WRRC-ASPA

Hydrologic Monitoring Network Handbook

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Contents

All coordinates presented here are in WGS-84 geographic coordinate system

1. Introduction

Quantifying hydrologic parameters such as precipitation, streamflow, evapotranspiration, and aquifer response are fundamental to understanding a region's hydrological budget, and thus the availability of water resources. This is particularly important in small island developing communities where critical water resources are limited. Climate and streamflow measurements provide information on ground and surface water supply, while measurement of aquifer parameters such as water level and salinity is imperative for understanding sub-surface water flow, transport, and availability. These hydrologic datasets are essential for design of sustainable water supply systems and for prediction or detection of acute threats to drinking water quality or availability. Objectives that benefit from incorporation of accurate hydrologic data include:

- Appraisal of water resources
- Providing input parameters for watershed and groundwater models
- Engineering design of structures and roads
- Identification of climate change impacts
- Support of water quality monitoring efforts
- Characterization of aquatic habitats

On Tutuila, American Samoa, weather monitoring and stream gauging operations were initiated by the United States Geological Survey (USGS) in the 1950s. However, as of 2008, all USGS monitoring activity on Tutuila had ceased. Although this legacy data remains as a valuable tool, climate change and variability continues to reduce its viability as time passes. Because this information is a critical component of sustainable water management, the University of Hawaii (UH) Water Resources Research Center (WRRC) and the territory's sole water utility, American Samoa Power Authority (ASPA) have entered into a cooperative agreement for the purpose of developing a new weather station, stream gauging, and aquifer monitoring network. The instruments used in this network are intended to be simple, robust, and easily maintained to ensure longevity and continuity of data. Weather stations have been placed at pre-existing ASPA leased locations, and stream gauges are sited near roads, bridges, or previously gauged sites for ease of access and maintenance. Aquifer data is monitored at available locations within the existing ASPA well network. The goal of this project is to produce publicly available long-term hydrological datasets for use in water resource management or other applications.

This report provides locations, descriptions, and care and maintenance recommendations for each of the 21 instruments in the ASPA-WRRC monitoring network as of August 2017. Each section provides an overview of the equipment used for the current iteration of the network, and each site is described to ensure that details about site access and particularities are documented. Procedures for maintenance and download for each instrument are also provided, as well as a status update regarding the still evolving methods being used for data processing. Recommendations for continuing upgrades to the network are given in Section 6, and a supplemental folder with user manuals and additional instructions for instruments has been compiled. Since the monitoring network is constantly evolving over time, this should be considered a living document that will benefit from revision as field conditions change.

2. Locations of monitoring instruments

The following map (Fig. 1) illustrates locations of weather stations, stream gauges, and aquifer monitoring sites.

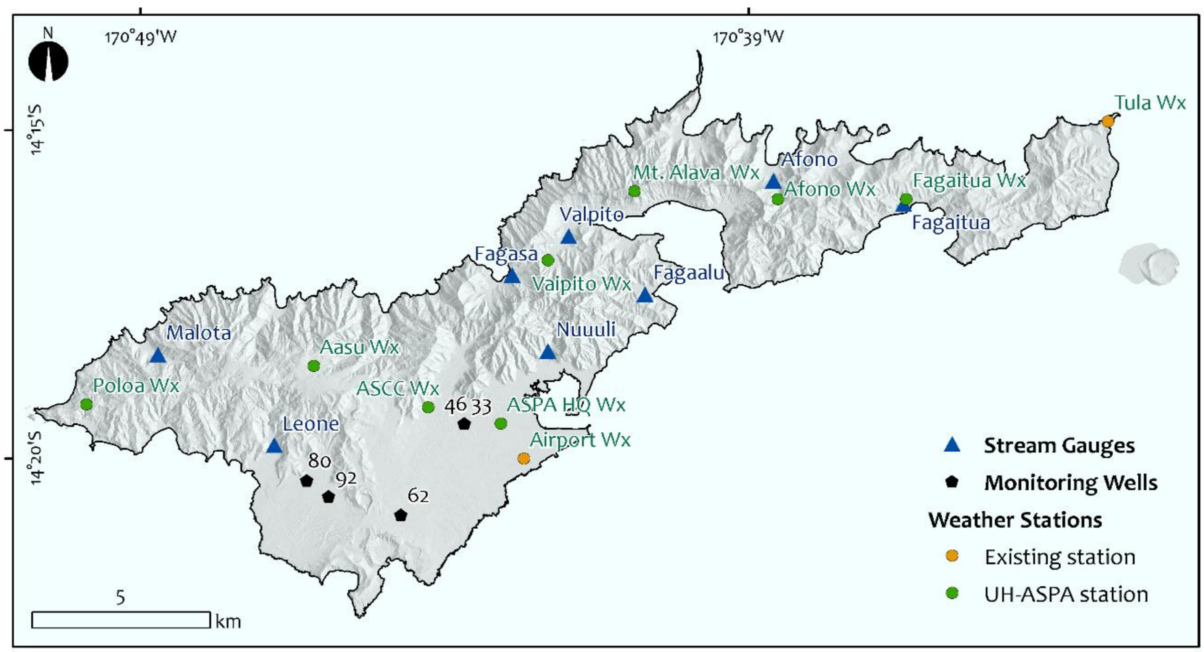


Figure 1. Locations and names of weather stations (*circles*), stream gauges (*triangles*), and aquifer monitoring locations (*pentagons*) in the ASPA-UH-WRRC monitoring network as of August 2017. Note, *orange circles* represent locations of long-term weather stations with open-access data that are maintained by other agencies outside of the ASPA-UH-WRRC weather station network.

3. Weather station overview

The ASPA-WRRC weather station (Wx) network consists of seven discrete stations or packages of instruments (of three different brands) as of August 2017. The stations all have the capability to record precipitation, temperature, relative humidity (RH), wind speed and direction, and solar radiation (SR). The Wx network covers most of the lateral extent of the island, from Poloa (at the western tip) to Fagaitua (in the Eastern District) (Fig 1). Additionally, there are two long-term stations outside of the WRRC-ASPA network located at the National Oceanic and Atmospheric Administration (NOAA) meteorological observatory at Cape Matatula on the easternmost tip of the island, and at the Pago Pago Airport (PPG) on the eastern Tafuna-Leone Plain, which provide online weather data. The ASPA-WRRC stations cover an elevation range from near sea level to 475 m at Mt. Alava. The station types include Four Spectrum Technologies Inc. WatchDog 2900ET weather stations (Spectrum item number 3350WD2), one Davis Vantage Pro2 Plus weather station (Davis Item #61612), and two custom built Campbell Scientific stations (parts list below).

The WatchDog 2900ET stations are generally mounted on 2-meter tall free standing 1.5" diameter galvanized steel poles supported by a weighted base. They are held upright by three guy wires leading from the ground to the top of the pole that are designed to keep the stations level and directionally oriented. The stations are set to log every 15 minutes, and at this interval the stations will log for a maximum of 90 days. In addition to the 2900ET stations, one Spectrum brand solar radiation meter is mounted on top of the most southerly large white ASPA Generations Department fuel tank within the compound. The instrument consists of a WatchDog 1200 Micro Station (Spectrum item number 3680WD1) housed in a small weatherproof case and a LightScout Silicon Pyranometer (Spectrum item number 3670I) mounted on top of a 2 m galvanized steel pole. The pyranometer sensor is intended to provide data to combine with data from the PPG airport weather station, which does not have a solar radiation meter.

The two Campbell Scientific stations consist of an RM Young Wind Sentry Set (03002-L12-PT), a CSL Temperature/RH Probe (CS215-L7-PT) in a 6-Plate Solar Radiation Shield (41303-5A), an Apogee SP-110 Pyranometer (CS300-L12-PT), a Texas Electronics Rain Gauge (0.01 inch per tip) with a 6-inch orifice (TE525-L10-PT), a Weather-Resistant 12 x 14-inch enclosure (ENC12/14-SC-MM) that houses a Wireless Modem Datalogger (CR300-WIFI), and a 12V Sealed Rechargeable Battery (BP12). The station is powered by a 10W Solar Panel (SP10-PT-SM). All part numbers refer to Campbell Scientific catalog model numbers. These components are mounted to custom welded free standing 2" diameter 3 m tall poles with a 1 m long crossbar anchored near the top. Each component is placed to minimize external interference and maximize the validity of each measurement. These stations are set to log every 15 minutes, will store over 90 days' worth of data, and can be downloaded wirelessly onto an apple or android device with LoggerLink, a free application from Campbell Scientific (https://www.campbellsci.com/loggerlink).

One Davis Vantage Pro Plus station is deployed on the roof of the Land Grant building at American Samoa Community College (ASCC) and is cared for and maintained by ASCC personnel. As of this writing, real-time data from this station are available at https://www.wunderground.com/personal-weather-station/dashboard?ID=IWESTERN499#history.

Although ideal weather station sites are difficult to find, every attempt was made to deploy stations at sites with the best balance of characteristics within the available terrain (WMO 1983; USEPA 1987; https://www.campbellsci.com/weather-station-siting). ASPA-WRRC weather station sites were selected based on the following criteria:

- Land ownership—sites already leased or owned by ASPA or ASCC, were highly prioritized.
- Minimization of obstructions—all attempts were made to find open fields or locations where trees do not block rainfall or wind.
- Spatial distribution—sites were selected to be as representative as possible of the variability in Tutuila's climate zonation based on elevation, aspect, location.

3.1 Weather station sites

3.1.1. Poloa Weather Station (Latitude: -14.3196, Longitude: -170.8308, Elevation: 143 m above sea level (asl))

The Poloa station was installed in late 2015 and instrumented with a Spectrum Instruments WatchDog 2900ET station. The station is located in a fairly open area with a generally westerly aspect, and sits at 141 m elevation. Some nearby trees may cause interference with rainfall, and especially wind measurements. The station is mounted roughly 2 m above the ground surface on a free standing pole within the grassy area enclosed by the Poloa water tank fencing. This site is located at the top of a steep road behind a local family's house. In the past, the family has requested that visitors stop at the house and check in with the family prior to heading up the hill to the water tank. This weather station has had issues with the rain bucket getting clogged, probably due to the nearby trees, and has also had issues with ants making nests inside the housing. It is highly recommended that tanglefoot be regularly applied to the upper section of the support pole to mitigate this problem.

