National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Protocol for Long Term Groundwater-Hydrology Monitoring in American Memorial Park, Commonwealth of the Northern Mariana Islands, and Kaloko-Honokōhau National Historic Park, Hawai‘i

Version 1.0

Natural Resource Report NPS/PACN/NRR—2011/472

ON THE COVER
NPS and USGS staff taking ground water samples at American Memorial Park in Saipan, Commonwealth of Northern Mariana Islands.
Photograph: National Park Service

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December 2011

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received formal, high-level peer review based on the importance of its content, or its potentially controversial or precedent-setting nature. Peer review was conducted by highly qualified individuals with subject area technical expertise and was overseen by a peer review manager.

This report is available from the Pacific Island Network I&M website (http://science.nature.nps.gov/im/units/pacn/) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

Please cite this publication as:
Izuka, S. K, J. A. Perreault, T. Jones, and K. Kozar. 2011. Protocol for long term groundwater-hydrology monitoring in American Memorial Park, Commonwealth of the Northern Mariana Islands, and Kaloko-Honokōhau National Historic Park, Hawai‘i: Version 1.0. Natural Resource Report NPS/PACN/NRR—2011/472. National Park Service, Fort Collins, Colorado.

NPS 483/111853, 466/11185, December 2011

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Executive Summary

The National Inventory and Monitoring (I&M) Program was established by the National Park Service (NPS) to identify and inventory the biological and geophysical resources of each park. It also establishes monitoring programs to quantify and understand the causes of changes in the condition of park resources. To ensure that monitoring is done effectively and consistently, the NPS requires the establishment of a set of monitoring protocols.

The Pacific Island Network (PACN) of the NPS oversees the I&M Program for parks on several islands in the tropical Pacific, including American Samoa, Guam, the Northern Mariana archipelago, and Hawai‘i. In some of these parks, the condition of certain near-shore natural features, such as anchialine ponds, fish ponds, mangrove shorelines, and wetlands are closely associated with the availability and quality of groundwater, which, in turn, are affected by anthropogenic factors in and near the park, such as urbanization, industrialization, and increased groundwater withdrawals. Groundwater is also affected by cycles and long-term trends in climate and sea level, whether natural or anthropogenic. Ecosystems reliant on the quantity and quality of groundwater include some that provide habitat for rare, endangered or threatened organisms. Because of the association between groundwater and biological resources, the PACN has proposed groundwater monitoring in two parks that lie on the coast of Pacific islands: American Memorial Park (AMME) on Saipan, Commonwealth of the Northern Mariana Islands, and Kaloko-Honokōhau National Historical Park (KAHO) on the island of Hawai‘i. This report describes protocols for monitoring groundwater resources in these parks. This protocol may be useful in other parks if hydrogeologic conditions, natural resources, and monitoring objectives are similar to those described here.

Setting

Because AMME and KAHO both lie on the coast of tropical Pacific islands, groundwater characteristics reflect interaction of fresh groundwater from the land and saltwater from the ocean. The source of fresh groundwater in tropical oceanic islands is precipitation, some of which recharges groundwater. The fresh groundwater forms a lens-shaped body underlain by salty groundwater from the ocean. Fresh water flows from inland areas where most recharge occurs and the lens is thicker to coastal areas where the lens is thinner and groundwater discharges to springs, streams, and the ocean. Some of the saltwater underlying the freshwater lens becomes entrained in the flowing freshwater and forms a transition zone of brackish water which also flows toward, and discharges near the coast. The overall thickness of the freshwater lens depends on the aquifer permeability and balance between groundwater recharge and discharge. In general, thinner lenses exist where the permeability is high or groundwater recharge rates are low.

The freshwater lens is in a state of long-term average dynamic equilibrium in which short-term imbalances may result from drought and seasonal variations, but over the long term, the average groundwater recharge rate is balanced by the average groundwater discharge rate. When the equilibrium is upset, whether by natural stresses, such as long-term climate change or by artificial stresses such as withdrawals from production wells or crop irrigation, the shape and size of the fresh water lens’ change. Also because of the fresh water lens is buoyed by underlying

saltwater permeating from the ocean, its position can be affected by changes in sea level resulting from climate change or island subsidence. Natural and artificial stresses can thus induce a change in the shape, size, or position of the freshwater lens.

In AMME and KAHO depressions in the land surface at the coast expose the top of the freshwater lens or brackish water in the transition zone and form surface-water bodies such as wetlands, lakes, ponds, and springs. If the freshwater lens shrinks, the water table will lower and the transition zone will encroach landward and upward, resulting in a lowering of water levels and increase in salinity of coastal surface-water bodies. Changes in the size of the freshwater lens also affect the rate of freshwater discharge to the ocean and therefore affect the salinity of nearshore waters. Factors that can affect groundwater include tidal fluctuations, seasonal variation in rainfall, multiyear climate cycles such as El Niño, changes in groundwater withdrawal from wells, changes in land use, discharge of wastewater, island subsidence, global sea-level rise, and global climate change.

Rationale for Monitoring

Because water levels and water quality of coastal surface-water bodies such as wetlands, fishponds, streams and anchialine ponds are closely tied to the dynamics of groundwater, ecosystems that rely on these coastal surface-water bodies are sensitive to changes in the groundwater system. Ecosystems reliant on submarine groundwater discharge may also be affected by changes to the groundwater system. Long-term monitoring provides data that can be used to identify changes in groundwater underlying AMME and KAHO, determine the possible causes of the changes, and assess how the changes may affect other resources that rely on or are connected to groundwater.

The groundwater date can also be used along with other hydrologic and climate data to construct and calibrate numerical models of groundwater flow and solute transport. Such models could be used to simulate historical groundwater conditions, as well as simulate hypothetical future conditions. The numerical model thus provides a powerful scientific and management tool.

Monitoring Objectives

The immediate objective of long-term groundwater monitoring is to collect data that indicate aspects of the groundwater systems in the parks, including 1) the present condition, 2) changes with time, 3) the periodicity and magnitude of long-term and short-term cyclical variations, and 40 the rate of change of long-term trends. A broader objective of the groundwater monitoring is to provide data that can be evaluated in combination with data from other studies, including other I&M Program monitoring. Such studies could assess interrelations among hydrologic, climatic, biologic, ecologic, and anthropogenic agents of change. For example, the data may be useful for 1) early detection of groundwater trends that may affect other natural resources; 20 assessment of the causes of the trends; 3) modeling and other analyses that can assist park resource management, and 4) the development of other research that contributes to the scientific understanding of the physical universe both within and outside the parks.

Groundwater Monitoring Program

The groundwater monitoring program for AMME and KAHO consists of periodic measurements of groundwater levels and specific conductance (a measure of salinity) in a selected well in each of the parks. Temperature, which is needed for the specific-conductance measurement, will also be monitored. Methods for monitoring these parameters are well-established, time-tested, and simple to implement and maintain. Also, water levels and salinity are widely recognized as fundamental to groundwater hydrology of oceanic islands. Much data from surrounding areas already exists, and can be compared with data from this monitoring program.

Wells used for monitoring should be deep enough to penetrate into the transition zone so that they are more likely to detect changes, such as a rise of the saltwater, before they affect park resources. Monitoring wells also should not be pumped or near pumped wells. Data from pumped wells are likely to be overwhelmed by the effects of pumping and therefore not representative of the overall groundwater conditions in the parks.

Groundwater monitoring in AMME and KAHO requires both periodic manual field measurements as well as continuous monitoring by automated instruments. The manual field measurements will be made during quarterly (once every three months) field visits. The automated instruments will be deployed so that measurements can continue between the quarterly field visits. The automated instruments allow measurements to be made more frequently (hourly or more) than would be practical using manual measurements alone. These frequent measurements are needed to gather enough data to reduce the effect of tides, which are known to cause short-term, high magnitude groundwater oscillations in KAHO and AMME. These tidal oscillations may obscure long-term trends such as those related to climate or sea-level rise.

Equipment

The most suitable instruments available at the time of this writing (2010) for meeting the objectives of the groundwater monitoring are described. Because instruments are likely to change as technology evolves over the decades of the monitoring program, specifications of the instruments are given here rather than specific manufacturers or models. The specifications can be used in the future to replace old technology with new instruments having the same or greater precision or accuracy.

A steel tape will be used to make the manual water-level measurements. An automated instrument known as a CTD (for conductance, temperature, and depth) will be used to log the specific conductance profile during the quarterly field visits, and set to continuously monitor specific conductance and water levels during the period between field visits. All instruments must undergo procedures for pre-use setup, periodic accuracy checks, calibration, and maintenance and quality assurance. Some of these procedures will be done by field personnel. Other procedures must be contracted out to labs because they require special equipment and knowledge that would be too costly to maintain at each park.

This protocol also requires a surveying level and rod and a handheld GPS. Other equipment required, such as a field laptop computer, a field vehicle, a standard set of tools, safety and emergency equipment, and personal protective clothing and equipment, are common to most field oriented work and are assumed to be available at the parks.

Data Handling, Analysis and Reporting

All data will undergo procedures for quality assurance, archiving, and periodic analysis. After each field visit, these procedures include 1) entering handwritten data from field notes into computer files and a central groundwater database; 2) importing data from the CTD to spreadsheets for initial processing, then transfer of processed data to the groundwater database; 3) checking all data to ensure accuracy and completeness; 4) review of the data by the project lead, and 5) archiving. The data will be analyzed and a report prepared annually. All reports will be prepared and peer-reviewed in accordance with NPS Natural Resource Publications guidelines and will be published in the NPS Natural Resource Report series. Reports will also be made available through the NPS Natural Resource Bibliography.

Personnel Requirements and Training

This protocol requires a project lead to oversee the groundwater monitoring program in both AMME and KAHO, plus two technicians in each park. The technicians are responsible for conducting all field-related tasks listed in this protocol, including the maintenance of field equipment. The technicians are also responsible for entering and checking data in the well files and will assist with the preparation of the preliminary monitoring report and the annual data summary. The designated lead field technician will also work closely with the project lead on various tasks. The project lead has the overall responsibility for the groundwater monitoring program, including 1) providing administrative and technical oversight of the project, 2) working with the lead technician to facilitate the monitoring, 3) providing the second review of data and approving the data as final, 4) preparing the preliminary monitoring report and interpreting the results to set up the long term monitoring phase, and 5) preparing the annual summaries and interpreting the results in terms of potential effects to the condition of park resources. The project lead may also conduct fieldwork on occasion to cover for a technician. The duties do not constitute full time employment (FTE) for any of these individuals, but multiple individuals are needed to ensure that adequate personnel are available to cover for sick leave and vacations, and that reviews are conducted by someone other than the one whose work is being reviewed. In addition, some tasks, such a level surveying, require at least two people. A two person field team is also preferred for safety reasons. Because none of the three individuals is full time, the monitoring can be assigned to staff having other duties in the National Park system, or to part-time employees. Personnel should be permanent employees, however, because the skills and insights needed to effectively conduct the monitoring takes time to acquire.

Services from Cooperating Agencies

Certain services will be contracted to cooperating agencies. The 32-hour training for all new field team members (project lead and field technicians) will be provided by contract with the USGS Pacific Islands Water Science Center (PIWSC). Tasks such as calibration of the steel tape will also be obtained by cooperative contract from the USGS-PIWSC for practical reasons.

Labor

Labor is estimated on the basis of having one project lead to oversee the groundwater monitoring program for AMME and KAHO, and two technicians (technician and lead technician) at each of the parks. Labor estimates also assume that only one well will be monitored in each park. Annual labor is estimated to be 178 hours (9% FTE) for the project lead, 113 hours (5 percent FTE) for each of the two lead technicians, and 99 hours (4 percent FTE) for each of the two technicians.

Each of these employees will need an additional 56 hours in the first year to account for ordering and checking of equipment and supplies and for field training.

Field Schedule

There is no seasonal aspect to the fieldwork in this protocol. The groundwater monitoring program is designed to be conducted throughout the year. The quarterly field visits can commence at anytime, but should be scheduled to minimize the effects of tides. The quarterly period between field visits must be maintained as much as possible, however, to minimize discontinuity in the data.

Facilities

The groundwater monitoring program requires standard office space and a secure computer system with workstations and a server to store the electronic data. Other facilities requirements for the groundwater monitoring program include a clean, well lighted workspace with a worktable or counter space, a few cubic meters of storage, and access to tap water, electric power, and standard office equipment.

Supplies and Services

Services of outside laboratories or contractors are needed for periodic instrument calibration. These services include calibration of the steel tape. Calibration of the CTD for specific conductance is done in the field by the technicians, but requires specific conductance standards made by an outside laboratory. Calibration checks of temperature are done in the laboratory by the technicians, but actual calibrations are normally done by the CTD manufacturer. Initial training will be provided by contract with the USGS; subsequent training may also be provided by contract with the USGS or in-house by NPS staff with thorough knowledge of the protocol.

Startup Costs and Annual Budgets

Estimates for startup costs and the annual budget are based on equipment prices and salary rates for federal employees in 2010. The estimated startup cost is $27,440, which includes costs for purchasing and checking new equipment and for training. The estimated annual budget is $11,120, which includes costs for conducting quarterly field work, data entry, checking and archiving, and the preparation of an annual report, as well as costs for services, such as periodic equipment calibration and replacement costs for equipment prorated over the life expectancy of the equipment.

Acknowledgments

This protocol was prepared under a cooperative agreement between the U.S. Geological Survey (USGS) and the NPS. Example data sets and helpful suggestions were provided by Delwyn Oki (USGS) and Todd Presley (USGS). Technical reviews of the draft document were provided by Paula Cutillo (NPS), Kolja Rotzoll (USGS), Dean Tucker (NPS), Roy Irwin (NPS), and Gary Rosenlieb (NPS).

Introduction

The national Inventory and Monitoring (I&M) Program was established by the National Park Service (NPS) to identify and inventory the biological and geophysical resources of each park and establish monitoring programs to quantify changes and detect trends in the condition of park resources, and understand the causes of changes (National Park Service 2008a). For the monitoring goals of the program, a number of indicators of resource conditions were identified. These indicators, referred to as “vital signs,” by the NPS, would be the subject of long-term monitoring efforts. To ensure that monitoring is done effectively and that data collected at one time in the monitoring period are comparable to data collected at any other time, the NPS requires the establishment of a set of protocols for monitoring of each vital sign. Each protocol would document (1) the objectives of the monitoring, (2) the sampling framework and survey design, (3) standardized step-by-step procedures for collecting, managing, and analyzing data, and (4) possible uses of the data (Oakley et al. 2003).

The Pacific Island Network (PACN) of the NPS oversees the I&M Program for parks on several islands in the tropical Pacific, including American Samoa, Guam, the Northern Mariana archipelago, and Hawaiʻi. In some of these parks, the condition of certain near-shore natural features, such as anchialine ponds, fish ponds, mangrove shorelines and wetlands, are closely associated with the availability and quality of groundwater, which, in turn, is affected by anthropogenic factors in and near the park, such as urbanization, industrialization, and increased groundwater withdrawals. Groundwater is also affected by cycles and long-term trends in climate and sea level, whether natural or anthropogenic. Ecosystems reliant on the quantity and quality of groundwater include some that provide habitat for rare, endangered, or threatened organisms. Because of the association between groundwater and biological resources, the PACN has identified groundwater hydrology as a vital sign for two parks that lie on the coast of Pacific islands: American Memorial Park (AMME) on Saipan, Commonwealth of Northern Mariana Islands, and Kaloko-Honokōhau National Historical Park (KAHO) on the island of Hawaiʻi (Figs. 1 and 2).

This report describes protocols for monitoring groundwater resources in selected parks of the PACN. In the development of the protocol, only the conditions and resources at AMME and KAHO were considered. This protocol may be useful in other parks if hydrogeologic conditions, natural resources, and monitoring objectives are similar to those described here.

The format of this report generally follows the outline of Oakley et al. (2003) for NPS I&M protocols, with minor modifications so that all elements can be contained in one document. Part 1 of the protocol is a narrative providing the background and setting of the selected parks, the scientific and management benefits of conducting groundwater monitoring in the parks, and the basis for and development of standard operating procedures (SOPs) that can be followed to ensure continuity and comparability of data collected over the life of the long-term groundwater monitoring program. Part 2 of the protocol has the SOPs, which are detailed instructions for conducting aspects of the groundwater monitoring, data processing, data archiving, and data reporting. Supplementary materials related to the protocol such as field data sheets and templates are in the Appendixes A-C. Appendix D contains information on protocol development.

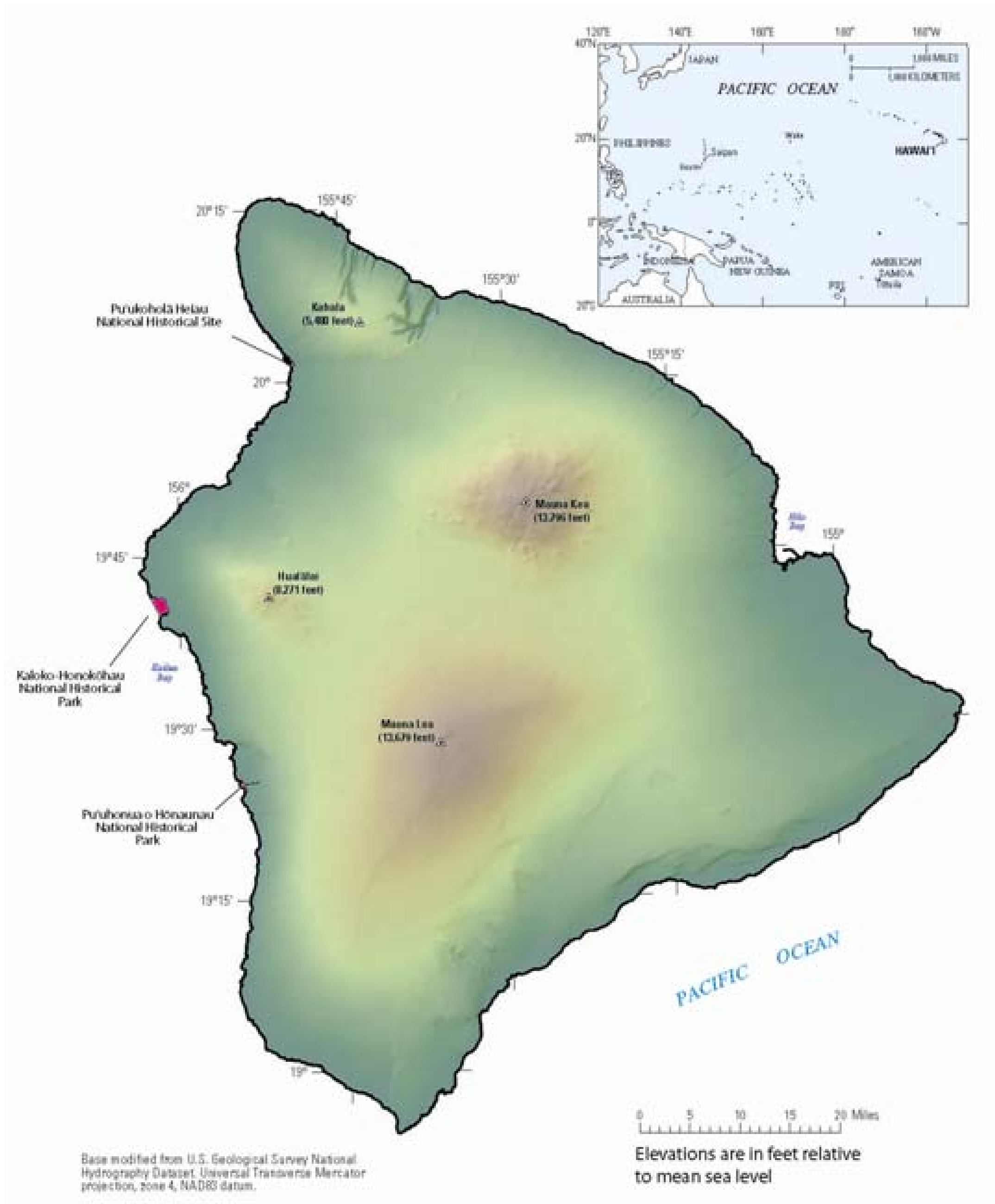

Figure 1. Island of Hawai'i.

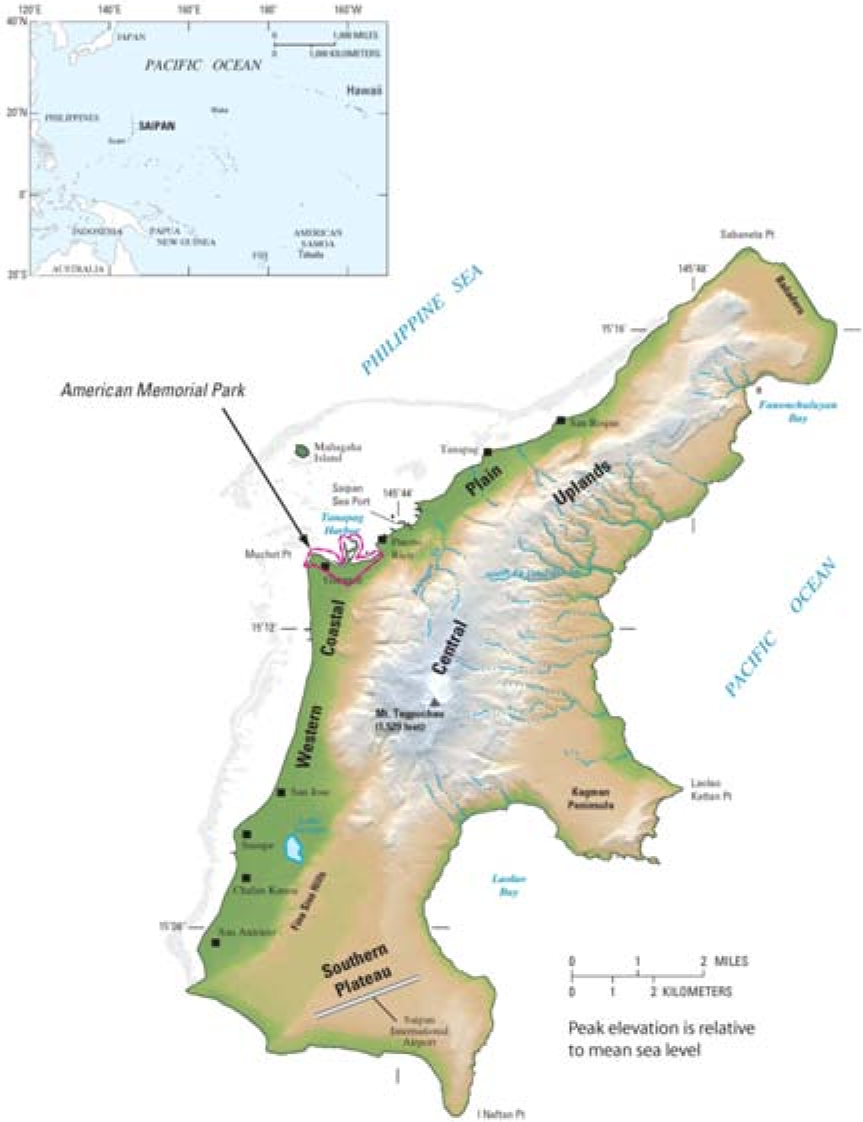

Figure 2. Saipan, Commonwealth of the Northern Mariana Islands (Perreault 2007).

General Park Settings

The two parks considered in this protocol are located on the coasts of islands in the tropical Pacific (Fig. 1 and 2), and thus share some broadly similar characteristics. In the tropical climate, temperatures are mild and seasonal variation is relatively small. Interaction between the land and the ocean also affects the natural and cultural resources in all of the parks. Groundwater characteristics in these parks reflect the interaction of fresh groundwater from the land and saltwater from the ocean. The parks differ substantially, however, in terms of geology, some specific aspects of climate, and potential for effects from nearby anthropogenic activity, all of which bear on the groundwater resources of the parks.

KAHO

KAHO lies on the west coast of the island of Hawai‘i, the largest (4,030-mi^2; highest elevation 13,796 ft) and geologically youngest island in the north-Pacific Hawai‘ian archipelago. The island is formed by five large basaltic shield volcanoes built by mid-plate, hot-spot volcanism (Stearns and Macdonald 1946, Clague and Dalrymple 1987). Each of the shield volcanoes is built by the accumulation of thousands of thin lava flows, which, owing to their high primary porosity and young age, have relative high permeability (Stearns and Macdonald 1946). Although Hawai‘i is in the tropics, its climate is influenced by trade winds that prevail during most of the year. Rainfall in some locations on Hawai‘i can exceed 240 in/yr, but on the western coast of the island, precipitation is low and evaporation is high because of the orographic rain-shadowing effect of the large mountains to the east (Fig. 3) (Giambelluca et al. 1986, Ekern and Chang 1985).

Although KAHO was established primarily for the preservation of historical and cultural resources (DeVerse 2006), the park has unique natural resources (some of which also have significant cultural aspects) within its boundaries. The 1,160-acre park has wetlands, anchialine pools, and Native Hawai‘ian fishponds that provide critical habitat for numerous species including some that are endangered (DeVerse 2006). Nearby urbanization and industrialization have the potential to affect groundwater in the park. To the east (up-gradient), changes in land-use zoning has enabled industrial growth; to the north, construction has begun on a residential development and golf course. Urbanization and population growth can result in increased groundwater withdrawals from wells, which have the potential to affect resources in these parks.

The island of Hawai‘i is actively subsiding due to isostatic adjustment to the mass of the island’s volcanoes on the oceanic crust (Moore 1987). Tide-gage data and studies of the age and depth of drowned ancient reefs off the western coast of Hawai‘i indicate a subsidence rate of about 2.5 mm/yr (0.008 ft/yr) (Moore and Fonari 1984, Moore 1987, Ludwig et al. 1991, Webster et al. 2007). This subsidence contributes to the apparent landward encroachment of the shoreline and therefore can affect the groundwater systems in coastal aquifers.

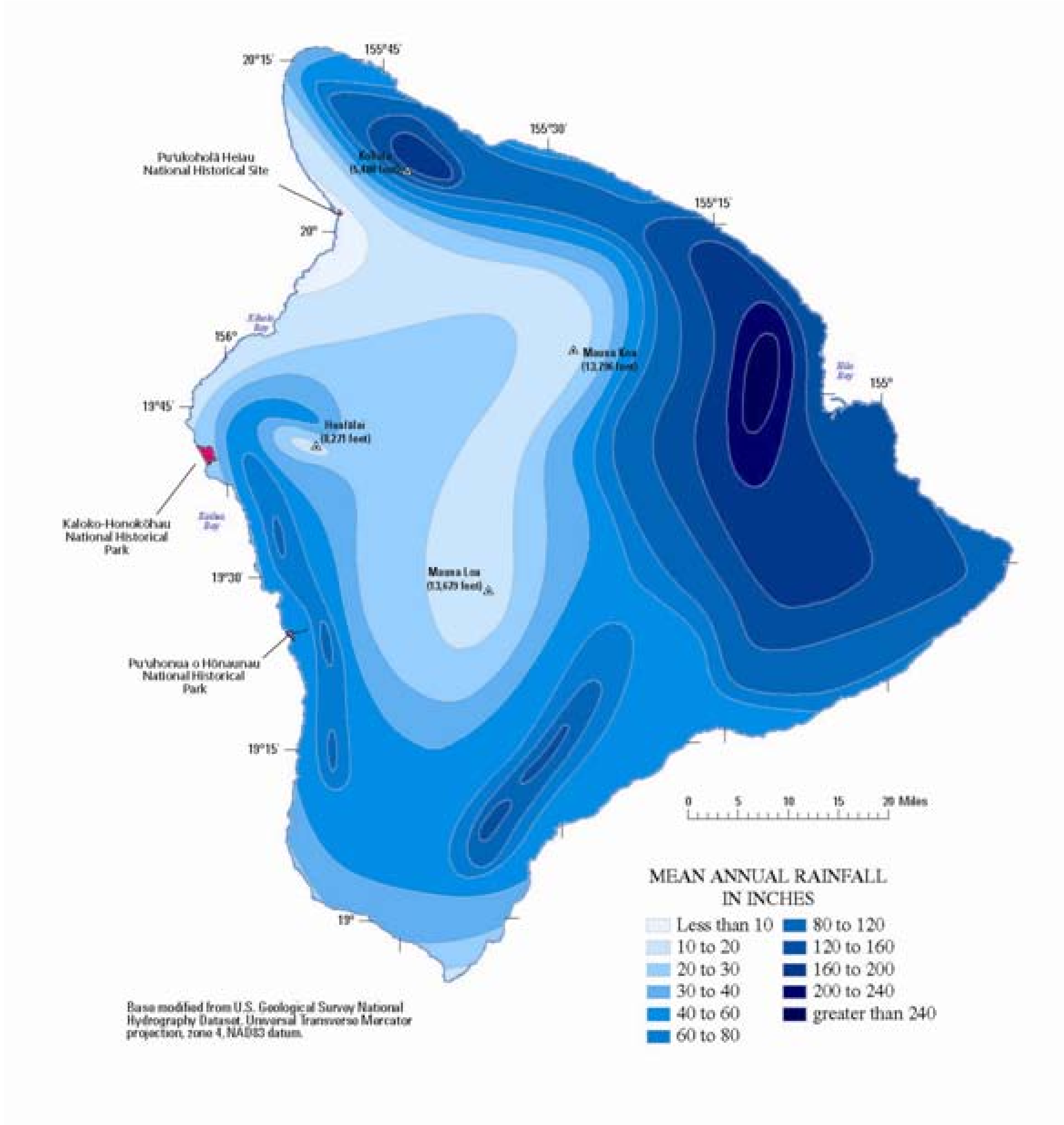

Figure 3. Distribution of mean annual rainfall on Hawai'i (Giambelluca et al. 1986).

AMME

The 133-acre AMME lies on the western coastal plain of the 48-square-mile western-Pacific island of Saipan (Fig. 2). Saipan has a base of island-arc volcanic rock (primarily ash and other pyroclastic deposits that have low hydraulic conductivity) overlain in most areas (including the area beneath AMME) by limestone formations having high hydraulic conductivity (Cloud et al. 1956, Carruth 2003). Because of its location in the low latitudes of the western Pacific, Saipan's climate is influenced by the seasonal movement of the intertropical convergence zone (ITCZ), a belt of rising air and high rainfall that hovers near the equator. Storms generated in the ITCZ bring much of Saipan's rainfall, which averages about 81 in/yr (van der Brug 1985).

The primary purpose of AMME is to commemorate those who fought in the Marianas campaign of World War II, but the park includes a Protected Natural Area Zone that contains a 28-acre mangrove shoreline and a 27-acre estuarine wetland system (Wagner 1990). The system's mosaic of marshy areas interspersed with emergent wetlands and mixed wet forests provides critical habitat for a variety of migratory and resident water birds including two endangered species. The wetland at AMME is the only federally protected area known to have viable populations of these species (U.S. Fish and Wildlife Service 1991, 1998). Estuarine wetland systems have become rare within the Mariana Islands, and as a result the AMME wetland has been identified as a "Mitigation Policy Resource Category 2" site by the U.S. Fish and Wildlife Service (Snyder 2006, Wagner 1990). The AMME wetland is directly connected to the underlying groundwater, which includes both fresh groundwater flowing toward the coast from the interior of Saipan, as well as saltwater permeating from the ocean (Perreault 2007).

Nearby urbanization and industrialization have the potential to affect groundwater at AMME. The village of Garapan to the south of the park has much of Saipan's highly developed visitor industry, which discharges high-salinity wastewater generated by desalination into storm drains that empty into an artificial wetland within the AMME boundary (Perreault 2007). Census statistics indicate that Saipan's population increased from about 15,000 to 62,000 between 1980 and 2000 (U.S. Census Bureau 2003), increasing urbanization and demand for drinking water (Perreault 2007).

Groundwater in Tropical Oceanic Islands

The source of fresh groundwater in tropical oceanic islands is precipitation (mostly rainfall, but on Hawaiʻi, also fog and snow). On islands with mountains, precipitation can be substantially heavier in windward and mountain areas than in leeward areas. Upon reaching the ground, precipitation can evaporate, run off the land surface to the ocean, or infiltrate the soil. Some of the water in the soil is transpired by plants (the net loss of water by evaporation and plant transpiration is known as evapotranspiration), and the remainder passes through the soil and recharges the aquifer (Fig. 4). Estimates of recharge on tropical Pacific islands range from about 10 to 50 percent of total precipitation; recharge generally varies with the spatial and temporal variations in precipitation (Shade and Nichols 1996, Vacher and Quinn 1997, Shade 1999, Oki 2002, Izuka et al. 2005).

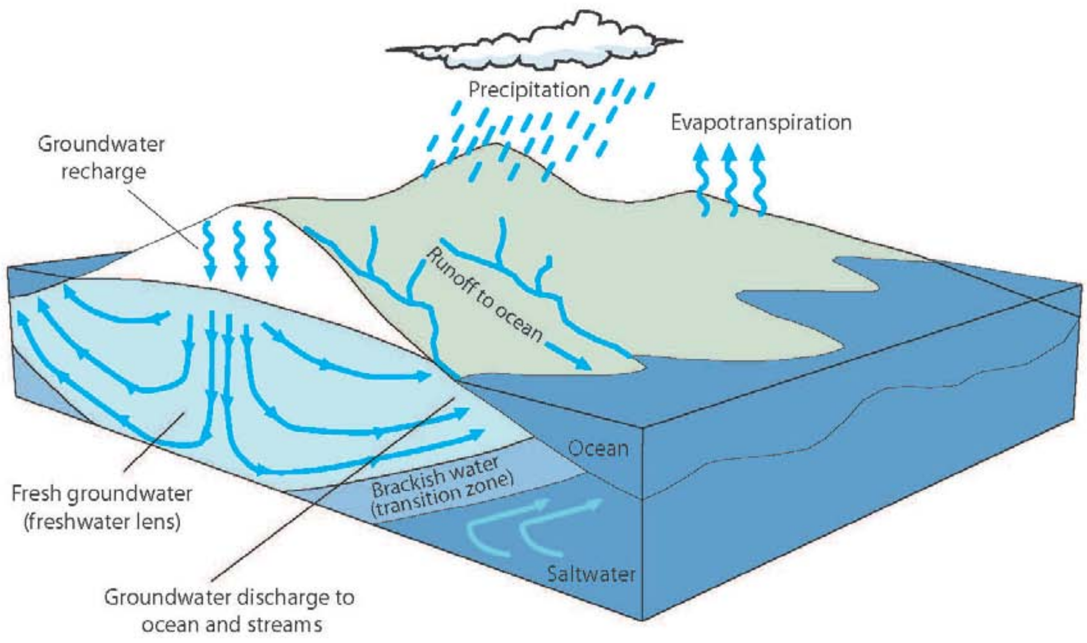

Figure 4. Conceptual model of groundwater in oceanic islands.

