15% NRW but it varies greatly per utility. Saipan should have adequate production when looking at population and production alone but losing 60% of the water causes huge demand needs on the aquifers and leads to over pumping.

Saipan Water Quality

Saipan has 13 aquifers throughout the island, each one varies in quality and quantity of water production. The main goal of sustainability of an aquifer is to continue to use it for many years to come without reducing quantity or quality of the water. Due to all the NRW issues and not being able to provide 24/7 water Saipan already has seen the freshwater lens decrease and brackish water upcone into the freshwater lens.

The sustainable goal is to prevent saltwater intrusion into the freshwater lens. Saipan has very small freshwater lens in most parts of the island and saltwater intrusion is already happening in many of these well fields. Figure 4 shown on the next page highlights the effects of over pumping or improper well development that has affected many Saipan wells.

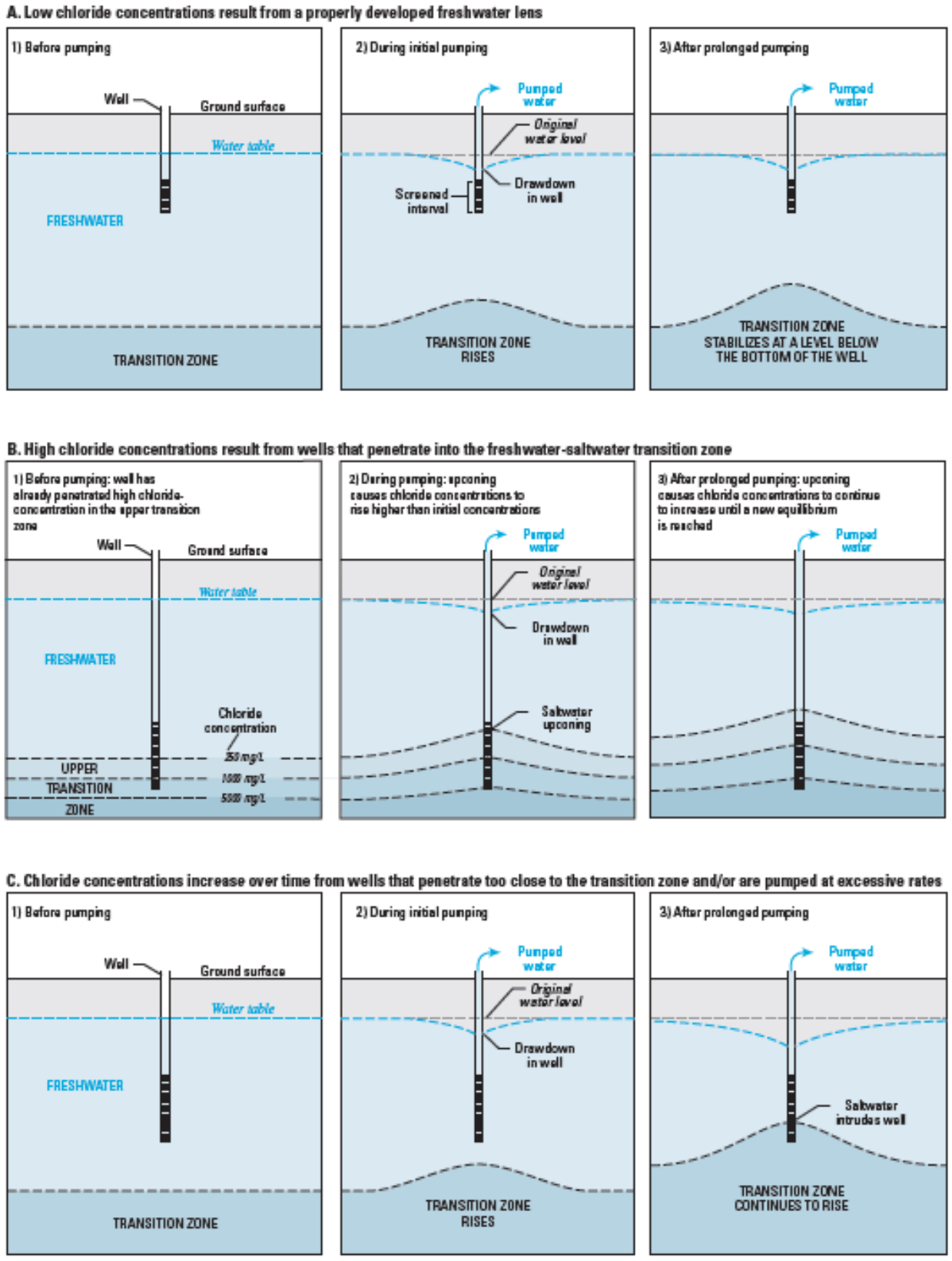

Figure 4 Well development (Carruth)

Chloride Concentration

The chloride concentration is a good baseline for judging the quality of the well water. USEPA recommends a secondary standard of 250 ppm (parts per million). Saipan varies per well field on the current chloride concentration but many already are over the secondary standard of 250 ppm.