3.1.2. Aasu Weather Station (Latitude: -14.3098, Longitude: -170.7715, Elevation: 358 m asl)

The Aasu weather station was originally installed as a Spectrum WatchDog 2900ET station in late 2015, and replaced with a Campbell Scientific weather station in early 2017. The station is located at 355 m elevation within the fenced enclosure of well 128, on top of Aloaou Mountain. This is one of the more ideal weather station sites as it is located in the middle of a relatively flat and open cow pasture. There are a limited number of small trees throughout the pasture, but they probably do not interfere with wind or rainfall measurements. The original Aasu watchdog station was mounted on a single pole at a height of 3 m to elevate it above the chain link fence surrounding the well, and the new Campbell station is now mounted at the same location on a three legged free standing support tower that is bolted to the concrete slab below. The SR meter, anemometer, and rain gauge are located at a height of 3 m above ground surface and temperature and RH sensors are mounted at 2 m above the ground. Access to well 128 is off of a paved concrete road accessed via a right turn within the village of Aasu while at the top of the main Aoloau Road.

3.1.3. Vaipito Weather Station (Latitude: -14.2829, Longitude: -170.7105, Elevation: 92 m asl)

This station is a Spectrum Instruments WatchDog 2900ET station and was installed in late 2015. It is located in an open valley with an easterly aspect and sits at 90 m elevation. The station is in a very open area and is mounted on a free standing pole at the edge of the Vaipito Reservoir within a fenced enclosure. The instrument sits at 2 m above ground surface. Access to the Vaipito reservoir is via concrete road—right turn going up the Fagasa Pass Road.

3.1.4. Mt. Alava Weather Station (Latitude: -14.2654, Longitude: -170.6879, Elevation: 477 m asl)

This station is located on a free standing pole at an elevation of 475 m on top of Mt. Alava, on the southerly side of the Mt. Alava trail, just beyond the top of the large staircase. To access this station the entire 2.5 mile Mt. Alava trail must be hiked or driven in an ATV. Trucks will not make it up the Mt. Alava trail. The station is not protected in a fenced enclosure and is therefore secured with a combination lock and chain to prevent tampering. Unfortunately, the rainfall and solar radiation readings are probably affected by the cable car structures and the wires above. This station may need to be mounted on a taller pole than the existing 2 m one, to more accurately record wind speeds. The station has been affected by ants.

3.1.5. Fagaitua Weather Station (Latitude: -14.26722, Longitude: -170.6171, Elevation: 55 m asl)

The Fagaitua site has a Spectrum WatchDog station located on top of the Fagaitua water tank. It was installed in early 2017 and is mounted on a short pole roughly 1.5 m above the roof of the tank. The tank itself is roughly 10 m above the ground and located atop a ridge, making the station significantly elevated above the ground. The ground elevation of the tank is 44 m. This is probably only a temporary station as the water tank is leaking and will need to be replaced in the near future. As of 2017, the Spectrum station computer module only records SR, wind speed and direction, temperature, and RH. A separate tipping rain bucket was installed to replace the faulty rain gauge and has a dedicated data logger made by RainWise Inc. The rain logger is downloaded with the RainWise software and records one data point per minute during active rainfall only. Therefore, a specific processing routine must be applied to this data. The Fagaitua tank is located at the top of a steep concrete road and has no vehicle turnaround at the top. The tank has a ladder that must be ascended to access the station, and past observations suggest this ladder may be a hangout for large yellow wasps.

3.1.6. ASPA Solar Radiation Meter (Latitude: -14.3203, Longitude: -170.7417, Elevation: 30 m asl)

This station consists of a small pyronanometer and a data logger only. The solar radiation meter is mounted on top of a 2 m pole attached to the top rail of the yellow staircase on the roughly 15 m tall southerly fuel tank at the ASPA compound, which sits at a ground elevation of 14.6 m. The station is accessed by hopping over the containment wall and walking up the yellow staircase to the top of the tank. This logger can be downloaded by the Spectrum Data Shuttle.

3.1.7. ASCC Weather Station (Latitude: -14.3203, Longitude: -170.7417, Elevation: 65 m asl)

This station is located at a ground elevation of 49 m and is mounted on top of the Land Grant building roof at a height of 16 m above the ground. This station replaces a former station that was deployed in the same location in the past. The station is maintained by Land Grant staff. Data is available by download from [https://www.wunderground.com/personal-weather-station/dashboard?ID=IWESTERN499.](https://www.wunderground.com/personal-weather-station/dashboard?ID=IWESTERN499)

3.1.8. Afono Weather Station (Latitude: -14.26738, Longitude: -170.65058, Elevation: 84 m asl)

The Afono weather station is a Campbell Scientific weather station and was installed on a custom built free standing tri-legged tower in early 2017. The tower is mounted in concrete foundation located in the north east corner of the Afono water tank enclosure. The SR meter, anemometer, and rain gauge are located at a height of 3 m above ground surface, and temperature and RH sensors are mounted at 2 m above the ground. The area around the weather station is generally grassy and open, but a nearby tree may provide some interference with rainfall and wind measurements. The site is located along the Afono pass road and sits at 81 m asl.

Out of Network Weather Stations

3.1.9. Pago Pago International Airport Weather Station (Latitude: -14.3333, Longitude: -170.7167, Elevation: 5m asl)

This station is located at an elevation of 5 m and is maintained by the National Weather Service. Data is available by request from the Pago Pago NWS office or can be downloaded at http://xmacis.rcc-acis.org/.

3.1.10. NOAA Cape Matatula Observatory Meteorological Station (Latitude: -14.2474, Longitude: -170.5645, Elevation: 75 m asl)

This station is located at an elevation of 75 m and is maintained by the NOAA Corps member that is stationed on Tutuila. Data is available by request from their office or by download from the web at: http://www.esrl.noaa.gov/gmd/dv/data/?parameter_name=Meteorology.

3.2 Weather station data processing

Weather station data is fairly straightforward to download, see weather station field instruction sheet below for tips on downloading Spectrum stations, online resources at https://www.campbellsci.com/loggerlink, for instructions on downloading Campbell weather stations with the LoggerLink app. The primary issue encountered so far with weather station data is accounting for malfunctions with the equipment, either with periods where data was not recorded, or with data entries that were inaccurate. At present, it is recommended that after downloading, data files should be plotted (with SpecWare for Spectrum stations, or LoggerLink for Campbell stations) and visually inspected to ensure that data is realistic, there are no outliers, and that the stations were recording for the entire performance period. Any gaps or obvious inaccuracies in the data should be documented on the log sheets (see Appendix B). WRRC is currently developing script-based protocols to plot and perform preliminary quality assurance/quality control routines to improve process automation. As of this writing, once data is visually inspected, the individual data files can be concatenated (combined) with other data files (Fig. 2) to add to the master data series that are posted on the ASPA website at http://www.aspower.com/Water-ASPA-weather-station-data.html.

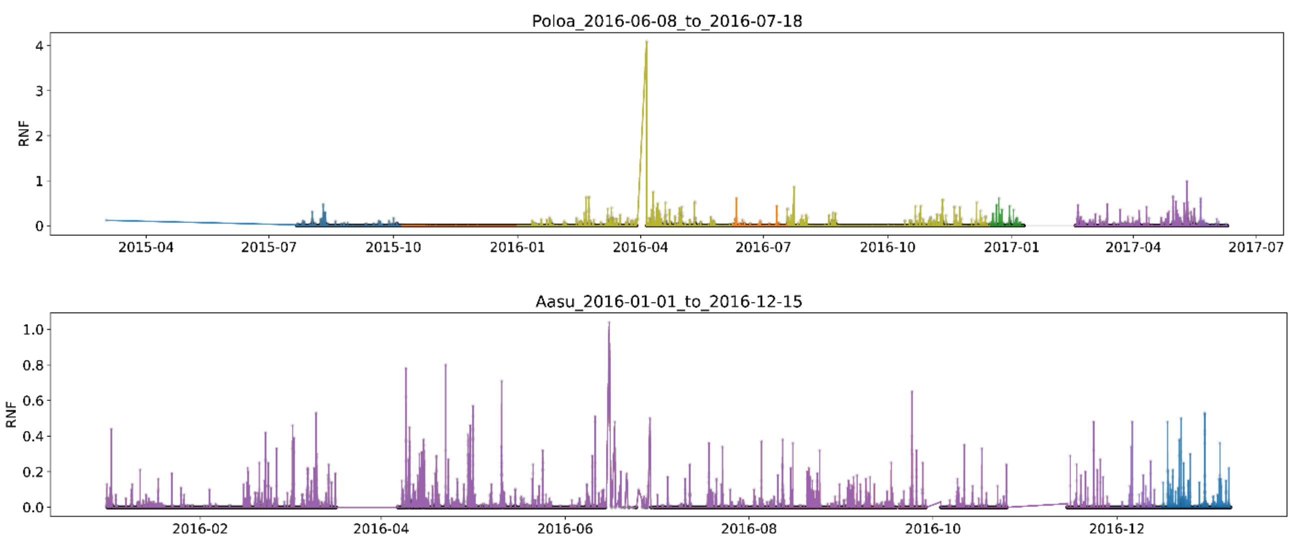


Figure 2. Example plots of concatenated rainfall data series. Note gaps in datasets due to instrument malfunction.

3.3 Weather station care and maintenance tips

The weather stations, like all electronic instruments deployed in the tropics, are vulnerable to a number of environmental stressors that can disrupt sensitive electronics. Stressors include: high moisture conditions, excessive heat and ultraviolet radiation, and cavity nesting insects. High-humidity levels combined with high temperatures cause rapid corrosion to susceptible metal parts. Thus, all fasteners used to secure instruments (e.g., nuts, bolts, and screws) should be made of a corrosion resistant material—brass is best, though stainless steel, aluminum, and galvanized steel are acceptable as well. It is recommended that normal steel hardware not be used, as after only a couple of years these items will rust to the point of falling apart, making disassembly and replacement very difficult. Plastics are resistant to corrosion, though many types degrade with exposure to sunlight.