Near coastal areas on larger islands, and throughout smaller islands and atolls, fresh groundwater in the saturated part of the aquifer forms a lens-shaped body underlain by saltwater from the ocean (Fig. 4). The freshwater lens is thickest near the center of the island and thins toward the coast. The overall thickness of the freshwater lens depends on the aquifer hydraulic conductivity (a measure of permeability) and rate of groundwater recharge—freshwater lenses are thinner where the hydraulic conductivity is high or groundwater recharge rates are low.

The saltwater and freshwater in the aquifer are dynamic. Freshwater in the lens flows from inland areas where most recharge occurs to coastal areas where groundwater discharges to springs, streams, and the ocean (Fig. 4). In the process, some of the saltwater underlying the freshwater lens becomes entrained in the flowing freshwater and forms a transition zone of brackish water. The brackish water in the transition zone also flows toward, and discharges near, the coast. The entrainment and flow of saltwater in the transition zone, in turn, sets up flow in the saltwater part of the aquifer. Saltwater from the ocean enters the aquifer, flows upward, becomes entrained in the transition zone, and is discharged as brackish water near the coast. Mixing in the transition zone can be further induced by the oscillations in groundwater caused by ocean tides, recharge fluctuations, and pumping from wells.

Because the freshwater lens floats buoyantly over the denser saltwater in the aquifer, the height of the lens above sea level is related to the thickness of the lens below sea level and the density difference between freshwater and saltwater. If there was no transition zone (that is, the contact between the freshwater lens and the underlying saltwater was a sharp interface) and the groundwater in the lens was static, the thickness of the freshwater lens below sea level could be computed using the Ghyben-Herzberg relation:

$$Z = 40h, \qquad \text{(eq. 1)}$$

where: Z is the thickness of the freshwater lens below sea level and h is the height of the lens above sea level. However, as discussed above, the freshwater lens is not static and a transition zone does exist. The Ghyben-Herzberg relation can therefore give only an approximation of the freshwater lens thickness. Even so, the relation is commonly used to estimate the thickness of the freshwater lens.

Relation between Groundwater and Surface Water

In some areas, including areas in AMME and KAHO, depressions in the land surface expose the top of the freshwater lens (the water table) or brackish water in the transition zone (Fig. 5). The exposed water table can take the form of wetlands, lakes, ponds, springs, or persistently flowing streams. If natural or artificial stresses induce a change in the shape, size, or position of the freshwater lens, the height of the water table and the position of the transition zone changes. These changes can affect water levels and salinity in the wetlands, lakes, and ponds, or the flow and salinity of springs and streams. If the freshwater lens shrinks, the water table will lower and the transition zone will encroach landward and upward, resulting in a lowering of water levels and increase in salinity of coastal surface-water bodies. If the freshwater lens grows, the water table will rise and the transition zone will move seaward and downward, resulting in a rise in water levels and decrease in salinity of coastal surface-water bodies. Changes in the size of the freshwater lens also affect the rate of freshwater discharge to the ocean and therefore affect the salinity of nearshore waters.

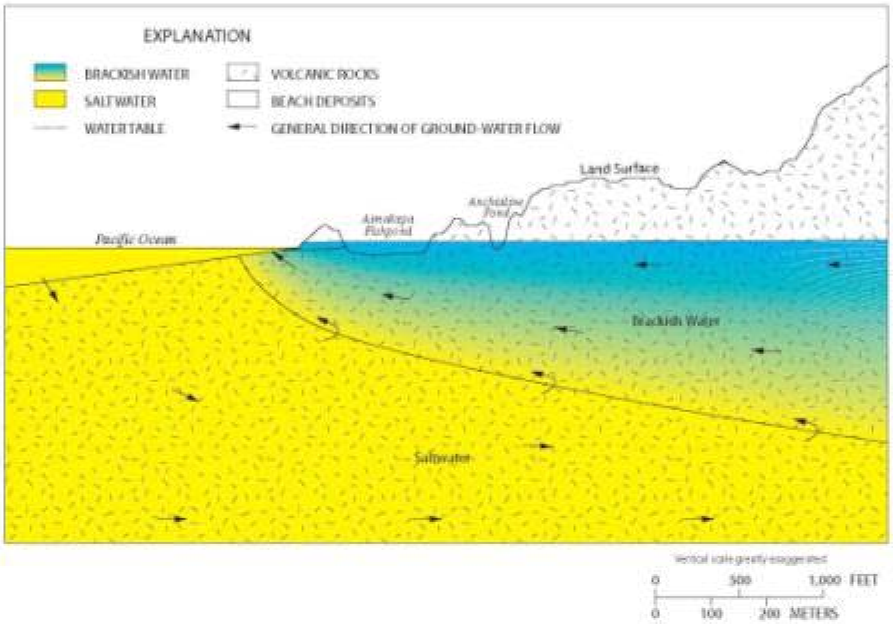

Figure 5. Schematic cross section of the groundwater flow system in Kaloko-Honokōhau National Historical Park, island of Hawaiʻi (Oki et al. 1999).

Factors That Can Affect Groundwater

The freshwater lens is in a state of long-term average dynamic equilibrium in which short-term imbalances may result from drought and seasonal variations but over the long term, the average groundwater recharge rate is balanced by the average groundwater discharge rate. When the equilibrium is upset, whether by natural stresses such as long-term climate change, or by artificial stresses such as groundwater withdrawals (from production wells) or crop irrigation, the shape and size of the freshwater lens change. If stresses persist long enough, the freshwater lens may achieve a new equilibrium in which the total input (recharge) again equals the total output (groundwater withdrawal plus natural discharge). Also, because the freshwater lens is buoyed by underlying saltwater permeating from the ocean, its position can be affected by changes in sea level.

Land-Use Changes

Certain land uses, both within and near the parks, can affect groundwater by reducing or enhancing recharge to the aquifer. The increase in paved surfaces and development of drainage systems to move water efficiently out of urbanized areas can result in an increase in surface runoff, thereby reducing the amount of water that can infiltrate the ground and recharge the aquifer. In contrast, irrigation using water diverted from streams can enhance groundwater recharge. Older, inefficient methods such as furrow or flood irrigation result in greater enhancement of groundwater recharge than more efficient agricultural methods such as drip irrigation. In some areas of Hawaiʻi, cessation of irrigation or changes in irrigation methods have resulted in a substantial change in groundwater recharge (Izuka et al. 2005, Engott and Vana 2007).

Urbanization may also include the development of groundwater resources. Withdrawal of water from wells in coastal areas has the effect of lowering the water table and causing the saltwater-freshwater transition zone to rise and move landward. Groundwater withdrawal thus has the potential to affect the water levels and salinity of coastal ponds, wetlands, and other habitats in the parks. Whether the pumping will substantially affect the groundwater resources of the parks depends on the pumping rate, hydraulic properties of the aquifer, distance between the wells and the hydrologic boundaries, and distance between the wells and the parks.

Climate Variations

Climate variations include cycles that occur at the seasonal time scale, cycles such as the El Niño/Southern Oscillation (ENSO) that have a periodicity of a few years, as well as gradual climate-change phenomena such as global temperature change that may last centuries to millennia. These climate variations affect groundwater by causing variations in: (1) precipitation and evapotranspiration and (2) sea level.

Variations in precipitation and evaporation can affect groundwater recharge and the availability of groundwater for human consumption and for natural biologic systems. During high-rainfall periods, recharge is increased and the fresh groundwater lens grows, resulting in a corresponding rise in water levels and downward shift of the transition zone. On the other hand, droughts cause the freshwater lens to shrink by lowering water levels in the aquifer and inducing the saltwater-freshwater transition zone to rise. A decline in groundwater recharge can also induce landward movement of the transition zone and saltwater permeating from the ocean, thereby affecting the water levels and salinity of ponds, lakes, and wetlands. Dry periods often correspond with increases in groundwater withdrawals from wells and the amount of water applied as irrigation.

Rainfall records from Hawaiʻi and Saipan show wet and dry seasons. In most dry leeward areas of Hawaiʻi, mean monthly rainfall is highest in January and lowest in June, but in the Kona area of the Island of Hawaiʻi (which includes KAHO), rainfall is higher in the summer months than the winter months (Giambelluca et al. 1986). Most graphs of mean monthly pan evaporation in Hawaiʻi prepared by Ekern and Chang (1985) show highest values in summer months and lowest values in winter months. In Saipan, the dry season extends from July through November and the wet season extends from January through May (Carruth 2003). El Niño events usually correspond with lower rainfall and droughts in the western Pacific and Hawaiʻi (Lander 2004, Ropelewski and Halpert 1987).

Variations in precipitation may also follow longer-term trends, the causes of which are not yet completely understood. For example, historical rainfall and streamflow data from Hawaiʻi show a statistically significant declining trend over much of the latter half of the 20th century (Oki 2004), but the cause is not known. Inasmuch as precipitation and evapotranspiration are strongly affected by temperature, changes to the hydrologic cycle are expected to result from global warming, but model projections for rainfall and droughts in the future have been highly variable (Frederick and Major 1997, Mimura et al. 2007). Recent downscaling studies indicate that precipitation in Hawaiʻi will most likely decrease by a few percent during the wet season and increase by a few percent during the dry season as a result of global warming (Timm and Diaz, 2009).

Climate change can induce sea-level changes by (1) changing atmospheric pressure, wind patterns and wind strength on the sea surface and (2) inducing thermal expansion or contraction of ocean water, and (3) changing the proportion of global water stored in glaciers versus that stored in oceans. A global change in sea level can change the position of the freshwater lens and the brackish water and saltwater underlying it, and thereby change the water level and salinity of the associated ponds, wetlands and springs. A rise in sea level can result not only in the inundation of the coastal parts of the parks, but also a landward and upward shift of salt and brackish groundwater and an increase in water levels and salinity of coastal ponds and wetlands that are not inundated. A lowering of sea level can result in the seaward and downward shift of the freshwater lens and brackish transition zone, and a decrease in water levels and salinity of coastal ponds and wetlands over time.

Fluctuations in trade winds and their associated ocean currents can cause seasonal and multi-year sea-level variations. Wyrtki (1974) showed the connection between seasonal fluctuations of currents and seasonal sea-level fluctuations of a few to tens of centimeters in the equatorial Pacific. Sea-level fluctuations related to ENSO cycles are also linked to wind patterns in the Pacific. During periods between El Niño events, trade winds and related ocean currents in the tropical Pacific cause sea level to rise in the western Pacific. During an El Niño event, the strength of the trade winds decreases, and water from the western Pacific flows back toward the east, resulting in a lowering of sea levels in the western Pacific and a rise in sea level in the eastern Pacific. Wyrtki (1977) noted that during the 1972 El Niño sea levels in Guam (in the western Pacific near Saipan) fell about 1.5 ft below mean sea level over a period of few months; in the central Pacific near Hawaiʻi, the sea-level change was less.

Long-term global climate change can also affect sea level by inducing the melting of land glaciers and by causing thermal expansion of ocean water. Global sea-level rise during the 20th century averaged about 1.7 mm/yr (0.06 in/yr), but the rate has accelerated during this period as a result of anthropogenic global warming (Bindoff et al. 2007). Satellite data indicate that in 1993-2003, the rate of global sea-level rise was 3.1 mm/yr (0.010 ft/yr) (Cazenave and Nerem 2004). The rate of sea-level rise is projected to be even higher as the 21^{st} century progresses, but the rate will depend on whether anthropogenic factors induce global warming (Bindoff et al. 2007).

Island Subsidence

Subsidence of oceanic islands can cause an apparent rise in sea level relative to present park shorelines. As discussed earlier, estimated subsidence of the island of Hawaiʻi is about 2.5 mm/yr (0.008 ft/yr) (Moore and Fonari 1984, Moore 1987, Ludwig et al. 1991, Webster et al. 2007). This subsidence rate combined with the current rate of global sea-level rise resulting from natural and anthropogenic climate change (3.1 mm/yr [0.010 ft/yr]; Cazenave and Nerem 2004) yields an apparent sea-level rise in KAHO of about 5.6 mm/yr (0.018 ft/yr). At this rate, the shorelines in these parks will rise by a foot in about 55 years. Because the rate of global sea-level rise is accelerating, however (Bindoff et al. 2007), a one-foot apparent rise in sea level may occur even sooner.

Rationale for Groundwater Monitoring in the Parks

Because water levels and water quality of coastal surface-water bodies such as wetlands, fishponds, streams, and anchialine ponds, are closely tied to the dynamics of groundwater, ecosystems that rely on the coastal surface-water bodies are sensitive to changes in the groundwater system. These changes are driven by natural and anthropogenic factors that affect the groundwater systems in most tropical oceanic islands. Changes in the size of the freshwater lens also affect the rate of freshwater discharge to the ocean and therefore affect the salinity of nearshore waters. Ecosystems reliant on submarine groundwater discharge may therefore be affected by changes to the groundwater system.

Long-term monitoring provides data that can be used to identify changes in groundwater underlying AMME and KAHO, determine the possible causes of the changes, and assess how the changes may affect other resources that rely on or are connected to groundwater. For example, water-level and salinity data from groundwater monitoring may show a trend of increasing salinity and decreasing water levels. Comparison of the groundwater data with data from other monitoring might show that lowering of groundwater levels and increasing salinity has resulted in the degradation of habitat in anchialine ponds and wetlands. Further comparison may show that the trend is linked to a natural phenomenon such as drought cycles, or global phenomenon such as climate change, which cannot be altered but for which plans can be made to mitigate adverse effects. Alternatively, the comparison may show that anthropogenic factors, such as a change in land use or an increase in well withdrawals in areas adjacent to the park, caused the increasing salinity and decreasing water levels, and that steps could be taken to remediate the conditions.

The long-term monitoring data can also be used along with other hydrologic and climate data to construct and calibrate a numerical model of groundwater flow and solute transport. Such a model could be used to simulate historical groundwater conditions, as well as simulate hypothetical future conditions. The numerical model thereby provides a powerful scientific and management tool that can be used to assess such issues as what will happen if present conditions remain unchanged or which remediation steps will be most effective.

Related Network Monitoring

The PACN I&M network currently has two protocols that are directly related to the groundwater monitoring protocol: Water quality in AMME and KAHO and anchialine pool communities in KAHO. Water quality monitoring is directly related to the solutes associated with groundwater. In KAHO, this monitoring takes place in anchialine pools which are surface expressions of the groundwater. Understanding how the groundwater is changing, particularly in regards to salt intrusion is important to the physical water characteristics of the anchialine pools. Changes in the groundwater levels and salinities can significantly affect the physical water characteristics of the pools, with groundwater generally sitting on top of the more dense oceanic waters. As the State of Hawaiʻi continues to develop water quality criteria for anchialine pools, it is increasingly important to understand the effects of groundwater on the physical characteristics of the anchialine pool environment.

The biotic component of anchialine pools can be affected by the changes in physical water quality characteristics of the individual anchialine pools in which they tend to reside. The reproduction of some of the anchialine pool species takes places in the subterranean system, while others reproduce in the pool itself. Changes in groundwater levels and salinities can have significant impacts on the biology of the pools, which provide the juvenile habitat for multiple candidate endangered species including *Megalagrion xanthomeles* and *Metabataeus lohena*. Understanding the groundwater dynamics of the system is important to understanding one of the key biotic linkages to the aquifer. The PACN has put a relatively high importance on monitoring these systems.

Groundwater Issues in KAHO

The geology and hydrology of the island of Hawaiʻi, including the island's western coast where KAHO lies, was comprehensively described by Stearns and Macdonald (1946). Data from wells drilled prior to the 1990s indicated that fresh groundwater beneath the western coast of Hawaiʻi had water levels of less than 10 ft above sea level and formed a thin freshwater lens, which was consistent with the dry climate and high aquifer hydraulic conductivities known in the area. In the early 1990s, however, exploratory drilling a few miles inland from the coast encountered groundwater levels that were several tens to hundreds of feet above sea level, indicating the presence of a thick body of fresh groundwater impounded by buried geologic structures, and spurring the construction of new wells and increases in groundwater withdrawal (Oki 1999). Although the impounding structures remain enigmatic, water probably flows from the high-level groundwater area, where most recharge occurs, through or around the impounding structures, and toward the adjacent low-level groundwater area including the area beneath KAHO (Fig. 6). Increases in groundwater withdrawals landward of the park therefore have the potential to affect groundwater resources beneath the park.

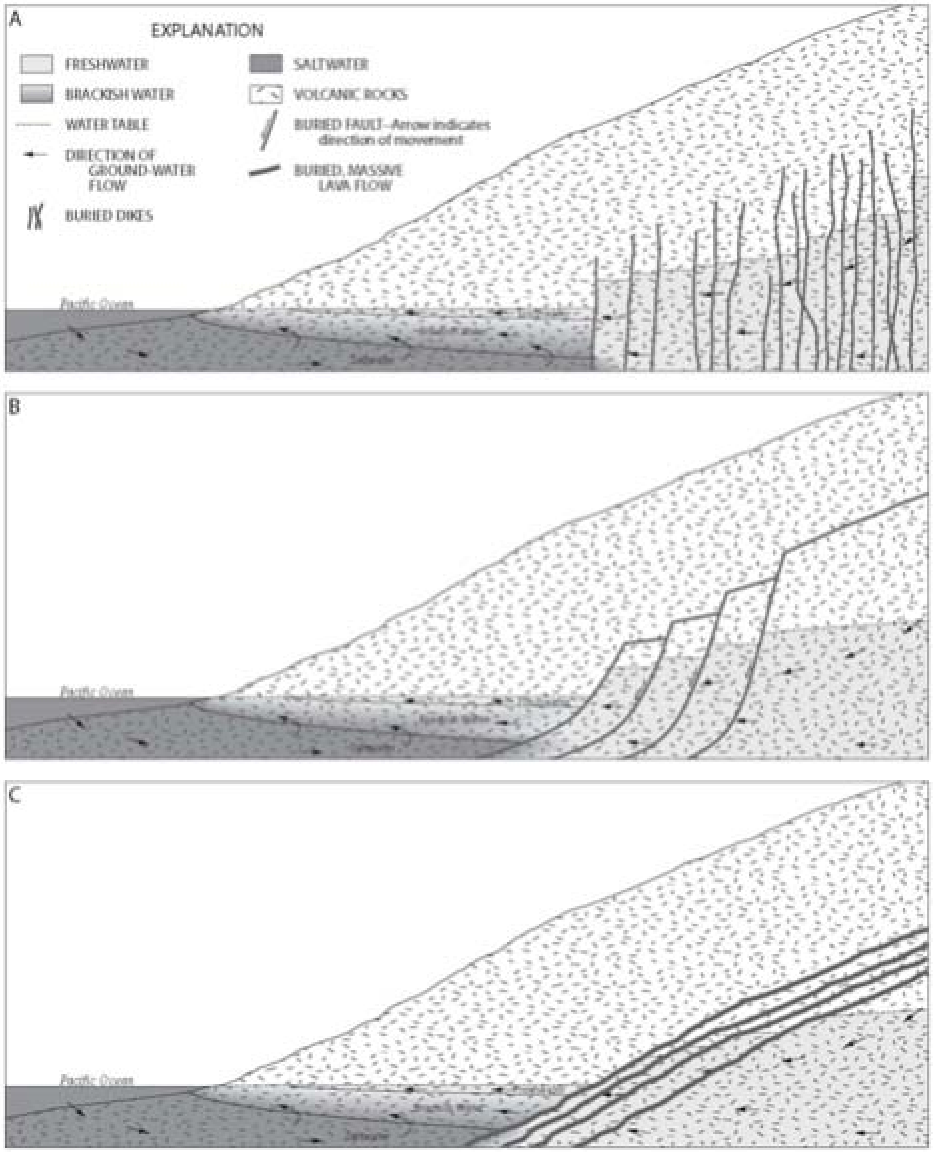

Figure 6. Schematic cross sections showing geologic structures that may be impounding groundwater to high levels in the Kona area, island of Hawai'i: (A) buried dike complex; (B) buried fault system; (C) buried, massive lava flows (Oki 1999).

KAHO is so close to the coast that the freshwater lens lies landward of the park, and groundwater beneath the park is part of the transition zone that lies between the freshwater lens and seawater permeating from the ocean (Fig. 5) (Oki et al. 1999). Salinity of groundwater in the park thus ranges from brackish to seawater. Groundwater salinity is lowest in the upper inland part of the aquifer and increases toward the ocean and with depth in the aquifer. The water table is less than about 2 feet above mean sea level and fluctuates daily by about 0.5 to 1.5 feet in response to ocean tides (Fig. 7).

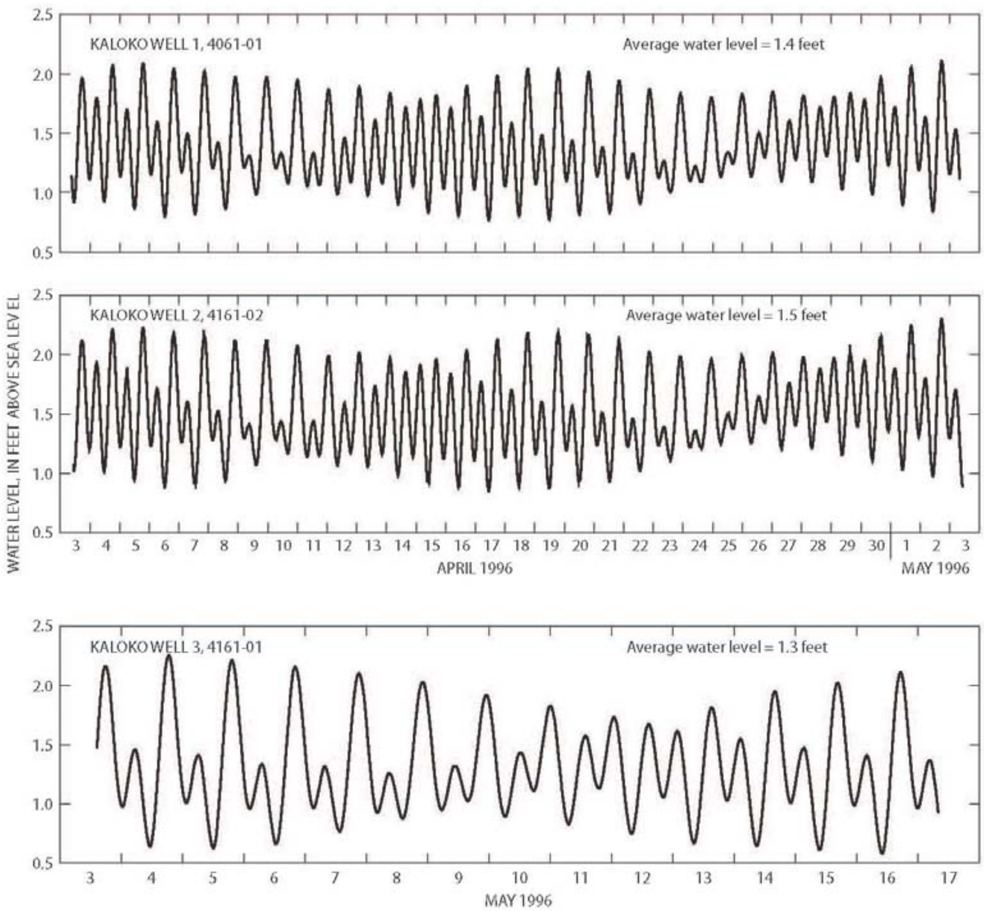

Figure 7. Water levels at wells 4061-01, 4161-02, and 4161-01 during 1996, Kaloko-Honokōhau National Historical Park, island of Hawai'i (Oki et al. 1999).

Groundwater recharge within KAHO is small because rainfall is low and evaporation is high. Most of the fresh groundwater that contributes to the formation of brackish water in the park comes from recharge in the high-level groundwater areas farther inland. The brackish water flowing through KAHO ultimately discharges to fishponds in the park or to the ocean. Depressions in the land surface that expose the brackish groundwater form anchialine ponds. The fishponds and anchialine ponds in the park are thus hydrologically connected to groundwater beneath the park as well as the inland high-level groundwater areas. Groundwater-model simulations indicate that increasing withdrawals from wells upgradient from KAHO will affect groundwater flow and salinity within the park (Oki et al. 1999). The potential effect of development and increased withdrawals from lands adjacent to KAHO is a major concern to the park's resource management.

Groundwater resources and the biological resources that depend on groundwater are also susceptible to climate change and island subsidence. Both phenomena can result in a shift in the position of the shoreline, which in turn may cause a change in the salinity of near-shore habitats, such as fishponds and anchialine ponds.

Groundwater Issues in AMME

AMME is situated on the limestone formations that overlie the core of island-arc volcanic rock in Saipan (Fig. 8). A freshwater lens exists in both the limestone and the volcanic core. In general, the lens is thickest near the middle of the island and thins toward the coast, but the lens thickness is also a function of aquifer permeability – the lens is thinner in the limestone than it is in the volcanic rock because the limestone has higher permeability. The high-permeability limestone formations constitute the principal aquifers on the island (Hoffmann et al. 1998, Carruth 2003). Withdrawal of groundwater from wells in the limestone has the potential to affect groundwater beneath AMME.

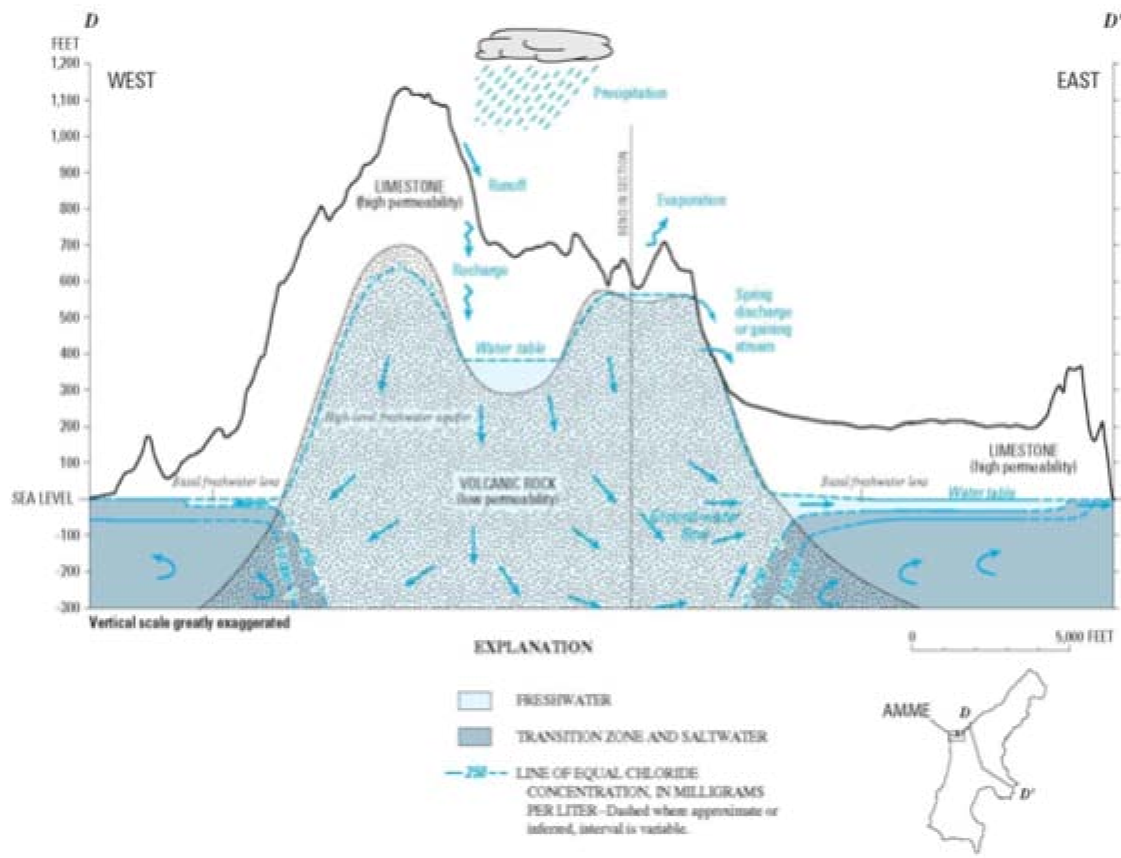

Figure 8. Hydrogeologic cross section through Saipan. Location of American Memorial Park (AMME) is shown on the location map (Carruth 2003).

Data collected in a reconnaissance study of the hydrology of AMME by Perreault (2007) show that water levels in the park’s natural wetland, as well as groundwater levels beneath the wetland, vary directly with ocean tides, which indicates that a close connection exists between groundwater, the wetland, and the ocean. Measurements of specific conductance (an indicator of salinity) indicate that the water in the wetland as well as groundwater beneath the wetland is brackish as a result of mixing of freshwater and water from the ocean. Perreault concluded that saltwater from the ocean enters the wetland primarily through groundwater, whereas freshwater enters the wetland from both direct rainfall and groundwater flow from the island's interior.

At the time of Perreault's (2007) study, disposal of reverse-osmosis wastewater from a village adjacent to the park was changing from surface to underground disposal. Surface disposal had created an artificial wetland near AMME; subsurface disposal was planned using injection wells, which are also near the park. Specific-conductance values in the artificial wetland were higher than that of seawater during the reconnaissance study. Whether the disposal of wastewater, either by surface or subsurface injection, had affected or will affect the AMME wetland, could not be determined within the scope of Perreault's reconnaissance study.

The scope of Perreault's (2007) study limited the conclusions that could be drawn, but the study identified additional hydrologic studies that could improve understanding of the hydrology of AMME. Among these studies was monitoring of water levels and salinity in wells in and near the park. Data from monitoring would be useful in assessing long-term and short-term hydrologic trends, effects of reverse-osmosis wastewater disposal, and the possible effects of groundwater withdrawal from areas surrounding AMME. The monitoring could also contribute data needed for the construction of a numerical groundwater flow model that can be used to assess the effects of past, present, and future natural and anthropogenic stresses on the hydrology of AMME, and to investigate how these effects can be mitigated.

Objectives of Groundwater Monitoring in the Parks

The immediate objective of long-term groundwater monitoring in AMME and KAHO is to collect data that indicate the following aspects of the groundwater systems in the parks:

1. The present condition.
2. How the groundwater resource is changing with time.
3. The periodicity and magnitude of long-term and short-term cyclical variations.
4. The rate of change of long-term trends.

Present condition will inform managers of the “baseline” that they are beginning their long-term study. All analysis is relative to this measurement. Given time the periodicity and magnitude of long term and short term cyclical variations can be determined; however, they serve to inform management of the natural variations in each well rather than create specific threshold conditions. Of significant concern for management are objectives 2 and 4: how the resource is changing with time and at what rate. These objectives will be the basis for threshold trigger points to management. As the biology in relation to salinity is still being determined, the initial threshold trigger points are not biologically based, but rather physically based. These trigger points can be changed once further information about the biology of the systems is better understood. Nevertheless, an increase of salinity greater than five parts per thousand in any well over a single wet and dry season will be considered a threshold trigger point to inform management immediately of condition changes. In addition, a long term increase in mean seasonal daily salinity (wet season or dry season) or decrease in mean seasonal daily water level (wet season or dry season) using a linear regression of the 5 year moving average seasonal means slope compared with the initial 5 year seasonal means slope using linear regression and a significance difference of $\alpha = 0.20$ will be considered a threshold for informing management. It must be stressed that these thresholds must be revisited as the biology of the systems becomes better understood.

A broader objective of the groundwater monitoring is to provide data that can be evaluated in combination with data from other studies including other I&M Program monitoring, to assess interrelations among hydrologic, climatic, biologic, ecologic, and anthropogenic agents of change. Uses of the data include:

1. Early detection of groundwater trends that may affect other natural resources of the parks.
2. Assessment of the physical-scientific basis for (i.e., the causes of) the changes, and the relation between the observed changes and known phenomena.
3. Support modeling and other analyses that can assist park resource management by determining the causes of past changes; extrapolating observed trends into the future; simulating hypothetical scenarios such as drought, land-use changes and increasing well withdrawals, and their effects on park resources; and assessing the effectiveness of mitigation and other management strategies.
4. Support hydrologic studies beyond the present scope of the I&M Program, or the development of other research that contributes to the scientific understanding of the physical universe both within and outside the parks.

Utility of the groundwater monitoring data, both alone and in combination with other data, is discussed in greater detail later in this narrative.

Monitoring Parameters

Relationship between inventoried natural resources in AMME and KAHO and the salt/brackish/fresh groundwater systems underlying these coastal parks can be monitored simply and effectively by measuring groundwater levels and salinity in selected wells in or near the parks. Monitoring groundwater levels and salinity is an ideal approach to meeting the objectives of the I&M Program for monitoring groundwater hydrology for the following reasons:

1. Data-collection methods are simple to implement and maintain over a long period of time, thus, training time, fieldwork, cost, and chances for errors are minimized, and the probability of collecting accurate, reliable data is increased.

2. Monitoring of groundwater levels and salinity has a long history, therefore well-established and time-tested methods already exist and numerous choices for instrumentation are available.

3. Data from groundwater and salinity monitoring in the PACN parks can be compared with historical data from surrounding areas.

4. Groundwater levels and salinity are recognized as fundamental to groundwater hydrology and are widely used as indicators of groundwater trends, therefore data from monitoring in the PACN parks will be readily interpretable in terms of current understanding of the hydrology of oceanic islands.

Groundwater Levels

Groundwater levels are fundamental to any groundwater study or assessment because they are indicative of changes in groundwater storage and flow. In island and coastal aquifers, groundwater levels, if measured accurately relative to sea level, are indicative of the thickness of the freshwater lens both above and below sea level. Variations in groundwater levels indicate changes in the thickness of the freshwater lens and possible changes in groundwater flow, and may foretell changes in water levels and quality in coastal surface-water bodies such as ponds, wetlands and springs.

Groundwater levels can be expressed relative to any datum or reference point, provided that datum is used consistently throughout a given application. In studies of island aquifers, groundwater levels are expressed in terms of elevation above sea level. The importance of knowing groundwater levels relative to sea level is apparent from the Ghyben-Herzberg relation (eq. 1). The relation can be used to estimate the thickness of certain parts of the freshwater lens from the elevation of the water table above sea level. Although the relation has limitations, it is still widely used to approximate freshwater lens thickness on the basis of the height of groundwater levels above sea level in island aquifers.

