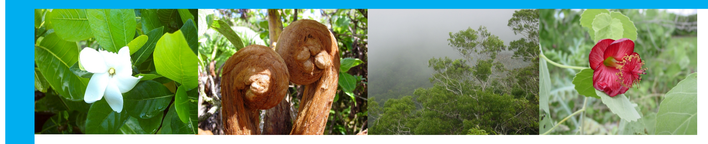

Prioritizing Watersheds From a Water Supply Perspective: Balancing Recharge, Production, Water Quality and Stakeholder Needs for Protection and Restoration Efforts

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1. Background

The Honolulu Board of Water Supply (BWS) recently prioritized watershed areas on Oahu from its water supply perspective, to meet two objectives. First, as a member of both the Koolau and Waianae Mountains Watershed Partnerships (KMWP and WMWP), the BWS prioritization results serve as input with respect to prioritizing watersheds for future cooperative protection / restoration work. Second, the BWS prioritization results serve as guidance for its own watershed management programs, to focus funding and implementation efforts.

2. Methods for Prioritizing Watersheds

There are many methods to prioritize watersheds, depending on stakeholder needs. Some examples include: prioritization focused on the population of a single plant or animal species that is targeted for either protection or eradication; prioritization based on the degree of water quality impairment along a river / stream channel; prioritization using risk assessment formulas that include the vulnerability of the watershed to water quality impairment and its current degree of impairment ; prioritization based on a matrix of weighted parameters, such as vegetation type, soil type, human uses, hydrology, and animal species.

The KMWP and WMWP were planning to use the last method, the matrix of weighted parameters, to take into account their range of stakeholder needs. The BWS therefore prioritized the watersheds on Oahu from a water supply perspective, understanding that this prioritization would be folded into the partnership's larger prioritizations, and also serve as a stand-alone prioritization for any solo BWS watershed protection / restoration work.

3. Watershed Prioritization Parameters

The BWS focused on two types of parameters, using fundamental concepts of water budgeting – groundwater recharge ("water in") and groundwater production ("water out").

Groundwater recharge parameters included:

- General soil / rock / vegetation type in each watershed (the ability to capture precipitation for groundwater recharge); and
- Relative rainfall amounts across watersheds (potential groundwater recharge amounts).

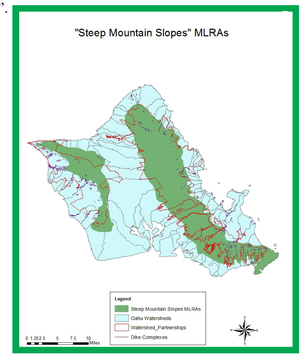
Groundwater production parameters included:

- Production amounts compared to the sustainable yields defined for watershed regions (how heavily groundwater is being extracted compared to its potential supply, and how much a particular aquifer is relied upon for water supply); and
- Relative chloride concentrations (how impacted a particular aquifer might be due to groundwater extraction).

4. General Soil / Rock / Vegetation Type

The U.S. Natural Resources Conservation Service (NRCS) produced the reference book titled, Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin. In this book, general soil, rock and vegetation types for the major islands of Hawaii are described.

On Oahu, the high mountainous areas of the Waianae and Koolau ranges are described as serving "primarily as areas of groundwater recharge" or as "watersheds for adjacent areas". The soil, rock and to some degree, vegetation cover are similar across these areas, and are classified very similarly, essentially called "Steep Mountain Slopes".

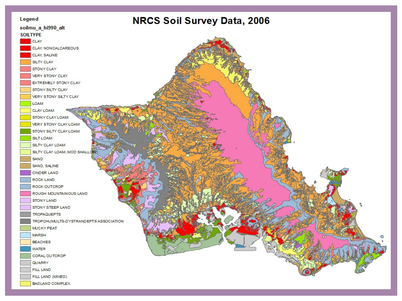


This map shows the "Steep Mountain Slopes" highlighted in green. It should be noted that the KMWP and WMWP partnership boundaries (shown on this map as thin red lines) correspond fairly well to the "Steep Mountain Slopes".

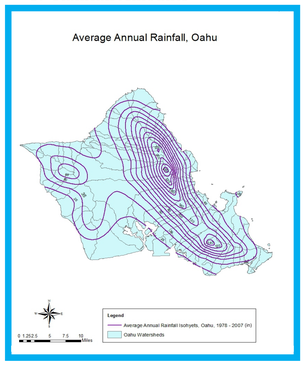
Also, dike complexes (shown on this map as thin purple lines) correspond in several locations to the "Steep Mountain Slopes". While this factor did not refine the prioritization of watersheds, it emphasized that steep mountain slopes may contain dike complexes, which are important components of capturing groundwater for recharge.

In addition to the Land Resource book, the NRCS continually publishes soil survey results for their ongoing studies completed across the United States. The latest soil survey information for Oahu is extremely detailed, and shows various rock and soil types along much of the steep mountain slopes of the Waianae and Koolau ranges.