Additionally, electronic components, such as weather station dataloggers, are highly sensitive to liquid water or excessive moisture. Electronics should always be protected in water tight housing. Due to Samoan weather conditions, it is essential that a supply of fresh desiccant is maintained inside of the housing at all times. Housings need to be checked periodically for water-tightness and always closed after maintenance. Depending on the size of the desiccant packet, it may need to be replaced on a monthly or quarterly basis. Fresh desiccant can be purchased inexpensively online. Most instruments can sustain the heat of direct sunlight, however, long-term exposure of many plastics to direct sun will eventually cause them to become brittle and fail. While the instruments themselves are generally made of materials designed to withstand outdoor use, fasteners such as zip ties or plastic signage may need to be occasionally replaced.

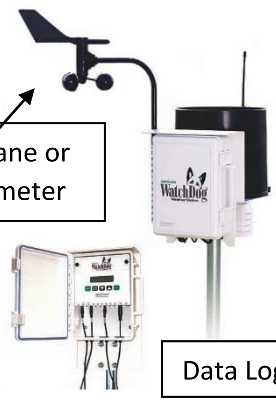
An environmental factor of particular concern in Samoa are ants and wasps, which build nests in any cavity they can find, including datalogger housings. This activity will wreak havoc on the instrument's circuitry. Ant attacks can be prevented by applying a sticky trap substance such as tanglefoot to the instrument mounting pole, thereby cutting off their walking path to the instrument. Wasps will not be stopped by this, and regular inspections should be performed in order to prevent nests from interfering with tipping bucket or anemometer functions. Dataloggers and power supplies in all of the weather stations are housed in weather tight boxes that are ideally sealed against insect entry. Insects are most likely to enter via wires through the bottom of the box, thus it is imperative that these seals be maintained and inspected regularly.

The stations should be kept as level as possible to keep rainfall and solar radiation measurements consistent. If station orientation is changed, the north bearing needs to be re-set to provide accurate wind direction data. If there are Wx issues, support should be available through the UH staff (cshuler @hawaii.edu), Spectrum tech (info@specmeters.com), or Campbell tech (info@campbellsci.com). A two-sided printable sheet is provided below that reviews weather station care and maintenance tips for field reference.

Weather Station Anatomy

Spectrum Stations

Tipping bucket rain gauge



Wind vane or anemometer

Data Logger

Pyronanometer or solar radiation sensor

Pyronanometer

Data Logger

ASPA-HQ Solar radiation sensor

Campbell Stations:

Data Logger and 12 V battery power supply housing

Tipping bucket rain gauge

Pyronanometer

Wind vane or anemometer

Temperature and humidity sensor shield

ASPA-UH-WRRC weather station maintenance tip-sheet (pg. 1)

Care and maintenance schedule:

- Data collection and preventative maintenance inspections should be performed **every 1-2 months** to ensure proper functioning and to minimize data gaps.
- Tanglefoot should be applied to support poles, and re-applied **every 1-3 months** to prevent hostile takeover of stations by ants.
- Batteries and desiccant packets will need to be replaced **every couple of months**
- Wx stations must be downloaded **every 90 days**. After this time they will begin to wrap memory and earlier data will be lost.
- Stations will probably need to be replaced **every 4-6 years.**

Keeping a station log

A station log should be maintained for each weather station that includes:
- Station serial numbers or names
- Dates that the site was visited
- Date range of the data being downloaded
- Maintenance that was performed
- Any issues with data readings or continuity

Proper maintenance of weather station components is essential for obtaining accurate data. Equipment must be in good operating condition, which requires a program of regular inspection and maintenance. The person in charge of the weather station can accomplish routine and simple maintenance. More difficult maintenance such as sensor calibration, sensor performance testing, and sensor component replacement, generally requires that the instrument be sent to the manufacturer.

Download, preventative maintenance, and inspection routine: every 1-2 months

- Check for biological infestations. Remove any insects or insect nests. Check accessible cavities such as the inside of the rain bucket, the white temperature/humidity sensor shield, the inside of the data logger case, and where the station mounts to the pole. Note how insects or other organisms are using/entering the station so you can stop them in the future.
- Check the rain gauge for debris, and poke a small wire through the bottom of the grate and into the drip hole to ensure that there is no blockage. You may have to remove the tipping bucket to clear out the drip hole (remove 4 Philips head screws on Spectrum buckets).
- Do a visual inspection of the anemometer at low wind speeds to make sure it spins smoothly.
- Check sensor leads and cables for cracking, deterioration, or damage by insects. Replace sensor cables if required.
- Check the mounting poles and guy-wires for structural damage, proper alignment, and for level/plumb.
- Download data and record the first and last date the data shuttle displays in the log-sheet.
- Please refer to the attached Watchdog 2900ET Manual and the WatchDog 1200 Micro Station Manual for further information

Weather station field instruction sheet (pg. 2)

Materials – *master key(s), gate codes (some may be 3278), Spectrum Data Shuttle, Device with Campbell LoggerLink app, tanglefoot, screwdrivers, log-sheet & pen, umbrella if rainy, crescent wrench to tighten mounting cables, (laptop computer, optional), stepstool for accessing tall stations, brushes or towels to clean stations*

☐ On **All** stations:
- Check that rain bucket is clear of leaves, and properly draining
- Perform visual inspection (detailed on other side)
- Scrape off old, and re-new Tangle Foot if needed
- Fill out log-sheet

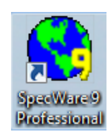
☐ Downloading **Spectrum** stations:
- Hit "display" button, cycle through parameters, check battery status
- Plug in data shuttle and start download.
- Replace batteries if below 50%
-

☐ Downloading **Campbell** stations:
- Get within 10 m of station.
- Connect to station with LoggerLink App
- Download data, save as .dat
- If Wi-Fi internet is available email .dat file to an address where the file can be downloaded and archived on the ASPA server

Downloading Spectrum data shuttle to a computer

1: Connect data shuttle to Black Dell laptop. (Needs to be the same computer each time)

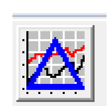
2: Open SpecWare program --->



3: Click on Logger (next to File) → click 'get watchdog 1000/2000 data' -

4: Download dialog will open, select all files to download from data shuttle. Do not reset for re-use

5: Open each data file, graph a couple properties to look for problems. ----(graph button)------->



6: if everything looks good then go to file → Export and export all months of data for station.

7: Save file as **stationname-mmddyy.txt**

8: Repeat for all stations

9: Once you are sure all data is collected, re-set data shuttle for re-use.

10: Save a backup copy of data on flash drive, hard drive, or cloud.

11: Email .txt or .csv files to the person who processes or posts data

4. Stream gauge overview

The ASPA-WRRC stream gauge network currently consists of eight gauges located on different streams throughout Tutuila. Site selection was made based on the following criteria:

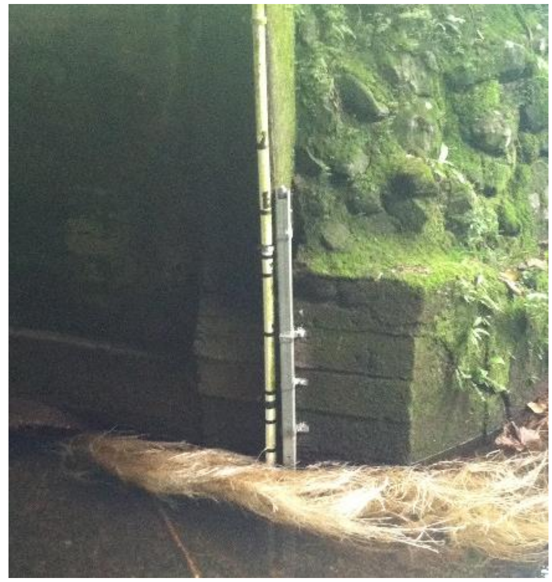
- Site access—sites where road access is available and where both sides of the stream are accessible (such as bridges) were highly prioritized.
- Proximity to historical gauges—where possible, sites were located at old USGS stream gauging sites.
- Bank and channel-control stability—sites with stable (bedrock or concrete) channels, (sides and bottoms) were preferred to sites composed of alluvial material (WMO 2010).
- Spatial distribution—sites were selected to be as representative as possible of the variability in Tutuila's different climactic and geological regions.

The stream gauges are instrumented with a stainless steel or titanium HOBO water level logging pressure transducer (PT) (model # U20-001-01 or U20-001-04-TI) that is installed in a durable steel housing. The housing is permanently mounted to an immobile structure such as a bridge or bedrock outcropping, and is held in place with concrete anchors and reinforced by concrete epoxy. The housings consist of a perforated 2-inch square galvanized steel pipe with a locking mechanism at the top. The locking mechanisms are outfitted with master-keyed brass padlocks and the mechanism is attached to the PT via a steel cable, which allows the PT to be removed for downloading and maintenance. Ideally, the bottom of the housing is constantly submerged in a pool or portion of the stream channel where the elevation of the water is controlled by a natural (channel control) or manmade (weir or dam) structure. The perforations in the housing allow water to enter and thus need to be kept clear of sediment and debris. The PT sits on a stationary bolt anchored through the bottom of the housing to maintain a consistent sensor elevation. The force of gravity, as well as some force applied by the steel cable attached to the PT is intended to keep the instrument in place. Also at each site, a staff gauge (a large metal ruler) has been bolted to an immobile streamside object so that the level of the stream can be visually assessed and recorded during site visits. These installations are designed to be permanent and withstand tampering and/or high flood conditions.

The feature that directly controls stream stage at any given point is termed the control feature. Most of the gauges in the ASPA-WRRC network have stage controls that are composed of natural objects on the streambed, such as large boulders, that serve to regulate the water height relative to flow. The PT stage measurements are sensitive to the configuration of these features and thus it is preferable to ensure they remain as consistent as possible. A few stations in the network have more stable control features such as concrete weirs or old dams.