In this protocol, water levels will be measured and recorded as a depth to water (DTW), which is the distance from a consistent measuring point (MP) to the top of the water in the well (Fig. 9). This distance is commonly measured by lowering a measuring tape into a well. The MP is a point at the top of the well, such as a spot on the top of the well casing that can be easily accessed by the tape each time a measurement is made. Whereas the top of the well casing may not be precisely horizontal, one point on the casing is permanently marked and used consistently as the MP. Monitoring changes in the DTW with time meet the monitoring objectives.

Converting the DTW to an elevation relative to sea level may be possible if reliable elevation benchmarks are nearby, but this not a mandatory part of the protocol.

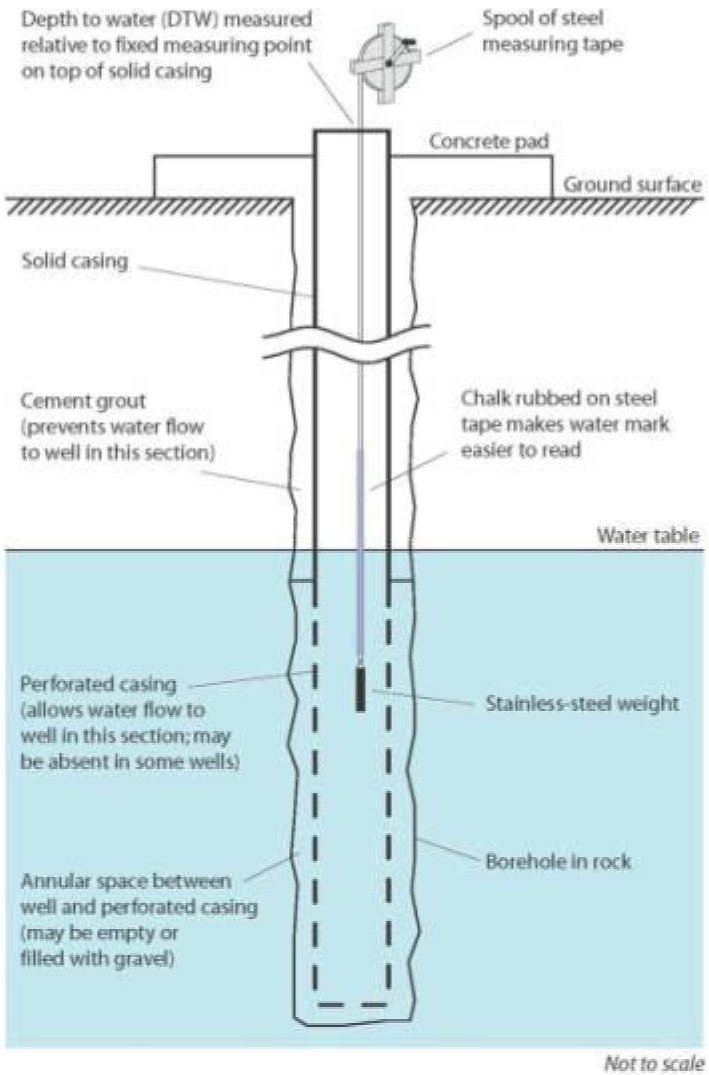

Figure 9. Using a chalked steel tape to measure water level in a typical well.

Salinity

Salinity measurements are also fundamental to groundwater studies in island and coastal aquifers, where the salinity of groundwater results from mixing of seawater and freshwater. Changes in salinity indicate migration of the transition zone and underlying saltwater, which can cause changes in the chemical environment in the coastal surface-water bodies. The principal cation in seawater is chloride, and its concentration is commonly used as an indicator of the presence of seawater in island groundwater. Chloride concentration can be determined by titration in either the laboratory or in the field.

Another commonly used indicator of salinity is the ability of the water to conduct an electrical current. In general, higher electrical conductance indicates higher salinity, but electrical conductance also depends on the amount and temperature of water though which the electrical current passes. To allow comparison, electrical-conductance measurements of fluids are commonly converted to specific electrical conductance (or simply, specific conductance). Specific conductance is a solution's ability to conduct electricity through a standard volume of water at a standard temperature, and is a measure of the concentration of the total dissolved ions in a solution. For dilute solutions such as natural groundwater, specific conductance is commonly expressed in units of microsiemens per centimeter at 25˚ C (µS/cm at 25˚ C). Specific conductance is simple to measure in the field using electronic instruments and is particularly useful in groundwater studies because a probe can be sent to make measurements in a remote location, for example in a deep well. Because temperature is integral to the specific-conductance measurements, most probes that measure electrical conductance of fluids also measure temperature, and many instruments automatically compensate for differences between the ambient water temperature and 25˚ C.

Specific conductance does not distinguish between ions that come from sea salt and those that come from other sources. Also, the relation between specific conductance and solute concentration depends on the type of solute. Whereas the solutes in groundwater come not only from seawater (which has a complex of several solutes itself) but also other physiochemical and biochemical sources, the relation of specific conductance to salinity varies from site to site. The relation can be derived for a given location by measuring specific-conductance and analyzing chloride concentrations in several samples and fitting a regression line. The relation can then be used to estimate chloride concentrations from specific conductance data.

Specific-conductance values can be converted to salinity (*S*) on the Practical Salinity Scale of 1978 (PSS78), which is currently the accepted definition of salinity in oceanography (Stewart 2008). On this scale, *S* is defined solely on the basis of the solution's electrical conductivity and therefore independent of the types of solutes present. An equation, adopted for water-quality monitoring by the USGS (Wagner et al. 2006) for computing *S* from specific conductance at 25˚ C was given by Schemel (2001):

$$S = K_1 + K_2 R^{1/2} + K_3 R + K_4 R^{3/2} + K_5 R^2 + K_6 R^{5/2}, \quad \text{(eq. 2)}$$

where R is the ratio of sample specific conductance to that of standard seawater, K_1 is 0.0120, K_2 is -0.2174, K_3 is 25.3283, K_4 is 13.7714, K_5 is -6.4778, and K_6 is 2.5842. The specific conductance of standard seawater is 53.087 mS/cm at 25˚ C (53,087 µS/cm at 25˚ C); to compute *R*, the units for the specific conductance of the sample and seawater standard must be the same. Values of *S* are dimensionless, but for most mixtures of seawater and freshwater, the value of *S* is approximately comparable to salinity or total-dissolved-solids (TDS) values expressed in parts per thousand or milligrams per liter. PSS78 was originally established for *S* ranging from 2 to 42. Equations to extend the scale to *S* below 2 have been proposed but Schemel (2001) writes that for most field studies, the increased precision from the extension is unnecessary because it is beyond the resolution of most field instruments.

Equation 2 is provided here for reference only; the conversion is not required for this protocol. Some instruments display salinity computed from measured specific conductance. The method for this computation may vary, however, from one instrument to the next. For this reason, the fundamental parameter specific conductance is monitored and archived in this protocol, rather than the derived parameter salinity.

Ideally, wells selected for long-term monitoring will penetrate into or through the transition zone so that the position of the transition zone can be directly measured and monitored over time. The salinity of the water in a well that penetrates through the transition zone will vary with depth (Fig. 10). Water in the upper part of the well may be fresh where that section of the well is in the freshwater lens. Where the well passes through the transition zone, the water salinity will increase with depth until the well penetrates into the underlying saltwater. The actual position of the transition zone in the well may differ slightly from its position in the aquifer, but changes in the position of the transition zone in the well are an indication of changes in the position of the transition zone in the aquifer.

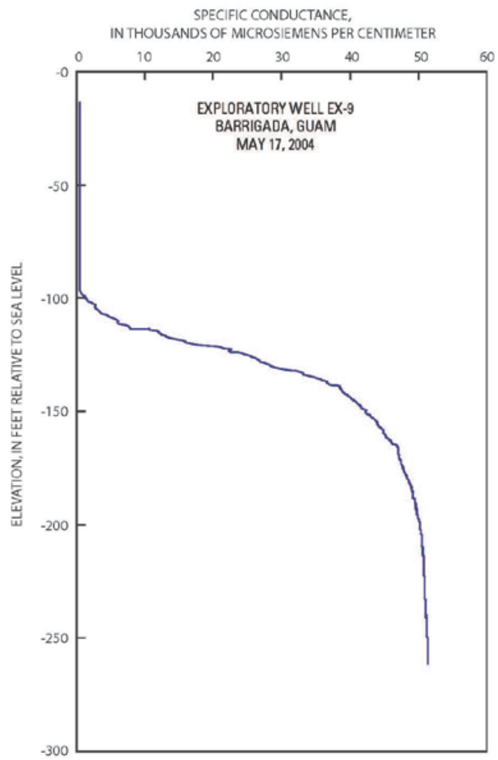

Figure 10. Example of a specific-conductance profile for a well penetrating through the transition zone.

The variation of salinity with depth in the monitoring well presents a problem for long-term monitoring because it is difficult to represent the salinity of a well with a single value, or track the changes of a single value with time. A common procedure prior to sampling is to purge the well of a volume of water equal to three volumes of the water in well (Lapham et al. 1995, Radtke et al. 2005). This homogenizes the water in the well and obliterates the variation of salinity with depth. Also, purging a well disturbs the water in the aquifer and tends to bring up salt water from below, resulting in a homogenized sample whose salinity may be higher than the true average of the salinity in the well before pumping. An alternative approach is to deploy an electronic probe through the water column in the well to measure the variation in specific conductance with depth (the specific-conductance profile; Fig. 10). After the profile is obtained, a monitoring instrument can be positioned at a fixed location in the well to automatically monitor variations in water levels and specific conductance (which indicate movement of the transition zone) with time. Electronic instruments that can be used to both measure the specific-conductance profile and to automatically monitor water-level and specific-conductance variations with time are discussed later in this protocol.

Use of Data

This groundwater monitoring protocol is designed for the collection of high-quality data that can be used to monitor the condition and aid in the management of groundwater and other natural resources reliant on groundwater in the parks. Water-level and salinity data gathered at the onset of monitoring will be immediately useful for assessing the parks' groundwater resources as they exist today, and provide critical information such as whether a freshwater lens exists beneath the parks, and if so, how thick the lens and transition zone are currently, and the influence of tides on the movement of the water table and transition zone. This data will also provide a baseline condition to which future data will be compared. As monitoring continues, the data will be progressively more useful for identifying changes and potential threats to groundwater-dependent park resources. Even after only a few years, the data can be analyzed for seasonal variations and assessment of changes that may indicate a threat to park resources can begin. Additional years of data will be useful for identifying longer-term trends, and utility of the monitoring for early detection of trends that may affect natural resources of the parks will increase.

Variations and trends, especially those of a cyclic nature, can be extrapolated into the future with some degree of confidence, but predictability is enhanced if causes of the variations are known. The water-level and salinity data from groundwater monitoring will also be useful in combination with time-series data from other monitoring efforts of the NPS I&M Program. Interrelations among hydrologic, climatic, biologic, ecologic, and anthropogenic agents of change can be used to assess the physical-scientific basis for the changes. Relation to known phenomena such as ENSO and global sea-level rise can be studied, and may contribute to the understanding of both known and as-yet unknown phenomena.

Integration of the groundwater data with other I&M Program data can also be used to model the response of the physical system to past changes, and simulate system response to future changes. For example, numerical groundwater modeling can analyze the complex relations among aquifer hydraulic properties, groundwater recharge, well production, groundwater levels, and groundwater salinity. Construction of a numerical groundwater model requires more than the data from the groundwater monitoring described in this protocol, but the long-term water-level and salinity data will be invaluable to the construction and calibration of the model, and can guide the collection of other data needed to complete the model. The predictive capability of a calibrated groundwater model is a powerful tool for the management of park resources. The model can be used to simulate hypothetical scenarios such as drought, land-use changes, increasing well withdrawals, and rising sea levels; project how observed trends will affect park resources in the future; and simulate and assess the effectiveness of mitigation and other management strategies.

The salinity and water-level data collected during the groundwater monitoring can also be useful to hydrologic studies beyond the present objectives of the I&M Program. For example, the aquifer hydraulic properties and conceptual model of groundwater flow developed as part of groundwater-flow modeling can be used to assess contaminant transport through the groundwater system. Data collected during the I&M Program and the discoveries made from them also have the potential to raise other research questions and lead to studies that contribute to the scientific understanding of not only the environments in the park, but also to the regional and global environment.

Groundwater Monitoring Design

The basic approach of this groundwater monitoring protocol is the periodic measurement of water levels and specific conductance in monitoring wells in or near PACN parks. The conditions and resources at AMME and KAHO were considered in the development of this protocol. Although each park has unique characteristics, a common approach can be used to monitor the groundwater vital sign in both parks. Using a common approach allows direct comparison of data from one park with another, which can be important in assessing ocean-wide and global phenomena. If necessary, the data collection described in this protocol can be supplemented by other data collections that address the specific needs of each park. Results of the long-term monitoring described in this protocol can also be used to assess whether other types of monitoring or studies are needed in the future.

Monitoring Wells

In most cases, access to groundwater for monitoring purposes requires a well. Although some aspects of groundwater can be monitored in naturally occurring springs or other natural surface manifestations of groundwater, wells provide a more stable and controllable platform on which to make repeated measurements over a long period. However, the expense of drilling new monitoring wells and the impact of well construction on the natural and cultural resources of the parks can be substantial. For this reason, the protocol described here uses existing wells. Suitability of wells for the purpose of this protocol was based on the following criteria:

1. Representativeness – Groundwater levels and salinity in the well must be representative of the aquifer that is connected to the critical natural and biological resources of the park.

2. Well depth – The selected wells penetrate below sea level. Ideally, the wells also penetrate into the transition zone or through most of the thickness of the freshwater lens. A deeper well is preferable for the objectives of the groundwater monitoring protocol because monitoring it is more likely to show changes, particularly a rise in the underlying saltwater, before they affect park resources.

3. Open interval – The open interval is the length of the well that is uncased or has a screened or perforated casing, allowing water from that section of the aquifer to enter the well. The open interval of a selected well should include most of the saturated part of the aquifer through which it penetrates.

4. Access – The selected wells are easily accessible on a regular basis to field personnel who will be carrying tools and other equipment.

5. Not pumped – Production (pumped) wells and wells near production wells were excluded from consideration because data from them are likely to be overwhelmed by the effects of pumping and therefore not representative of the overall groundwater conditions in the parks.

Measurement Frequency

Measurements in wells can be made manually or by deploying automated electronic sensors and data loggers. Manual measurements are relatively simple to make and require lower initial equipment expenses, but the frequency of measurements is limited to the frequency of visits to the monitoring wells. Manual measurements cannot reasonably be made on a continuous, long-term basis more frequently than daily, and in most cases, labor costs preclude field visits that are more frequent than monthly or bimonthly. For practical reasons, frequent measurements require the use of electronic sensors and automated data loggers. This approach requires equipment that is more costly and complicated to use, but the instruments can be set to automatically make measurements as frequently as desired. The frequency of automated measurements is limited primarily by the volume of data that can be stored in the logger, practically handled, checked for accuracy, and archived. Despite the higher costs, the benefit of high-frequency automated data collection is a substantial improvement in the ability to identify gradual but persistent groundwater trends that may impact park resources in the long term.

Higher frequency measurements are needed if the monitoring is expected to yield information on short-term variations. High-frequency measurements are also needed where high-magnitude, short-term oscillations, such as tidal effects, obscure long-term trends such as those or related to climate cycles or sea-level rise. For example, tides cause water levels in wells in KAHO to fluctuate by about 1.5 ft (Fig. 7) (Oki et al. 1999). Tidal data and tidal-efficiency estimates given by Perreault (2007) indicate that groundwater response to tides in AMME may be on the order of 1 to 2 ft. These tidal-driven fluctuations take place within the few hours of a tidal cycle. By comparison, groundwater level changes resulting from longer-term processes such as climate change, sea-level change, and urbanization, may be much more gradual even though the long-term net effect may be large.

Appendix D, Protocol Development, explains how the obscuring effect of the tidal overprint can be significantly reduced by making measurements at high frequency (hourly or more) and computing averages over a longer period, such as daily or monthly. Similar averaging has been used to filter out the tidal signal from tide gage data so that phenomena such as island subsidence (Moore 1987) and ENSO-related sea-level variations (Wyrtki 1974) could be studied. In this protocol, manual measurements made during quarterly field visits (once every three months) will be supplemented by automated measurements made every 15 minutes. To filter out the effects of high-frequency cycles such as tides, daily averages will be computed from the 15-minute data.

Measuring Instruments

Numerous instrument options exist for the measurement of groundwater levels and specific conductance. Described here are the most suitable ideal instruments known to be available at the time of this writing for meeting the objectives of the groundwater monitoring protocol for the PACN parks. Instruments are likely to change, however, as technology evolves over the decades of the monitoring program. The purpose of this section is not to recommend a particular manufacturer or model, but to give the specifications of the instruments, particularly with regard to minimum precision. Given these specifications, old instruments can be replaced with new instruments having the same or greater precision, even if manufacturers and models change.

Manual Water-Level Measurements

The traditional USGS procedure for measuring groundwater levels uses a steel tape, which is rubbed with chalk so that a clear water mark is made when the tape is lowered into a well (Koterba et al. 1995) (Fig. 9). Recently, the use of an electrical measuring tape (a tape with a sensor at the end that emits an audible or visual signal when the sensor touches water) has become increasingly common because of its simplicity, but concern has been raised about the inaccuracies due to stretching or mishandling. Side-by-side comparisons indicate that measurements made with a commonly used model of electrical tape differed significantly from those made with a National Institute of Standards and Technology (NIST) certified steel tape (D.S. Oki, USGS, oral communication, 2007). Because of the uncertainty currently inherent in electrical tapes, this protocol has adopted the use of the steel-tape-and-chalk method.

Assurance of the accuracy of the steel tape will be maintained by periodic calibration (Table 1). The calibration involves comparing, under controlled conditions, measurements made using the steel tape to measurements made using a NIST-certified tape, and if necessary, computing correction coefficients. The steel tape will be calibrated before it is first used, and thereafter at least once every 5 years. Although this calibration schedule is not frequent, the calibration process is complex; therefore the procedures are not included in this protocol. The calibration can be done by an organization (such as the USGS or NIST) that regularly calibrates its tapes against a NIST-certified reference tape. Proper maintenance will be followed, however, between calibrations. The steel tape will be carefully and neatly rewound on the spool after each use. Twists, kinks and other abuse will be avoided because they can result in inaccurate measurements. Every steel measuring tape will have a log book in which repairs and calibrations are recorded as well as the initials of the person performing these tasks. Unambiguous connection between the log book and the steel measuring tape will be maintained by recording the manufacturer, model description, and serial number of the tape in the log book. In addition, the maintenance recommendations of the manufacturer will also be followed.

Table 1. Frequency of accuracy checks and calibration of the instruments used in the groundwater monitoring program.

Instrument		Task	Frequency
Steel measuring tape		Calibrate	Every 5 years
CTD			
	Specific conductance	Calibrate	In field, before each use
	Temperature	Check accuracy	Annually
	Pressure	Calibrate	In field, before each use

Automated Specific-Conductance and Water-Level Measurements

This groundwater monitoring protocol requires automated measurements of specific conductance and water level. An electronic instrument designed to simultaneously measure and record conductance, temperature, and depth (CTD) can be used for both of these tasks. Most modern CTDs have electronic sensors for conductivity, temperature, and pressure housed in a single probe together with a microprocessor, clock, and programmable data logger. For monitoring during the period between field visits, the CTD can be programmed to make measurements at regular intervals (e.g., every 15 minutes), then positioned at a fixed location in the water column (Fig. 11). Specific conductance is computed from conductivity and temperature; depth of submergence of the CTD is computed from pressure. Changes in submergence depth indicate changes in water level. Changes in specific conductance indicate movement of the transition zone.

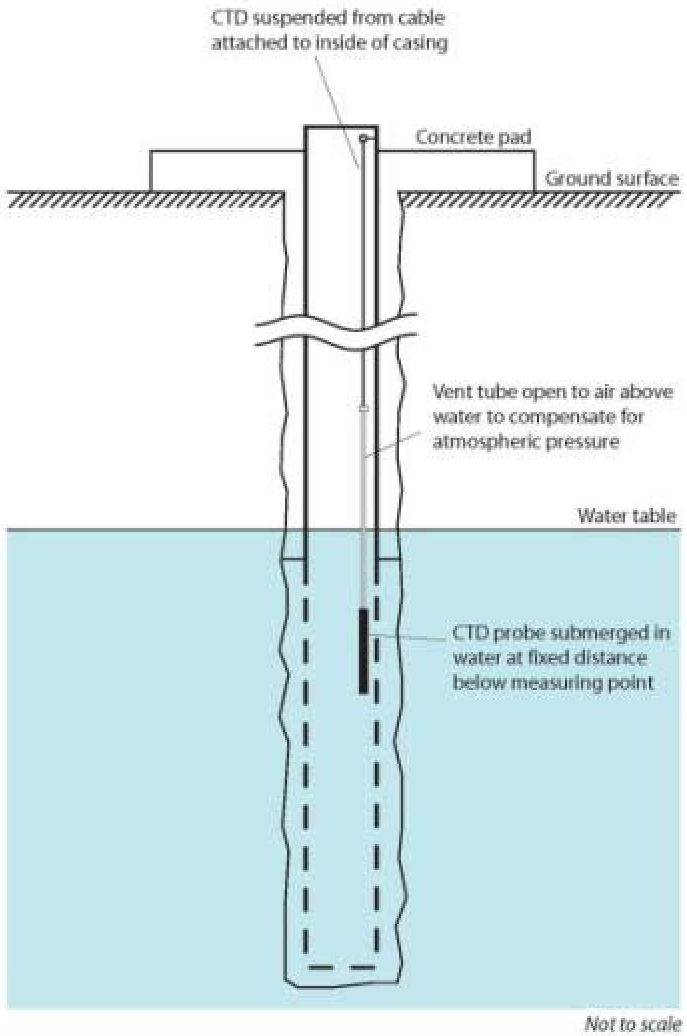

Figure 11. Deployment of automated conductance-temperature-depth instrument (CTD) in water in monitoring well.

The CTD can also be used to measure the variation of specific-conductance with depth (specific-conductance profile). The CTD can be programmed to make measurements at a frequent interval (e.g., every second) and lowered through the water column in the well.

At least two CTDs will be needed for each well in the groundwater monitoring program. Specifications for the CTD required for this protocol are given in SOP 7. A field laptop computer is also needed to operate and program the CTD; hardware and software requirements for the computer depend on the CTD manufacturer.

The CTD has an electronic sensor to measure the electrical conductance of the fluid in which it is immersed. The CTD computes specific conductance from the raw electrical-conductance output of the sensor. Each sensor has a range of specific-conductance values over which it is optimal.

The objectives of this groundwater monitoring protocol require a probe that is capable of measuring accurately within a range of at least 1,000 to 50,000 µS/cm at 25˚ C.

The CTD also measures pressure, which can be converted to depth of submergence of the probe:

$$P = g\rho D_S + P_{atm} \qquad \text{(eq. 3)}$$

where P is pressure measured by the CTD, ρ is water density, g is the acceleration due to gravity (a constant), D_S is the depth of submergence, and P_{atm} is atmospheric pressure. Solving eq. 3 for D_S, gives the equation for computing submergence depth from pressure:

$$D_S = (P - P_{atm})(\rho g)^{-1} \qquad \text{(eq. 4)}$$

Most CTD models compensate for P_{atm} and its variations by venting the sensor to the atmosphere through a tube whose top end is above the water surface. Alternatively, some non-vented CTD models use a second device to monitor concurrent P_{atm} at the water surface, then make a correction during post processing. When the CTD is vented or otherwise compensated for P_{atm}, the relation between D_S and pressure measured by a compensated CTD (P_{CTD}) becomes:

$$D_S = P_{CTD} (\rho g)^{-1} \qquad \text{(eq. 5)}$$

The values of ρ and g vary from one location to another and with salinity of the water in the well. Some CTDs will automatically compute D_S from P_{CTD} using eq. 5, but the computed D_S may be inaccurate because they assume values of ρ and g that are not be valid in the coastal parks of the PACN network, where groundwater can have a brackish or higher salinity. Salinity affects pressure because saltwater is denser than freshwater. Average sea water, for example, is about 2.5 percent denser than freshwater. In this protocol, the factor $(\rho g)^{-1}$ will be determined empirically using values of D_S and P_{CTD} measured in the field using the CTD in the well that will be monitored (SOP 16). The slope ($M_{D/P}$) of the straight-line relationship between D_S and P_{CTD} approximates $(\rho g)^{-1}$.

$$D_S = P_{CTD} M_{D/P} \qquad \text{(eq. 6)}$$

The DTW can then be computed by subtracting D_S from the preset distance between the MP and CTD sensor (SOP 19).

Quality assurance of the automated water-level and specific-conductance measurements is maintained by periodic checks of the accuracy and calibration of the CTD (Table 1) and by following the manufacturer’s instructions. Every CTD will have a log book containing the manufacturer, model description, and serial number, and a record of repairs, calibrations, and accuracy checks as well as the initials of the person performing the tests. Calibration of specific conductance will be done at each site. The calibration consists of measuring the specific conductance of solutions (standards) having known specific conductance (SOP 15). These standards are made under laboratory conditions using reagent-grade water and solutes and can be obtained from chemical-supply laboratories. At least two standards will be used having known specific-conductance values approximately spanning the range of expected specific conductance in the wells (in most cases this will be less than 1,300 µS/cm at 25˚ C for freshwater and about 50,000 µS/cm at 25˚ C for seawater [Hem 1985]). If the specific-conductance values indicated by the probe differ from the known values by more than 5 percent, the probe will be recalibrated according to the instructions of the manufacturer. Conductance standards must be used only once and must not be used past their expiration date. Standards will be stored in a manner that minimizes evaporation. The probe will be cleaned by irrigating with distilled or deionized water immediately after use to prevent corrosion and the deposition of salts by evaporation.

The CTD temperature accuracy will be checked annually together with other temperature-sensing sondes used in the I&M program. Accurate temperature measurement is needed for the specific-conductance computation. The temperature check involves comparing the CTD's temperature readings, at several points within the instrument's operational range, against temperature readings of a thermometer certified by NIST. If the difference between the NIST-certified thermometer and the CTD exceeds the temperature accuracy listed in the manufacturer's specifications, the CTD should be returned to the manufacturer for replacement, recalibration, or repair.

Field Methods

Because monitoring of groundwater levels and salinity have a long history, well-established methods and standard procedures exist to ensure accuracy and consistency of the data. The methods and SOPs in this groundwater monitoring protocol primarily follow those used by the USGS (for example, Koterba et al. 1995, Radtke et al. 2005). Adjustments have been made, however, to meet objectives specific to the groundwater monitoring protocol for the PACN I&M Program. This section presents an overview of the procedures, technical basis, and necessary equipment for the field methods. Explicit field methods are described in the SOPs.

Field Notes

Field notes are one of the two fundamental forms of data in this protocol (the other being digital data from the CTD). Because field notes may be the only record of some data, they must be carefully and thoroughly taken and kept safe from damage or loss. In this protocol, field notes include any data or notes written by hand while in the field, whether in field data sheets or in notebooks. Much of the information gathered in the field during the preliminary and long-term monitoring will be recorded by hand on paper field notes. Field data sheets have been developed to facilitate efficient and consistent field notes (Appendix A). Each field person will also keep a field notebook. The contents and organization of a field notebook varies by individual, but extensive, verbose notes are almost always more useful than terse notes, even if some of the notes are redundant with data in the field data sheets.

Because fieldwork is outdoors and near water, all field notes should be written on waterproof paper using hard pencil or other waterproof media (most ordinary ink is not waterproof). A supply of blank field data sheets from Appendix A can be made by waterproof printing (such as with laser printer or photocopier) onto weatherproof paper. Blank waterproof paper and field notebooks with waterproof paper are available from suppliers of engineering and scientific equipment.

Measurement Units and Precision

This protocol requires measurements of length, temperature, latitude and longitude, date and time of day, pressure, and specific conductance. Units and precision for each of the parameters in this protocol are specified in SOP 3.

Monitoring

Groundwater monitoring in the parks will consist of making periodic measurements of water level and specific conductance in wells. This protocol uses an approach in which manual measurements are made during quarterly field visits and automated measurements are made between field visits by a CTD positioned at a fixed location in the water column (Fig. 11). The CTD will be programmed to measure and record depth, temperature, and specific conductance every 15 minutes. The CTD will be positioned at the same depth each time it is deployed throughout the monitoring period. If the water level fluctuates during monitoring, the CTD will show a fluctuation in its depth of submergence, which can be converted to DTW. If the CTD is initially placed in the transition zone and the transition zone moves up or down during monitoring, the CTD will record a change in specific conductance.

Preparation and Preliminary Tasks

This protocol assumes that administrative requirements, such as permission and permits to use the well, have been obtained. The protocol also assumes that sufficient data exist for the monitoring well to (1) ensure that the well is suitable for the purposes of monitoring, (2) determine the most ideal location to set the CTD for automated monitoring, (3) assess the magnitude and frequency of periodic oscillations that result from short-term cycles such as tides, (4) determine the magnitude and frequency of variations that may result from non-cyclical stresses, such as groundwater pumping, irrigation, and rainstorms, and (4) evaluate any other variations that may have a bearing on groundwater monitoring. If sufficient data are not available, a preliminary monitoring phase may be warranted (see Appendix D).

Acquisition and specifications for equipment needed for the groundwater monitoring program are described in SOP 4, and SOPs 6-11. Currently the PACN network has and is utilizing the *In-Situ Aquatroll 200*®. While this protocol does not specify continued use of this instrument, nor does it endorse any specific brand or company, because this is the instrument the PACN network used to collect their baseline information, the current technical specifications of this instrument in relation to accuracy, precision, and bias should be maintained or exceeded in future network instrumentation and instrument purchases. Prior to field work, the equipment will be checked to ensure that they operate correctly and that calibrations are current (Table 1), and supplies will be checked to ensure that they are adequately stocked. The SOPs and pertinent parts of this narrative and references will be reviewed, and photocopies of important information will be assembled to take into the field (original documents will not be taken into the field).

The MP for the monitoring well and three nearby reference marks (RMs), if they don't already exist, must be established during the first field visit (SOP 12). The MP will be marked by cutting a notch in the top of the well casing using a file or saw. This MP will be used throughout the monitoring period to ensure that water-level measurements taken in the well on different occasions can be compared. Three clearly marked RMs will be established on stable foundations (ones that are not likely to move over the period of the monitoring). Examples of ideal RMs are a USGS or NGS brass monument or a stainless-steel or brass bolt cemented into a hole drilled into a bedrock outcrop. The purpose of the RMs is to provide points from which the MP can be periodically checked, and to re-establish the MP if it is altered or destroyed. The RMs will be far enough from each other and the MP so that if one is intentionally or unintentionally disturbed, the others are not likely to also be disturbed. The MPs and RMs will be near enough, however, that the difference between the MP and RMs can be determined by level survey within an accuracy of 0.01 ft. The MP and RMs will be photographed and adequately described in the field notes so that they can be found on later field visits.

Fieldwork

Fieldwork for the groundwater monitoring program is done during quarterly field visits to the monitoring wells. Most of the fieldwork tasks are done on every visit, but some tasks are done only annually (Table 2).

Table 2. Summary of field and data-handling procedures for quarterly field visits for long-term monitoring using automated approach.

Order	Task	Frequency
1.	Inspect measuring point and reference points	Each visit
2.	Resurvey measuring point elevations relative to reference marks	Annual
3.	Recover CTD, transfer data to field computer and make backup copy	Each visit
4.	Measure DTW	Each visit
5.	Transfer CTD data to field computer and make backup copy	Each visit
6.	Inspect CTD cable	Each visit
7.	If CTD is due for annual accuracy check for temperature, replace with backup CTD	Annually
8.	Calibrate CTD for specific conductance	Each visit
9.	Determine specific-conductance profile and slope of pressure depth relation ($M_{D/P}$)	Annually
10.	Re-measure DTW	Each visit
11.	Deploy CTD	Each visit
12.	Photograph site, especially significant changes	Each visit
13.	Begin data processing immediately upon return from field	Each visit
14.	Review and finalize data	Each visit
15.	Prepare annual data summary	Each visit

Each Field Visit

Tasks done on each visit include inspecting the measuring point and reference points; measuring the DTW; recovering, downloading, and redeploying the CTD; and photographing the site (Table 2). The protocol requires that the DTW be measured more than once during each field visit because water levels are dynamic and can change significantly during the time it takes to complete field work. The timing between manual DTW measurements and recovery and redeployment of the CTD is critical because the manual DTW measurements are used to convert the CTD's submergence depth to water levels relative to the MP. The small diameter of the AMME and KAHO wells precludes making manual DTW measurements while the CTD is also in the well. However, one manual DTW measurement should be made as close as possible to the time the last CTD measurement was made before its recovery; another manual DTW measurement should be made as close as possible to the time of the first CTD measurement after it is redeployed.

When the CTD is recovered, its data will be transferred to a field computer, the transfer verified, and a backup copy made (depending on the design of the CTD, it may or may not be necessary to clear the instrument's memory). On most field visits, the CTD can be redeployed after re-measuring the cable-vent-tube-CTD assembly to determine the depth of the specific-conductance sensor below the MP, checking the accuracy of and/or calibrating the specific conductance sensor (consult manufacturer's instructions regarding pressure-sensor calibration), and conducting routine maintenance. Once a year, the CTD will be taken back to the laboratory for temperature calibration. In these cases, the CTD recovered from the well will be replaced by the second CTD. This protocol uses two CTDs in an alternating system to ensure continuity of data in situations such as this. Whenever one CTD must be removed from the field, the second CTD can be deployed in the well so that data collection continues.

The CTD will be positioned at the same location in the well each time it is deployed so that measurements will be comparable throughout the monitoring period. Initially, the CTD will be set within the transition zone. After years of monitoring, however, the position of the transition zone may have risen or lowered such that the CTD is no longer in the transition zone. If the CTD is substantially above or below the transition zone, it is less useful in tracking the movement of the transition zone, therefore it may be necessary to reposition the CTD. If the entire water column of the well is fresh (less than 1,000 µS/cm at 25˚ C), or only the upper part of the transition zone (less than 25,000 µS/cm at 25˚ C) is present, the CTD will be placed as deep as possible within the limitations of the instrument and without allowing the CTD to touch the bottom of the well. If the entire water column of the well has the salinity of seawater (greater than 50,000 µS/cm), or only the lower part of the transition zone (greater than 25,000 µS/cm) is present, the CTD will be placed near the top of the water column but deep enough that it will remain submerged even if there is a change in water level. Repositioning the CTD should, however, occur rarely, if ever, and should only be done after careful consideration of tradeoff between the need for continuity versus the need to monitor the most ideal location.