These rock and soil types are relatively well-drained and therefore more suitable for groundwater recharge, compared to the clayey soils shown at lower elevations. All of these classifications and their locations support the Land Resource descriptions of the "Steep Mountain Slopes".



5. Rainfall Amounts



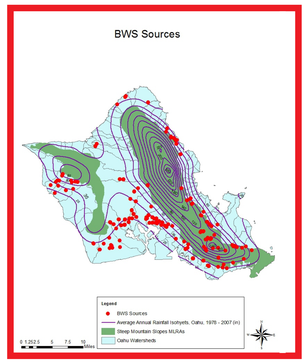
The University of Hawaii recently issued a Rainfall Atlas of Hawaii, presenting mean rainfall for the major islands over the 30-year period 1978 –2007. Historic rainfall measurements taken at over 1,000 stations were used to develop the Rainfall Atlas maps. To the left is a map based on the Atlas showing average annual rainfall across Oahu for that 30 – year period.

As expected, there are higher amounts of rainfall along the steep mountain slopes of the Waianae and Koolau ranges compared to rainfall at lower elevations, which reflects the capacity of the higher mountain slopes to capture precipitation. This supports the previously discussed NRCS classification of the "Steep Mountain Slopes" as serving "primarily as areas of groundwater recharge".

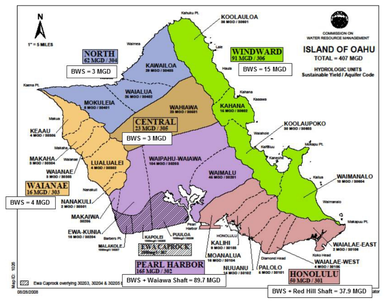
6. Groundwater Production Amounts

The BWS is the primary groundwater supplier for Oahu. Maps such as the following, which display the Board's groundwater sources (as the red dots) show production occurring across much of the island. One other significant groundwater producer is the U.S. Navy, whose largest production occurs at its Waiawa and Red Hill Shafts.

Groundwater production on Oahu is limited according to "Sustainable Yield". Sustainable Yield may be defined as the maximum groundwater extraction rate that can be sustained without draining the subject aquifer. Sustainable Yield values are defined by the State Commission on Water Resource Management for the Hydrologic Units (aquifers) across Oahu.



The Commission produced a map that conveniently groups Sustainable Yield values according to BWS production sectors, as shown by the different colors on the map:



The BWS reviewed groundwater production from its sources and the Navy's sources for Calendar Year 2011, and compared production to the Sustainable Yield values by sector. Based on this analysis, it appears that groundwater production is well below the Sustainable Yield values by sector, although the Pearl Harbor, Honolulu and Waianae sectors are starting to narrow this gap.

7. Chloride Concentrations

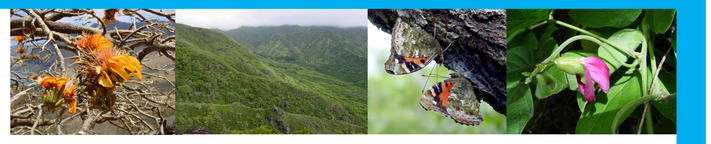
In order to more realistically evaluate a source's potential for chloride degradation, one should consider both the measured chloride concentrations and the source's rate of groundwater production. In other words, a source might exhibit high chloride concentrations, but if this source is rarely used, it might not be as significant in terms of prioritizing the source's watershed.

The BWS accounted for both chloride concentrations and production rates by applying mathematical "indexing", or weighting. In other words, each source's production rate was multiplied by its latest known chloride concentration. Based on this indexing, the highest indexed sources are associated mainly with the BWS Pearl Harbor and Honolulu production sectors.

8. Prioritization and Recommendations

Based on our review of the abovementioned parameters, the BWS began prioritizing the watersheds on Oahu. First, for convenience the watersheds were separated into the Waianae and Koolau mountain ranges. Next, four lists of watersheds were generated, which were subsequently further prioritized:

Potentially High Recharge Watersheds – Waianae	Potentially High Production / High Chloride Watersheds – Waianae
Kaupuni	**Makaha**
Makaha	Kamaileunu
Keaau	**Kaupuni**
Makua	Makaiwa
Kawaihapai	Kaloi
Pahole	Honouliuli
Makaleha	
Waialua	
Kaukonahua	



Some notes regarding how these four lists were generated:

The NRCS "Steep Mountain Slopes" and soil survey classifications were extensive and did not sufficiently narrow the list of watersheds on Oahu; therefore, rainfall was relied upon as the primary parameter.

Rainfall isohyets of 50 inches and above for the Waianae range and 120 inches and above for the Koolau range were used to define the watersheds with the potentially highest recharge. These isohyets were chosen based on several factors.