4.1 Stream gauge sites

4.1.1. Nuuuli Gauge (Latitude: -14.3060, Longitude: -170.7105, Elevation: 18 m asl)



The Nuuuli stream gauge is located on the river left side of a small bridge that crosses the stream near the back of Lepapa Valley. The site is accessed by turning north off of the main road at the Family Mart and continuing up the valley until the first right turn over a bridge is seen. This site has been a USGS low-flow partial record site, and potentially a continuous record site also. Additionally, this bridge was instrumented with a temporary stream gauge by a researcher from San Diego for a couple of years prior to this project; however, that instrument has since been removed. A staff gauge (with English graduations in 10ths of feet) is mounted to the PT housing and can be read from across the stream. At this site, the channel is controlled on both sides by the bridge abutments and the gauging pool is fairly deep (about 40 cm at low water). The level control currently consists of a rock bar and is subject to being moved in a flood. Data consistency at this site would be improved by installation of a weir. Both high- and low-flow discharge measurements have been taken underneath or just downstream of the bridge.

Benchmarks and Datum	Latitude	Longitude	PT Location (from datum line)	Benchmark Description
River right datum point	-14.3060	-170.7105	Downstream, on river left bridge abutment	Rusted rebar piece protruding from bridge concrete. Level with bolt on river left
River left datum point				1/4" steel bolt installed in top of bridge on river left

4.1.2. Fagaalu Gauge (Latitude: -14.2915, Longitude: -170.6852, Elevation: 4 m asl)

The Fagaalu stream gauge is located on the river left side of a concrete bridge that crosses the stream at the easterly end of the Lyndon Baines Johnson (LBJ) Hospital parking lot. This is the most downstream vehicular traffic bridge, of two similar bridges, leaving the LBJ facility. The site is accessed by turning into the first entrance of the LBJ parking lot and proceeding around the back of the emergency room. The stream at this point is channelized with gabions, and the gauge is located under the bridge. Climbing down into the channel is required to access the gauge. This is definitely not recommended at high flows. A metric staff gauge is located directly across the stream on the river right side of the bridge. The channel is controlled on both sides by the bridge abutments, and the level is primarily controlled by channel control mechanisms. Thus, the site is especially vulnerable to dynamic changes caused by the movement of sediment or vegetation. This site has been reported to be subject to channel scour and fill in the past, as well as intrusion of excessive vegetation. Also at this same location, a stream gauge was installed by a researcher from San Diego, and was maintained by American Samoa Environmental Protection Agency (ASEPA) staff for couple of years prior to this project. However, since that time maintenance on that gauge has ceased. Data consistency at this site would be greatly improved by the installation of a weir. Both high- and low-flow discharge measurements have been taken about 50 m downstream of the bridge at a straight section just above a small footbridge.

Benchmarks and Datum	Latitude	Longitude	PT Location (from datum line)	BM Description
River right datum point	-14.2915	-170.6852	On line, on RL bridge abutment	1/4" bolt drilled in concrete around 46cm mark on the staff gauge, level to the top keeper bolts on the PT housing
River left datum point				The top keeper bolts on the PT housing

4.1.3. Fagasa Gauge (Latitude: -14.2867, Longitude: -170.7198, Elevation: 7 m asl)

The Fagasa stream gauge is located on the river right side of a small bridge leading to a family's house. The bridge crosses the stream directly off of the right side of the main road to Fagasa Village, and is located about 100 m up from the coastline. The channel is deep and hard to get into, so the housing has been extended to the top of the bridge where the PT can be accessed without climbing down. A staff gauge (with English graduations in 10ths of feet) is mounted to the PT housing and can be read from across the stream. At this site, the channel is controlled on both sides by the bridge abutments and the gauging pool is deep. At low water the level is controlled by a boulder jam below the pool. This site has been a USGS low-flow partial record site in the past. At the time of this writing this pool is habitat for a number of large freshwater eels. The level control is vulnerable movement in a flood, so data consistency at this site would be improved by installation of a weir. Discharge measurements are difficult to take on this steep and rocky section of stream and both high and low flows have been measured about 15m downstream of the bridge in a reasonably straight section.

Benchmarks and Datum	Latitude	Longitude	PT Location (from datum line)	BM Description
River right datum point	-14.2867	-170.7198	On line, on RR bridge abutment	Top mounting bolt (in concrete) of gauge housing
River left datum point				1/4" bolt in wall just below concrete corner

4.1.4. Leone Gauge (Latitude: -14.3299, Longitude: -170.7818, Elevation: 7 m asl)

The Leone stream gauge is located on river left and is mounted to a sloping concrete wall adjacent to a large concrete bridge leading to a local family's house. The site is accessed through another family's front yard. The bridge is visible on the western side of the Leone Valley Road, which is accessed by turning north off the main road at the large Catholic Church in Leone Village. The road really starts up at the back of the church parking lot and is difficult to find. The stream channel is wide, and is easily accessible by scrambling down the sloping concrete banks above the bridge. A staff gauge (with English graduations in 10ths of feet) is located directly across the stream on the right side of the bridge. The level control for this site is a very stable flow over a weir type structure created by the base of the bridge support. The water flows into a compartment under the bridge, which poses a significant water safety hazard at high flows. Do not be swept into the area under the bridge, as this could have serious consequences. Though the site is fairly stable, the PT housing may be subject to sedimentation and needs to be regularly checked to ensure it is kept clear of debris. The channel directly in front of the bridge is an ideal location for gauging measurements, though it may become dangerous at high flows.

Benchmarks and Datum	Latitude	Longitude	PT Location (from datum line)	BM Description
River right datum point	-14.3299	-14.3299	1 m upstream, on RL bridge abutment	1/4" bolt on top part of bridge
River left datum point				1/4" bolt on top part of bridge

4.1.5. Vaipito Gauge (Latitude: -14.2768, Longitude: -170.7051, Elevation: 14 m asl)

The Vaipito stream gauge is located at an out of use and fully sediment-filled village water reservoir located in a local family's backyard. This site was previously instrumented by the USGS, and still retains the old stilling well, which was cleaned out and put back into use. The site is accessed from a side road that is about 500 m up the Fagasa Pass Road. The side road crosses a bridge on the south side of the Fagasa Pass Road and is located next to a blue painted bus stop. From the side road, the backyard is accessed through a left turn into a narrow driveway between rock walls just before the road curves right. In early 2014, the site was instrumented with a short housing on the river right side of the stream that was directly mounted to the dam itself. This location was impacted by excessive sedimentation, therefore, on 26 April 2017 the old USGS stilling well was renovated and the PT was moved from the short housing to a new one inside the stilling well. Two old USGS staff gauges are intact at the site. One gauge is mounted inside of the stilling well and another is located outside of the stilling well. The level for this site is controlled by the dam, which makes a stable u-notch weir type structure. Discharge measurements can be taken at a location about 30 m upstream of the dam at a straight section of the steam, or measurements can be taken at the location of the stilling well. Due to the significant drop below the dam, caution should always be exercised when wading at this site.

Benchmarks and Datum	Latitude	Longitude	PT Location (from datum line)	BM Description
River right datum point	-14.2768	-14.2768	Downstream, on RR front side of dam	Location level with BM RL, right below (~3 ft toward stream from) large tree marked temporarily by rebar stake. (gone as of 2017)
River left datum point				1/4" bolt on top part of retaining wall on house side, ~14 ft upstream from dam

4.1.6. Maloata Gauge (Latitude: -14.3166, Longitude: -170.8287, Elevation: 22 m asl)

The Maloata stream gauge is located on the river right side of the stream, upstream of the main road crossing. The site is accessed by the main road to Maloata Valley, and the PT housing is visible from the road.The PT housing is mounted to a large boulder and is suspended in a slow moving pool behind the road culvert/ford. The level is controlled by the road culvert/ford. At low flow the stream stage is controlled by the rocks in front of the culverts, and at high flow the water flows over the road and the stage is controlled by a combination of water flowing though the culverts and over the sloping road surface. The channel banks are natural material consisting of large boulders that may or may not be stable. A staff gauge (with English graduations in 10ths of feet) is mounted on a river left boulder upstream from the road and downstream from the PT housing. This stream was a USGS continuous record site in the past, though the original site was located about 100 to 200 m upstream at an old, now broken, village water system dam. Quality discharge measurements are difficult to take on this steep and rocky section and both high- and low-flow measurements have been taken in the pool just above the road crossing, or upstream of the old USGS site.

Benchmarks and Datum	Latitude	Longitude	PT Location (from datum line)	BM Description
River right datum point	-14.3166	-14.3166	On line, on RL mounted to boulder	1/4" bolt drilled in at level to top bolts on housing, in big rock
River left datum point				The top keeper bolts on the PT housing

4.1.7. Afono Gauge (Latitude: -14.26264, Longitude: -170.6517, Elevation: 14 m asl)

The Afono stream gauge is located at the site of an older USGS continuous record gaging station, and utilizes the old stilling well on river left that remains at the site. In addition to the old stilling well, the site has remnants of a small concrete weir that controls low flows. The gauge was installed in early 2017. The stream is channelized by gabions on the left side of the stream, however the river-right side is a natural bank of alluvium. The site is located on the side of the Afono Village access road, and a small log footbridge extends across the stream. The PT housing is constructed in the same style as the other gauges in the ASPA network, but is located inside of the old stilling well, which needs to be unlocked at the top for access to the transducer, or at the bottom for access to the bottom of the well (for cleaning and maintenance). Upon installation, the stilling well was filled with sediment (and prawns), and it is likely that sediment will need to be removed periodically in the future. A staff gauge is strapped to the outside of the stilling well for easy reading.

Benchmarks and Datum	Latitude	Longitude	PT Location (from datum line)	BM Description
River right datum point	-14.2626	-170.6517	Inside of stilling well about 0.7 m into the bank	At bottom of coconut tree, directly across stream from stilling well
River left datum point				Rightmost hole in stilling well about 2 m height (sits below door when closed)

4.1.8. Fagaitua Gauge (Latitude: -14.26847, Longitude: -170.61781, Elevation: 10 m asl)

The Fagaitua stream gauge is located on a small residential bridge. The bridge serves a single family's home, and is located just below the confluence that brings together the two main branches of Fagaitua Stream.
The PT was installed in early 2017, in a short housing strapped to the river-left side of the bridge abutment. A temporary staff gauge consisting of a construction ruler was installed, but a more durable gauge is needed as a replacement. Upon installation, the area under the bridge was cleared of large rocks, a task which may need to be repeated periodically after large floods. Discharge measurements have primarily been taken just downstream of the bridge. The site is accessed by turning north off of the main road and heading up a small concrete road that passes the Fagaitua water tank. The bridge is just past the water tank, north-west of a dirt turnaround, at the local senator's house.