Annual Tasks

Tasks done annually include checking the coordinates of the well, measuring the specific-conductance profile, determining the slope of the pressure-depth relation ($M_{D/P,}$ eq. 6), and resurveying the elevation of the measuring point relative to the reference points. Data for determination of $M_{D/P}$ will be collected simultaneously with the data for the specific-conductance profile. The specific procedure differs for AMME and KAHO because of differences in well diameter, but the basic procedure is to program the CTD to measure and record specific conductance and pressure at a one-second interval. The CTD will then be lowered through the water column, pausing for about 30 seconds at 0.5-foot intervals (SOP 16). After transiting through the water column, the CTD is withdrawn, and the data are downloaded from the CTD. Values of P_{CTD} from the CTD will be plotted against corresponding values of the depth of submergence at each pause (D_{CTD}), and $M_{D/P}$ will be determined by regression analysis. The specific-conductance profile will be obtained from the CTD data, and adjusted to the measuring point using the DTW measurements and the computed $M_{D/P}$ value. Because there is a possibility that the water levels in a tidally influenced well will change during the profiling, it is important to accomplish the profiling in as brief a time as possible. It is also helpful to schedule the profiling during a part of the tidal cycle when changes are least rapid (see "Field Schedule" below).

If there is evidence during a field visit that the MP or RMs have been disturbed or defaced, they will be resurveyed immediately rather than waiting for the next opportunity based on the annual schedule. The need to re-establish a new MP should be rare, but if it does arise, the new MP must be surveyed relative to the existing RMs in order to compute the difference between the new MP and the old MP. This is critical for maintaining continuity and comparability between data collected relative to the old MP and data collected relative to the new MP. Photographs of the site will be taken as necessary, particularly to document changes such as growth or loss of vegetation, new roads and buildings in or near the park, changes to the well or the MP, or changes to the reference elevation mark. The relative difference in elevation between the RMs and the MP should be checked annually.

After Fieldwork

Data will be processed and archived as soon as possible after returning from the field. Prompt data processing ensures that details of the field visit are fresh in the memories of the field personnel and reduces the chances of accidental loss or misplacement of data. Equipment will be cleaned, maintained, and stored properly in a manner that is consistent with the SOPs in this protocol and the manufacturers' instructions.

Specific Considerations for AMME

Two existing wells within AMME can be used for the groundwater monitoring program described in this protocol (Fig. 12, Appendix E). Other wells in and near the park are not adequately constructed to meet the objectives of long-term monitoring. Wells AMP05 and AMP13 were used by Perreault (2007) in his reconnaissance study of the groundwater resources of AMME, and therefore have MPs that were surveyed to a vertical precision of 0.01 ft using National Geodetic Survey (NGS) stations. Water levels in both wells are influenced by tides, and specific-conductance data indicate that the wells have a mixture of fresh groundwater and seawater. Because the wells were part of Perreault's (2007) reconnaissance study, some water-level data already exist, including measurements made synoptically (simultaneously) with measurements in 11 other wells in and near the park. These synoptic measurements help place any new data collected from these wells in a broader areal and temporal context.

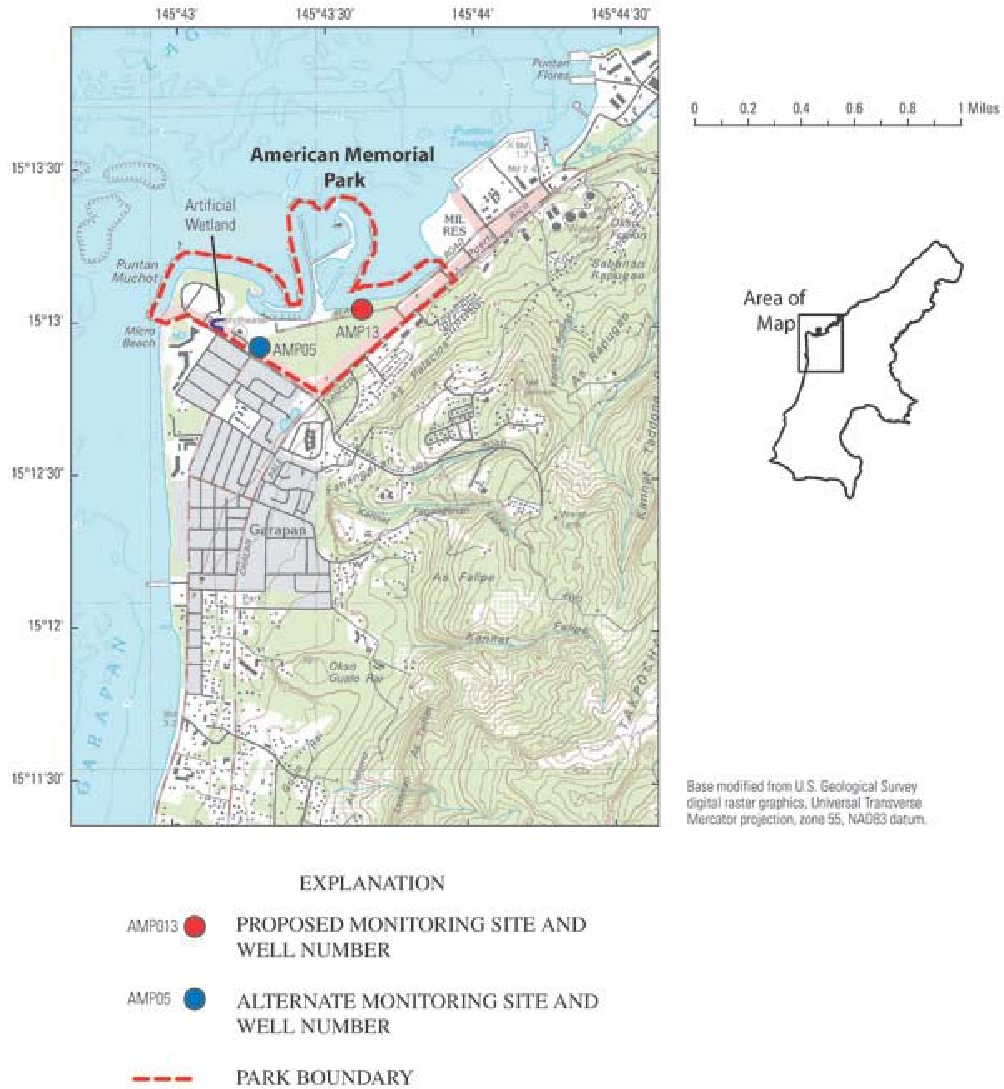

Figure 12. American Memorial Park (AMME), Saipan, Commonwealth of the Northern Mariana Islands.

Well AMP13 is located on the eastern side of the park, about midway between the natural wetland and the park's shoreline on the Philippine Sea (Fig. 12). Well AMP13 is proposed as the primary well for the groundwater monitoring program because it is more likely to show variations in water levels and salinity that are related to factors affecting the ocean, the natural wetland, and the larger groundwater system of Saipan. Also, data from the well are less likely to be overwhelmed by the effects of the reverse-osmosis wastewater discharge to the west of the park. Well AMP05 is located on the western side of AMME, closer to the artificial wetland that formed as a result of discharge of wastewater from reverse osmosis (Fig. 12). The well is proposed as a secondary site because monitoring the effects of high-salinity wastewater discharge on the natural resources of AMME may be of interest to park managers. Both wells have a 1-inch diameter casing set within a 6-inch diameter surface casing with a bolt-on metal cap (Fig. 13). The metal cap is flush with the ground surface; the top of the 1-inch casing has been cut a few centimeters below the cap. Well AMP05 is 6.0 ft deep; well AMP13 is 6.3 ft deep. During a reconnaissance in February 2010, a measuring point and reference marks were established at these wells.

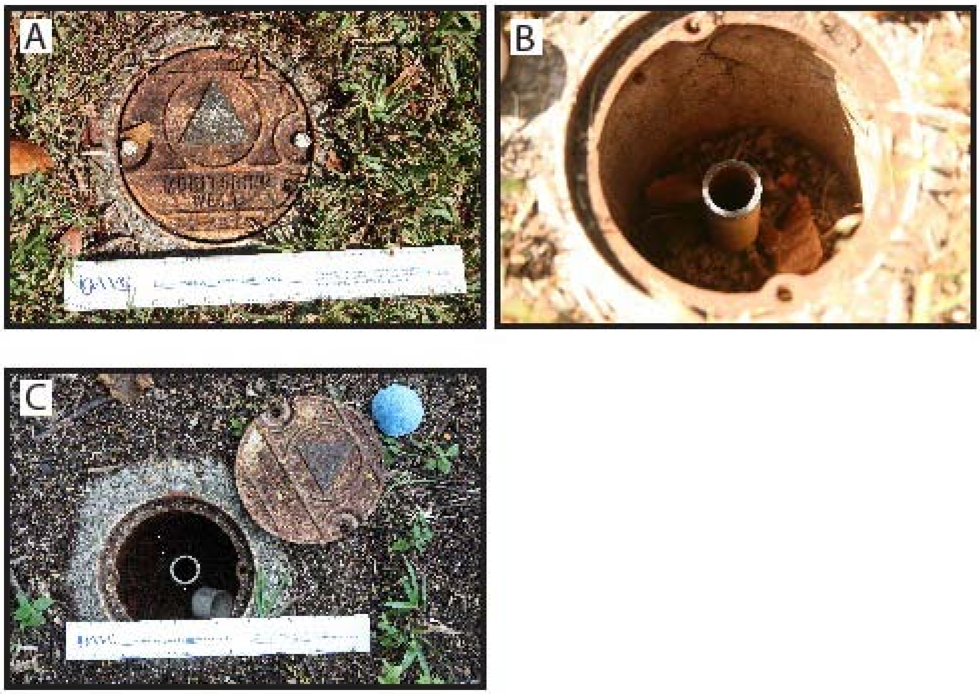

Figure 13. Photographs of monitor wells in American Memorial Park (AMME), Saipan, Commonwealth of the Northern Mariana Islands: A) cover of well AMP05, B) one-inch well casing in AMP05, and C) AMP 13. Covers are about six inches in diameter.

A CTD was deployed in each well during the period from February 8 to March 17, 2010 for preliminary monitoring of water levels and specific conductance. During the preliminary monitoring period, DTW in well AMP05 fluctuated from 2.36 to 2.67 ft; DTW in well AMP13 fluctuated between 1.38 and 3.29 ft (Fig. 14). The water-level fluctuations at both wells are consistent with wells that are influenced by ocean tides. The fluctuation range was greater at well AMP13 (1.38 ft) than at AMP05 (0.30 ft) which is consistent with AMP13 being closer to the ocean. The monitoring period included spring and neap tides, which are apparent in the pattern of water-level fluctuations, particularly in well AMP13.

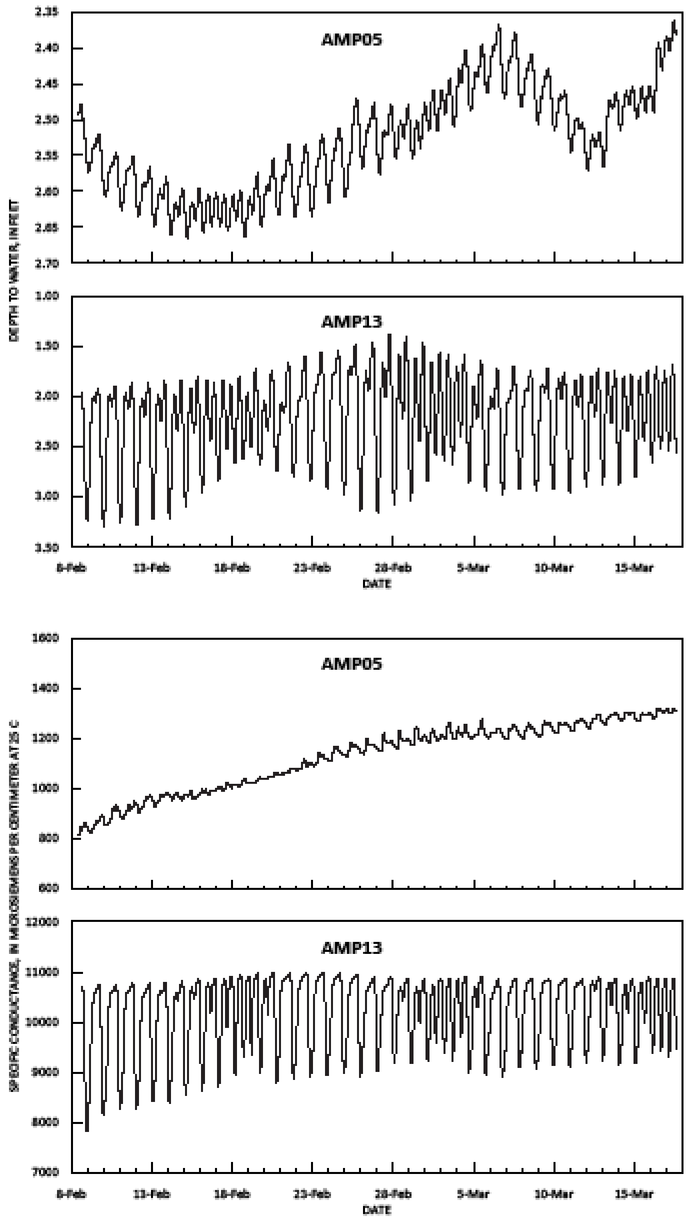

Figure 14. Variation of water levels and specific conductance in wells AMP05 and AMP13, American Memorial Park (AMME), Saipan, CNMI, during the period from February 8 to March 17, 2010.

Specific conductance also fluctuated with tides. During the monitoring period, specific conductance varied from 815 to 1319 µS/cm at well AMP05 and 7,831 to 10,992 µS/cm at well AMP13 (Fig. 14). The higher specific conductance and greater range of variability at well AMP13 is consistent with the well's closer proximity to the ocean. Specific-conductance profiles measured at both wells on February 8, 2010 show an increase in conductance with depth (Fig. 15). Well AMP05 showed an increase from 806 µS/cm at 3.0 ft below the measuring point, to 822 µS/cm at 6.0 ft below the measuring point. In well AMP13 specific conductance was 8774 at 2.5 ft below the measuring point, and increased to 9,153 at 6 ft below the measuring point.

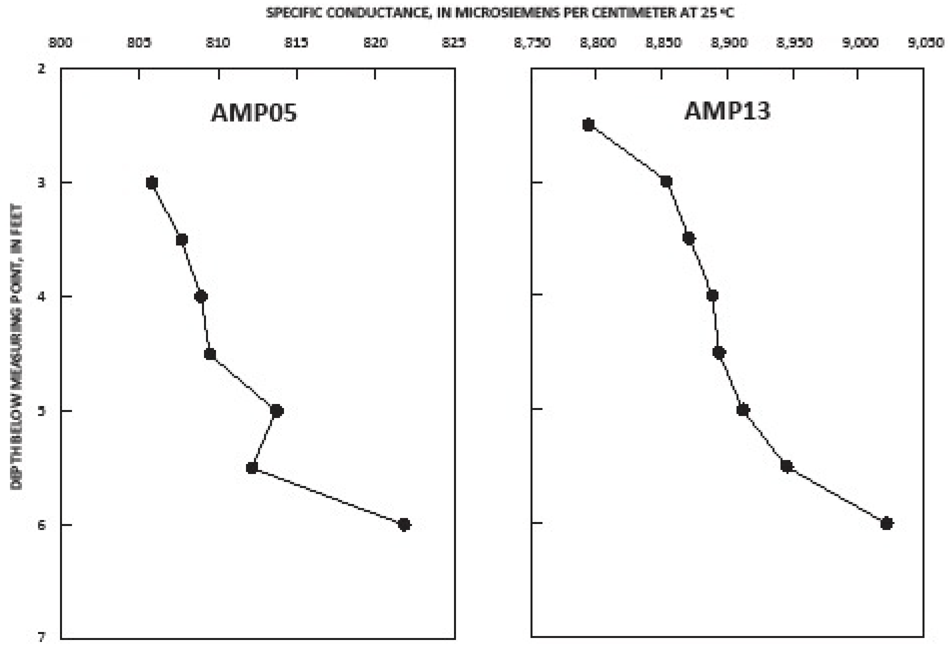

Figure 15. Variation of the specific conductance with depth in wells AMP05 and AMP13, AMME, CNMI, on February 8, 2010.

The water-level and specific-conductance data collected during the reconnaissance and preliminary monitoring provide useful information for setting the CTD for long-term monitoring. As discussed, the ideal depth to set the CTD for long-term monitoring is at the midpoint of the transition zone. However, neither AMP05 nor AMP13 penetrates to the transition zone midpoint. In this case, the CTD should be set as deep as possible without risking sensor fouling that can occur at the bottom of the well. The CTD should also be deployed at a depth where it will always remain submerged, that is, it should be set deeper than the expected fluctuations in water level for the given well. The preliminary monitoring data indicates that the water levels in well AMP13 fluctuate about 1.38 ft, and it is possible that fluctuation will be greater under certain conditions that arise during long-term monitoring. There is less concern at well AMP05 where water-level fluctuation is only about 0.30 ft. During preliminary monitoring, the CTD was set at 5.30 ft below the measuring point in AMP05 and 5.33 ft below the measuring point in AMP13. These depths can be used for the long-term monitoring to ensure that the CTDs remain submerged and monitor as close to the transition-zone midpoint as practical.

Specific Considerations for KAHO

Three wells drilled in 1996 as part of the study of the groundwater resources in KAHO described by Oki et al. (1999) can be used for long-term groundwater monitoring (Fig. 16, Appendix E). Oki et al. (1999) monitored these wells for about a month and showed that water levels in the wells are strongly influenced by tides and that the general slope of the water table in the park was toward the west (toward the coast). They also estimated that the water in the wells was brackish, containing a mixture of 13 to 25 percent seawater, and showed that salinity increased with depth in the wells. Because data already exists for these wells and much is known about the wells relative to the regional groundwater resources in the park, the wells are ideal candidates for continued long-term monitoring.

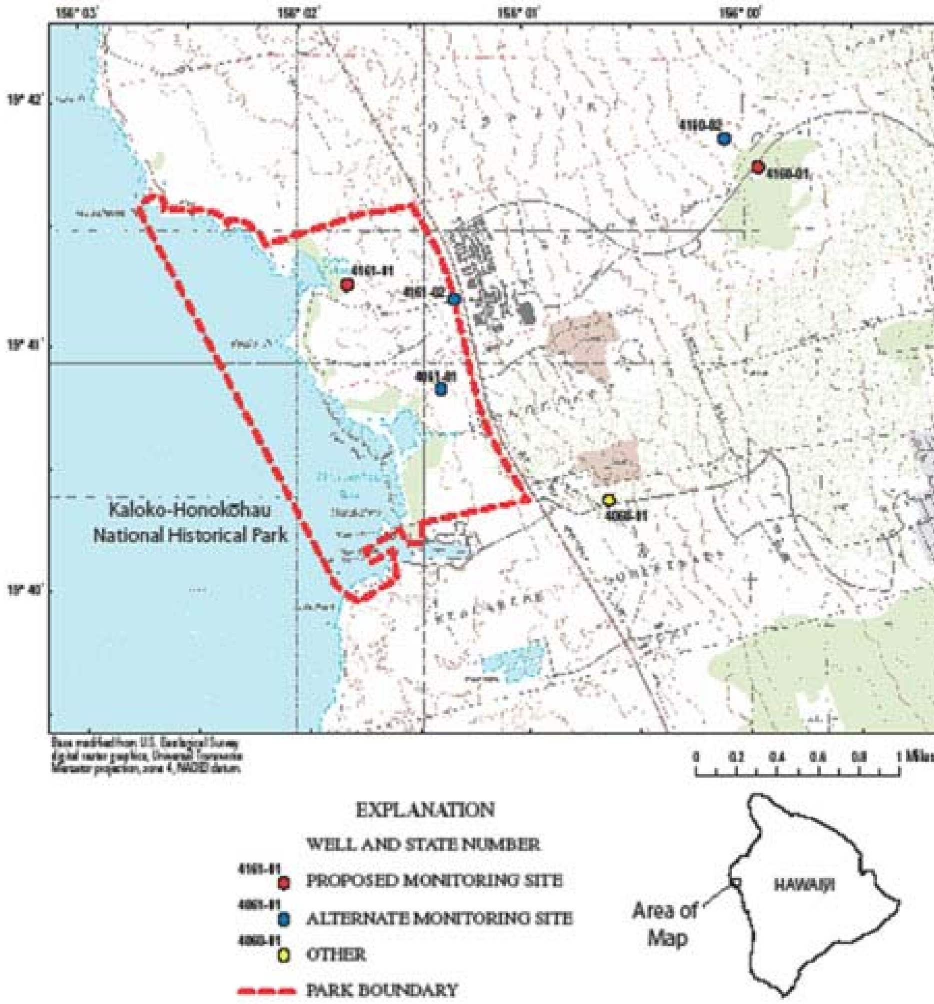

Figure 16. Kaloko-Honokōhau National Historical Park, (KAHO), island of Hawai'i.

All three wells are adequately constructed to meet the needs of long-term groundwater monitoring. Well 4161-01 is proposed as the primary well for the long-term groundwater program because of its proximity to a significant ecologic feature, the Kaloko Fishpond (Fig. 16). The other two monitoring wells, 4061-01 and 4161-02, are proposed as alternate sites. KAHO park management has requested that well 4160-01, a former irrigation well outside the park, be monitored concurrently with well 4161-01 inside the park. The objective of monitoring well 4160-01 is to gather data from a well upgradient of the park.

Wells 4161-01, 4061-01 and 4161-02 are currently being monitored by the USGS in cooperation with the NPS. Data from the monitoring will be used in a numerical model to assess how climate change, land development, and other changes may affect park resources in the future. The current monitoring uses procedures similar to those described in this protocol, and therefore offer a baseline dataset on which the monitoring in this protocol can build. To maintain consistency, the CTDs for the monitoring described in this protocol should be deployed at the same depths as those in the current monitoring. Plans are already in place to transfer the monitoring from the USGS to the NPS staff in 2010 (D.S. Oki, USGS, oral communication, 2010).

Data Handling, Analysis, and Reporting

After field collection, all data will undergo procedures for quality assurance, archiving, and periodic analysis and reporting. These procedures are divisible into two stages: (1) data processing, which includes all data handling from the time of field collection to archiving of final data, and (2) data analysis and reporting, which includes an annual report that analyzes and summarizes the groundwater monitoring data.

Well Numbers

To organize the data, each well in the network will be assigned a unique well number. This number will be used in all field notes, field data sheets, interim data-processing files, and is needed to link data in various tables in the groundwater database. The number shall consist of the NPS park abbreviation (AMME or KAHO), followed by a sequential number representing the order in which the well was placed in the network. For example, the first well in the AMME network would be given the number AMME_001. If another well is established in the AMME monitoring network, it would be given the number AMME_002.

Wells may already have one or more identification numbers given by state, federal, or local agencies, or by the well owner. These numbers cannot be used for this protocol because they likely do not follow a consistent format, which is needed for linking database files in this protocol. Numbers from other agencies can, however, be incorporated as part of the descriptive well name to help keep track of synonymies among the various well numbers.

Data Workspaces and Repositories

Some data will consist of hand-written information, such as field data sheets and field notes; part of this data will be transcribed to computer data files during processing and analysis. Electronic data files will also be produced from the CTD. Data handling and analysis therefore require workspace and storage for both physical materials (e.g., paper and compact disks) and electronic data while they are being worked, as well as repositories for the archiving of preliminary and final data sets. To accommodate these needs, two basic components constitute the workspace and repositories for the groundwater data: (1) well files, which include paper and electronic subcomponents, and (2) the groundwater database which stores and serves final data.

Well Files

A well file is the fundamental component for information storage for the groundwater monitoring program. Whereas only a select portion of the data will be archived in the groundwater database, nearly all data from the groundwater monitoring program will be placed, in some form, in the well file. A well file will be created for each well in the groundwater monitoring network (SOP 17). The well file will have two subcomponents (Table 3):

1. Paper – which will contain all of the original field notes, any storage media (disks, flash memory, etc.) used to backup data in the field, and any other physical materials that are essential for maintaining thorough records of each well in the network

2. Electronic – will contain data uploaded from the CTD as well as any other electronic data created during data processing.

Table 3. Contents of the well file.

Well-file component	Contents
Paper	Station analysis (printed copy of electronic version) Selected photographs and photograph log (printed copy of electronic version) Original field notes and field-data forms Electronic storage media used to backup data in the field
Electronic	Station analysis (Appendix B) Photographs and photograph log Scans of field notes and field sheets Unaltered data uploaded from CTD Screened CTD data with computed DTW and calibration adjustments Metadata for CTD data processing

Figure 17 shows the suggested folder structure and naming conventions for the electronic subcomponent of the well file. The electronic well file for a given well will consist of a folder identified by the well number. Within this folder are folders labeled by the date of the field visit on which the data were collected. Each of the dated folders have subfolders for CTD data, scans of field data sheets, and photographs.

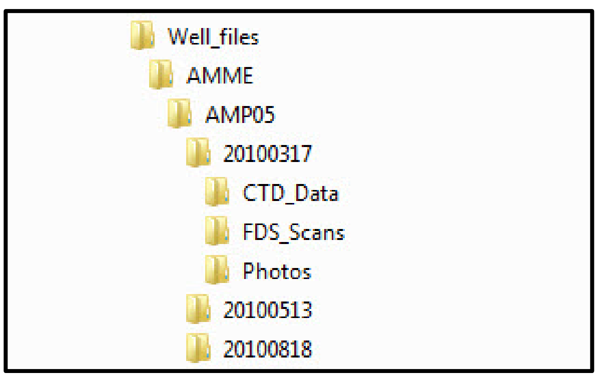

Figure 17. Suggested folder structure for the electronic subcomponent of the well file for the groundwater monitoring protocol.

Each well file will contain a station analysis (Appendix B), which is the primary location for metadata related to the groundwater monitoring activities at the well. The station analysis is a running log that documents, from the start of monitoring, all relevant information such as name, location, monitoring history, instruments used, history of data processing and archiving, and remarks that include significant historical events such as storms and vandalism. The station analysis will be updated periodically with information collected during the long-term monitoring period. The station analysis will be created as an electronic document (using a word-processor or other suitable program). The electronic document will be stored in the top-level folder in the electronic component of the well file (for example, folder AMME_001 in Fig. 17). After every update, a paper copy of the station analysis will be printed and placed in the paper component of the well file, replacing the previous version.

Database

Data from the groundwater monitoring protocol will ultimately be stored in STORET, the database used by the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency 2008). The structure of the proposed groundwater database consists of a primary table containing the basic information about each well in the monitoring network and four secondary tables containing the field-visit history and monitoring data. The secondary tables will be linked to the primary table by the well number. The details of the database structure are described in SOP 18. Hand-written data can be transcribed either into tables or into database forms after each field visit; data files from the CTD can be imported to a spreadsheet for initial processing and computations, then output in a standard format that can be imported to the database. The database forms and tables for importing data will be created when the groundwater monitoring protocol is implemented and the specific nature of the CTD output, which varies by model, is known.

Data Processing

Data processing has three steps: (1) initial data handling and processing, (2) data checking and quality assurance, and (3) final review. All of these steps are completed quarterly, after each field visit.

Initial Data Handling

Handwritten Data and Digital Photographs

As soon as possible after returning from the field, electronic scanned images will be made of all handwritten data, including field notes and completed field forms (SOP 19). The original handwritten data will then be archived in the paper subcomponent of the well file and the scanned files will be archived in the electronic subcomponent of the well folder. A printed copy of the scans will be used for all further data processing.

Hand-written data will include manual measurements of specific conductance and DTW. These specific-conductance and DTW measurements will be transcribed from the field notes onto forms in the groundwater database (SOP 19). The initials of the person transcribing the data will be entered along with the data. Data in the data base at the end of this stage will be designated “provisional” while undergoing checking, quality assurance, and review procedures.

As soon as possible after returning from the field, digital photographs will be uploaded from the camera or storage device into a subfolder in the electronic subcomponent of the well file (Fig. 17; SOP 19). A photograph log explaining the date, time, photographer, and subject of the photograph will be created as a text file. This log will also be placed in the subfolder with the digital photographs. A selection of important photographs may be printed and the prints placed in the paper subcomponent of the well file.

CTD Data

The CTD data will be transferred from the field laptop computer to the electronic subcomponent of the well file (Fig. 17). The backup copy of the data made in the field will be placed in the paper component of the well folder. A separate text file for metadata will be created for each CTD data file. This metadata file will be a log of all actions taken during the data processing. Header information will include the well number; well name; latitude and longitude; beginning and ending dates and times of the data to which the metadata pertain; the brand, model and serial number of the CTD; and name of the person who uploaded the data from the field computer. All significant processing steps, including checking and review, should be logged in the metadata, along with the name of the person completing the steps. The original unaltered data transferred from the CTD will be archived together with its metadata in the electronic subcomponent of the well file.

A copy of the CTD data will be made and used for screening to eliminate obvious errors or spurious readings (SOP 19). The screening will be done by importing the data into a spreadsheet and making a plot of each parameter (pressure, temperature, and specific conductance) (Fig. 18). The data will initially be checked against the field notes to ensure that they are in agreement. For example, the first DTW measurement made after the CTD was deployed should correspond in time with a pressure value indicating that the CTD was submerged. Other aspects, such as the time of CTD submergence or withdrawal recorded in the field notes, should correspond with pressure changes recorded by the CTD.

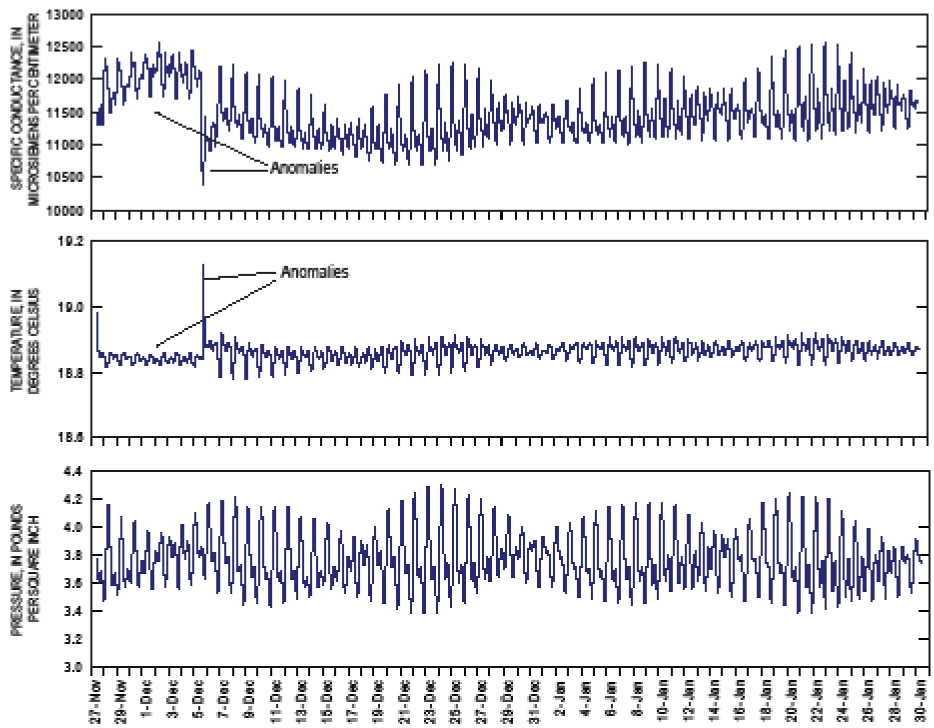

Figure 18. Example specific-conductance, temperature, and pressure data from a vented automatic conductance-temperature-depth (CTD) instrument deployed in a coastal well.

Note the presence of anomalies that should be investigated during the data-screening process to determine cause. Some anomalies are real changes in pressure, temperature, or specific conductance, while other anomalies may be due to instrument error.

If the data agree with the field notes, further data screening can be conducted (SOP 19). Spurious data that may have been recorded while the CTD was being lowered into place or withdrawn from the well will be removed from the screened data set. If there are observations or known events that would have a detrimental effect on the data being logged by the CTD (for example, vandalism or other obvious tampering of the CTD), that interval of data will also be removed from the screened data set. This data will also be graphed in time-series plots (data versus time) to further search for anomalies that may indicate instrument malfunction (Fig. 18). Not all anomalies are due to instrument error, however. Such “real” anomalies *should not* be removed from the data. Some anomalies are real changes in pressure, temperature, or specific conductance that might arise as a result of episodic events, such as pulses of groundwater recharge following a rainstorm. How groundwater responds to such events can differ from one location to the next. Persons involved in data processing should therefore be aware of how certain events are manifest in the groundwater data for the particular monitoring well, so that anomalies caused by these events are not mistaken for instrument errors. In general, an anomaly should be investigated thoroughly and all possible real causes exhausted before the data are deemed to be due to instrument malfunction. If the anomalies are truly due to instrument malfunction, the erroneous data should be removed from the screened data set and a note added to the metadata explaining the section (period of time) of the deleted data and the reasons for the deletion. If the CTD data are replete with spurious values, a note will be made in the metadata and in the station analysis, the instrument will be checked and, if necessary, repaired or replaced. A detailed account of the screening, especially any data that were removed and the reasons for the removal, shall be recorded in the metadata. After the screening process is complete, the screened spreadsheet will be exported as a text file and both the text file and spreadsheet will be archived in the electronic subcomponent of the well file (Fig. 17).

A copy of the screened data will be created and imported into another spreadsheet for the purposes of computing DTW. The spreadsheet with the computed and corrected values will be exported as a text file and both the text file and spreadsheet will be archived in the electronic subcomponent of the well file (Fig. 17). The initials of the person transcribing the data will be entered along with the data. The data will also be imported into the groundwater database and given a “provisional” status while undergoing checking, quality assurance, and review procedures described below.

Checking Data for Accuracy

Field data sheets, spreadsheets, and data entered into the database will be checked to ensure that all computations are correct, screening results are reasonable, data were recorded and entered into the database correctly, and protocols were followed (SOP 20). The checking will be done by someone other than the person who did the data entry and initial computations.