First, these isohyet patterns roughly correspond with the boundaries of the "Steep Mountain Slopes", particularly along the Koolau range. Second, using GIS isohyet maps / data, we calculated land area and rainfall volumes for each isohyet interval. Based on these calculations, the areas that fall within the abovementioned isohyets plus those higher in value capture approximately one-third of the total rainfall for their respective mountain range, while encompassing slightly less than 17 percent of the total land area of Oahu. Finally, these isohyets serve as useful median values for selecting watersheds:

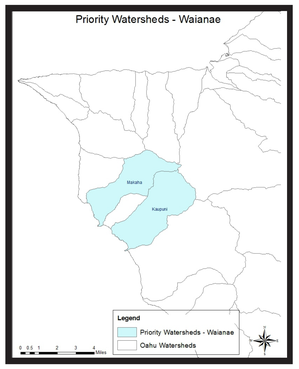
Potentially High Recharge Watersheds – Koolau	Potentially High Production / High Chloride Watersheds – Koolau
Waimea	**Waikele**
Kawainui (North)	**Waiawa**
Kawaiiki	Kapakahi
Opaeula	**Waimalu**
Helemano	**Kalauao**
Poamoho	Aiea
Kaukonahua	**Halawa**
Waikele	**Moanalua**
Waiawa	Kalihi
Waimalu	Kapalama
Kalauao	**Nuuanu**
Halawa	**Makiki**
Moanalua	**Manoa-Palolo**
Nuuanu	Ala Wai
Makiki	Waialaenui
Manoa-Palolo	Wailupe
Malaekahana	Kuliouou
Kahawainui	**Punaluu**
Wailele	
Koloa	
Kaipapau	
Maakua	
Waipuhi	
Kaluanui	
Punaluu	
Kahana	
Waikane	
Waiahole	
Kaalaea	
Waihec	
Kahaluu	
Kawainui (South)	

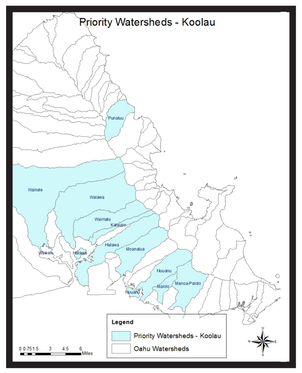
higher-value isohyets tend to capture too few watersheds to be beneficial, while lower-value isohyets tend to capture too many watersheds to be practical.

With respect to potentially high production / high chloride watersheds, we selected watersheds having sources within the Pearl Harbor, Honolulu and Waianae sectors, based on their relatively high production compared to their Sustainable Yields. As a cross-check and to further refine the list of watersheds, watersheds having sources exceeding a 1.0 index (i.e., production x chloride) were selected; these comprised roughly the top quarter of all sources indexed. It happened that these sources were already in the Pearl Harbor and Honolulu sectors noted earlier for high index values.

Because these four lists were still rather extensive, further prioritization was done by selecting those watersheds that are present on both the "Potentially High Recharge" and "Potentially High Production / High Chloride" lists for their respective mountain range.

Following are location maps for the final "Priority" lists, one list for Waianae watersheds and one list for Koolau watersheds.





It should be noted that, in addition to all the prioritization parameters covered, the demand from major agricultural irrigation systems was also considered. The Wahiawa, Waiahole, and Waimanalo irrigation systems encompass about 30 miles, 25 miles, and 15 miles of transmission ditch, respectively. The systems draw a mixture of groundwater and surface water, from the following watersheds:

Wahiawa Irrigation System: Kaukonahua
Waiahole Irrigation System: Kahana, Waikane, Waiahole, Waiawa
Waimanalo Irrigation System: Kawainui (South)

Because all of these watersheds already appear on the "Potentially High Recharge" lists (Waiawa appears on both the "Potentially High Recharge" and "Potentially High Production / High Chloride" lists), the watersheds were incorporated into the final prioritization recommendations.

Our recommended strategy for future watershed protection / restoration work is as follows:

- First priority: Focus efforts on watersheds that appear on both "Potentially High Recharge" and "Potentially High Production / High Chloride" lists.
- Second priority: Focus efforts on other watersheds appearing on only the "Potentially High Recharge" lists, particularly those associated with the Wahiawa, Waiahole, and Waimanalo irrigation systems.
- Third priority: Focus efforts on other watersheds appearing on only the "Potentially High Production / High Chloride" lists if certain high recharge watersheds are infeasible for protection / restoration work, due to factors such as difficult site access or a high degree of protection measures already in place.

The reasoning behind these levels of prioritization is that most of the factors affecting the "potentially high recharge" watersheds (such as rainfall) cannot readily be altered (e.g., a long period of time is needed to redevelop a good forest canopy), while the primary factor affecting the "high production / high chloride" watersheds (i.e., production rates) can be altered to some degree if needed, by shifting pumping patterns.

Finally, this effort was limited to identifying entire watersheds, although it is understood that the focus for future projects will be in the higher-elevation portions of these watersheds, above the target isohyets mentioned previously. Selecting specific project sites is left to future efforts.