Benchmarks and Datum	Latitude	Longitude	PT Location (from datum line)	BM Description
River right datum point	-14.2685	-170.6178	Just below benchmark mounted to short section of bridge that sticks out	Right point at corner, underside of downstream end of bridge, marked by bolt in concrete
River left datum point				Left point at corner, underside of downstream end of bridge, marked by bolt in concrete

4.2 Stream gauge site development

To convert stage data into stream discharge information and maintain consistency throughout long-term data collection, a number of pieces of information must be gathered and kept up-to-date:

1. Surveyed locations of benchmarks located outside of the stream channel (Harrelson et al. 1994)
2. Cross section channel profiles
3. Longitudinal stream profiles
4. Continuous water stage or level via pressure transducer measurements
5. Spot checks of water level to verify against transducer data
6. Repeated manual streamflow measurements at all flow stages

These components are discussed in more detail below.

4.2.1. Benchmarks and Local Datums

The height or stage of the water level in a stream is the primary variable used to assess streamflow. This height is generally recorded relative to a local point of known elevation or datum. The pressure transducer records the water column height above its sensor intake. This value must be referenced to the height above or below a fixed datum because the location of the pressure transducer could potentially change through time (due to floods or movement of the gauge housing). A convenient and long-lasting method to accomplish this is to set local benchmarks outside of the stream channel that define a stable reference elevation. Ideally benchmarks are developed and documented through the use of land survey techniques. Benchmarks can be constructed with a pin and concrete, or natural objects such as large rocks can be used. Regardless, the ideal attributes of a good bench mark are (1) located away from the stream where its position will not be disturbed by large floods, (2) be large and heavy enough to maintain a stable position and elevation through time, and (3) last as long as the expected life of the stream gauge. Once benchmarks are selected, a local datum elevation can be defined. In the ASPA network, this datum elevation is generally defined as the horizontal line connecting two points at the same elevation—one each on the right and left side of the stream bank. At this time, these datum point benchmarks are the only established benchmarks in the system. However, it would be more ideal to establish a permanent off-stream benchmark at each site and then survey the datum point benchmarks into the permanent benchmark.

At most of the ASPA-WRRC sites, the datum elevation is generally established at the top of the stream bank or on the abutments of bridges. Each datum point is recorded as either the river right or river left point and a string stretched between the two should create a horizontal stream perpendicular line.

4.2.2. Cross-sectional and Longitudinal Channel Profiles

Upon installation of each gauge, a cross-sectional profile was performed to record the shape and dimensions of the stream channel at the gauge location. This cross section generally follows the axis of the horizontal datum line and is located as close as possible to the pressure transducer. This measurement is useful for observing and quantifying changes in stream channel morphology and is also used for calculation of the wetted perimeter, which is used in the estimation of streamflow with analytical solutions such as Manning's equation. Also these solutions may also require measurement of the longitudinal slope of the water surface, or more specifically the energy grade line. This can be approximated by measuring the slope of the bottom of the stream channel. However, this is only an approximation based on the assumption that the water surface slope follows the channel slope, which is not always true. Longitudinal profiles for some but not all of the gauge sites in the ASPA system were measured in 2016. Another option for approximating channel slope is to use topographic data, which has been performed for all ASPA sites.

Cross-section and longitudinal profiles were recorded at baseflow stage. At each cross-section point the vertical distance between the datum line and the streambed was recorded. The height of the water level was also recorded. Data was plotted and the wetted perimeter was calculated by iterating the length of the stream channel under water at 1 cm incremental increases in water stage height. Longitudinal profiles were performed with basic land surveying techniques. The elevation change in the water surface and channel bottom were measured as far as practical up and downstream from each gauge site. At all sites, and especially at sites where it was not possible to perform a longitudinal profile, the channel and bank slope was measured using a profiling tool on a 1 m resolution DEM in ArcGIS.

4.2.3. Stage Measurement

The heart of each stream gauge is a HOBO PT. These instruments essentially measure the height of the water column above their sensor port. More specifically, they measure the pressure supplied by the weight of the water column plus pressure provided by atmospheric pressure. Since the atmospheric pressure varies throughout the day and during weather events, this variation must be removed from the PT measurement to obtain the true height of the water. An explanation of this process, barometric pressure compensation, is provided in Section 4.3.1.

The PT's are currently set to measure water level at 15 min intervals. In the future, this could be changed to 10 min intervals if desired, since water levels in Tutuila's streams change rapidly. At 15 min intervals, the pressure transducers will record data for a number of months. However, considering the harsh environment where the gauges are located, it is best to check on each gauge, download data, and clear any obstructions on a monthly basis. This generates a lot of individual data files to be processed (Fig. 3). Files can be manually processed using a spreadsheet program such as MS Excel and the HOBOware Pro software to perform barometric compensation. However, as this process is time consuming and error-prone, using script based batch processing methods are preferred. At present, WRRC is developing scripts to automate data processing and these are intended to be made available to ASPA in a user-friendly form in the near future.

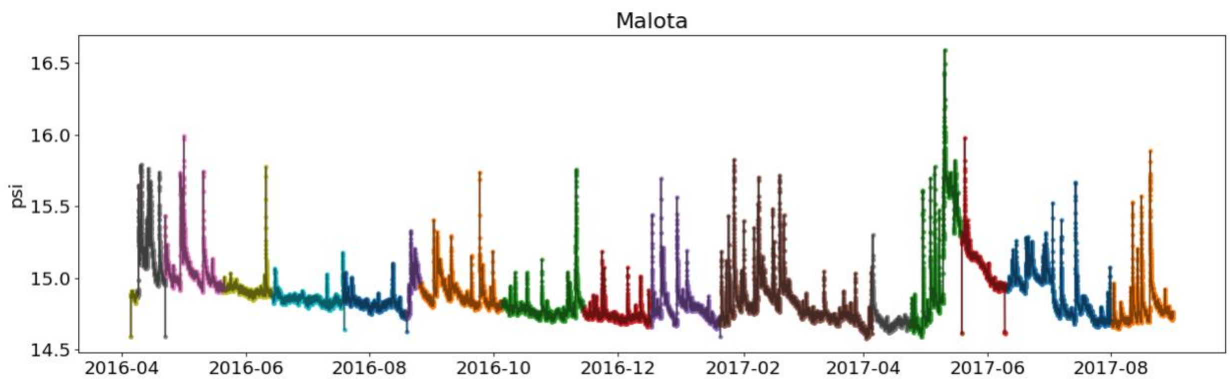


Figure 3. Example of batch processing output for raw streamflow files. Each color line represents data from an individual download event.

4.3 Stream measurement data processing and rating curves

The fundamental piece of information stream gauges measure is the stream's stage, or height. However, the primary piece of information that most applications are interested in is stream discharge (Q). Manual streamflow measurements are the gold standard for calculating discharge from stage, though it is possible to roughly estimate discharge based on analytical solutions such as Manning's equation. Additionally, variation in barometric (air) pressure necessitates compensation for this effect so that true stage heights can be calculated.

4.3.1. Barometric Pressure Compensation

The HOBO PTs are set to log pressure and temperature every 15 min. This data forms a continuous sequence of pressure data, which is equal to the sum of the water column pressure above the instrument and the barometric pressure at each site (Fig. 4). The cyclical and variable effects of barometric pressure must be compensated for to calculate a true water level from the pressure reading. This is accomplished by recording barometric pressure in the open air with a separate instrument, a barometer (essentially another water level logger that is sitting in a desk drawer somewhere), and subtracting the barometric pressure from the stream PT data during post-processing. Barometers should be deployed in any location that is not sealed off from the outside air (e.g., closed Pelican cases are a bad location). Good locations include desk drawers or hanging in an open room. Well-sealed air-conditioned rooms could potentially cause artificial pressure gradients, but as long as the room has a reasonable amount of ventilation there should not be a problem. At least two (one for backup) continuously logging barometers should be deployed in an easily accessible location on the island at any given time. Since Tutuila is relatively small, inter-island variations in barometric pressure are probably insignificant enough to be ignored, thus any barometer on the island should be acceptable for compensation of stage data from any stream gauge on the island. However, if it is later found that there is significant variation in barometric pressure between different parts of the island, each region should have its own barometer deployed and barometric compensation can be performed with region specific data.

The barometers currently deployed at the ASPA headquarters are plastic HOBO level loggers (U20L-04). Although these loggers are supposedly waterproof, they are better suited for non-submerged use, and probably should not be substituted for broken PT's in the water. Generally, performing the barometric compensation involves downloading barometer and stream-stage data to one computer and lining up the datasets based on date and time. Some interpolation may need to be done if time steps in the datasets are out of synch. The barometric pressure readings are subtracted from the stream PT readings, and the resulting pressure value can then be converted to water height. Automatic barometric compensation can also be performed by the HOBOWARE pro software on individual .hobo files. It is possible to manually baro-correct PT data from other brands of barometers, and script based programs can help to automate barometric compensation even further.

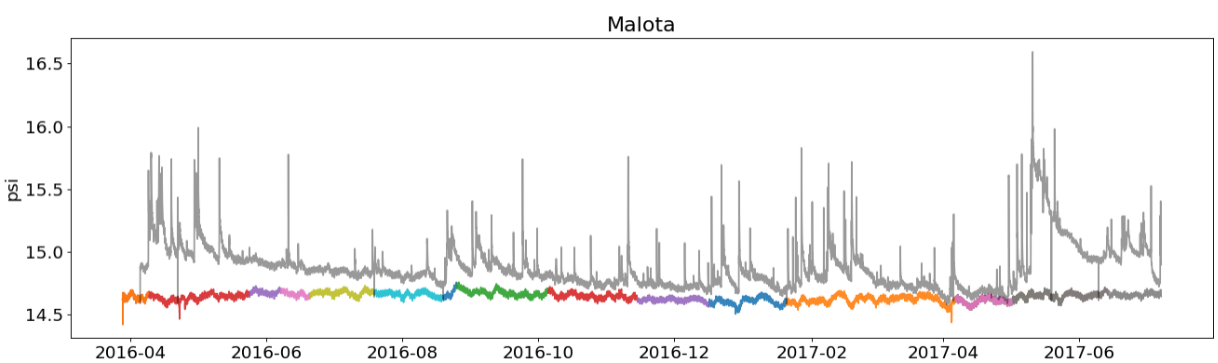


Figure 4. Example plot of raw stream stage data (grey line) and barometric pressure data (colored lines) from a barometer located at ASPA HQ. The barometric pressure data is subtracted from the stage data to obtain height of the water column above the PT.