The person doing the checking may make minor corrections provided the corrections are noted in the metadata. Substantial errors should be brought to the attention of the project lead, who will determine whether the data files should be returned to the person who entered or computed the data. Corrections to original field data sheets should be rare, but if needed, they will be made by drawing a line through the error and writing the correction nearby. Under no circumstances shall any entry be erased.

After the check is complete, the initials of the person doing the checking will be recorded on the field data sheets, in the metadata in the electronic well file, and in the appropriate field in the groundwater database. The data will then be submitted for a final review.

Final Review

A final review of the checked data will be conducted by the project lead to ensure that (1) measured data are correct and free of spurious values, (2) computed values are correct, (3) all aspects of the data collection and quality assurance were conducted according to the SOPs in this protocol, and (4) data have been properly archived (SOP 21). If errors or other problems are found, the project lead shall discuss them with the persons responsible for data entry, computation, and checking, and appropriate corrections shall be made. If it is determined that an erroneous data value is due to circumstances that cannot be corrected, the value will be omitted from the archive of final data and a note placed in the station analysis. If the review indicates that one or more SOPs were not followed during data collection, handling, or processing, the project lead may send the data back for processing according to the SOP. If it is not possible to retroactively follow the SOP, the project lead shall decide whether the failure to follow the SOP has compromised the quality of the data; if so, the data value will be omitted from the final data set. The final review is also an opportunity to evaluate and rectify problems, and evaluate where the SOPs can be improved.

Data approved during the final review will be considered correct. The project lead will indicate final approval of materials by entering his or her initials in the appropriate field in the groundwater database, and changing the status of the data in the database from “provisional” to “final” in the groundwater database.

Data Analysis and Reporting

Reports will also be published annually summarizing data and analysis of the long-term monitoring. All reports will be prepared and peer-reviewed in accordance with NPS Natural Resource Publications guidelines and be published in the NPS Natural Resource Report series (National Park Service, 2008b). Reports will also be made available through the NPS Integrated Resource Management Application (IRMA), an internet-based catalog, search, and management tool.

The purpose of the annual summary is to (1) summarize the voluminous automated data collected in a year and report daily and monthly averages, and (2) provide an opportunity to compare data collected in one year to that collected in previous years. The comparison not only ensures that the collection of data is conducted in a consistent manner, but also allows analysis for trends. Because the computation of daily averages reduces the effect of tides on the water-level data (as discussed earlier), the daily mean values will be useful for identifying long-term trends, especially when several years of consecutive data are available.

An outline of the annual long-term monitoring report is given in SOP 22. The report consists of three sections: (1) introduction, (2) study area, (3) methods, (4) results, and (5) discussion. The background section will specify the period of data summarized in the report as well as provide the general setting, geology, potential stresses to the water system, well name and geographic coordinates, well-construction details, measuring-point and reference-point locations and relative elevations, and a brief discussion of methods and data sets.

The data section will include tables of the manual DTW measurements (including date and time of measurement) for the year. The data section will also have a graph of the annual specific-conductance profile.

Daily means from the 15-minute CTD data will be computed using the following equation:

$$\boldsymbol{m}_{\mathrm{d}} = \left(\sum_{t=0}^{t=2345} v_t\right) / n \qquad \text{(eq. 7)}$$

where $\boldsymbol{m}_{\mathrm{d}}$ is the daily mean value, $t = 0$ is midnight at the beginning of the day, $t = 2345$ is the time of the last reading for the day (at 2345 h), $\boldsymbol{v}_t$ is the value whose daily mean is being computed, and $\boldsymbol{n}$ is the number of values in the average (note that the midnight value belongs to the day to come, not the day that has passed). Daily mean values will be computed only for days having a nearly complete set of 15-minute measurements (i.e., missing no more than nine of the 15-minute measurements). The daily mean DTW and specific conductance will be included in the report. The daily mean values will also be shown as time-series graphs for all data collected from the start of monitoring through the current year.

The evaluation section of the report will discuss any shifts or trends that are apparent in the data. If shifts or trends are apparent, the data collection, instrumentation, calibration, data entry and review will be re-examined to ensure that the shift is not artificial. If the shift or trend is not artificial, possible causes will be discussed. After several years of monitoring, the transition zone may have changed such that the CTD is no longer within it. If this is the case, the evaluation section will also discuss whether the CTD must be repositioned. Any repositioning of the CTD will also be recorded in the electronic and paper components of the well folders, metadata, and annual summaries for the year in which the repositioning was made. As discussed previously, repositioning the CTD should, however, occur rarely, if ever, and should only be done after careful consideration of tradeoff between the need for continuity versus the need to monitor the most ideal location.

Personnel Requirements and Training

This protocol requires the services of personnel who have the skills and motivation to collect accurate scientific data and are trained in the objective of the monitoring, background of the monitoring strategy, execution of all SOPs, and interpretation of water-level and salinity data. Two field technicians, at minimum, are needed at each park (AMME and KAHO) to fully conduct the groundwater monitoring protocol in a park. In addition, one project lead is needed to oversee the groundwater monitoring in these two parks. The duties do not constitute full-time employment (FTE) for any of these individuals, but multiple individuals are needed to ensure that adequate personnel are available to cover for sick leave and vacations, and that reviews are conducted by someone other than the one whose work is being reviewed. In addition, some tasks, such as level surveying, require at least two people. A two-person field team is also preferred for safety reasons. Because none of the individuals is full time, the monitoring can be assigned to staff having other duties in the NPS system, or to part-time employees. The training and skill sets needed to effectively conduct the monitoring take time to acquire, however, and a person will develop valuable insights over years of monitoring. For this reason, the duties of this protocol should not be assigned to temporary employees.

Field Technicians

The ultimate goal of the field technicians is to collect and archive accurate groundwater-level and specific-conductance data over a long period of time. Two are required for each park where implemented. The individual parks will be responsible for providing one technician and I&M will provide the other field technician. The tasks listed here and in the SOPs are detailed steps to achieve this goal. The technicians are responsible for conducting all field-related tasks listed in this protocol, including the maintenance of field equipment. The technicians are also responsible for entering and checking data in the well files. In addition, the technicians will assist with the preparation of the preliminary-monitoring report and the annual data summary.

The I&M biological technician in each park will be designated the lead field technician. The lead field technician will have added responsibilities of working with the project lead to purchase equipment, obtain permissions and permits to use or access the wells, and notify landowners or well owners prior to each field visit if required.

Qualifications and Training

The technician and lead technician positions will be filled by individuals with at least a high-school diploma or equivalent; a strong aptitude for math, science, and technical reasoning; above-average computer skills; attention to detail, and insistence for accuracy. Technicians will also be physically able to conduct the fieldwork, which may include driving long distances, hiking with field equipment, and lifting up to 50 pounds.

This protocol and its SOPs are designed to provide sufficient information to maintain an effective groundwater monitoring program in the National Parks, but new technicians will be required to attend a training course on the overall objectives and purpose of the monitoring; establishing, operating, and maintaining a groundwater monitoring station; using and maintaining equipment; and data-archiving procedures (SOP 2). The course will include both classroom and practical field instruction, and focus on the SOPs in this protocol. The course will be about 32 hours, and can be conducted by the USGS (see “Services from Cooperating Agencies” below) or by qualified NPS staff that have thorough knowledge of the groundwater protocol. Field experience, beyond classroom or specialized training, is an essential part of developing the skills needed to successfully maintain a groundwater monitoring program. New personnel must spend time in the field under the guidance of an experienced field technician or project lead.

Project Lead

The project lead has the overall responsibility for the groundwater monitoring program. The duties of the project lead include: (1) providing administrative and technical oversight of the program; (2) working with the lead technician to obtain necessary permits and permissions, equipment, supplies, and services; (3) providing the final review of data and approving the data as final and ready for publication; and (4) preparing the annual summaries and interpreting the results in terms of potential effects to the condition of park resources and the possible causes of observed changes. The project lead may also conduct fieldwork on occasion to cover for a technician on vacation or sick leave.

Qualifications and Training

The minimum educational requirement for the project lead is a bachelor's degree in one of the natural sciences, mathematics, or engineering. The project lead will have excellent written and oral communication skills, especially with regard to presenting scientific data, and be proficient with computers and have the ability to adapt to new computer technologies. Organization and project-management skills are also essential.

Because the project lead may occasionally cover for an absent technician, the project lead must be able to perform all the tasks of a technician, undergo training (including field experience) equivalent to that received by the technicians, and have the same physical capabilities required for technicians. Because a substantial part of the project lead's duties is to interpret the data from the groundwater monitoring, the project lead will have a firm understanding of groundwater hydrology of coastal aquifers, what factors induce changes in the groundwater system, and how those changes relate to the resources of each park in the project lead's domain. A minimal understanding can be obtained from this protocol narrative. It is expected that the project lead acquire a broader understanding through coursework and self-guided study. The science of groundwater and the factors that affect it are in constant flux, and scientific understanding of some phenomena, such as global warming and sea level rise is changing rapidly. The project lead will maintain knowledge of current information on these phenomena.

Services from Cooperating Agencies

Certain services may need to be contracted to cooperating agencies. Initially, the 32-hour training for all new field team members (project lead and field technicians) will be provided by contract with the USGS-PIWSC. The USGS has monitored the Nation's water resources for more than a century and has developed and refined methods for groundwater data collection and archiving. The PIWSC has a long history of groundwater monitoring and analysis in the Pacific islands. Subsequent training of new technicians can be contracted with the USGS or provided by NPS staff that have complete knowledge of the protocol.

Tasks such as calibration of some instruments are impractical to accomplish using NPS personnel because the occasional nature of these tasks does not warrant the additional training required and expense of purchasing and maintaining the necessary equipment. These services may also be obtained by cooperative-contract basis from the USGS-PIWSC or through instrument vendors.

Operational Requirements

The operational requirements described here assume that the technician's primary duty station is on the same island as the parks they service, and that round-trip travel time to the monitoring wells averages about two hours. The primary duty station of the project lead is assumed to be on the island of Hawai‘i. The operational requirements also assume that AMME has two wells and KAHO has three wells being monitored.

Labor

The annual labor estimates assume that one project lead oversees the groundwater monitoring program for both AMME and KAHO. Annual labor for the project lead is estimated to be 90 hours (5 percent FTE), with an additional 56 hours in the startup year to cover labor for training and ordering and testing of equipment and supplies (Table 4).

Table 4. Estimated annual labor for groundwater monitoring program assuming one well per park.

Duties	Labor (hours per year)		
	Project lead	Lead technician	Technician
Administrative duties	16	8	0
Monitoring			
Fieldwork preparation	16	16	8
Fieldwork	6	32	32
Data processing	NA	8	4
Data checking	16	8	4
Analysis	20	0	0
Report	16	8	0
Total	90	80	48
Percent FTE	5	4	2.8
Additional for startup year	56	56	56
Additional startup FTE percent	3	3	3

The annual labor estimates assume that two technicians (one technician and one lead technician) are assigned to each park. Estimated labor for each lead technician is 80 hours (4 percent FTE) with an additional 56 hours in the startup year (Table 4). Labor for each technician is estimated to be 48 hours (2.8 percent FTE) with minimal additional hours in the startup year.

Field Schedule

Hawai‘i and Saipan lie in the tropics; therefore, there are few seasonal constraints on field schedule. There is no seasonal aspect to the fieldwork in this protocol because the groundwater monitoring program is designed to be conducted throughout the year. The monitoring can be initiated at any time of the year, with the quarterly field visits continuing thereafter. However, the strong tidal signals in wells in AMME and KAHO can cause rapid water-level changes during certain parts of the tidal cycle, and thus affect the accuracy and efficiency of field measurements made during quarterly field visits. To avoid this problem, the quarterly field visits can be scheduled for a time in the tidal cycle when water-level changes are least rapid, such as near the peak of high tide or the trough of low tide. It is important to note that although the tidal signal in a well is driven by ocean tides, the signal in the well usually lags that of the ocean. Therefore, the scheduling should be based on the tidal signal *of the well*, not that of the ocean tides. The timing of the tidal signal in the well will become apparent after processing of the first few months of data; the scheduling of subsequent visits can be adjusted accordingly. Fieldwork can continue during rainy seasons, although occasional severe weather may require postponement of field activities for a few days. The quarterly period between field visits should be maintained as much as possible, however, to ensure that the CTD is working and to minimize discontinuity in the data.

Equipment and Facilities

Field

The primary instruments required for the groundwater monitoring program are the steel measuring tape and CTD. A surveying level and rod are also required for establishing MPs and reference points, and a handheld GPS is required for determining the geographic coordinates of the monitoring wells. Specifications for these instruments are given in SOPs 4 and 6-11.

Other equipment required for the groundwater monitoring program are common to most field-oriented work, and are assumed to be available at the parks, or can be shared with other I&M programs. This equipment includes a field laptop computer, a field vehicle, a standard set of tools, safety and emergency equipment, and personal protective clothing and equipment.

Office

The groundwater monitoring team will require a clean, well-lighted workspace with a worktable or counter space, a few cubic meters of storage, and access to tap water, electric power, and standard office equipment. The storage of the paper component of the well file requires file-cabinet space in an area that is safe from water, fire, insects, or other agents of damage. The filing cabinet should be at a location easily accessible to the groundwater monitoring team.

Computer

Both the groundwater database and the electronic component of the well folder shall be stored on a section of a networked server that has been reserved for this project. Each member of the groundwater monitoring team shall have a computer workstation linked to the server and have appropriate read/write permissions. The server and workstations should have a schedule of regular backups and be protected from inadvertent or malicious data corruption. The server should, however, provide some accessibility to outside entities for the purpose of data retrieval.

Other equipment

Deionized water for rinsing the CTD probe may be purchased, but if deionized water is needed for other I&M programs, it may be more cost effective to purchase a water deionizer. Some CTDs require desiccant, which must be replaced periodically. If a laboratory oven is available, used desiccant may be recharged by drying in the oven at a temperature and for a period specified by the manufacturer.

Supplies and Services

Services of outside laboratories, equipment manufacturers, or contractors are needed for periodic instrument calibration and supplies. Accuracy checks and calibration of the CTD for specific-conductance are done in the field by the technicians, but require specific-conductance standards made by an outside laboratory. Accuracy checks of temperature are done in the laboratory by the technicians, but actual calibrations are normally done by the CTD manufacturer. Accuracy check and calibration of the steel tape will be done by the USGS or NIST. Initial training will be provided by contract with the

USGS; subsequent training may also be provided by contract with the USGS or in-house by NPS staff with thorough knowledge of the protocol.

Budget

Startup Costs

Startup costs include costs for purchasing and checking new equipment and for training. Estimates are based on 2010 equipment prices and an hourly salary of $30 for the project lead, $20 for the lead technician, and $20 for the technician. The salaries include benefits, and assume that the project lead has a grade of 12 on the federal civilian general schedule (GS), the lead technician has a grade of GS 7, and the technician has a grade of GS 7. The total estimated startup cost is $27,440 (Table 5).

Table 5. Startup costs for the groundwater monitoring program assuming one well per park.

Item		Cost
Equipment		
	CTD	$ 3,200
	Steel measuring tape	1,000
	GPS	400
	Surveying equipment	1,600
	Safety clothing and equipment	500
	Subtotal	$ 6,700
Services and supplies		
	Steel tape calibration	$ 700
	Training	7,900
	Specific conductance standards	300
	Miscellaneous	100
	Subtotal	$ 9,000
Labor		
	Project Lead	$ 4,380
	Lead Technician AMME	2,720
	Technician AMME	960
	Lead Technician KAHO	2,720
	Technician KAHO	960
	Subtotal	$ 11,740
Total		$ 27,440

Annual Budget

The annual budget includes costs for conducting quarterly field work, data entry, checking and archiving, and the preparation of an annual report. The budget also includes costs for services, such as periodic equipment calibration. The annual budget also anticipates that most equipment will need replacement after 10 years (5 years for CTDs) and that new staff will be hired and need to be trained every 5 years. Prorated costs for these expenses are included in the budget. The estimated annual budget for the groundwater monitoring program is $11,120 (Table 6).

Table 6. Annual costs for the groundwater monitoring program, assuming one well per park.

Item	Cost
Equipment[1]	$ 1,000
Services and supplies	
CTD calibration[2]	$ 300
Steel tape calibration[3]	100
Training	1,600
Specific conductance standards	200
Miscellaneous	100
Subtotal	$ 2,300
Labor	
Project Lead	$ 2,700
Lead Technician AMME	1,600
Technician AMME	960
Lead Technician KAHO	1,600
Technician KAHO	960
Subtotal	$ 7,820
Total	$ 11,120

[1] Sum of replacement costs for all equipment prorated over expected longevity.

[2] Approximate; actual cost depends on manufacturer's recommendations.

[3] Cost prorated over 5-year interval between calibrations.

Protocol Revisions

The science of groundwater is likely to advance over the period of this monitoring. These advances may lead to far-reaching changes such as our conceptual understanding of groundwater in island and coastal aquifers, or smaller changes such as improved instrumentation. It is therefore likely that this groundwater monitoring protocol will require revisions in the future. A guideline for revising this protocol is provided in SOP 1. Revisions may be made to the main body of the protocol (narrative), or to individual SOPs, field data sheets, or templates. In all of these cases, revisions will be designated by version numbers having numerals on the left and right of a decimal point. Original versions of all parts of the protocol have been given the version number 1.0. Major revisions will be designated by sequentially increasing the digit on the left of the decimal (e.g., 2.0, 3.0, 4.0...). Minor revisions will be designated by sequentially increasing the digit on the right of the decimal (e.g., 1.1, 1.2, 1.3...). A history of all revisions will be maintained using the template in Appendix C.

Revisions to the Narrative

Revisions to the narrative are likely to lead to changes in other parts of the narrative and one or more of the SOPs, field data sheets, or templates. A revision of the narrative is therefore considered a revision of the entire protocol, and will be designated by a new version number in the title. Any revision to the narrative that has a large impact on the protocol as a whole constitutes a major revision. Examples of major revisions to the narrative include (1) a change in the conceptual understanding of groundwater occurrence in the parks, (2) a change in the rationale or objectives for the groundwater monitoring in the parks, (3) a change in monitoring parameters, or (4) substantial changes in the groundwater monitoring design or data handling, analysis, reporting, quality assurance or archiving. Minor revisions to the narrative are those that have a limited effect on the protocol as a whole, and may include small changes in the use of the data, monitoring-well selection, measurement frequency, instrumentation, specific procedures for fieldwork and data processing, personnel requirement and training, field schedule, or supplies and services. Budget fluctuations resulting from inflation or other economic factors can be handled administratively without revising this protocol.

Revisions to the SOPs, Field Forms, and Templates

In most cases, a revision of an SOP is a procedural change that affects only that SOP or perhaps one or two other SOPs. Similarly, a revision of a field data sheet or template has a limited effect on the protocol as a whole. Revisions to an SOP, field data sheet, or template are therefore designated by a change only in the version number of the affected SOP, field data sheet, or template. Revisions may be major or minor. Major revisions are those that result in a substantial change in the SOP, field form, or template. Minor revisions are those that affect only a small portion of the document.

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Appendix A: Field Data Sheets (FDS)

FDS 1- Quarterly Field Visits

FDS 2- Establishing and Checking Measuring Point, Reference Marks, and CTD Support

FDS 3- Specific-Conductance Profile and Pressure-Depth Relation

Field Data Sheet 1
Quarterly Field Visits

Date__________ Party_________________________________ Checked by_________ Date________
Well name and location____
MP and RMs OK? ________________ Date last surveyed _____________________________________

Recover CTD and Measure DTW Immediately
Time of CTD recovery________________
Measured DTW (ft below MP):
Start time_______________
1st: Hold________ Cut________ DTW________ 2nd: Hold_______ Cut_______ DTW_______
End time________________
Avg. of 1st and 2nd measured DTW______________ Corrected w/ calibration table________________

Upload CTD data, Inspect Cables and Vent Tube
Time: On CTD clock _______________ On field watch/computer synch. with reference______________
Reset CTD clock? ____
Upload data from CTD: Filename(s), location:____
Backup copies: Filename(s), location ____
Cable and vent tube OK?____
Date of last determination of sp.- cond. profile and $M_{D/P}$ ____________________ (conduct SOP 16 if due)

Determine the depth of the specific-conductance sensor below the MP

Sketch CTD-vent-tube-cable assembly in relation to MP and support (See fig. 5-1 in SOP 5). Label sketch with dimensions.	**A) Distance between sp.-cond. sensor of CTD and point (eyebolt) where cable attaches to well (length A in fig. 5-1 in SOP 5)** **__________________feet** **B) Distance from MP to the point (eyebolt) where the CTD cable attaches to the well casing (distance B in fig. 5-1 of SOP 5).** **__________________feet** **Eyebolt above or below MP? (circle one)** **Depth of the specific-conductance sensor below the MP (if eyebolt is below MP, add length A and B. If eyebolt is above MP, subtract length B from length A)** **__________________feet**

CTD Specific-Conductance Calibration Prior to Redeployment
CTD serial number or other identification: _______________

Standard		CTL		Percent difference[1]	Notes
Value	Units	Reading	Units		

[1] Percent difference must be less than 5

Measure DTW Immediately Before CTD Deployment
Measured DTW (ft below MP):
Start time_______________
1st: Hold________ Cut________ DTW________ 2nd: Hold_______ Cut_______ DTW_______
End time________________
Avg. of 1st and 2nd measured DTW______________ Corrected w/ calibration table________________

Deploy CTD
Depth(ft below MP) _______________ Time_______________
Time of first automatic CTD reading _______________

Notes

Field Data Sheet 2

Establishing and Checking Measuring Point, Reference Marks, and CTD Support

Date_______________ Party____ Checked by__________
Well name and location____
Lat._____________________ Long.______________________ EPE__________ Datum_____________

MP and RMs
Description of MP and RMs

Sketch map of MP and RM locations

Level Notes for MP and RMs

Pass Peg Test? _____

Station	BS	HI	FS	Elev.	Remarks
MP	---	---	---	0	

Sketch of CTD support with distance labels
Distance between MP and CTD support ________________
Notes

Field Data Sheet 3
Specific-Conductance Profile and Pressure-Depth Relation

Date_______________ Party____ Checked by__________
Well name and location____
Lat._____________________ Long._____________________ EPE__________ Datum_____________

CTD Specific-Conductance Calibration
CTD serial number or other identification: _______________

Standard		CTD		Percent difference	Notes
Value	Units	Reading	Units		

[1] Percent difference must be less than 5

Specific-Conductance Profile and Pressure-Depth Relation

Measured DTW (ft below MP) at start:
Start time_______________
1st: Hold________ Cut________ DTW________ 2nd: Hold_______ Cut_______ DTW_______
End time________________
Avg. of 1st and 2nd measured DTW______________ Corrected w/ calibration table________________

Time (hh:mm)		Depth ($D_{CTD,}$ in ft below MP)	Specific conductance		Pressure ($P_{CTD,}$ in PSI)	Remarks
From	To		Reading	Units		

CTL Specific-Conductance Profile (continued)

Time (hh:mm)		Depth (D_{CTD}, in ft below MP)	Specific conductance		Pressure (P_{CTD}, in PSI)	Remarks
From	To		Reading	Units		

Measured DTW (ft below MP) at end:
Start time_______________
1st: Hold________ Cut________ DTW________ 2nd: Hold_______ Cut_______ DTW_______
End time________________
Avg. of 1st and 2nd measured DTW______________ Corrected w/ calibration table________________

On field computer spreadsheet, plot P_{CTD} on x-axis and D_C on y-axis and fit regression line. Determine slope of regression line ($M_{D/P}$) and record below:

$M_{D/P}$ = ______________

Notes

Appendix B: Template for Station Analysis

The Station Analysis is a running history of the station since its establishment. A Station Analysis is initiated for each well at the time the well is established as part of the monitoring network. This initial Station Analysis contains the details of the well at the time it was established. Once the initial Station Analysis is checked and accepted after review, its contents should not be altered. Updates are used to add information during the ensuing monitoring. Once an update is checked, reviewed and accepted, it also should not be altered.

Any significant changes, incidents or observations that relate to the station, its data, or procedures for handling and processing its data, should be recorded in the Station Analysis using updates. Examples are changes to the well or monitoring instruments, damage or vandalism, changes in MP or RMs, missing data and cause, instrument failure, or other field or data-processing observations, incidents or changes.

STATION ANALYSIS

Well Number and Name: [Provide well name and number]

Date Established: [Date monitoring started] **Author:** [Author of initial Station Analysis]

Location: [Provide latitude, longitude, and brief description of landmarks and other useful location information]

Aquifer or Geologic Formation: [Provide aquifer name or name of geologic formation penetrated by the well]

Well Characteristics: [Briefly describe well-construction data such as depth; diameter and depth interval of solid casing and/or perforated or screened casing, if any; depth interval of open or uncased hole, if any; grouting and gravel packing in annular space, if any]

Measuring Point: [Describe measuring point.]

Established reference marks:

Ref. mark	Location	Elev. relative to MP (feet)	Last surveyed	
			Date	By
[RM and number]	[Briefly describe RM and its distance and direction from MP]	[Elevation relative to MP]	[Date last surveyed]	[Survey personnel]
[RM and number]	[Briefly describe RM and its distance and direction from MP]	[Elevation relative to MP]	[Date last surveyed]	[Survey personnel]
[RM and number]	[Briefly describe RM and its distance and direction from MP]	[Elevation relative to MP]	[Date last surveyed]	[Survey personnel]

Monitoring Parameters: [List the parameters monitored at this station and the monitoring start dates for each parameter.]

Equipment/Instruments: [Describe make and model of each instrument and the parameters measured. Also describe any regularly scheduled calibration for each instrument and whether a correction factor is applied]

Remarks: [Report any significant field or data-processing observations or incidents]

Data Repository: [Give address of paper well file and computer and path name for the archived electronic files]

UPDATE [Use updates as needed to describe changes or significant observations.]

Date: [Date of update] **Author:** [Author of update]

Update: [Narrative describing nature of the update, such as changes to the well or monitoring instruments, damage or vandalism, changes in MP or RMs, missing records and cause, or any other significant field or data-processing observations, incidents or changes. Be sure to thoroughly describe any changes, including the personnel involved.]

Appendix C: Revision History

This history records all revisions to the protocol, whether the revisions are major or minor, or affect the entire protocol or only a limited part of it.
In most cases, a revision of an SOP is a procedural change that affects only that SOP or perhaps one or two other SOPs. Similarly, a revision of a field form or template has a limited effect on the protocol as a whole. Revisions to an SOP, field form, or template are therefore designated by a change only in the version number of the affected SOP, field form, or template. Revisions may be major or minor. Major revisions are those that result in a substantial change in the SOP, field form, or template. Minor revisions are those that affect only a small portion of the document. For each revision, create an entry using the following template, and attach it below the last entry in the history.

New Title and Version Number: [For example, "SOP 6 –Specifications for the CTL, version 1.1"]

Replaces: [For example, "SOP 6 –Specifications for the CTL, version 1.0"]

Date: [Date of revision adoption]

Author: [Name of person writing revision]

Changes made: [Describe in detail the changes that were made. Also describe other areas of the protocol that may have been required revision as a result of the changes described here.]

Reasons for Change: [Describe in detail the reasons for the changes that were made.]

Authority: [Describe the persons (PACN project leads, other expertise) involved in the revision and the decision to adopt it. Also describe how meetings were conducted (face-to-face, email, telephone, etc.)].

Appendix D: Protocol Development

This appendix serves to provide some history to the development of the protocol.

Introduction

The groundwater protocol evolved through several stages during which a larger subset of PACN parks, multiple monitoring phases, and alternate monitoring approaches were considered. The purpose of this appendix is to describe the other parks and approaches that were considered and the rationale for eliminating them from the final protocol. In addition to documenting important aspects of the protocol development, this discussion will be useful if the groundwater monitoring program is expanded to the excluded parks or if new technologies and approaches become available in the future.

Other PACN Parks Considered

Early in the development of the groundwater monitoring protocol, the Pacific Island Network (PACN) considered groundwater monitoring in four parks that have natural near-shore features that may be affected by natural and anthropogenic changes in groundwater quantity and quality. These four parks included American Memorial Park (AMME) on Saipan, Commonwealth of the Northern Mariana Islands, and Kaloko-Honokōhau National Historical Park (KAHO), Pu'uhonua o Hōnaunau National Historical Park (PUHO), and Pu'ukoholā Heiau National Historic Site (PUHE) on the island of Hawai‘i. Because all of these parks lie on the coast of tropical Pacific islands, groundwater characteristics reflect interaction of fresh groundwater from the land and saltwater from the ocean. Although PUHO and PUHE could benefit from the monitoring of water levels and salinity described in this protocol, they were ultimately dropped from the groundwater monitoring program because of a lack of suitable wells. These parks could be incorporated into the groundwater monitoring program in the future if new wells can be constructed or if further investigation indicates that wells outside but near the parks can provide adequate monitoring sites.

Hydrology of PUHO and PUHE

Similar to KAHO, PUHO and PUHE lie on the west coast of the island of Hawai‘i (Fig. D1, D2). These parks therefore share several climatic, geologic, hydrologic, and ecologic similarities with KAHO. Fresh groundwater forms a thin lens overlying salty groundwater in a high permeability lava-flow aquifer. Fresh groundwater flows from inland areas of recharge to coastal areas of discharge. As with KAHO, PUHO lies in an area with a relatively low-elevation water table which is juxtaposed, in the inland direction, with an enigmatic high-level groundwater body. Although the relation between the high- and low-level groundwater bodies is not completely understood, water from the high-level groundwater area probably flows toward the area beneath KAHO and PUHO, and groundwater withdrawals from the high level groundwater body has the potential to affect water levels and salinity beneath these parks.

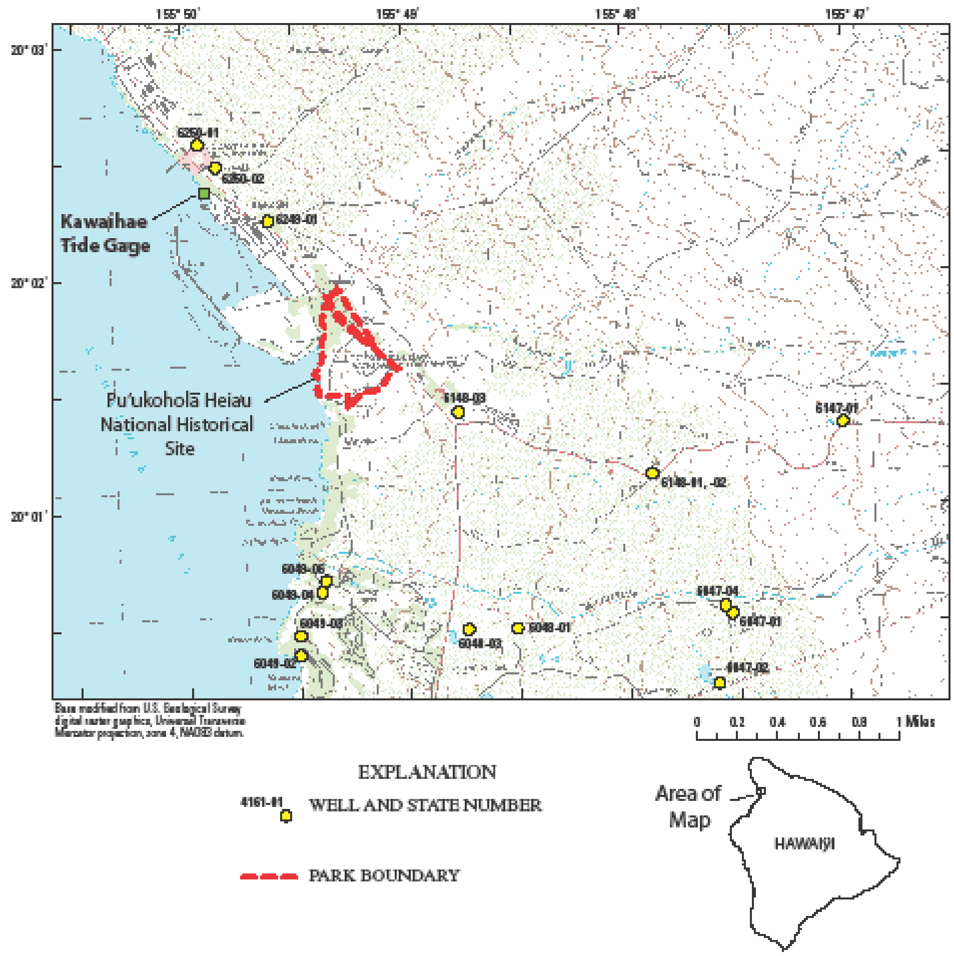

Figure D1. Puʻukoholā Heiau National Historical Site (PUHE), island of Hawaiʻi.

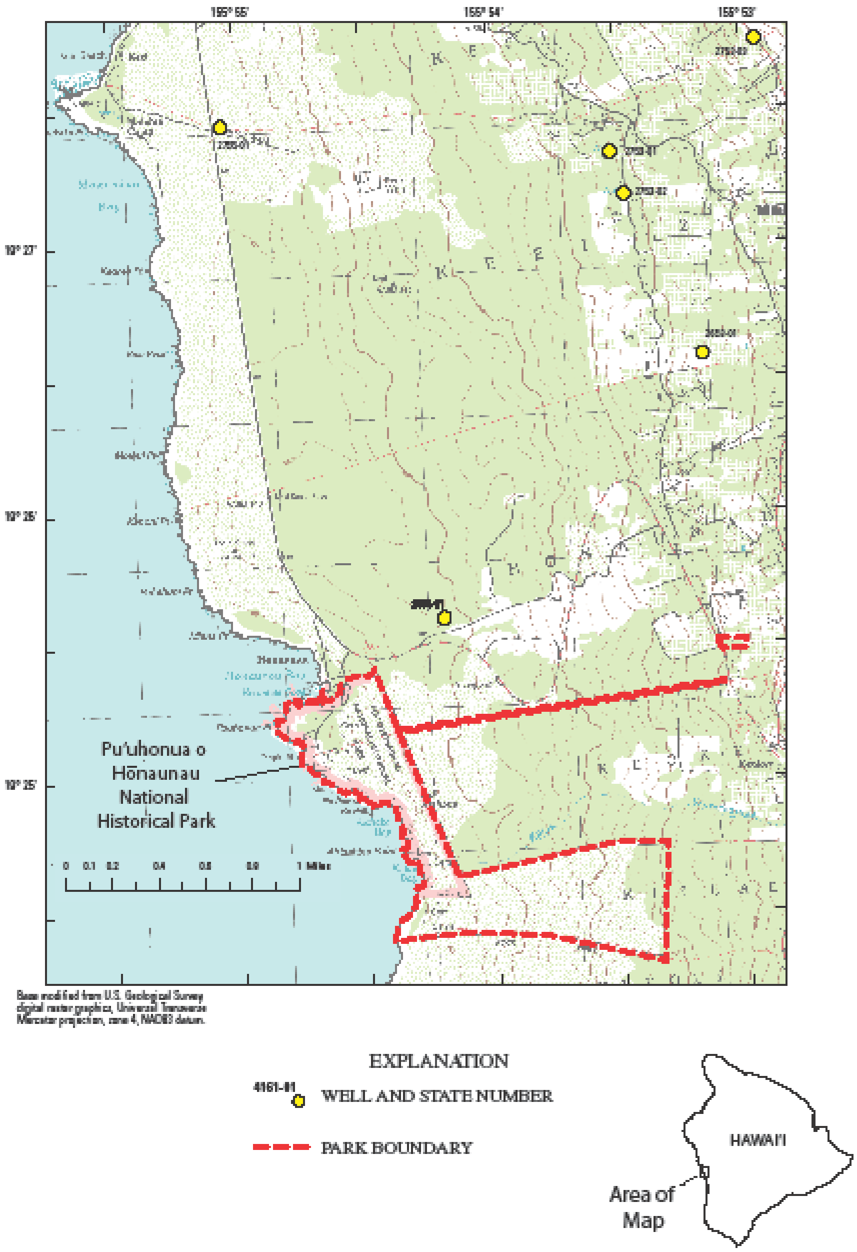

Figure D2. Pu‘uhonua o Hōnaunau National Historical Park (PUHO), island of Hawai‘i.