[Mgal/d, million gallons per day; mg/L, milligrams per liter; --, not applicable]

Well field location	Well field name	Number of pumped wells	Pumpage[1] (Mgal/d)	Mean daily volume-weighted chloride concentration[2] (mg/L)
Southern Saipan	Isley Field	35	2.53	849
	Obyan	13	0.91	296
	Koblerville	20	2.13	1,425
	Dan Dan	6	0.41	710
	San Vicente	4	0.31	1,116
	Chalan Kiya	2	0.12	1,990
Subtotal		80	6.41	--
Mean daily volume-weighted chloride-concentration value for all southern Saipan well fields				985
Central Saipan	Kagman	15	1.07	1,017
	Sablan Quarry	11	0.84	557
	Akgak	6	0.56	63
	Capital Hill	3	0.38	63
	Calhoun (Navy Hill)	2	0.35	1,421
	Maui IV area	3	0.29	2,853
	Puerto Rico	2	0.18	2,300
	Gualo Rai	2	0.09	1,074
	Donni Springs	--	0.36	73
Subtotal		44	4.12	--
Mean daily volume-weighted chloride-concentration value for all central Saipan well fields				843
Northern Saipan	Marpi Quarry (As Matuis)	3	0.40	2,044
	Tanapag I and II and Achugao Springs	--	0.22	91
Subtotal		3	0.62	--
Mean daily volume-weighted chloride-concentration value for all northern Saipan well fields				1,343
Total		127	11.15	--
Mean daily volume-weighted chloride-concentration value for all Saipan well fields				953

[1] Daily well-field production determined by multiplying the cumulative well discharge in gallons per minute by 1,440 minutes/day; the method is considered reasonable because all wells are operated continuously.

[2] Calculated with chloride and pumpage data from Commonwealth Utilities Corporation.

Figure 5 Chloride Concentration of Saipan Well Fields 1998 (Carruth)

In figure 5, shown above, the data shows most of the well fields above the 250 ppm. More recent data from 2016 entry point information from CUC tells that the following well field information as follows:

1. Marpi Quarry – 1,412 ppm
2. Calhoun – 360 ppm
3. Sablan Quarry (Rapago)- 453 ppm
4. Akgak (agag) – 25.6 ppm
5. Capital Hill – 28 ppm
6. Donnie Springs – 44.4 ppm

7. Puerto Rico – 273 ppm
8. Maui IV - 327 ppm
9. Gualo Rai – 759 ppm
10. Kanat Tabla (Isley Field) – 813 ppm
11. Obyan – 373 ppm
12. Koblerville – 515 ppm
13. San Vicente – 914 ppm
14. Dandan – 825 ppm
15. Chalan Kiya – no longer active well

The data shows across the board improvement in all well fields when it comes to chloride concentrations. This is a very good sign for CUC and Saipan when it comes to sustainability of the well fields. CUC generally pumps all the wells is has online 24/7. This practice is normal but ideally you would pump the wells a few hours per day to get the needed production and then rest the wells as much as possible.

Regardless of improvement, most of the aquifers are already well above the 250 ppm secondary standard threshold set up by the EPA. This shows that the aquifers are generally not producing quality water and salt water upconing has already started to effect the system. The improvement is a great sign but CUC should not be satisfied until they are at least under the 250 ppm chloride concentration. The best way forward will be to slowly decrease production on the wells that have high chloride contents until they find a balance that is acceptable to aquifer sustainability while meeting or beating the secondary standards set by EPA. Meanwhile providing water to all customers 24 hours per day.

Technological Advancements

There are many new technologies out there and some technologies have been around for a long time. To keep the well fields sustainable in Saipan for years to come they need to continue to make efficiency improvements to reduce the amount of water needing to be pumped daily.

SCADA

Scada or supervisory control and data acquisition is a very useful tool that can be implemented in many different ways to ensure sustainability of wells. CUC currently doesn't have any SCADA controls but is looking into future options of SCADA. When one thinks about aquifer protection and sustainability the main concern is the life of the aquifer. As described earlier if utilities can keep brackish and salty water out of the freshwater lens the aquifer can have increased longevity.

SCADA can assist with this by incorporating chloride monitoring at well heads. If you installed monitoring with data control the CUC could have set points for wells that would shut off the wells if they started to draw up too high of chloride content in the water. This would ensure sustainability of the aquifer but they also need enough production to supply water to the people. Therefore, monitoring tank levels would need to be the main factor in deciding when a well should be shut down.

Flow control

Certain control valves can restrict flow or reduce pressures to areas during certain times of the day. Reducing pressure overnight can save water by reducing the amount of flow to possible leaks, thefts, or other NRW. Pressure reducing valves on individual homes or commercial customers can also reduce water usage as many items such as showering do not need 80 psi when 50 psi is completely adequate. The less water each customer uses allows water production to be decreased.

In-line metering

Monitoring flow rates with either SCADA controlled flowmeters or manual readings of flowmeters can help locate troublesome areas that are taking a lot of water for the size of the community. SCADA would be the desired monitoring as you can set alarms to send operators if flowrates get abnormally high. This helps utilities find leaks or large thefts quickly to reduce system losses.