4.3.2. Manual Flow Measurements

Manual discharge measurements are imperative for developing rating curves. This process involves taking flow measurements while the PT is deployed and logging, and recording exact measurement time and date so that both datasets can be matched up. It is best to avoid removing and downloading the PT during a flow measurement site visit, as the PT will sometimes record erroneous data while it is out of the housing. At present, ASPA is equipped with a SonTec FlowTracker to take manual flow measurements. This instrument measures point based water velocity (SonTek/YSI, 2001), and offers real-time calculation tools to assess stream discharge via the velocity-area method (Turnipseed and Sauer 2010). Basic operation instructions can be found at: (https://www.epa.gov/sites/production/files/region8/qa/FlowTrackerOperationSOP.doc) and detailed instructions are given in SonTek (2007). In addition to the standard 2 m long wading rod included with the FlowTracker, ASPA is also equipped with a custom 4 m long high-flow rod, for measuring stream discharge when water levels are too high to be safely waded. The high-flow rod allows operation of the FlowTracker and application of the same velocity-area method while standing on an overhanging structure (such as a bridge). An ideal rating curve would contain representative flow measurements for all possible stream stages. While it is often difficult to be in the right place at the right time to capture very high-flow events, the more high-flow events that can be measured, the more accurate the curve will be. Additionally, regularly scheduled ongoing flow measurements should be taken to assess if rating curves are still accurate. If it is found that the stream control has changed to the point where a rating curve is no longer applicable, it may be necessary to re-develop the rating curve.

4.3.3. Rating Curves

An empirical relationship that describes how the stream stage increases or decreases with a corresponding change in Q is called a rating curve (WMO 2010). Since this relationship is unique to each gauging location, a separate curve for each site must be developed. Rating curves are developed by taking manual measurements of stream discharge at many different stream heights, and comparing these measurements to concurrent stream stage measurements from the continuously logging PT. Once discharge and stage data are temporally matched up (Fig. 5), a curve can be plotted through the data (Fig. 6). While this curve may be approximated with linear, logarithmic, or power functions, in reality the relationship often reflects a combination of these relationships as the channel geometry and control features change with higher or lower stream stage. At present in the ASPA-WRRC stream gauging network, rating curve development is ongoing. Preliminary rating curves use a relationship based on a modified Manning's discharge calculation (Fetter 2000) to incorporate how channel geometry affects cross-sectional area at different stream stages. This relationship is still under development pending acquisition of additional high-flow measurements.

Generally, the water height at any point in a stream is controlled by the next proximal downstream feature that water flows over, such as a weir or rock bar (dam control), or simply by the slope of the stream bed (channel control). If the control feature changes, due to rocks being moved in a flood, for example, then the rating curve may need to be modified with a correction factor or it may need to be entirely re-developed. Rating curve development is performed by taking concurrent measurements of discharge and stage at many different stream heights and plotting a curve through the data. This relationship can take the form of a linear, logarithmic, power—or a combination of these functions—and is unique to the specific channel geometry at the site. On Tutuila, rating curve development has been initiated by WRRC. However, more high flow data is needed and curves should also be regularly checked and maintained by ASPA personnel.

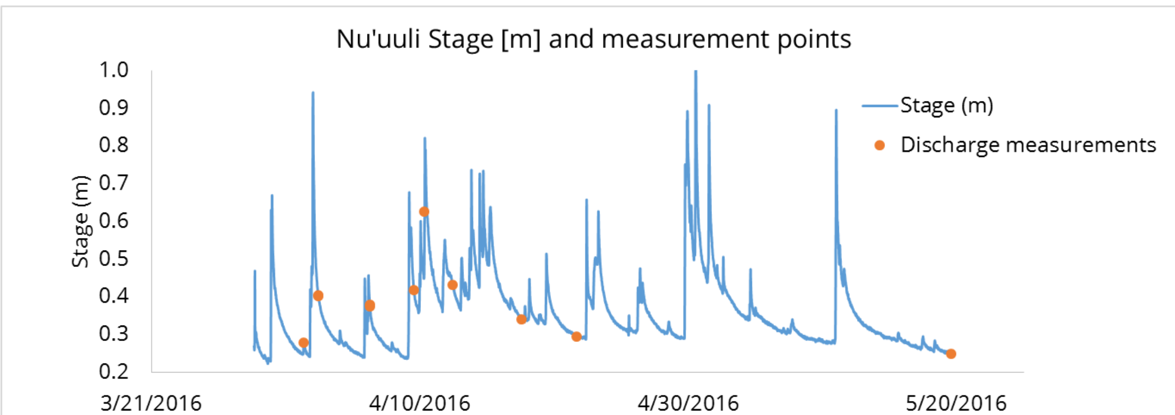


Figure 5. Example of stream stage and times where streamflow measurements were taken.

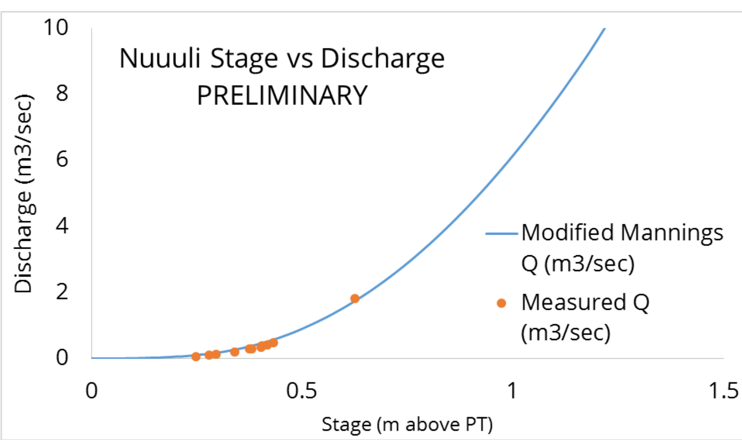


Figure 6. Example stage-discharge rating curve relationship based on modified Manning's discharge calculation

4.4 Stream Gauge Care and Maintenance Tips

The reference elevation, or datum, on WRRC stream gauges generally takes the form of two points on the banks of the stream, across which a string can be stretched to make a horizontal stream-perpendicular line. Stage measurements must be converted into the reference frame of this datum so calculations can be performed in a coordinate system that remains stable through time, despite any potential channel modification. Since all of the components of site geometry (e.g., PT height, channel shape) must be known to keep stage measurements within a consistent reference frame, maintenance should be focused on maintaining the consistency of these distances. Also is it important to ensure any changes from natural perturbations or planned maintenance are measured and documented. Benchmark locations should be maintained so they remain visible and easy to find.

Most gauges in the ASPA-WRRC network have stage controls composed of natural objects on the streambed, such as large boulders, that serve to regulate the water height relative to flow. Unlike a well-built concrete weir, these features are vulnerable to being rearranged in floods. The PT stage measurements are sensitive to the configuration of these features and thus maintaining as much consistency as possible with them is important. Cleaning out organic debris or smaller cobbles that can clog up the stage controls will help to keep data comparable. Maintaining good photographic records of stage controls is helpful for knowing when and how changes have occurred. See Appendix A for recent photographs of control features.

Sediment buildup inside of or around pressure transducer housings is also problematic, as this can either push the transducer up in elevation, giving an incorrect reading, or it can hydraulically disconnect the stream from the water level in the PT housing. Removal of any sediment in or around the PT housing during monthly downloads should control the issue, and if it is found that there are chronic sedimentation issues with any gauges, relocation could be considered.

A stream gauge maintenance tip-sheet is included.

Stream gauge care and maintenance tip sheet (pg. 1)
General tips

Care and maintenance schedule:

- Pressure transducers should be download and re-launched **monthly**, the stage reading from the staff gauge should also be noted at each site visit
- Barometers should also be download every month. However, they do not have to be re-launched each month, only when their data capacity is getting full.
- To maintain rating curves, a regular flow measurement at least **once every other month** is recommended.
- Grease lock if needed or at least every **3 months**
- To improve rating curves, high-flow measurements should be taken when heavy rains flood streams; this can be done **as frequently as possible** until rating curves have sufficient data
- To understand if and how channel and stage controls change with flood events, stream control structures should be photographed **every 6 months** and compared with past photos to assess the degree of change.
- Pressure transducer battery life will probably necessitate replacement of the instrument **every 2-4 years**.

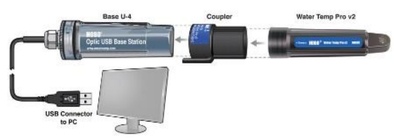
Preventative maintenance, and inspection routine: every 1-2 months

- If excessive sediment builds up around transducers it needs to be cleared. Implementation of mechanisms for preventing sedimentation are recommended.
- If pressure transducers are found to be dirty, they should be rinsed off or gently scrubbed with a brush. See attached HOBO user manual for cleaning instructions.
- If it is found that the instrument is not being held in a stable position within the housing, an alternate solution must be devised as it is of key importance that the base datum from which the water level is measured must not change.
- It is essential that multiple barometers (have at least one backup) are kept in a safe location where they are exposed to the atmosphere and can be downloaded regularly.
- Again, in addition to downloading data, regular collection of discharge data is imperative for developing rating curves. Of particular importance is collection of data when heavy rain events swell streams, as high flows are difficult to capture.