It is not known whether a similar juxtaposition of high- and low-level groundwater exists near PUHE; regardless, groundwater withdrawals landward of the park have the potential to affect groundwater resources beneath the park. PUHO has wetlands, anchialine pools, and Native Hawai‘ian fishponds that provide critical habitat for numerous species including some that are endangered (DeVerse, 2006). In addition, PUHO has freshwater springs, a cliff-side habitat for rare plants, coastal strand communities, and a dry-land forest (Else, 2006a). PUHE has an intermittent stream and springs that support a small ephemeral pond and mixohaline wetland environment, providing habitat for freshwater plants and birds, and park staff have re-introduced numerous endangered native plants (Else, 2006b).

Nearby urbanization and industrialization have the potential to affect groundwater in PUHO. Land use up-gradient from PUHO has followed a trend away from small-scale agriculture and toward housing development. PUHE does not face significant imminent threats from nearby urbanization, but there is ongoing expansion of the nearby boat harbor, and the area's population continues to grow. Urbanization and population growth can result in increased groundwater withdrawals from wells and decreased recharge, which in turn can affect groundwater resources in the parks. Other forces, such as tides, climate cycles, sea-level rise, and island subsidence can also affect groundwater resources in PUHO and PUHE.

The groundwater resources of PUHO and PUHE have not been studied as extensively as those of KAHO, but it is likely that their groundwater systems also share similarities. For example, anchialine ponds in PUHO are probably connected to groundwater as are the ponds in KAHO. Other surface-water bodies in PUHO and PUHE, such as freshwater springs and wetlands, are almost certainly connected to groundwater, although the specific nature of their connection has not been studied. It is not known how closely the intermittent stream and ephemeral ponds in PUHE are connected to groundwater.

Monitoring Wells for PUHO and PUHE **–** No wells exist within the current PUHE and PUHO boundaries (Figs. D1 and D2). The nearest existing well to PUHO, well 2554-01, is located about 0.4 mi inland from the northeastern corner of the park. The nearest existing well to PUHE, well 6148-03, is located about 0.4 mi southeast of the park, but it could not be located in a recent reconnaissance of the area. The next nearest well to PUHE, 6249-01, is about 0.5 northwest of the park. Although these wells lie outside the parks, they probably penetrate the same groundwater system that underlies the parks, thus monitoring these wells could provide data that has relevance to the resources within the park. It is not known, however, how closely representative data from these wells would be. Other wells in the vicinity of PUHO and PUHE are currently being pumped, and therefore are not suitable for the objectives described in this protocol. Consideration of groundwater monitoring at PUHE and PUHO was therefore excluded from the final protocol, and postponed until a better assessment of cost of the program versus benefit can be made.

Other Approaches Considered

Because the original scope of the groundwater protocol document included four parks (AMME, KAHO, PUHO, and PUHE) the approaches considered during protocol development were kept general enough to accommodate the wide variety of physical, personnel, and fiscal constraints that may potentially be encountered. For example, inclusion of AMME and KAHO in the final protocol only required consideration of existing wells for which hydrologic and construction data are already available. On the other hand, inclusion of PUHO and PUHE would have required consideration of wells that do not presently exist but may be constructed in the future.

Two options for the long-term monitoring phase were considered during protocol development: (1) monitoring using a manual approach in which measurements are made manually once every two months, or (2) monitoring using an automated approach in which manual measurements are made bimonthly and a CTD is deployed to automatically continue measurements between the bimonthly visits and at a much higher frequency than is possible using the manual measurements only. The automated approach was adopted for the final protocol; it is described in detail in the protocol narrative. The rationale for selecting the automated approach over the manual approach is discussed below.

Higher-frequency measurements are needed if the monitoring is expected to yield information on short-term variations. High-frequency measurements may also be needed if high-magnitude, short-term oscillations exist, such as tidal effects, that may obscure long-term trends such as those related to climate cycles or sea-level rise. For example, in KAHO, tides cause water levels in wells to fluctuate by about 1.5 ft (Fig. D3) (Oki et al., 1999); tidal influences on groundwater in PUHE and PUHO are probably similar. Tidal data and tidal-efficiency estimates given by Perreault (2007) indicate that in AMME, groundwater response to tides may be on the order of 1 to 2 ft. These tidal-driven fluctuations take place within the few hours of a tidal cycle. By comparison, groundwater-level changes resulting from longer-term processes such as climate change, sea-level change, and urbanization, may be much more gradual even though the long-term net effect may be large.

The graphs in Figure D4 show how the tidal effect can obscure long-term trends in water-level measurements at wells in parks on the west coast of Hawaiʻi if monitoring is limited to bimonthly manual measurements. The graphs were created from hourly tide-gage data from Kawaihae Harbor near PUHE for the period 1997 to 2007 (NOAA, 2007). To simulate the oscillation of water levels in a hypothetical well in one of the west Hawaiʻi parks, the hourly tide data were multiplied by a factor of 0.75 to account for the difference in magnitude of the tidal signal measured in a well to that measured in an ocean tide gage (based on data for KAHO from Oki et al., 1999) (Fig. D4A). The data set was then randomly sampled by computer on intervals ranging between 57 and 63 days (about 2 months) to simulate bimonthly groundwater level measurements. A plot of these simulated measurements (red dots in Fig. D4B) indicates that there is likely to be so much scatter due to tides that other trends will be difficult to discern, even after 10 years of monitoring. However, if the groundwater-level measurements were made on an hourly rather than bimonthly frequency, the effect of tides on the data could be substantially reduced by computing the daily mean of hourly measurements (blue dots in Fig. D4B). This would substantially increase the ability to detect gradual changes in the groundwater system. The plot of the daily mean of the hourly water levels from the simulated groundwater-level record shows a gradual rise in water levels, which is consistent with the combined effects of island subsidence and global sea-level rise.

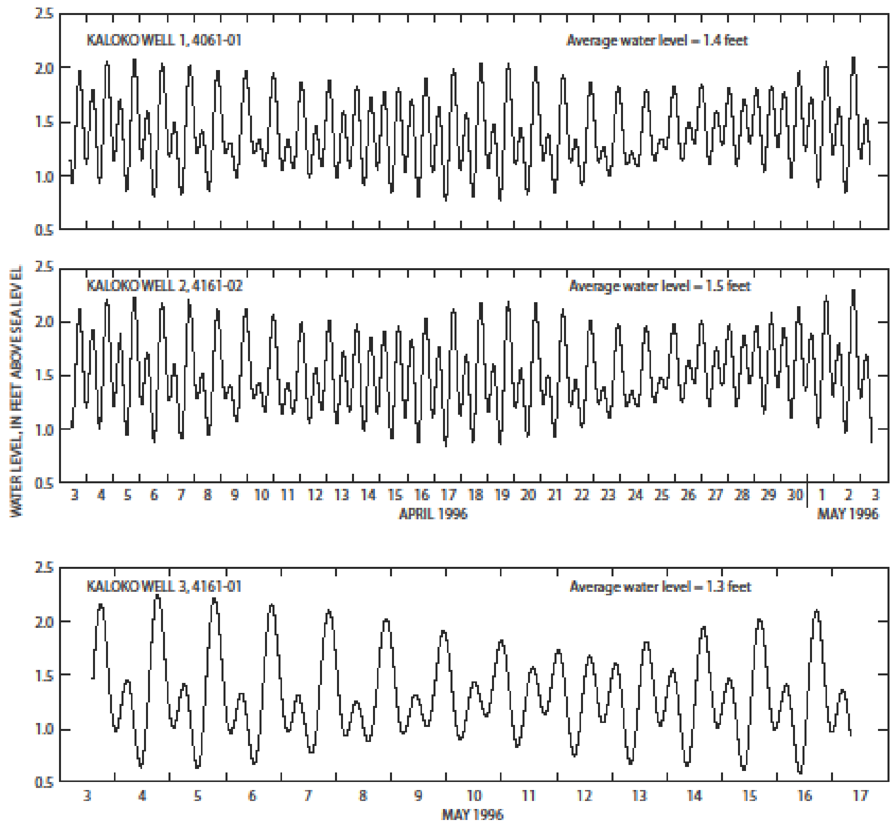

Figure D3. Water levels at wells 4061-01, 4161-02, and 4161-01 during 1996, Kaloko-Honokōhau National Historical Park, island of Hawai‘i.

The graphs in Figure D4 show how the tidal effect can obscure long-term trends in water-level measurements at wells in parks on the west coast of Hawai‘i if monitoring is limited to bimonthly manual measurements. The graphs were created from hourly tide-gage data from Kawaihae Harbor near PUHE for the period 1997 to 2007 (NOAA, 2007). To simulate the oscillation of water levels in a hypothetical well in one of the west Hawai‘i parks, the hourly tide data were multiplied by a factor of 0.75 to account for the difference in magnitude of the tidal signal measured in a well to that measured in an ocean tide gage (based on data for KAHO from Oki et al., 1999) (Fig. D4A).

The data set was then randomly sampled by computer on intervals ranging between 57 and 63 days (about 2 months) to simulate bimonthly groundwater level measurements. A plot of these simulated measurements (red dots in Fig. D4B) indicates that there is likely to be so much scatter due to tides that other trends will be difficult to discern, even after 10 years of monitoring. However, if the groundwater-level measurements were made on an hourly rather than bimonthly frequency, the effect of tides on the data could be substantially reduced by computing the daily mean of hourly measurements (blue dots in Fig. D4B). This would substantially increase the ability to detect gradual changes in the groundwater system. The plot of the daily mean of the hourly water levels from the simulated groundwater-level record shows a gradual rise in water levels, which is consistent with the combined effects of island subsidence and global sea-level rise.

The foregoing discussion demonstrates that discerning long-term trends from groundwater data that have a strong tidal signal requires high-frequency measurements that cannot be achieved by manual measurements alone. Manual measurements cannot reasonably be made on a continuous, long-term basis more frequently than daily, and in most cases, labor costs preclude field visits that are more frequent than monthly or bimonthly. The objectives of the groundwater monitoring program require high-frequency data that can only be obtained using the automated approach. The automated approach requires more costly equipment that is more complicated to use, but the instruments can be set to automatically make measurements as frequently as desired. The frequency of automated measurements is limited primarily by the volume of data that can be stored in the CTD, practically handled, checked for accuracy, and archived. The benefit of high-frequency automated data collection is a substantial improvement in the ability to identify gradual but persistent groundwater trends that may impact park resources in the long term.

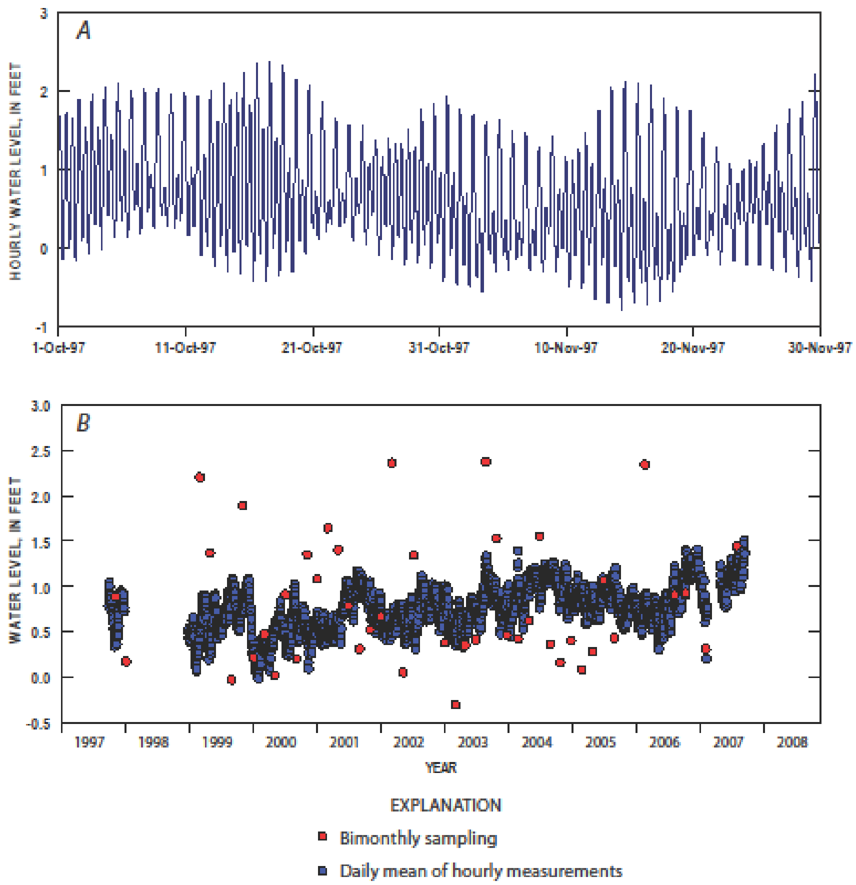

Figure D4. Graphs of tide-gauge and simulated groundwater level data. A, 60 days of hourly tide data from Kawaihae Harbor, Hawai'i (National Oceanic and Atmospheric Administration, 2007). B, 10 years of simulated groundwater level data -- red dots show simulated data sampled on a bimonthly basis and blue dots show the daily mean of hourly data.

Preliminary Monitoring

The monitoring described in the final groundwater protocol pertains specifically to the wells in AMME and KAHO, for which hydrologic and construction data exist. To adapt the protocol to other parks, a preliminary monitoring phase is required. The preliminary monitoring phase is a brief period of surveying and monitoring to gather information needed to set up the long-term monitoring.

Preparation – If the monitoring wells are not within the parks, permission must be acquired from the well owners and land owners. The time required to obtain initial permission varies greatly among owners, therefore steps to obtain initial permission should be started as early as practicable. Prior to approaching an owner for the first time for permission to use a well, a clear written statement should be prepared describing such items as the reasons for the request, benefits of the monitoring, and details of the entry or well use such as frequency, places that will be visited, roads that will be used, gates that will be entered, and pre-visit notification that will be given. Even with such a statement, long negotiations for permission may result because of legal issues, especially liability. Familiarity with the Federal tort law and its limitations can help expedite these negotiations. Once permission is secured, steps can be taken to prepare for fieldwork.

Fieldwork – The fieldwork for the preliminary monitoring is summarized in Table D1. The fieldwork includes taking steps to initiate the monitoring, such as the determining the geographic coordinates of the well and establishing the MP and RMs. The MP is marked by cutting a notch in the top of the well casing using a file or saw. This MP will be used throughout the monitoring period to ensure that water-level measurements taken in the well on different occasions can be compared. Three clearly marked RMs must be established on stable foundations (ones that are not likely to move over the period of the monitoring). Examples of ideal RMs are a USGS or NGS brass monument or a stainless-steel or brass bolt cemented or into a hole drilled into a rock outcrop. The purpose of the RMs is to provide a point from which the MP can be periodically checked, and to reestablish the MP if it is altered or destroyed. The RMs should be far enough from the each other and the MP so that if one is intentionally or unintentionally disturbed, the others are not likely to also be disturbed. The MPs and RMs should be near enough, however, that the difference between the MP and RMs can be determined by level survey within an accuracy of 0.01 ft. The characteristics of the MP and RMs must be adequately described in the field notes and photographed, so that these locations can be found on later field visits.

Table D1. Summary of field and data-handling procedures for preliminary monitoring [DTW, depth to water; CTD, automatic sensor and data logger for specific-conductance, temperature, and depth].

1.	Determine geographic coordinates of well
2.	Establish measuring point and reference marks
3.	Measure DTW and determine specific-conductance profile
4.	Calibrate CTD for depth
5.	Deploy CTD
6.	Photograph site
7.	Depart site
8.	Return to site after one month
9.	Measure DTW and determine specific-conductance profile
10.	Recover CTD, transfer data to field computer, and make backup copy
11.	Establish well file
12.	Begin data processing immediately upon return from field
13.	Review and finalize data
14.	Analyze data; use results for initiation of long-term monitoring

After the MP and RMs are established, the depth to water (DTW) and specific conductance profiles are determined using methods (including appropriate calibration checks) similar to those described for long-term monitoring in the protocol narrative. It is essential that the natural salinity stratification of the water in the well is preserved prior to and during these measurements. Any object lowered or dropped into the water column will disturb the stratification to some degree, but care must be taken to minimize this disturbance as much as possible. The CTD is then deployed to make automated measurements of the specific conductance and water levels. The CTD data logger should be set to make automatic measurements at 15-minute intervals so that short-term variations, such as those caused by tides or pumping from nearby production wells, can be studied. The CTD should be fixed at a depth within the transition zone. If the transition zone is within the water column of the well, it will appear as a rapid rise (with depth) in the specific-conductance profile (Fig. D5). If the entire transition zone is present in the well's water column, the CTD will be placed at a depth corresponding to a specific conductance of 25,000 µS/cm at 25˚ C (about 50 percent seawater). If the entire water column of the well is fresh, or only the upper part of the transition zone (less than 25,000 µS/cm at 25˚ C) is present, the CTD will be placed as deep as possible within the limitations of the instrument and its vent tube. If the entire water column of the well has the salinity of seawater (greater than 45,000 µS/cm at 25˚ C), or only the lower part of the transition zone (greater than 25,000 µS/cm at 25˚ C) is present, the CTD will be placed near the top of the water column but deep enough that it will remain submerged even if there is a change in water level. After the CTD has been deployed, the DTW is measured again.

As in the long-term monitoring described in the protocol narrative and SOPs, the DTW must be measured manually several times during the field visit because the groundwater system is dynamic and can change substantially during field work. It is therefore also important that each DTW measurement is recorded in the field notes along with the date and time. The date and time of the DTW measurements made while the CTD is deployed are particularly important because they are needed to convert the depth measured by the CTD to water levels measured relative to the MP.

The site should be photographed to adequately document conditions at the time of the preliminary monitoring. Photographs at a minimum should include (1) a view of the well and surrounding area, (2) a close up of the well casing, (3) a close up of the MP on the well, (4) a view of the RMs and surrounding area, preferably with a view of the well, and (5) a close up of the RMs. The site can then be secured and vacated.

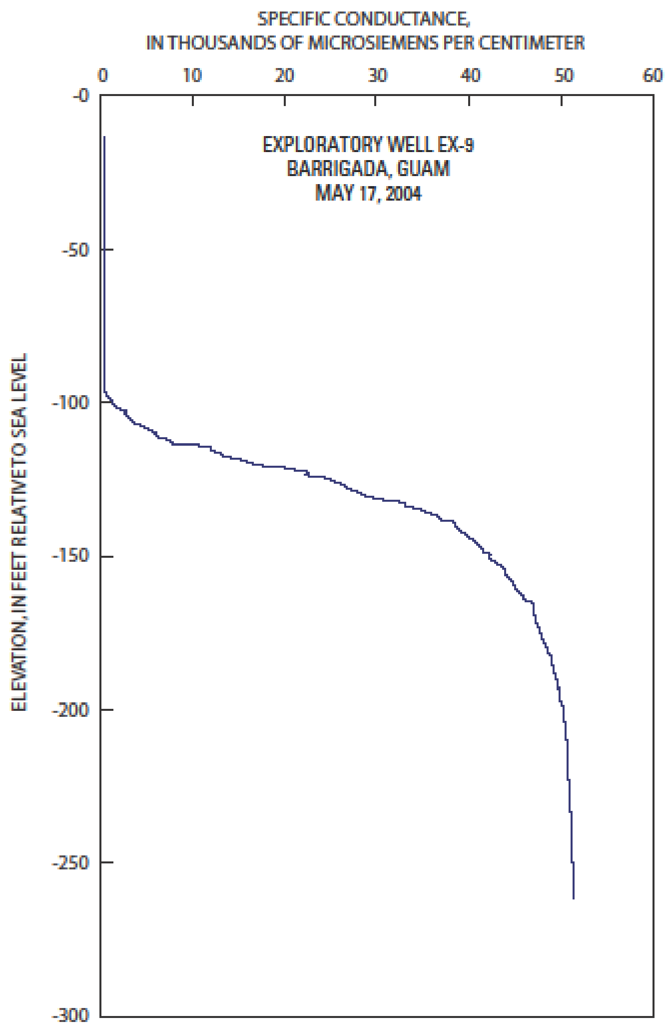

Figure D5. Example of a specific-conductance profile for a well penetrating through the transition zone.

After about a month, the well site should be revisited and the DTW and specific conductance profile will be measured again, the CTD recovered using methods (including appropriate steps for specific conductance calibration checks, CTD depth calibration, and data retrieval and backups) similar to those described for long-term monitoring in the protocol narrative. The data should be analyzed and the results used for initiation of long-term monitoring.

Data Handling and Analysis. – Data from the preliminary monitoring should undergo the same procedures for data entry, checking, review and archival as described for long-term monitoring. The preliminary monitoring provides data that can be analyzed to determine the suitability of the well for the objectives of the groundwater monitoring program. The suitability of the well can be assessed on the basis of how sensitive the water level and specific conductance are to the changes of interest in the groundwater monitoring program. Because the purpose of the groundwater monitoring is to serve as a vital sign for the condition of other park resources, the water level and specific conductance of the water in the monitoring well should be sensitive to the same factors that affect park resources. A well suitable for monitoring changes in groundwater salinity should have a profile showing a wide range of specific conductance that increases with depth. A well having only a small range of specific conductance may also be useful if the range is midway between that of freshwater or seawater. If the entire water column of the well has the specific conductance of seawater (about 50,000 µS/cm at 25˚ C), the well is open to a part of the aquifer that is below the transition zone; as a result, the ability to detect changes in the size of the freshwater lens or the position of the transition zone is significantly diminished. Similarly, if the well has the salinity of freshwater (less than about 1,300 µS/cm at 25˚ C), it has not penetrated far enough to reach the transition zone, and is therefore less useful in tracking movement of the transition zone.

The preliminary monitoring also provides data that can be used to determine the depth at which to set the CTD during long-term monitoring. Ideally, the CTD will be set at a depth corresponding to a specific-conductance value that is midway between that of saltwater and freshwater, or about 25,000 µS/cm at 25˚ C. If the entire water column of the well is fresh, or only the upper part of the transition zone (less than 25,000 µS/cm at 25˚ C) is present, the CTD should be placed as deep as possible within the limitations of the instrument. If the entire water column of the well has the salinity of seawater (greater than 45,000 µS/cm at 25˚ C), or only the lower part of the transition zone (greater than 25,000 µS/cm at 25˚ C) is present, the CTD should be placed near the top of the water column but deep enough that it will remain submerged even if there is a change in water level.

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Appendix E: Well Construction Data

The following table contains the construction data for the wells in American Memorial Park (AMME), Commonwealth of the Northern Mariana Islands, and Kaloko-Honokōhau National Historic Park (KAHO), Hawai‘i (NAD 83, North American Datum of 1983; WGS 84, World Geodetic System of 1984; N.A., not available)

Park	**KAHO**	**KAHO**	**KAHO**	**AMME**	**AMME**
Well	4161-01	4061-01	4161-02	AMP13	AMP05
Primary/secondary	Primary	Secondary	Secondary	Primary	Secondary
Coordinates					
Latitude (decimal degrees)	19.6872 N	19.6784 N	19.6859 N	15.2175 N	15.2154 N
Longitude (decimal degrees)	156.0292 W	156.0222 W	156.0235 W	145.7268 E	145.7210 E
System	NAD83	NAD83	NAD83	WGS84	WGS84
Casing diameter (inches)	2	2	2	1	1
Depth (feet from top of casing)	31	43	60	6.3	6.0
Casing depths (feet from top of casing)					
Solid	0 - 21	0 - 33	0 - 50	NA	NA
Screen or perforated	21 - 31	33 - 43	50 - 60	NA	NA
Elevation of top of casing (feet above mean sea level)	23.92	37.99	56.02	3.44	3.64

Appendix F: Groundwater Monitoring Database Documentation

The database for this project consists of four types of tables: core tables describing the “who, where and when” of data collection, project-specific tables, lookup tables that contain domain constraints for other tables, and cross reference tables that link lookup tables with data tables. Although core tables are based on PACN standards, they may contain fields, domains or descriptions that have been added or altered to meet project objectives.
The database includes the following standard tables:

tbl_Sites	Sample sites: individual parks
tbl_Locations	Sample locations: groundwater wells
tbl_Events	Quarterly field visits
tbl_Images	Images associated with wells

The following are project-specific data tables:

tbl_Analytical_Procedures	User entered analytical procedures. Imported table structure from NPSTORET.
tbl_CTD_Data	Groundwater monitoring results downloaded from the CTD data logger.
tbl_CTD_Calibration	Table to store the CTD instrument information, linked to CTD calibration readings.
tbl_CTD_Results	Groundwater monitoring results; imported from results file downloaded from CTD.
tbl_DTW	Depth to water information from quarterly field visits.
tbl_Field_Procedures	User entered field procedures. Imported table structure from NPSTORET.
tbl_Gear_Configurations	User entered gear configurations. Imported table structure from NPSTORET.
tb_Labs	User entered labs. Imported table structure from NPSTORET.
tbl_Lab_Sample_Prep	User entered lab sample preparation procedures. Imported table structure from NPSTORET.
tbl_Pressure_Depth_Relation	
tbl_SpCond_Depth	Table that stores information for the depth of the specific-conductance sensor below the MP on quarterly field visits.
tbl_SpCond_Readings	Table that stores CTD specific conductance calibration readings.
tbl_Well_Metadata	Table stores metadata for well measuring point, reference marks, and CTD support.
tbl_Well_Test	Table that stores measuring point metadata.

The following are a few of the more prominent, standard lookup tables:

tlu_Characteristics	User entered characteristic definitions (parameters that are measured)
tlu_Contacts	Contacts related to the water quality protocol
tlu_Enumerations	List of source values for drop down lists.
tlu_Unit_of_Measure	Look up table of units of measure from NPSTORET

The following are cross reference tables:

xref_Event_Contacts	Cross-reference table between events and contacts

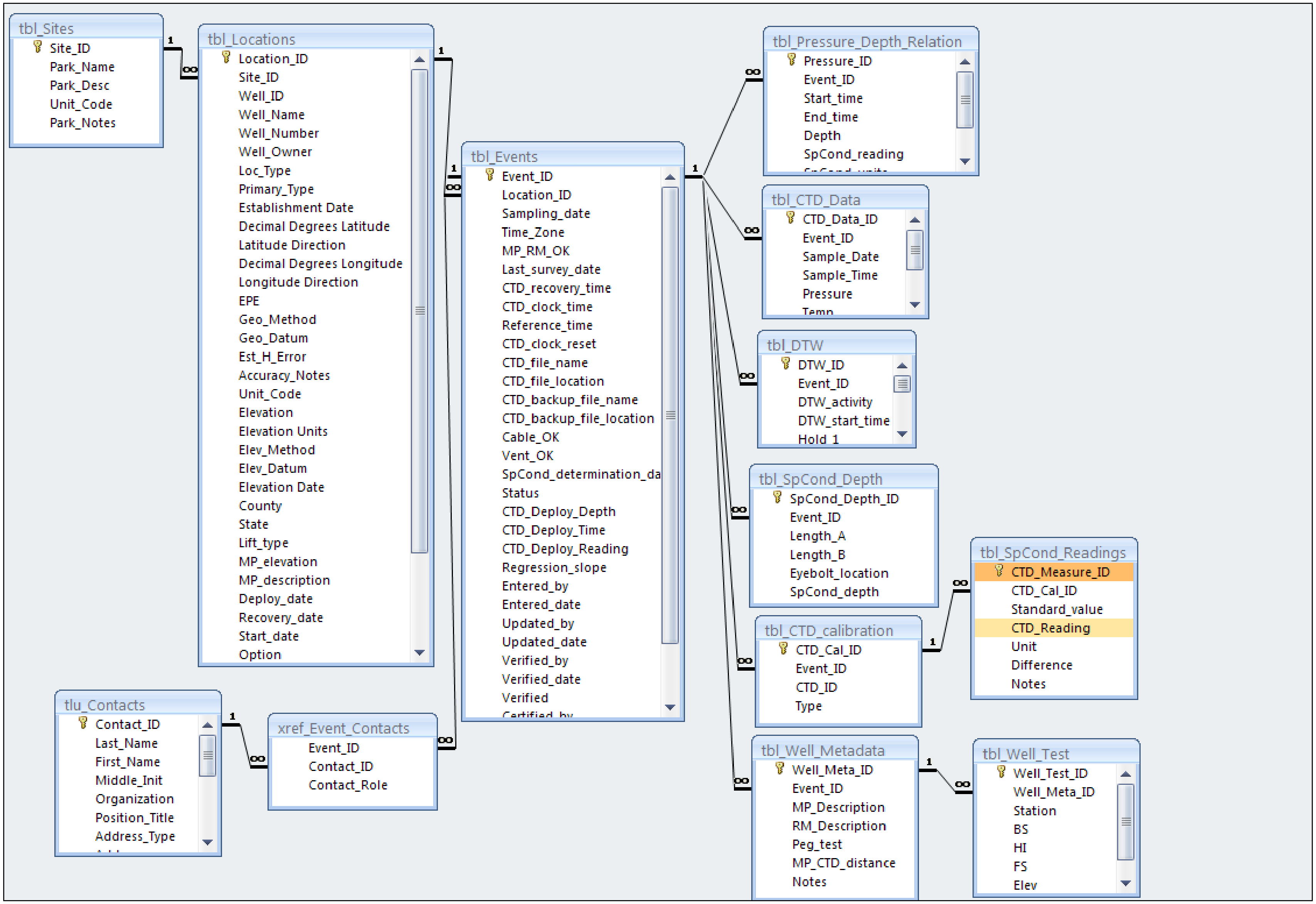

Figure F1. Data model for the Groundwater Monitoring database.

Tables

tbl_Analytical_Procedures — User entered analytical procedures. Imported table structure from NPSTORET.

Field Name	Primary?	Field Type	Field	Field Description
Analytical_ID	Yes	Other	16	Analytical procedure unique identifier
Citation	No	Memo	0	Analytical procedure citation
D_Last_update_TS	No	Date/Time	8	Date/Time of Last Update - automatically stamp today's date/time in before update event
D_UserID_code	No	Text	8	Who last updated the record - automatically filled in by whoever logged on the system
Description_text	No	Memo	0	Analytical procedure description text
Equip_Name	No	Text	50	The name of the equipment being used for the analytical procedure
Equip_Type	No	Text	50	The type of equipment being used for the analytical procedure
ID_Code	No	Text	15	Abbreviated name or identifying code for the analytical procedure - for NPSTORET
Name	No	Text	120	Full title of analytical procedure
National_Procedure	No	Text	50	Comparable national procedure

tbl_CTD_Calibration — Table to store the CTD instrument information, linked to CTD calibration readings.

Field Name	Primary?	Field Type	Field	Field Description
CTD_Cal_ID	Yes	Text	50	Unique record identifier
CTD_ID	No	Text	50	CTD serial number of other identification
Event_ID	No	Text	255	Link to tbl_Events
Type	No	Text	255	Calibration type, i.e. redeployment or SpCond profile

tbl_CTD_Data — Groundwater monitoring results; imported from results file downloaded from CTD.

Field Name	Primary?	Field Type	Field	Field Description
CTD_Data_ID	Yes	Text	50	Unique record identifier
Actual_Cond	No	Double	8	Actual conductance recorded in micro-siemens
Depth	No	Double	8	Depth recorded in feet
Event_ID	No	Text	255	Link to tbl_Events
Pressure	No	Double	8	Pressure recorded in PSI

Sample_Date	No	Date/Time	8	Date the reading was recorded
Sample_Time	No	Date/Time	8	Time the reading was recorded
Sp_Cond	No	Double	8	Specific conductance recorded in micro-siemens
Temp	No	Double	8	Temperature recorded in degrees Celsius

tbl_Db_Revisions Database revision history data.

Field Name	Primary?	Field Type	Field	Field Description
Revision_ID	Yes	Text	50	Database revision (version) number or code
Db_Meta_ID	No	Text	50	Link to tbl_DB_Meta
Revision_Contact_ID	No	Text	50	Link to tlu_Contacts
Revision_Date	No	Date/Time	8	Database revision date
Revision_Desc	No	Memo	0	Revision description
Revision_Reason	No	Memo	0	Reason for the database revision

tbl_DTW Depth to water information from quarterly field visits.

Field Name	Primary?	Field Type	Field	Field Description
DTW_ID	Yes	Text	50	Unique record identifier
Cut_1	No	Double	8	First measured cut
Cut_2	No	Double	8	Seconde measured cut
DTW_1	No	Double	8	First depth to water calculated from the hold and cut
DTW_2	No	Double	8	Second depth to water calculated from the hold and cut
DTW_activity	No	Text	10	What type of data is being collected, after CTD recovery or before CTD deployment?
DTW_average	No	Double	8	Average of first and second measured DTW if the values are within .01 feet
DTW_calibrated	No	Double	8	Corrected with calibration table
DTW_end_time	No	Date/Time	8	End time of measured DTW data collection
DTW_start_time	No	Date/Time	8	Start time of measured DTW data collection
Event_ID	No	Text	50	Link to tbl_Events
Hold_1	No	Double	8	First measured hold
Hold_2	No	Double	8	Second measured hold

tbl_Events Quarterly field visits.