Water Treatment

The other option CUC and Saipan have is to treat water. There are a variety of treatment systems that can help improve water quality. Treatments can be done to the groundwater, seawater, and surface water sources. Water treatment generally adds a lot of cost but may be needed to conserve the aquifers life for years to come.

Groundwater treatment

Groundwater treatment for the current water sources would mainly be used to treat the existing water supply and make it better quality for the customers. It may not improve the aquifer life as much as other alternative but it would allow the CUC to provide better quality water to its customers.

Surface Water Treatment

Surface water treatment is highly regulated by the EPA but it could add a lot of source water to Saipan by reducing the needed groundwater. Saipan has a few springs that are considered ground water so those would need treatment prior to distributing it to the customers. Multiple treatment paths could be looked at including slow sand filtration, conventional treatment plants, microfiltration, reverse osmosis, and ultraviolet water treatment systems.

All these treatment systems could be considered to help reduce the need of the groundwater. Generally speaking, when adding treatment, it will add costs to the utility, but to provide better quality water and protect the aquifer, stakeholders would need to look at the cost-benefit or life cycle cost model.

Seawater Treatment

Treating seawater is a normal practice for the resorts on Saipan. The process involves pumping ocean water or very brackish water into a reverse osmosis treatment plant. The reverse osmosis (RO) filters nearly everything out of the water, providing you with purified water, similar to what you would get from a bottled water company.

The RO process is very energy intensive as it takes a lot of pressure to filter the water thru the process. For CUC to undertake this, rates would have to be increased. This process could be used to supplement

areas that have poor quality water or to take pressure off the aquifers but it would add costs to the utility and its customers.

Sustainable Well Operation

The main goal of this paper is to plan out a way to continue to sustain the aquifers on Saipan. To make this happen a lot of data needs to be targeted and tracked to show how the system is improving or maintaining over time. Due to the many issues involved with CUC and the island of Saipan's aquifer conditions, a multifaceted approach to sustainability would be the best course of action in my current opinion.

The CUC needs to continue to track and reduce as much NRW as possible. This single handedly could eliminate the aquifer concerns based on the estimated current population of the island. Each repaired leak, theft of services elimination, newly metered customer, and reduced unbilled authorized water will greatly affect the ability to extend water service to all customers 24 hours per day. This also will create a future position that will allow operators to rest wells, allowing the aquifer to recharge its freshwater.

Incorporating new and improved technologies to the CUC can also greatly affect the ability to improve services and create a more sustainable aquifer system. SCADA can play a huge factor in tracking production, distribution, and chloride content which can lead to timely responses to new leaks or theft of service cases. Flow control and in-line metering also can reduce water system needs, directly allowing CUC to reduce flow rates of the wells and improve water quality.

Treatment technologies should be looked at especially regarding areas with existing springs or other sources of surface water. By adding additional water treatment CUC can eliminate some of the capacity needs from well fields. Even if it is seasonal water treatment, having this alternative can take a load off the current aquifers, by using surface water with treatment during rainy seasons and going back to the groundwater sources during dry seasons. Any additional water source if economically feasible should be looked at to increase the sustainability of the aquifers for years to come. CUC currently has the Achugao Springs and a rainwater catchment at the Saipan International Airport that could be used with one of the surface water treatments listed above.

Conclusion

Water aquifer sustainability is a huge concern for all utilities across the world. Any system that pumps groundwater should be thinking of the sustainability of that water source. Island water systems need to be even more aware of the concerns due to the limited land area and the influence of salt water intrusion. The island of Saipan currently has poor water quality when looking at the chloride content of the water and since they do not have enough water to provide 24/7 water they need to be extremely concerned with the life of their aquifer. To create a system of sustainability reducing the NRW is a key piece of the puzzle for the CUC.

The water system is very fragile due to the lack of source water and huge losses the utility has, so proper implementation of new technology can greatly benefit the future aquifer sustainability. New water

sources, leak detection, pressure reducing valves, and in-line flow meters all can assist the utility with extending the life of their aquifers. The baseline goals should be to get to 24/7 water, decrease pumping where possible, and improve the quality of the aquifers. CUC can accomplish this by tracking down all water usage, keeping leaks and theft to a minimum, and making systematic improvements to the islands water system.

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Glossary

Aquifer - in hydrology, rock layer that contains water and releases it in appreciable amounts. The rock contains water-filled pore spaces, and, when the spaces are connected, the water is able to flow through the matrix of the rock. An aquifer also may be called a water-bearing stratum, lens, or zone. (Encyclopedia Britannica)

CNMI – The Commonwealth of the Northern Mariana Islands; is a string of 15 islands in the NW South Pacific Ocean. The main inhabited islands are Rota, Tinian, and Saipan. The island chain follows the Northern Mariana Trench and is just north of Guam. The CNMI is a US Commonwealth Territory and is populated with approximately 55,000 people.

Non-revenue water (NRW) - is water that has been produced and is lost or not billed for utility systems. Losses can be real losses (through leaks, sometimes also referred to as physical losses) or apparent losses of uses of utility or by firefighting including (flushing, firefighting or charitable uses).

Percolate – To cause to pass through a permeable substance especially for extracting a soluble constituent. (Encyclopedia Britannica)