Stream gauge download and maintenance sheet (pg. 2)
Field procedures

Materials – *master key, laptop computer, HoboReader (USB basestation), lock oil, log-sheet & pen, river shoes, gloves/shovel for clearing sediment*

- ☐ Unlock and remove logger. Ensure housing is not covered/full of sediment on outside or inside. If sediment accumulation has built up, clear it out and make a note in logsheets. Station location may have to be changed.
- ☐ Look at staff gauge, note water level (in *tenths* of feet (or cm at Faga'alu)) and date/time on log sheet
- ☐ Note any changes in channel geometry or control structure (generally after floods)
- ☐ Fill out log-sheet. (don't forget to look at battery status of logger)
- ☐ Download logger with HoboWare Pro:



HoboWare steps

- Connect logger to computer with the Hobo Optic USB base station
- Press readout button: It looks like this: ------------>
- Choose stop logger option (make sure you have
- downloaded the data before restarting)
- Logger will download, and will be stopped
- Look at data for quality check purposes.
- Save project file in form **stationname-mmddyy.hobo** (month,day,year), save in a folder named in the form **mm-dd-yy** (date of download)
- Set loging interval at 15 minutes, rename logger as **stationname-#-month** ----------->
- Start logger at an even interval of 15 minutes (on the hour, 30, 15, or 45 minutes after)
- Make sure logger is 'launched' or 'awaiting delayed start' with ----------------->
- Save file as: **sitename-mmddyy.csv**
- Save a backup copy of data on flash drive, hard drive, or cloud.

Office procedures

- Download BaroLogger with HoboWare (same steps as above). Fill out a row in the log-sheet for BaroLogger, too.
- Save file as: **Baro1-mmddyy.csv** or **Baro2-mmddyy.csv**
- Email all .csv files to Katrina and Chris
- Ensure staff gauge water levels, and download date/times are logged in logbook
- Transfer logbook data to a spreadsheet

Contact Katrina (katrinam@aspower.com) or Chris (cshuler@hawaii.edu) if there are any problems.

5. Aquifer Monitoring Overview

As of this writing, five dedicated aquifer monitoring locations have been established on Tutuila. Two of these locations are active ASPA telemetered production wells, and three are ASPA monitoring wells with installed data loggers. Parameters measured at both site types include water level and electrical conductivity (which can be converted to salinity or Cl^-).

Telemetered ASPA production well sites are active wells that pump water to the distribution system almost continuously. These sites generally have AC power available and have a supply pipe that brings a pressurized stream of water to the surface whenever the well is on. While not all wells in the ASPA system are connected to the ASPA radio-telemetry (SCADA) system, the wells selected as aquifer monitoring sites are connected to SCADA.

Dedicated monitoring well sites in the ASPA network generally consist of an open borehole with a capping system welded onto the top of the casing. The three existing monitoring wells are generally cased to about 100 ft depth. In wells 80 and 92 the capping system consists of an 8 inch steel plate with a 2-inch diameter threaded steel coupling welded into it, and in Well 46 the coupling has a 1.5-inch orifice. A threaded PVC cap seals the well from contamination. This cap is connected to the end of a fiberglass reinforced tape, which connects and suspends the datalogger housing at a fixed depth below the water table. The datalogger housing consists of a perforated 1.25 inch PVC casing with a HOBO water level logger (U20-001-01) and a HOBO conductivity logger (U24-002-C) that fit tightly inside. The loggers record data at 15 min intervals, and have enough memory to store over 90 days' worth of data. The loggers must be manually pulled up to download data. The three monitoring wells are re-purposed production wells (with pulled out pumps), and it is highly recommended that upon future abandonment of production wells, these sites also be converted to monitoring wells in order to expand the spatial distribution and utility of the groundwater monitoring network.

5.1 Aquifer monitoring sites

5.1.1. Production Well 33 (Latitude: -14.32437, Longitude: -170.73215, Elevation: 23.6 m asl)

Well 33 was selected because it is central to a high-production well-field region, is designated as a groundwater under the direct influence of surface water (GUDI) well, and because it has an ASPA telemetry (SCADA) system already installed. The aquifer monitoring instruments deployed at this well transmit analog signals through the SCADA network so data can be interpreted, logged, and read out at ASPA headquarters via the ClearSCADA human machine interface (HMI, fancy word for software). Water levels are read by a Geokon (4500c) small diameter vibrating-wire piezometer that is installed below the water table through the well's sounding tube. This instrument is directly wired to a Geokon (8020-59) frequency to an analog converter that outputs a 4-20 mA signal to the SCADA system. Electrical conductivity is monitored in the production stream with an Aquametrix (AS-M-1-P-1) contacting conductivity sensor with stainless steel electrodes connected to an Aquametrix (AM-2250TX) Transmitter that converts the conductivity sensor output to a 4-20 mA signal. The sensor is mounted in a brass housing that is hot-tapped to the main production line, before in-line chlorination. The sensor housing has a ball valve on the bottom that allows a small drip of water to escape so that a minimal flow past the sensor is maintained. (Note: we still need to measure the height of the measuring point above the concrete slab).

5.1.2. Production Well 62 (Latitude: -14.347566, Longitude: -170.748702, Elevation: 63.3 m asl)

Well 62 was selected because the Iliili well-field region produces a significant quantity of water and because Well 62 is a non-GUDI well with a SCADA system installed. The aquifer monitoring instruments deployed at this well transmit data to the ASPA SCADA system as they do at Well 33. An identical (to Well 33) Geokon (4500c) piezometer connected to a Geokon (8020-59) frequency to analog converter is installed below the water table to measure water level. At Well 62, electrical conductivity is monitored in the production stream by a different instrument, an Aquametrix (ES-5-C-1) toroidal non-contacting conductivity sensor with a direct 4-20 mA output. The sensor is loop powered and does not require an additional transmitter. The toroidal sensor is mounted in a flow through type housing that is double hot-tapped to the main production line, before in-line chlorination. The sensor housing has two ball valves, which allow pressure reduction and modulation of flow through the sensor. Well 62 has no well-pad riser, but the casing itself extends 62 cm off of the concrete well slab, and the top of the sounding tube stands about 20 cm above the casing top.

5.1.3. Monitoring Well 46 (Latitude: -14.324392, Longitude: -170.732229, Elevation: 23.5 m asl)

Well 46 was shut down in 2016, since it is designated as a GUDI well and is located less than 10 m to the west of Well 33. Therefore, pumping effects from Well 33, pumping at an average of 200 GPM, will most certainly be reflected in the water levels at Well 46. The well pump was pulled out in 2016 and a steel plate with a 1.5 inch threaded port was welded on to the top of the casing in early 2017. The instrument package deployed in August 2017 consists of a HOBO water level logger (U20-001-01) and a HOBO conductivity logger (U24-002-C) inside of a PVC casing that was deployed at 25 m below the casing lip. At the time of deployment, the water level was 23.4 m below land surface and weather conditions had been dry for a number of days. The fiberglass tape suspending the instruments is tied to the PVC cap at the top of the well to maintain a consistent depth below the casing. Excess tape was stored discretely inside of an old pipe running from the well port to the side of the wellhead slab. Water level measurements were taken from the top of the threaded port.

5.1.4. Monitoring Well 92 (Latitude: -14.342872, Longitude: -170.767561, Elevation: 49.0 m asl)

Well 92 was put out of production prior to 2013. It is located between two other active pumping wells—Well 91 located about 230 m to the south and Well 93 located about 140 m to the north. Therefore its water level is likely affected somewhat by the pumping drawdown in these wells, which both pump at an average rate around 200 to 300 GPM. A steel plate with a 2 inch threaded port was welded on to the top of the casing in late 2017. The instrument package deployed in August 2017 consists of a HOBO water level logger (U20-001-01) and a HOBO conductivity logger (U24-002-C) inside of a PVC casing deployed at 51.5 m below the top of the casing. At the time of deployment, the water level was 49.2 m below land surface and weather conditions had been dry for a number of days. Well 92 has two well-pad risers that together stand 53 cm above the concrete well slab, and the top of the 2 inch diameter monitoring well port stands 8 cm above the concrete well slab. The measuring point where water level measurements were taken is the lip of the threaded port. The fiberglass tape suspending the instruments is tied to the PVC cap to maintain a consistent depth below the casing and excess tape was stored discretely inside of an old pipe running from the well port to the side of the wellhead slab.

5.1.5. Monitoring well 80 (Latitude: -14.33889, Longitude: -170.77324, Elevation: 43.8 m asl)

Well 80 was designated as a contaminated well and was abandoned in 2014. Well 80 is located about 180 m to the northeast of Well 70, which typically pumps at about 350 to 400 GPM. Well 80’s water level may be somewhat affected by pumping drawdown at Well 70. Typical static water levels at Well 80 are around 40 to 42 m below land surface. A steel plate with a 2 inch threaded port was welded on to the top of the casing in late 2017. The well-pad riser stands 21 cm off of the concrete well slab, and the top of the 2 inch diameter monitoring well port stands 8 cm above the concrete well slab. As of this writing, the sensor package has not been deployed due to complications with potentially hazardous items located at the bottom of the well. Once the well is logged and cleaned out, the sensor package should be deployed about 2 m below water level.

5.2 Monitoring Well Care and Maintenance Tips

The HOBO PT and conductivity loggers deployed in monitoring wells are exposed to different environmental conditions than those in streams. While hazards of moving water are nonexistent in wells, potential stagnation of water within the well bore may contribute to increased rates of corrosion or biofouling. Additionally, higher salinities in wells located in areas with thinner freshwater lenses may expose instruments to more corrosion. Loggers should be inspected for signs of these conditions at each download event. If biofouling is detected (i.e., logger is slimy or has visible biological growth) it can be immersed in and gently cleaned with a 10% bleach solution, or warm soapy water. If crusty deposits are found on HOBO conductivity sensors, they can be immersed in vinegar and water to dissolve the corrosion. See (http://www.onsetcomp.com/product-cleaning-reference-guide) for detailed instructions on cleaning HOBO PT's (model U20-001) and conductivity loggers (model U24-002-C).

Water levels measured by the PT are relative to the depth of the logger in the well. This distance must be carefully measured and kept consistent from a fixed reference point. Typically, this is done by using a water level tape/probe to determine the water level below a measuring point, which is generally defined as the lip of the sounding tube or the monitoring well port. Because the height of the measurement points may change, measurements of the well-pad riser and sounding tube length should be maintained and updated anytime the well is modified. The measuring point and well-slab elevations should ideally be professionally surveyed to establish their altitude above sea level so that water level measurements can be reported relative to sea level.