Field Name	Primary?	Field Type	Field	Field Description
Event_ID	Yes	Text	50	Unique record identifier
Cable_OK	No	Boolean	1	Is the cable ok?
Certified	No	Boolean	1	Whether the data has been certified
Certified_by	No	Text	50	Person who certified data for accuracy and completeness

Certified_date	No	Date/Time	8	Date on which data were certified
CTD_backup_file_location	No	Text	255	Backup location of uploaded data file from CTD
CTD_backup_file_name	No	Text	255	Backup filename of uploaded data from CTD
CTD_clock_reset	No	Boolean	1	Reset CTD clock?
CTD_clock_time	No	Date/Time	8	Time on CTD clock at recovery
CTD_Deploy_Depth	No	Long Integer	4	CTD deployment depth (feet below MP)
CTD_Deploy_Reading	No	Date/Time	8	Time of first automatic CTD reading after deployment
CTD_Deploy_Time	No	Date/Time	8	CTD deployment time
CTD_file_location	No	Text	255	Location of uploaded data file from CTD
CTD_file_name	No	Text	255	Filename of uploaded data from CTD
CTD_recovery_time	No	Date/Time	8	Time of CTD recovery
Entered_by	No	Text	255	Person who entered the data
Entered_date	No	Date/Time	8	Date on which data were entered
Last_survey_date	No	Date/Time	8	Date well was last surveyed
Location_ID	No	Text	50	Link to tbl_Locations
MP_RM_OK	No	Boolean	1	Measuring point and reference marker ok?
Notes	No	Memo	0	Notes about quarterly field visit
Reference_time	No	Date/Time	8	Time on field watch/computer synch. with reference
Sampling_date	No	Date/Time	8	Quarterly field visit date
SpCond_determination_date	No	Date/Time	8	Date of last determination of specific conductance profile and Md/p.
Status	No	Text	20	Status, i.e. preliminary or final
Time_Zone	No	Text	4	Time zone
Updated_by	No	Text	50	Who updated the data
Updated_date	No	Date/Time	8	When the data was updated
Vent_OK	No	Boolean	1	Is the vent ok?
Verified	No	Boolean	1	Whether the data has been verified
Verified_by	No	Text	50	Person who verified accurate data transcription
Verified_date	No	Date/Time	8	Date on which data were verified
Well_Meta_ID	No	Text	255	Link to tbl_Well_Metadata
Well_Test_ID	No	Text	255	Link to tbl_Well_Test

tbl_Field_Procedures User entered field procedures. Imported table structure from NPSTORET.

Field Name	Primary?	Field Type	Field	Field Description
Field_ID	Yes	Other	16	Unique field procedure identifier

Citation	No	Text	50	Field procedure citation
D_Last_update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event
D_UserID_code	No	Text	8	Who last updated the record - automatically filled in by whoever logged on the system
Description_text	No	Memo	0	Descriptive text that provides more information about the field sampling procedure
Field_gear_type	No	Text	25	Category of field gear used (eg. Water Sampler, Net/Vertical Tow, Benthic Dredge, Benthic Corer, etc.)
ID_Code	No	Text	10	Short name or code for field sampling procedure - for NPSTORET
Name	No	Text	60	Full name of the sampling procedure

tbl_Gear_Configurations — User entered gear configurations. Imported table structure from NPSTORET.

Field Name	Primary?	Field Type	Field	Field Description
Gear_ID	Yes	Other	16	Gear configuration unique identifier
D_Last_update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event
D_UserID_code	No	Text	8	Who last updated the record - automatically filled in by whoever logged on the system
Description_Text	No	Memo	0	Specification/details about the tear configuration
Gear_Name	No	Text	50	The name of the gear for the configuration
Gear_Type	No	Text	50	The type of gear for the configuration
ID_Code	No	Text	10	Code identifying gear configuration within the organization - for NPSTORET
Model_Number	No	Text	50	The model number of the gear.
Name	No	Text	30	Name of the gear configuration

tbl_Images — Images associated with wells.

Field Name	Primary?	Field Type	Field	Field Description
Image_ID	Yes	Text	50	Unique identifier for image records
Base_Path	No	Text	255	The base file path for the linked image file. This will stay the same no matter where the root folder is.
Image_Date	No	Date/Time	8	Date on which the image was created, if different from the sampling event date
Image_Edit_Notes	No	Memo	0	Comments about the editing or processing performed on the image
Image_Filename	No	Text	255	Name of the image including extension (.jpg) but without the image path
Image_Label	No	Text	255	Image caption or label
Image_Notes	No	Memo	0	Notes or comments about the image
Image_Project_Path	No	Text	255	Location of the image from the main project folder or image library

Image_Source	No	Text	255	Name of the person or organization that created the image
Image_Time	No	Date/Time	8	Time image was taken
Is_Edited_Version	No	Boolean	1	Indicates whether this version of the image is the edited [originals = False]
Root_Path	No	Text	255	The root path for the linked image file. This will change upon re-linking of database.
Site_ID	No	Text	255	Link to tbl_Sites

tbl_Lab_Sample_Prep — User entered lab sample preparation procedures. Imported table structure from NPSTORET.

Field Name	Primary?	Field Type	Field	Field Description
Lab_Sample_ID	Yes	Other	16	Lab sample preparation procedure unique identifier
D_Last_update_TS	No	Date/Time	8	Date/Time of Last Update - automatically stamp today's date/time in before update event
D_UserID_code	No	Text	8	Who last updated the record - automatically filled in by whoever logged on the system
Description_Text	No	Memo	0	Lab sample preparation procedure description text
ID_Code	No	Text	15	Abbreviated name or identifying code for the lab sample preparation procedure - for NPSTORET
Name	No	Text	120	Full title for the lab sample preparation procedure

tbl_Labs — User entered labs. Imported table structure from NPSTORET.

Field Name	Primary?	Field Type	Field	Field Description
Lab_ID	Yes	Other	16	Laboratory unique indentifier
Address_ID	No	Other	16	Link to tlu_Addresses
City	No	Text	50	City of the lab
Comments	No	Text	50	Any comments about the lab
D_Last_update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event
D_UserID_Code	No	Text	8	Who last updated the record - automatically filled in by whoever logged on the system
Electronic_address	No	Text	50	Email address of the lab
ID_Code	No	Text	8	Lab ID Code - for NPSTORET
Name	No	Text	60	Lab Name
State	No	Text	2	State of the lab
Street_Address	No	Text	50	Street address of the lab
Zip_code	No	Text	5	Zip code of lab

tbl_Locations — Sampling unit locations.

Field Name	Primary?	Field Type	Field	Field Description
Location_ID	Yes	Text	50	Location identifier
Accuracy_Notes	No	Text	255	Positional accuracy notes

Checked_by	No	Text	50	Who checked the data
County	No	Text	50	Name of Station's primary County reported in all capitol letters (NPSTORET required)
Decimal Degrees Latitude	No	Double	8	Decimal Degrees Latitude (NPSTORET required)
Decimal Degrees Longitude	No	Double	8	Decimal Degrees Longitude (NPSTORET required)
Deploy_date	No	Date/Time	8	Preliminary monitoring deployment date
Depth Units	No	Text	2	Depth units of measure (cm, m, mi, km, in, ft)
Elev_Datum	No	Text	50	Elevational datum
Elev_Method	No	Text	50	Elevational method
Elevation	No	Double	8	Station's elevation
Elevation Date	No	Date/Time	8	Date elevation was determined
Elevation Units	No	Text	2	Elevation units of measure (ft or m). Required if Elevation is given
Entered_by	No	Text	50	Who entered the data
EPE	No	Text	255	Estimated position error (feet)
Est_H_Error	No	Single	4	Estimated horizontal accuracy
Establishment Date	No	Date/Time	8	Date on which Station was established (MM-DD-YYYY)
Geo_Datum	No	Text	50	Datum of mapping ellipsoid (NPSTORET required)
Geo_Method	No	Text	50	Geospatial method (NPSTORET required)
Latitude Direction	No	Text	5	Latitude direction. Defaults to N
Lift_type	No	Text	10	Type of lift (NPSTORET required)
Loc_Notes	No	Memo	0	General notes on the location; Information specific to the station
Loc_Type	No	Text	25	Well's primary classification, i.e. groundwater
Longitude Direction	No	Text	4	Longitude direction. Defaults to W
MP_description	No	Text	255	Measuring point description
MP_elevation	No	Text	255	Measuring point elevation
Option	No	Text	255	Long-term monitoring option
Primary_Type	No	Text	50	Station's primary classification (NPSTORET required)
Recovery_date	No	Date/Time	8	Preliminary monitoring recovery date
Site_ID	No	Text	50	Link to tbl_Sites
Start_date	No	Date/Time	8	Long-term monitoring start date
State	No	Text	2	Two-digit postal abbreviation of Station's primary State (NPSTORET required)
Travel Directions	No	Memo	0	Travel directions (by route, track, path, waterway, etc.) to reach the station
Unit_Code	No	Text	12	Park, Monument or Network code

Water Depth	No	Double	8	Typical Depth of Water at sampling location
Well_ID	No	Text	50	Unique well identifier (NPSTORET required)
Well_Name	No	Text	100	Name of the well
Well_Number	No	Long Integer	4	Well number (NPSTORET required)
Well_Owner	No	Text	255	Well owner or operator name (NPSTORET required)

tbl_PreserveTransportStorage

User entered preservation, transport, and storage procedures. Imported table structure from NPSTORET.

Field Name	Primary?	Field Type	Field	Field Description
Preserve_ID	Yes	Other	16	Preserve, transport, and storage unique identifier
Container_color	No	Text	10	Color of container used to collect and transport the sample
Container_size_msr	No	Single	4	Size of container used to collect and transport the sample
Container_size_un	No	Text	3	Units of container size
Container_type_nm	No	Text	32	Type of container used to collect and transport the sample
D_Last_update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event
D_UserID_code	No	Text	8	Who last updated the record - automatically filled in by whoever logged on the system
ID_Code	No	Text	10	Short name or code for sample preservation, transport, and storage procedure - for NPSTORET
Name	No	Text	30	Full name of the sample preservation, transport, and storage procedure
Presrv_strge_prcdr	No	Memo	0	Chemical preservation and storage procedure description
Temp_presrv_type	No	Text	25	Name of the type of physical preservation

tbl_Pressure_Depth_Relation

Specific-conductance profile and pressure-depth relation information.

Field Name	Primary?	Field Type	Field	Field Description
Pressure_ID	Yes	Text	50	Event identifier
Depth	No	Long Integer	4	Dctd in feet below MP
End_time	No	Date/Time	8	End time
Event_ID	No	Text	50	Link to tbl_Events
Notes	No	Text	255	Any remarks about the records.
Pressure	No	Long Integer	4	Pctd in PSI
SpCond_reading	No	Long Integer	4	Specific conductance reading
SpCond_units	No	Text	255	Specific conductance units
Start_time	No	Date/Time	8	Start time

tbl_Sites — Location aggregations.

Field Name	Primary?	Field Type	Field	Field Description
Site_ID	Yes	Text	50	No description
Park_Desc	No	Text	255	Description for a site
Park_Name	No	Text	100	Unique name or code for a site (
Park_Notes	No	Memo	0	General notes on the site
Unit_Code	No	Text	12	Park, Monument or Network code

tbl_SpCond_Depth — Table that stores information for the depth of the specific-conductance sensor below the MP on quarterly field visits.

Field Name	Primary?	Field Type	Field	Field Description
SpCond_Depth_ID	Yes	Text	50	Unique record identifier
Event_ID	No	Text	50	Link to tbl_Events
Eyebolt_location	No	Text	6	Eyebolt above or below MP?
Length_A	No	Double	8	Distance between specific conductance sensor of CTD and point (eyebolt) where cable attaches to well.
Length_B	No	Double	8	Distance from MP to the point (eyebolt) where the CTD cable attaches to the well casing.
SpCond_depth	No	Double	8	Depth of the specific-conductance sensor below the MP (if eyebolt is below MP, add length A and B. If eyebolt is above MP substract length B from length A)

tbl_SpCond_Readings — Table that stores CTD specific conductance calibration readings.

Field Name	Primary?	Field Type	Field	Field Description
CTD_Measure_ID	Yes	Text	50	Unique record identifier
CTD_Cal_ID	No	Text	50	Link to tbl_CTD_calibration
CTD_Reading	No	Double	8	CTD reading
CTD_unit	No	Text	255	CTD units
Difference	No	Long Integer	4	Percent difference
Notes	No	Memo	0	Notes about specific conductance calibration
Standard_unit	No	Text	255	Standard units
Standard_value	No	Double	8	Standard value

tbl_Well_Metadata — Table stores metadata for well measuring point, reference marks, and CTD support.

Field Name	Primary?	Field Type	Field	Field Description
Well_Meta_ID	Yes	Text	50	Unique record identifier
Image_ID	No	Text	50	Link to tbl_Images which contains sketch of MP and RM locations and CTD support with distance labels

Location_ID	No	Text	50	Link to tbl_Locations (wells)
MP_CTD_distance	No	Long Integer	4	Distance between measuring point and CTD support
MP_Description	No	Memo	0	Measuring point (MP) description
Notes	No	Memo	0	Notes
Peg_test	No	Boolean	1	Pass peg test?
RM_Description	No	Memo	0	Reference marks (RM) desciption

tbl_Well_Test Table that stores peg test data.

Field Name	Primary?	Field Type	Field	Field Description
Well_test_ID	Yes	Text	50	Unique record identifier
BS	No	Long Integer	4	Backsight
Elev	No	Long Integer	4	Elevation
FS	No	Long Integer	4	Foresight
HI	No	Long Integer	4	Height
Location_ID	No	Text	50	Lookup to tbl_Locations (well)
Notes	No	Memo	0	Remarks

tlu_Characteristics User entered characteristic definitions (parameters that are measured)

Field Name	Primary?	Field Type	Field	Field Description
Char_ID	Yes	Text	50	Unique record identifier
Analytical_ID	No	Other	16	Link to analytical procedure
Char_Description	No	Memo	0	Describe or define more completely the characteristic definition
Char_Type	No	Text	50	What is the data type of the associated characteristic
Comp_Ind_CD	No	Text	1	Has the characteristic has been adequately defined (minimally required fields entered) for data entry
Det_Quant_Description	No	Text	255	Describe the meaning of the detection and/or quantification limits
Detection_Limit	No	Double	8	Least amount of the target substance that could be detected by the instrument or analytical process that was used to determine the result. Above this value, the target substance is presumed to be present.
Display_Name	No	Text	60	Official EPA Characteristic Display Name

Dur_Basis_Type	No	Text	10	Time period over which a measurement was made
Field_ID	No	Other	16	Link to field sampling procedure
Field_Lab	No	Text	13	Where was the characteristic was measured
Gear_ID	No	Other	16	Link to gear configuration procedures
Handling_Proc	No	Other	16	Link to transport, preserve and storage procedures
Lab_Sample_ID	No	Other	16	Link to lab sampl preparation procedure
LocCharNameCode	No	Text	60	Organization's Local Name for the Characteristic Definition
Lower_Quantity_Limit	No	Double	8	Lower Quantification Limit (often referred to as the Practical Quantitation Limit - PQL) represents the smallest amount of the target substance or characteristic that could be quantified by the instrument or analytical process.
Medium	No	Text	50	Medium in which the characteristic is measured
Sample_Fraction	No	Text	50	No description
Sequence_Number	No	Single	4	Sequence number used for ordering characteristics on the results form. Characteristics are ordered in ascending order by sequence number.
ShowFilteredUnits	No	Boolean	1	Flag for whether to display all possible STORET units or filter the units based on the characteristic
Statistic_Type	No	Text	18	What type of statistic is the reported result value
Temp_Basis	No	Text	8	What is the controlled temperature at which the sample was maintained during analysis
Unit_ID	No	Other	16	Unit of Measure unique identifier
Update_TS	No	Date/Time	8	Date/Time of last update - automatically stamp today's date/time in before update event
Upper_Quantity_Limit	No	Double	8	Largest amount of the target substance that could be quantified by the instrument or analytical process. Values above the lower and below the upper quantification limits are reported as valid numeric results in STORET.
UserID	No	Text	8	Who last updated the record - automatically filled in by whoever logged on the system
Value_Type	No	Text	10	What type of value is the reported result
Wt_Basis_Type	No	Text	12	What is the form of the sample (or portion of the sample) that is associated with the result value

tlu_Contacts Contact data for project-related personnel.

Field Name	Primary?	Field Type	Field	Field Description
Contact_ID	Yes	Text	50	Unique identifier for contact records
Address	No	Text	50	Street address

Address_Type	No	Text	50	Address (mailing, physical, both) type
Address2	No	Text	50	Address line 2, suite, apartment number
City	No	Text	50	City or town
Contact_Notes	No	Memo	0	Contact notes
Country	No	Text	50	Country
Email_Address	No	Text	50	E-mail address
First_Name	No	Text	50	First name
Last_Name	No	Text	50	Last name
Middle_Init	No	Text	4	Middle initial
Organization	No	Text	50	Organization or employer
Position_Title	No	Text	50	Title or position description
State_Code	No	Text	8	State or province
Work_Extension	No	Text	50	hone extension
Work_Phone	No	Text	50	Phone number
Zip_Code	No	Text	50	Zip code

tlu_Enumerations List of source values for drop down lists.

Field Name	Primary?	Field Type	Field	Field Description
Sort_Order	Yes	Long Integer	4	No description
Enum_Code	No	Text	8	No description
Enum_Description	No	Memo	0	No description
Enum_Group	No	Text	50	No description

tlu_Unit_of_Measure Look up table of units of measure from NPSTORET

Field Name	Primary?	Field Type	Field	Field Description
Description_Text	No	Text	50	Description of unit of measure
Display_Name	No	Text	10	Display name
Short_Form_Name	No	Text	10	Abbreviated unit of measure
Unit_ID	No	Other	16	Unique record identifier
UOM_Type	No	Text	5	Unit of measure type

xref_Event_Contacts Cross-reference table between events and contacts.

Field Name	Primary?	Field Type	Field	Field Description
Contact_ID	No	Text	50	Link to tlu_Contacts
Contact_Role	No	Text	50	The contact's role in the protocol
Event_ID	No	Text	50	Link to tbl_Events

Appendix G: Standard Operating Procedures

Standard Operating Procedure (SOP) # 1: Instructions for Making Revisions

Standard Operating Procedure (SOP) # 2: Personnel, Education, Skills and Training

Standard Operating Procedure (SOP) # 3: Measurement Units and Precision

Standard Operating Procedure (SOP) # 4: Acquisition and Maintenance of Equipment and Supplies

Standard Operating Procedure (SOP) # 5: Quarterly Field Visits

Standard Operating Procedure (SOP) # 6: Specifications/Maintenance for the Steel Measuring Tape

Standard Operating Procedure (SOP) # 7: Specifications for the CTD and Preparation for First Use

Standard Operating Procedure (SOP) # 8: Maintenance of the CTD

Standard Operating Procedure (SOP) # 9: Acquisition and Storage of Specific-Conductance Standards

Standard Operating Procedure (SOP) # 10: Specifications for the GPS and Preparations Prior to Use

Standard Operating Procedure (SOP) # 11: Specifications for Surveying Equipment

Standard Operating Procedure (SOP) # 12: Establishing Measuring Point, Reference Marks and CTD Support

Standard Operating Procedure (SOP) # 13: Checking the Measuring Point and Reference Point

Standard Operating Procedure (SOP) # 14: Measuring Depth to Water (DTW)

Standard Operating Procedure (SOP) # 15: Calibration of the CTD for specific-conductance

Standard Operating Procedure (SOP) # 16: Specific-conductance Profile and Pressure-Depth Relation

Standard Operating Procedure (SOP) # 17: Workspace Set-up and Records Management

Standard Operating Procedure (SOP) # 18: Managing Photographic Images

Standard Operating Procedure (SOP) # 19: Initial Data Processing

Standard Operating Procedure (SOP) # 20: Data Entry and Verification

Standard Operating Procedure (SOP) # 21: Checking Data for Accuracy

Standard Operating Procedure (SOP) # 22: Data Quality Review and Certification

Standard Operating Procedure (SOP) # 23: Metadata Development

Standard Operating Procedure (SOP) # 24: Product Delivery Specifications

Standard Operating Procedure (SOP) # 25: Product Posting and Delivery

Standard Operating Procedure (SOP) # 26: Annual Data Analyses and Reporting for the Long-Term Monitoring

Standard Operating Procedure (SOP) # 27: Safety

Main

This section contains five main SOPs that address broad procedure categories of this protocol. The main SOPs each use a number of the more specific SOPs (6 through 22). Many of the SOPs require recording data in field notes. Field data sheets (FDS) have been developed to facilitate efficient and consistent field notes (Appendix A). Each person who goes into the field should also keep a field notebook. The contents and organization of a field notebook varies by individual, but extensive notes are almost always more useful than terse notes, even if some of the notes are redundant with data in the field data sheets.

Standard Operating Procedure (SOP) # 1: Instructions for Making Revisions

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

The protocol may require revisions as the science of groundwater advances. This SOP describes the procedure for making revisions. This procedure applies to all revisions of this protocol, regardless of whether the revisions affect the entire protocol or only a limited part of it.

1. Any member of the monitoring team can initiate a revision. Scientists and other persons outside of the team can also suggest revisions by contacting the project lead.
2. The primary responsibility for revision of this protocol rests with the project lead. It is strongly advised that the project lead consult with the technicians, the USGS, and other sources of expertise before finalizing any revisions.
3. Revisions are designated by version numbers. Original versions of all parts of the protocol have been given the version number 1.0. Major revisions are designated by sequentially increasing the digit on the left of the decimal (e.g., 2.0, 3.0, 4.0...); minor revisions are designated by sequentially increasing the digit on the right of the decimal (e.g., 1.1, 1.2, 1.3...). Table 1-1 provides a guide to determine whether a revision is major or minor.
4. As a general rule, budgetary fluctuations resulting from inflation or other economic factors do not warrant a change in the protocol. These adjustments can be handled administratively.
5. A revision to the narrative is designated by a change in the version number in the protocol title. A revision to an SOP, FDS, or template is designated by a change only in the version number of the affected SOP, FDS, or template.
7. All revisions, regardless of whether they are major or minor or what part of the protocol they affect, are recorded in chronological order in the revision history (Appendix C).

Table 1-1. Revision types and actions with respect to numbering. [SOP, (standard operating procedure); FDS, (field data sheet)]

Revision type	Description	Action with respect to version numbering
Major revision of narrative	Any substantial revision to the protocol, such as changes in the concepts of groundwater occurrence, monitoring rationale or objectives, or monitoring parameters, or major changes in monitoring design, data handling, analysis, reporting, quality assurance or archival	In version number of protocol title, increase number to left of decimal by one
Minor revision of narrative	Revisions of parts of the protocol, but having limited effect on the protocol as a whole. Examples: small changes in the use of the data, monitoring-well selection, measurement frequency, instrumentation, specific procedures for fieldwork and data processing, personnel requirement and training, field schedule, or supplies and services	In version number of protocol title, increase number to right of decimal by one
Major revision of SOP, FDS, or template	Revisions that result in a change in all or a substantial part of the SOP, FDS, or template	In version number of the SOP, FDS, or template, increase number to left of decimal by one
Minor revision of SOP, FDS, or template	Revisions that affect only a small part of the SOP, FDS, or template	In version number of the SOP, FDS, or template, increase number to right of decimal by one

Standard Operating Procedure (SOP) # 2: Personnel, Education, Skills and Training

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

The groundwater monitoring protocol requires a team of three people: (1) project lead, (2) lead technician, and (3) technician. The minimum required skills and background education of these individuals is as follows:

1. Project Lead – bachelor's degree in one of the natural sciences, math, or engineering; strong written and oral communication skills, organization and management skills, and proficiency with computers and ability to adapt to new computer technologies.
2. Lead Technician and Technician – high school diploma or GED; strong aptitude in math, science, and technical reasoning; above-average computer skills; attention to detail, and insistence on accuracy.

Specialized Training

The project lead, lead technician, and technician also must complete a specialized 32-hour training course on the overall objectives and purpose of the monitoring; establishing, operating, and maintaining a groundwater monitoring station; using and maintaining equipment; and data-archival procedures. The course will include both classroom and practical field instruction, and will be conducted by the USGS. A course outline is provided in Table 2-1.

Field experience

Field experience, beyond classroom or specialized training, is an essential part of developing the skills needed to successfully maintain a groundwater monitoring program. New personnel must spend time in the field under the guidance of an experienced field technician or project lead.

Additional Study

The project lead is expected to acquire and maintain, through self-guided study, a firm understanding of groundwater hydrology of coastal aquifers, what factors induce changes in the groundwater system, and how those changes relate to the resources of each park in the project lead's domain.

Table 2-1. Course outline for 32-hour training for technicians and project lead.[CTD, instrument for monitoring conductance, temperature, and water depth]

Day 1	Preliminaries, introductions, schedule of course activities
	Protocol objectives
	Geography, climate, geology, hydrology of Hawaiʻi and Saipan
	Causes of water-level and salinity fluctuations
	Overview of the Groundwater Monitoring Protocol
	    Rationale, objectives
	    Basic monitoring strategy
	    Groundwater levels
	    Salinity
	    Wells
	    Instruments
	    Fieldwork
	    Data handling
	    Personnel
	Equipment preparation
	    Load software
	    Preparing CTD cable
	    Checking CTD for specific conductance, temperature
	Level surveying

Day 2	Orientation, field preparation for initiation of long-term monitoring (classroom) Field trip to monitor well site – initiation of long-term monitoring Return to classroom, process field notes, field data sheets, and photographs
Day 3	Orientation, field preparation for quarterly field visits (classroom) Field trip to monitor well site -- fieldwork for quarterly field visits Process field notes, field data sheets, and photographs

Day 4	Data Handling, Analysis, and Reporting
	    Objectives – quality assurance, archival, and periodic analysis and reporting.
	    Well Numbers
	    Data Workspaces, Data Files, and Databases
	    Initial data handling and processing
	    Checking Data for Accuracy
	    Review of Field data
	    Annual Data Analysis and Reporting for Long-Term Monitoring

Standard Operating Procedure (SOP) # 3: Measurement Units and Precision

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

This protocol requires measurements of length, temperature, latitude and longitude, date and time of day. To provide a basis for consistent measurement, units and precision for each of the parameters in this protocol are specified in Table 3-1.

Table 3-1. Units, precision, and geographic coordinate system for measurements made in the groundwater monitoring program. [MP: (Measuring point); RM: (reference mark); DTW: (depth to water); EPE: (estimated position error of geographic coordinates); WGS 84: (World Geodetic System of 1984); N.A.: (not applicable)]

Parameter	Units	Precision
MP, RM, DTW, and depth measurements in specific-conductance profile	feet	0.01 feet
Specific conductance	microsiemens per centimeter	1 microsiemens per centimeter
Temperature	degrees Celsius	0.1 degree
Latitude, longitude	decimal degrees	4 decimal places
Geographic coordinate system	WGS 84	N.A.
EPE	feet	foot
Pressure	pounds per square inch	0.0014 pounds per square inch
Time of day	hour and minute, local time	1 minute
Date	year, month and day, local time	1 day

Standard Operating Procedure (SOP) # 4: Acquisition and Maintenance of Equipment and Supplies

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

The groundwater monitoring protocol requires the following equipment, properly set up, as well as supplies for their proper calibration and maintenance.

1. Steel measuring tape (SOP 6)
2. CTD (SOP 7, 8). At each park, a minimum of one CTD per well plus one spare will be required.
3. GPS (SOP 10)
4. Automatic level (also known as an automatic-compensating or self-leveling level) and rod for surveying the MP and RMs (SOP 11).
5. Other types of common equipment, such as a digital camera, field laptop computer, standard tools, a field vehicle, and safety equipment are not specifically listed here because they are assumed to already be available.

Standard Operating Procedure (SOP) # 5: Quarterly Field Visits

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

The purpose of the quarterly field visits is to make measurements and recover and upload data from the CTD. This SOP assumes that a spare CTD is available so that monitoring can continue in the event that a CTD must be removed from the site (e.g., for annual recalibration). The CTD in the well prior to arrival is here called the working CTD; the CTD brought to the site is called the replacement CTD. Under normal circumstances, this exchange is required only once per year to allow recalibration of the CTDs. This SOP requires FDS 1.

1. These procedures are to be followed every three months for the duration of the monitoring program. To ensure continuity of the monitoring data, the three-month interval should be maintained as closely as possible. Allowances for deviation from the quarterly schedule can be made to avoid weekends, holidays, and inclement weather, but the deviation should be no more than 5 days.
2. Strong tidal signals in wells can cause rapid water-level changes that affect the accuracy and efficiency of field measurements. Field visits can be scheduled for a time when water-level changes are least rapid, such as near the peak of high tide or the trough of low tide. Important note: the tidal signal in a well usually lags that of the ocean; therefore, the scheduling should be based on the tidal signal of the well, not the ocean. Consult CTD water-level data from previous site visits to help estimate when high and low tides will occur in the well.
3. Prepare for quarterly field visits.
   - A. One to two months before field visit.
     - 1) Ensure adequate supplies are available (Table 5-1)
     - 2) Ensure that all instruments work and calibrations are current (Table 5-2).
     - 3) The elevation of the MPs and RMs must be checked annually. Determine whether these tasks are due on the upcoming field visit, and if so, review SOP 13 and prepare the surveying equipment.
     - 4) Ensure that right-of-entry or well-use agreement is valid for scheduled field work.
     - 5) Review field notes and field data sheets from previous field visit to determine if equipment repairs, calibrations, or replacement will be necessary. If so, take appropriate action.
   - B. One to two weeks before field visit:
     - 1) Review SOP 6 and associated SOPs.

   2) If necessary, notify landowners or well owners in accordance with right-of-entry or well-use agreements.
   3) Prepare copies of important information (Table 5-3)
   4) Arrange for transportation to the field site.

   C. One to two days before field visit:
   1) Gather equipment and supplies (Table 5-1).
   2) Test instruments and ensure batteries are charged.
   3) Check accuracy of all field timepieces against a consistent time reference.

4. Mobilize to field site.
5. Remove any covers, caps or other obstruction to the well.
6. Follow precautions to prevent dropping tools or other objects in a well.
   A. Avoid holding or placing objects directly over an open well unless absolutely necessary.
   B. When it is necessary to hold a tool over a well momentarily to make a measurement, ensure that the object is held securely or is tethered to something that cannot be pulled into the well if the object is accidentally dropped.
   C. Avoid using anything that may contaminate the water in the aquifer if it is accidentally dropped into the well (for example, lead weights, mercury thermometers, hazardous chemicals)
7. Inspect the MP and RMs. If they appear to have been damaged, resurvey them (SOP 13) or, if necessary, re-establish them (SOP 12). Regardless of appearance, the MP and RMs must be resurveyed on an annual basis.
8. With drawing the CTD and making a DTW measurement – The goal in this step is to make the DTW measurement as close as possible to the last CTD measurement. Therefore it is ideal to remove the CTD as close as possible to but *after* the time of the last CTD reading. For example, the CTD should have been set to make a measurement every 15 minutes, therefore, if the time is 8:12, wait until the CTD has made its 8:15 measurement, then remove the CTD at 8:16 (the extra minute allows for the possibility that the CTD clock may have drifted). Because the DTW must be measured immediately thereafter, it is helpful to have the steel tape chalked and ready for deployment.
   A. Withdraw the CTD – In relatively shallow wells (50 feet or less) it may be possible to withdraw the CTD without rewinding the cable or vent tube on a spool or detaching them from their support on the well casing, but care must be taken to avoid tangles or kinks.
   B. Immediately after removing the CTD, measure the DTW (SOP 14) and record it and the time on the field data sheet.
9. Upload data from the CTD.
   A. Connect the CTD to a field computer and check the clock (follow manufacturer's instructions). Compare the CTD time with that of a timepiece that has been checked and synchronized against a consistent time reference. If there is any discrepancy, record it on the field data sheet.
   B. Transfer CTD data to field computer.
   C. Create a backup copy of the data on a storage device that can be physically detached from the computer (for example, a compact disk or flash drive).
   D. Open data files to confirm that the transfer and backup were successful.
   E. If the data transfer and backup were successful, the memory of the CTD can be cleared if necessary to make space for additional data. This may not be necessary for some CTD

models which have large memory capacity and will overwrite the oldest data first if memory is exceeded. Consult manufacturer's instructions.

10. Inspect the CTD cable, vent tube, and support. If any conditions exist that may have affected the operation of the CTD, make a note on the field data sheet.
11. Determine if the cable, vent tube or support are deteriorating and may need replacement in the near future; replacement may take several weeks (SOP 7).
12. If the working CTD is due for annual temperature calibration check, remove it from the vent tube and attach the replacement CTD. The replacement CTD is now the working CTD.
13. Determine the depth of the specific-conductance sensor below the MP.
    A. Consult the most recent CTD cable preparation (SOP 7) to determine the distance between the specific-conductance sensor and the point (eyebolt) where the cable will attach to the well (length A in Fig. 5-1). Enter value in the field data sheet.
    B. Consult the most recent installation of the CTD support (SOP 12) to determine the distance from the MP to the to the point (eyebolt) where the CTD cable attaches to the well casing (length B in Fig. 5-1). Enter value in the field data sheet.
    C. Compute depth of the specific-conductance sensor below the MP. If eyebolt is below MP, add length A and B. If eyebolt is above MP, subtract length B from length A. Record result on the field data sheet. Note: this depth should be constant throughout the monitoring. On rare occasions, data analysis in SOP 22 may indicate that the monitoring depth should be changed.
14. Calibrate the working CTD for specific conductance (SOP 15).
15. If annual determination of the specific conductance profile and slope of pressure-depth relation ($M_{D/P}$) are due, conduct this now (SOP 16).
16. Synchronize the CTD clock with a timepiece (watch or field computer) that has been checked and synchronized against a consistent time reference.
17. Set the CTD logger to record at 15-minute intervals, on the quarter hour, and start the logger.
18. If the CTD uses desiccant, replace old desiccant with fresh desiccant.
19. Measure the DTW (SOP 14) and record date and time on the field data sheet.
20. Deploy the working CTD as soon as possible after the DTW measurement.
    A. Secure the CTD cable or vent tube to the inside of the casing.
    B. Lower the CTD into the well until it is submerged about one or two feet below the surface of the water and gently agitate to dislodge any air bubbles that may be trapped against the sensors in the CTD housing (air bubbles can cause erroneous CTD readings).
    C. Lower the CTD into the well and set it the prescribed depth.
21. Take digital photographs, if necessary. Photograph significant changes from the previous visit, especially with regard to the well, the MP and RMs, field conditions, and nearby activities (e.g., roadwork, construction, flooding, etc.) that may affect groundwater. Make use of labels, signs, etc., as well as field notes to help with later identification of subjects in the photographs. Use rulers or other objects to indicate the size of the subject.
22. Replace any caps or covers that were removed from the well.
23. Depart site.
24. Begin data processing immediately upon return from the field (SOP 19, 20).
25. Review and finalize data (SOP 21)
26. If annual data summary is due, prepare report (SOP 22).