6. Continuing and Future Work

6.1 Weather Stations

The current Wx network includes multiple types and brands of weather stations. Through using these stations over 2 years, ASPA and WRRC staff have begun to prefer Campbell stations over other brands, although they do cost (≈$3,000.00) about twice as much as the Davis and Spectrum stations (≈$1,500.00). Also, the one Davis Station in the network has had fewer maintenance problems and data gaps then the Spectrum stations, which seem to have numerous electronic and design issues that make them perform poorly in American Samoa's humid climate. As stations are replaced, and as other funds become available to support the network, it is recommended that additional Campbell stations be purchased and installed to replace existing Spectrum stations. Additionally, the Campbell stations dataloggers can be purchased with an integrated Wi-Fi chip that allows the potential for connection to a telemetry system, either through the existing ASPA SCADA network (once it is upgraded to handle digital input) or potentially through development of a dedicated long-range Wi-Fi network.

6.2 Stream Gauges

In addition to continued development and upkeep of rating curves, stream gauge sites need to continually be monitored for changes in channel geometry or changes in control features, as streams are highly dynamic environments due to reworking and moving of sediments and rocks during floods. A close watch on data consistency is essential for detecting changes, as well as retaining staff with familiarity with the sites through regular visits. Other researchers on Tutuila (A. Messina, personal communication) have observed that baseflow discharge is fairly consistent after multiple days without rain. For example, if a stream's baseflow stage has suddenly shifted, especially if the shift occurs after a large rain event, then a shift in the stage/discharge relationship may need to be applied. This shift may only need to be applied to the low-discharge part of the rating curve, since higher stages are controlled more by channel slope than by the placement of streambed boulders.

More work is also needed to accurately survey the gauging sites, establishing at least 3 fixed benchmarks, and clearly documenting the height of pressure transducers in relation to the datum. To maintain a good record of channel and level control geometries, a photo log should be kept, whereas erodible stream bank features and level control features (rocks downstream of the PT deployment) should be photographed and archived for comparison through time. Examples of these logs from 2015 are presented in Appendix B.

To significantly increase gauging site stability, a long-term priority would be to install weirs (flow-over dams) immediately below the stream gauge housings. These structures are generally made of concrete and keep water level control much more stationary than natural controls.

6.3 Well Monitoring Instruments

As of 2017 test installation of aquifer monitoring instruments in production and monitoring wells is still ongoing. Multiple types of sensors have been deployed at different sites, and their long-term efficacy, as well as their ability to maintain connectivity with the ASPA telemetry network will continue to be assessed for the next two years.

Ultimately it would be ideal to expand the monitoring network to contain 10 to 20 monitoring wells with at least 2 wells located in each significantly sized well field on the island. This would provide sufficient observation points for calibration and/or validation of numerical groundwater models. Additionally, incorporation of water level and conductivity instruments could be performed concurrently with the expansion of the ASPA SCADA telemetry network. Water level and conductivity information is as useful as flow and system pressure information, and thus the relatively small investment in outfitting the SCADA system with the capability to measure these parameters would benefit operational and scientific objectives.

The University of Hawaii Water Resources Research Center is committed to assisting with the development of the monitoring network and has committed to providing technical assistance for the initial three years of this project and, contingent on funding, afterwards. It is ideal for ASPA personnel to build the long-term capacity within the organization to perform regular maintenance, data collection, data analysis, re-installation, and development of rating curves in a sustainable manner. This information will benefit water resources management and the American Samoan people for years to come.

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Appendices

Appendix A. level control geometry photo log

Control structure for Nuuuli gage, rock bar in background. April 2016

Control structure for Fagaalu gage, downstream channel control. April 2016

Control structure for Malota gage, rocks piled at culvert entrances. April 2016

Control structure for Vaipito gage, lip of dam. April 2016

Control structure for Leone gage, lip of bridge base. April 2017

Control structure for Fagasa gage, rock bar in top center of top photo. Note position of red rock in both photos. April 2016

Control structure for Fagaitua gage, rocks center of photo. April 2017

Terrible photo of control structure for Afono gage, shows old USGS concrete weir structure. Weir has a gap in the middle where a large boulder has lodged. April 2017

Appendix B. Log sheets

Detailed and accurate log sheets should be maintained for stream gauges, weather stations, and monitoring wells. Ideally the log sheets would contain information pertaining to installation conditions and procedures, events that did or may have affected data integrity, routine documentation of when downloads occurred, and records of any maintenance performed.

While log sheet templates can be printed and filled out in the field, it will be much more beneficial in the long run to have an electronic version of the log sheets. If possible, it would be useful to have a master copy of the log-sheet hosted online so that all logged information can be stored, accessed, and benefit from some sort of version control.

Stream gauge network log-sheet						
Site name:	**Date & Time**	**Date range of data download**	**Logger battery status**	**Staff gage height**	**Maintenance performed**	**Notes**

Weather station network log-sheet						
Station name:	Date & Time	Date range of data download	Battery status	Shuttle battery	Maintenance performed	Notes

Monitoring well logger network log-sheet						
Site name:	**Date & Time**	**Date range of data download**	**Logger battery status**	**Water level [m]**	**Maintenance performed**	**Notes**

Appendix C. Technician position description recommendations

Due to the wide scope and complex nature of the tasks required to upkeep hydrologic monitoring instruments, it is recommended that a skilled technician be employed on a full to half time basis to keep instruments in working order and to ensure that data quality is maintained. This person's tasks will include downloading data, maintaining instruments, assessing data quality, and determining the need for, and implementing, future data collection campaigns. The technician should be equipped with a broad skill set including the technical and computer skills to work with high-tech instruments, the mechanical skills to maintain mounts, deployments, and stream channelization, as well as the environmental skills to work in challenging weather conditions and in wilderness areas distant from roads. An example of position a description is given below.

Job Description and required tasks:

- Maintaining operational condition of a multitude of instruments in the island wide network, including weather stations, pressure transducers in streams, and data loggers in groundwater wells.
- Regularly downloading data from weather stations, pressure transducers in streams, and data loggers in groundwater wells
- Troubleshooting malfunctioning instruments, suspect data, and changes in site conditions
- Basic analysis and (QA/QC) (quality assurance and quality control) of collected data.
- Operation of down-hole instruments during well maintenance, pump tests, and for regular water level logging.
- Taking water samples and field measurements of water quality parameters such as conductivity, chloride content and microbial indicators
- Conducting regular stream flow measurements and development/upkeep of rating curves
- Procuring replacement instruments and parts
- Posting data on a website
- Interacting and communicating with off island technical support personnel such as University of Hawaii collaborators or instrument manufacturers
- Engaging in and assisting with ASPA technical studies, (such as the GUDI studies)

Skills required

- Competence with MS Excel or equivalent spreadsheet/data organization programs
- Familiarity with instrument support computer software programs
- A valid U.S. or American Samoa driver's license
- Sufficient physical fitness to climb 10-foot-tall towers, hike up to 10 miles per day, and ability to lift 60 pounds.
- Willingness to work in challenging weather conditions and to wade in hip-deep streams
- Strong swimming ability
- Comfort working in wilderness settings
- Intermediate construction abilities
- Strong communication skills, both spoken and written

Minimum Qualifications:

BS in science or engineering field preferably geology, hydrology, environmental science, electrical, civil, or environmental engineering. Or equivalent experience.

Appendix D. List of supplementary documents:

1: Logbook record as of August 2017

2: Spectrum Technologies Inc. Watchdog 2900ET Manual

3: HOBO U20 Water Level Logger Manual

4: WatchDog 1200 Micro Station Manual

5: LightScout Silicon Pyranometer Manual

6: HOBOWare Software Quick Start Guide

7: SpecWare9 Software Manual

8: FlowTrackerOperationSOP.pdf

9: SonTek_2007_Flow_Tracker_Manual.pdf

10: Campbell_loggerlink_App_for_android.pdf

11: Campbell_loggerlink_App_for_ios.pdf

Appendix E. List of monitoring equipment purchased and deployed for network

Item	Qty.	Date purchased	Location	Funded by*
Geokon Model 4500 Piezometer	1	April-2014	ASPA-HQ	WRRIP 2013
ENO Scientific 2010 Wellsounder PRO	1	May-2014	ASPA-HQ	WRRIP 2013
Spectrum WatchDog 2900ET Weather Station	4	March-2015	Field	WRRIP 2015
Spectrum WatchDog 1000/2000 Series Data Shuttle	1	March-2015	Field	WRRIP 2015
WatchDog 1200 Micro Station with LightScout Silicon Pyranometer	1	March-2015	Field	WRRIP 2015
Wireless Vantage Pro2 Plus wireless with UV and solar light sensors with radiation shield	1	March-2015	ASCC Land Grant	WRRIP 2015
Onset HOBO Water Level and Temperature Data Loggers	8	May-2015 & July-2017	Field	WRRC local funds
Onset HOBO Water Level and Temperature Data Logger Titanium	4	May-2015	Field	WRRC local funds
FlowTracker Handheld ADV	1	May-2015	UH-WRRC	WRRC local funds
Teledyne StreamPro ADCP	1	May-2015	UH-WRRC	WRRC local funds
Rigid R86116K Hammer drill	1	May-2015	ASPA-HQ	WRRC local funds
FlowTracker Handheld ADV	1	January-2017	ASPA-HQ	MVD-2016
Campbell Scientific custom Wi-Fi weather station	2	March-2017	Field	MVD-2016
Onset HOBO Fresh Water Conductivity Data Logger	3	July-2017	Field	MVD-2016
Geokon Model 4500 Piezometer	2	July-2017	Field	MVD-2016
AquaMetrix ES toroidal conductivity sensor	1	July-2017	Field	MVD-2016
Aquametrix AS Conductivity Sensor	1	July-2017	Field	MVD-2016
RAINEW RAINLOG2.0 - Rain gauge with data logger	11	September-2017	Field	MVD-2016

***MVD – Making a Visible Difference, Region IX U.S. EPA - Tutuila Hydrogeological Exploration**
***WRRIP – Water Resources Research Institutes Program, USGS continuing funding**
***WRRC – University of Hawaii Water Resources Research Center**

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