Table 5-1. List of field equipment and supplies for the quarterly field visits. [SOP: (standard operating procedure); CTD: (instrument for monitoring conductance, temperature, and water depth); GPS: (Global positioning system); NPS: (National Park Service)]

Steel measuring tape, chalk, and rags	
CTD (or replacement CTD) with vent tube, cable, properly prepared, maintained and checked (SOP 7, 8). Also, any other associated tools or equipment recommended or supplied by the CTD manufacturer (desiccant, calibration tools, computer interfaces, etc.)	
GPS, properly prepared, maintained and checked (SOP 10)	
Field data sheet (FDS 1; also FDS3 if annual measurement of specific-conductance profile and pressure-depth relation is due)	
Squirt bottle with deionized water	
Specific-conductance standards – at least two standards spanning the range of expected specific conductance to be measured in the field.	
Spare eye bolts or other fasteners (for CTD cable and vent tube)	
Surveying equipment (if annual check of MP and RMs is due, or if MP and RMs must be reestablished)	
	Automatic level and tripod
	Field data sheet (FDS 2)
	Surveying rod
	Hammer drill or other tool for boring into concrete or rock, with appropriate bits
	Stainless steel or brass bolts to use as reference markers
	Cement or epoxy for affixing bolts to rock or concrete
Maps of site, copies of notes or a summary of information from previous field trips (original field notes and field data sheets from previous field trips should not be taken into the field).	
Directional compass	
Watch or other device for accurately determining time, set to a consistent time reference.	
Field computer and separate storage device or media (compact disk, flash drive, etc.)	
Digital camera	
Standard tools, such as hammer, screw drivers, wrenches, pliers, pocket knife, file, hacksaw, power drill with bits for boring into steel, etc.	
Personal-protective clothing and safety and emergency supplies and equipment, as required by the policies of the NPS as well as state, federal, and local laws.	

Table 5-2. Calibration and maintenance schedule for the instruments used in the groundwater monitoring program. [CTD, instrument for monitoring conductance, temperature, and water depth]

Instrument/sensor		Frequency
Steel measuring tape		Every 5 years
CTD		
	Specific conductance	In field, before each use
	Temperature	Annually
	Pressure	Refer to manufacturer's instructions

Table 5-3. List of important information to take into field during quarterly field visits.

Copies (not originals) of notes from previous field visits
Location maps
Copies of photographs
Copies (not originals) of field notes and field data sheets from previous visits
Any other material related to the well's location and identification

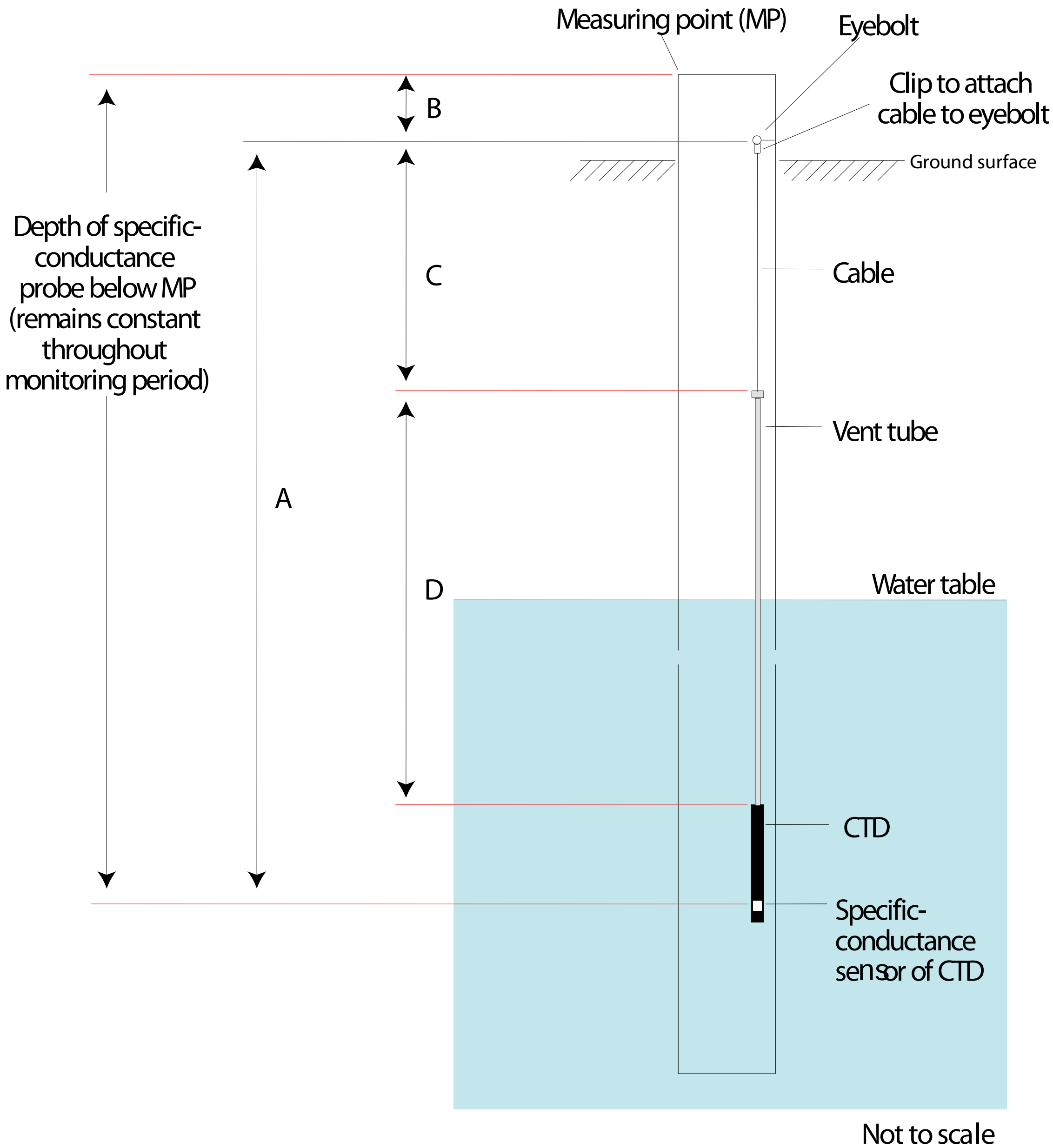

Figure 5-1. Dimensions pertaining to the depth of the conductance-temperature-depth (CTD) probe deployed in a monitoring well: (A) distance between the point where the cable will be attached to the eyebolt in the well casing and the point on the CTD where specific conductance is measured, (B) distance between the eyebolt and the MP, (C) length of the cable, and (D) length of the vent tube.

Equipment

Specifications, initial preparation, and calibration and maintenance of equipment required for the groundwater monitoring protocol are listed in this section. The specifications do not include any manufacturer or instrument model because advances in technology will likely develop during the course of the monitoring program or that some equipment, particularly electronic instruments, will become obsolete. Instead, the specifications provide the basic functions of the instruments, and the minimum accuracy required to meet the needs of the groundwater monitoring program. If future technology can increase efficiency, accuracy, or safety, that technology can be adopted if it has the same basic functionality and meets the minimum specifications for accuracy outlined in this section.

This section lists the main types of equipment needed for the groundwater monitoring program. Other types of common equipment, such as a digital camera, field laptop computer, standard tools, a field vehicle, and safety equipment are not listed because they are assumed to already be available.

Standard Operating Procedure (SOP) # 6: Specifications/Maintenance for the Steel Measuring Tape

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

The steel measuring tape is used to measure the depth to the water surface (DTW) in a well (Fig. 6-1). The SOP for DTW measurements (SOP 14) also requires chalk that will be applied to the steel tape so that the water mark can be easily read. Specifications for the steel measuring tape are given in Table 6-1.

Maintenance of the steel tape should follow the recommendations in the manufacturer's instructions. Some additional procedures that are required to maintain the accuracy of the steel tape are listed below.

1. After each use, carefully rewind the steel tape to avoid twists, kinks, and other deformities that can lead to inaccurate depth measurements.
2. Avoid exposing the tape to excessive heat, such as from prolonged exposure to sunlight.
3. Keep the tape clean and dry to reduce corrosion.
4. The steel measuring tape must be calibrated for length (by the USGS or NIST) every 5 years.

Table 6-1. Specifications for the steel measuring tape.

Material	Steel
Minimum width	0.25 inch
Minimum thickness	0.016 inch
Minimum length	100 feet
Measurement graduations	Every 1, 0.1, and 0.01 feet
Numbers on graduations	Every 1 and 0.1 foot
Printed markings and numbers	Raised or stamped into steel of tape
Location of zero mark	Approximately 1 foot from end of tape
Termination	Steel D-ring
Mounting	Spool with supporting handle and crank

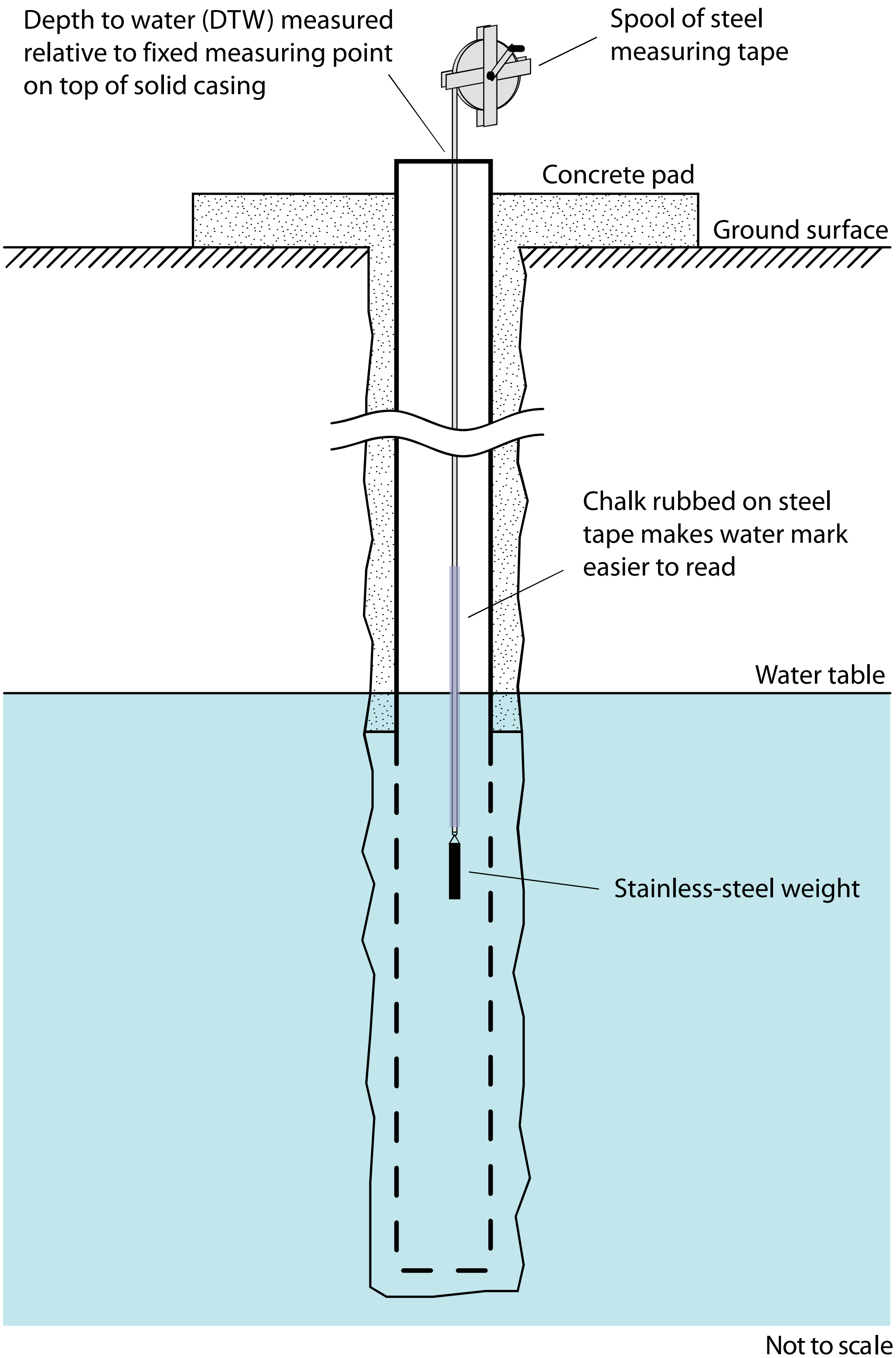

Figure 6-1. Measuring depth to water (DTW) with a steel measuring tape.

Standard Operating Procedure (SOP) # 7: Specifications for the CTD and Preparation for First Use

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

The CTD is used to automatically monitor depth and specific electrical conductance of the water in which it is submerged. The CTD has electronic specific-conductance, temperature, and pressure sensors housed in a single probe together with a data logger. The probe also houses some type of power supply, such as rechargeable or replaceable batteries. The data logger in the probe can be set to measure and record depth, temperature, and specific conductance at a specified time interval. The probe can then be lowered (using a standard cable) into a well until it is submerged at a selected depth beneath the water surface. The CTD can then be left to make and record measurements for months. After a period of monitoring, the CTD can be removed from the well and the data downloaded from the CTD to a field computer. The CTD can then be serviced (cleaned, batteries replaced, data logger reset, etc.) and redeployed in the well.

The CTD determines water depth on the basis of pressure that it senses while it is submerged. Fluctuations in atmospheric pressure can also be detected by the CTD and can lead to erroneous depth determinations. The SOPs in this protocol use a CTD with a vent tube that extends above the water surface to compensate for the atmospheric fluctuations (Fig. 7-1). Specifications for the CTD are given in Table 7-1.

A new CTD must be prepared before it is used to make field measurements. The preparation includes the following steps.

1. Inspect the instrument to ensure that it has been shipped intact.
2. Read the manufacturer’s instructions.
3. Prepare a log book. This log book will be used to record all calibrations, maintenance, and repairs made to the CTD. Record the device type (CTD), manufacturer, model, serial number, date of purchase, and vendor on the cover and first page of the log book.
4. Install batteries and conduct any tests recommended by the manufacturer’s instructions. Record the date, results of tests, and name of the person conducting the tests in the log book.
5. Program the CTD to record data for the following parameters: Date and Time, Elapsed Time in seconds, Pressure (PSI), Temperature (C), Depth (ft), Specific Conductance, and Salinity.
6. For wells that are more than 20 feet deep such as those in KAHO, it may not be economical to purchase a vent tube long enough to reach the surface (Fig. 7-1). If so, a stainless-steel cable that is strong enough to support the CTD can be attached to the top of the vent tube (see

manufacturer's instructions). A clip can be attached to the end of the cable to facilitate attachment to the well.

7. New cables and vent tubes commonly have a curl from being shipped in a coil or wound on a spool. This curl must be straightened before monitoring can begin. Lay the cable and vent tube out straight for a few days prior to deployment (this can be done in a hallway or warehouse). If the cable and vent tube are not straightened before deployment, they will gradually straighten over a few days in the well, which may result in unusable data from the first few days of monitoring.
8. Adjust the length of the cable and its attachment to the vent tube so that the specific conductance sensor will hang in the well at the specified depth below the MP (see "Monitoring Sites in KAHO and AMME" in narrative), taking into consideration that the support for the CTD (e.g., eyebolt in the well casing) may be higher or lower than the MP (Fig. 7-1). It is critically important that once monitoring is initiated, the depth of the specific conductance sensor of the CTD relative to the MP remain constant (the exception is when data analysis in SOP 22 indicates the depth should be changed). This depth is a function of (1) the position of the sensor on the CTD, (2) the length of the vent tube, (3), the length of the cable and any clips used to facilitate attachment, and (4) the position of the support (e.g., eyebolt used to suspend the CTD from the casing), relative to the MP. If any of these four parameters changes, e.g., an old vent tube needs replacing, one of the other parameters, e.g., cable length, must be adjusted so that the CTD specific-conductance sensor hangs at the same depth below the MP.
9. To help ensure that the depth of the specific conductance sensor remains constant, whenever a cable or vent tube is installed or replaced, measure the length of the distance from point where the cable will be attached to the well to the point on the CTD where specific conductance is measured (length A in Fig. 7-1). Do this using the flowing steps:
   A. Attach the vent tube and cable to the CTD, and lay the entire assembly on a straight, horizontal surface. Ensure that the entire assembly is straight.
   B. Locate the precise position of the specific-conductance sensor on the CTD. This information may be in the manufacturer's instructions; if not contact the manufacturer.
   C. Use the steel tape to measure precisely (to the nearest 0.01 ft) the distance between the point where the cable will be attached to the well to the point on the CTD where specific conductance is measured (length A in Fig. 7-1)
   D. Record this distance in the log book.
   E. In some CTD models, the attachment to the well is adjustable. If possible, mark the position of the attachment so that it is easy to visually determine if it has been inadvertently moved.

10 Check the accuracy of the CTD for temperature – this check should be done annually by the NPS staff concurrently with temperature calibration of other multiparameter sondes used in the I&M program.

11. Check accuracy of the CTD's specific-conductance probe (SOP 15).

Table 7-1. Specifications for the specific-conductance-temperature-depth (CTD) probe.

Type		**Specific conductance, temperature, pressure sensor with internal data logger and clock.**
Pressure compensation to atmosphere[1]		Vent tube
Maximum length		1.5 feet
Maximum diameter		1 inch
Material		Corrosion resistant, non toxic (for example, stainless steel)
Power		Internal battery, 5-year minimum life before replacement or recharging
Sampling frequency		Time based, adjustable, at least 1 measurement per second
Temperature		
	Range	-5˚ C to +45˚ C
	Accuracy	±0.2˚ C
Specific conductance		
	Range	0 to 50,000 µS/cm at 25˚ C
	Accuracy	Greater of ±1 percent of reading or ±2 µS/cm at 25˚ C
	Other requirement	Automatic temperature compensation to 25˚ C.
Depth (computed from pressure)		
	Range	0 to 35 feet (0-15 PSI)
	Accuracy	±0.07 feet (±0.03 PSI)
	Other requirement	Compensation for atmospheric pressure fluctuations[1]
Memory		
	Type	Non volatile
	Capacity	16,000 measurements of all parameters

[1] Pressure sensor must be compensated for variations in atmospheric pressure. In this protocol, the specified CTD uses a vent tube open to the air above the water surface. Vent tubes of various lengths are available from the manufacturer. The vent tube must be long enough to ensure that the top of the tube does not become submerged at any time during its deployment in the well, regardless of how much the water level changes.

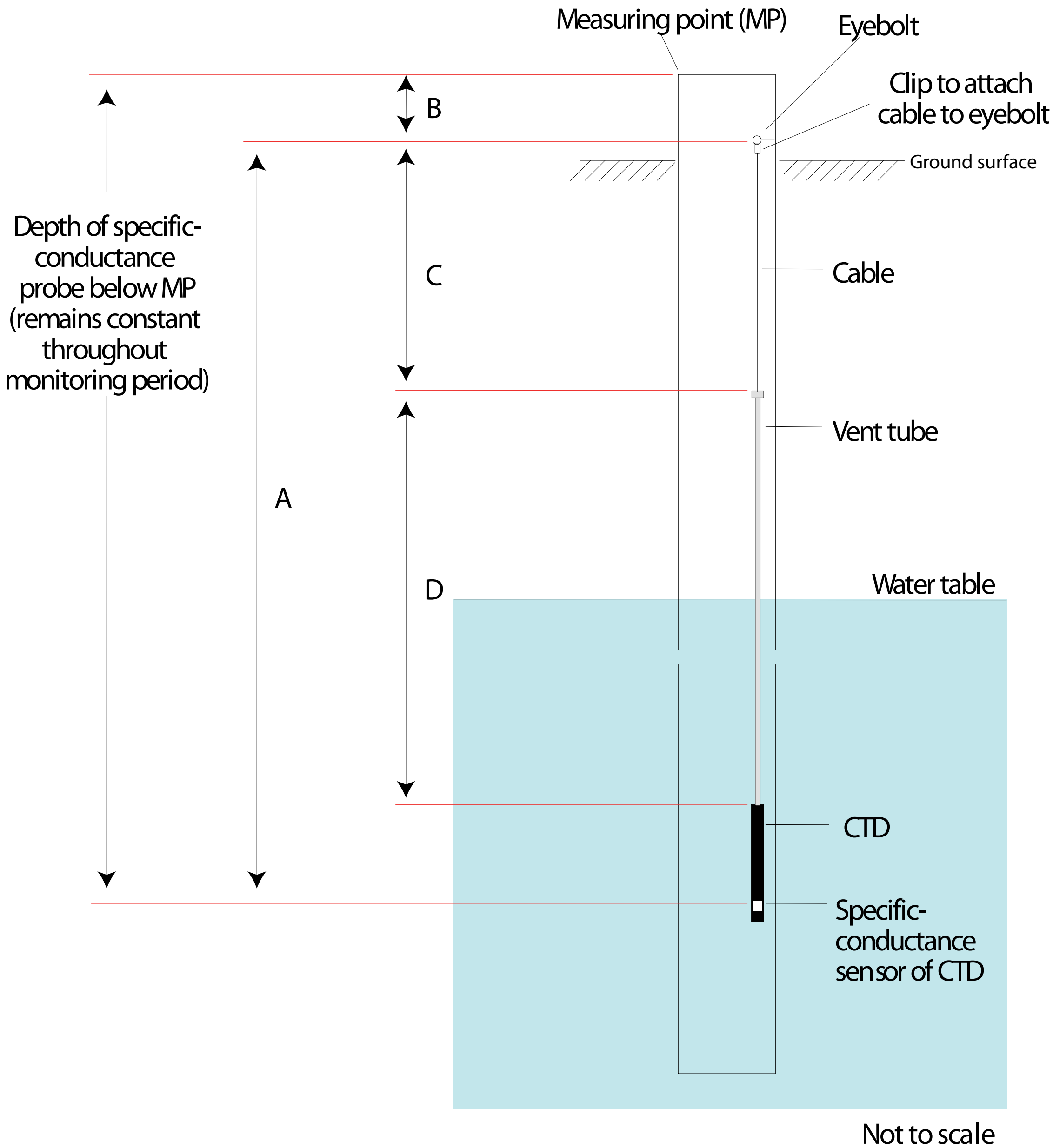

Figure 7-1. Dimensions pertaining to the depth of the conductance-temperature-depth (CTD) probe deployed in a monitoring well: (A) distance between the point where the cable will be attached to the eyebolt in the well casing and the point on the CTD where specific conductance is measured, (B) distance between the eyebolt and the MP, (C) length of the cable, and (D) length of the vent tube.

Standard Operating Procedure (SOP) # 8: Maintenance of the CTD

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

Maintenance of the CTD should follow the recommendations in the manufacturer's instructions.

Some additional procedures that are required to maintain the accuracy of the CTD are listed below.

1. Whenever the CTD is pulled from or lowered into a well, handle the cable and vent tube carefully to avoid curling, twists, kinks, and other deformities that can lead to inaccurate depth measurements. If the cable or vent tube becomes deformed, it should be replaced (SOP 7).
2. Ensure that the vent tube does not become kinked, plugged, or otherwise blocked from allowing free flow of air. Also ensure that the tube is not punctured, torn, or otherwise perforated. Vent tubes that have been compromised must be replaced (SOP 7).
3. Avoid exposing the CTD and vent tube to excessive heat, such as from prolonged exposure to sunlight.
4. Do not allow the top of the vent tube to become submerged in the water of the well or any other liquid.
5. Keep sensors clean to eliminate inaccuracies caused by residues from previous samples. In most cases, sensors can be kept clean by rinsing thoroughly with deionized water before and after making a measurement. For residue that is more difficult to remove, consult the manufacturer's instructions.
6. Sensors may be temporarily stored in deionized water for short periods between measurements. For long-term storage, store sensors clean and dry.
7. The accuracy of the CTD for temperature must be checked annually – This temperature calibration check will be done by NPS staff concurrently with calibration of other multiparameter sondes used in the I&M program.
8. The CTD must be calibrated for specific conductance in the field before each deployment (SOP 15).
9. Some CTDs with small-diameter vent tubes use desiccant to keep the vent tube clear of moisture. If the CTD uses desiccant, it is critical that the desiccant is installed and maintained so that it functions properly because AMME and KAHO are both in the humid tropics. Desiccant should be recharged or replaced on a regular basis.

Standard Operating Procedure (SOP) # 9: Acquisition and Storage of Specific-Conductance Standards

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

Specific-conductance standards are solutions (usually potassium chloride dissolved in water) having precisely known specific conductance. These standards are needed for the calibration of the CTD and must be acquired from a reliable quality-controlled laboratory or suppliers of chemical reagents.

1. ***Accuracy.* –** The known specific conductance of the standards must be accurate to within 1%.
2. **Range of Specific Conductance. –** At least two specific-conductance standards are needed for each calibration. These standards should have known specific-conductance values that are close to the highest and lowest specific-conductance values expected in the field. During a preliminary reconnaissance in AMME in February 2010, specific conductance in wells AMP05 and AMP13 ranged from 815 to 10,992 µS/cm at 25˚ C; therefore, one standard should be about 800 µS/cm at 25˚ C and the second standard should be about 10,000 µS/cm at 25˚ C. Specific conductance in wells in KAHO generally range from about 9,500 to 15,000 µS/cm at 25˚ C; therefore, one standard should be about 5,000 µS/cm at 25˚ C and the second standard should be about 25,000 µS/cm at 25˚ C. These standard values should be adjusted if the specific conductance values of the wells in these parks changes significantly over time.
3. **Quantity. –** Because the sensor end of the CTD must be submerged in the standards during calibration, the quantity of standard required depends on the model of instruments being used. Calibration of the CTD may require as much as 0.5 liter of both the high and low standard per calibration. Standards also have an expiration date, however, so they should not be over stocked. As a general rule, a four-month supply of standards should be kept readily available for calibration.
4. **Handling *and Storage.* –** The standards should be kept in the containers in which they came until they are needed. Usually these are sealed to slow evaporation. As soon as possible after delivery, label the standards' containers with the expiration date. Discard standards that have expired, been frozen, begun to evaporate, or show other signs of degradation. Any aliquots of standards that were poured out of the original containers (for the purpose of calibrating the CTD, for example) must be discarded after use (they must not be poured back into the original containers).

Standard Operating Procedure (SOP) # 10: Specifications for the GPS and Preparations Prior to Use

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

This SOP provides the minimum specifications for the GPS units used in the groundwater monitoring protocol. Whereas the GPS is commonly used in scientific field work, it is assumed that the field technicians already have a conceptual understanding about how the systems work and what their limitations are. The GPS in this protocol is used solely for the purpose of determining the geographic coordinates (latitude and longitude) of the monitor wells. Although many hand-held GPS units have a barometric altimeter, the accuracy of the altimeter is ***not*** sufficient for surveying or checking measuring point (MP) or reference mark (RM) elevations (SOP 12, 13).

1. Specifications for the GPS
   A. High-sensitivity multichannel receiver, to allow accurate readings even under forest canopy or near buildings.
   B. Wide Area Augmentation System (WAAS) enabled.
   C. Waterproof
   D. Minimum battery life of 14 hours
2. Preparation Prior to Use
   A. Read manufacturer's instructions, and be familiar with proper operation of the instrument.
   B. Install batteries and run tests as directed by the manufacturer.
   C. Set the GPS to the appropriate geodetic datum. Currently, the datum for Hawai‘i is the North American Datum of 1983 (NAD83) and the datum for Saipan is the 1984 World Geodetic System (WGS84).

Standard Operating Procedure (SOP) # 11: Specifications for Surveying Equipment

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

This SOP assumes that field personnel have a functional knowledge of conducting a rod-and-level survey for the purposes of determining relative elevation. Many types and models of surveying equipment are capable of meeting the requirements for the groundwater monitoring protocol. Options range from the standard automatic level to sophisticated electronic levels. The choice is a function of convenience and cost. The minimum requirements for the surveying equipment are given below.

1. The instrument must be at least an automatic level (also known as self-leveling level). Older leveling technologies (e.g., hand levels, dumpy levels) are not suitable for this protocol. The basic automatic level requires the user to read the surveying rod optically. The more sophisticated electronic level reads the survey rod electronically using a barcode rod which greatly reduces surveying time and the chance for transcription errors. Although electronic levels are more costly, their ease of use and special feature greatly reduce the likelihood of improper use.
2. Optical scope of at least 24 X magnification. Even if the instrument is an electronic level, it should have the ability to make optical measurements in case field conditions prevent electronic measurements.
3. Readout of electronic levels should be displayed to thousandths of a foot.
4. Tripod must be specifically designed for supporting the level instrument.
5. Rod specifications
    A. Graduated in hundredths of a foot. Even if one side of the rod has a bar code for an electronic level, the opposite side should have graduations for optical measurements, in case field conditions prevent electronic measurement.
    B. Must have level-bubble to aid in holding the rod vertical.

Fieldwork Elements

The SOPs for fieldwork elements, SOPs 12 – 16, give detailed procedures for field tasks that appear in more than one of the main SOPs.

Standard Operating Procedure (SOP) # 12: Establishing Measuring Point, Reference Marks and CTD Support

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

The measuring point (MP) is the point to which all DTW measurements, as well as the depth of specific-conductance measurements, will be referenced for a given well (Fig. 12-1). Reference marks (RMs) are installed near the well as backup reference elevations so that if the MP is destroyed or otherwise becomes unusable, a new MP can be established and the RMs can be used to determine the difference between the elevation of the old MP and the new MP. This assures that DTW measurements made using the old and new MPs are comparable. The CTD support is an eyebolt or other permanent device installed on the well casing for the purposes of attaching the CTD cable and/or vent tube. The goal is to hang the CTD in the same location throughout the monitoring period.

This SOP assumes that personnel have the knowledge and ability to conduct an accurate rod-and-level survey using standard surveying techniques, including conducting a peg test of the leveling instrument. Also, whereas many different types of surveying equipment exist, this SOP assumes that the personnel conducting the survey are proficient in the operation and maintenance of their equipment. This SOP requires FDS 2.

1. Conduct a peg test. If the instrument fails the test, make adjustments in accordance with the manufacturer's instructions.
2. Remove any cover, cap or other obstruction to the MP and well. Follow precautions for working near wells.
   - A. Avoid holding or placing objects directly over an open well unless absolutely necessary.
   - B. When it is necessary to hold a tool over a well momentarily to make a measurement, ensure that the object is held securely or is tethered to something that cannot be pulled into the well if the object is accidentally dropped.
   - C. Avoid using anything that may contaminate the water in the aquifer if it is accidentally dropped into the well (for example, lead weights, mercury thermometers, hazardous chemicals)
3. This SOP covers both (1) the establishment of a MP and RMs for the first time at a new well, and (2) replacement of a preexisting MP that has been moved or otherwise disturbed so that it is no longer reliable (as determined in SOP 13).
   - A. If this SOP is being used to establish the MP and RMs for the first time at a new well, proceed to steps 4 through 10.

B. If it has been determined through routine inspection (SOP 13) that the MP has been disturbed but one or more of the RMs are intact:
   (1) Use techniques described in steps 4-6 (below) to create a new mark that will serve as the replacement MP.
   (2) Determine the elevation of the replacement MP relative to those of the undisturbed RMs (steps 9-11).
   (3) Use these measurements to compute the elevation difference between the old and replacement MPs so that data collected using the replacement MP can be adjusted to be comparable with data collected using the old MP.

C. If it has been determined that one of the RMs has been disturbed but the MP is intact:
   (1) Use techniques described in steps 7-8 to establish a new RM.
   (2) Determine the elevation of the new RM relative to that of the MP, as described in steps 9-10.

4. Select a point on the well casing to serve as the MP. The MP should be on a stable part of the well casing and easily accessible for DTW measurements. Avoid unstable rusty areas of the casing, and pipes, wires, hinges, or other obstructions that can make DTW measurements difficult (it is helpful to have the steel tape lowered into the well while selecting the MP to ensure that measurements can be made).
5. Mark the MP permanently and unambiguously by cutting a small, narrow notch (about 0.0625 in. wide and 0.0625 in. deep) into the top of the casing. A file or hacksaw is useful for this purpose. Do not make the notch so wide that the steel tape rests in it; the MP is the top of the notch, not the bottom.
6. Record the location and characteristics of the MP (e.g., "single notch on northeast of 12-inch steel casing.") and make a sketch in the field form.
7. Select three points for the RMs. The RMs must be on a stable surface such as the corner of the concrete pad of a building or an outcrop of bedrock. The goal is to select points that are unlikely to be destroyed or moved during the monitoring period (several decades), or at least it is very unlikely that all three RMs and the MP will be destroyed or moved at the same time.
8. Mark the RMs permanently and unambiguously. A common method of marking RMs is drilling a hole into the rock or concrete and cementing a stainless steel or brass bolt in the hole (a hammer drill is useful for this purpose). The goal is to ensure that the RMs will not move and can be clearly identified in subsequent trips.
9. Using standard rod-and-level surveying techniques, determine the elevation of all RMs relative to the MP. Record all data on the field data sheet (FDS 2).
   A. Set the automatic level at a location between the MP and one of the RMs.
   B. Make a back-sight (BS) measurement to the MP and compute the height of instrument (HI).
   C. Make a foresight (FS) measurement toward the RM and compute the elevation of the RM.
   D. Move the level instrument and repeat setup procedure. The move need not be far, just enough so that the instrument is in a different location.
   E. Make a BS measurement to the RM and compute the new HI.
   F. Make a FS measurement toward the MP and compute the elevation of the RM. The computed elevation of the MP should be zero. If it is not, the difference is considered the closure error. The closure error must be 0.01 ft or less. If it is not, the procedure (9A thorough 9F) must be repeated.
   G. Repeat this procedure for all RMs.

10. Make an annotated sketch map showing the location of the well, MP, and all RMs (FDS 2).
11. Install the CTD support. This support is a secure device, such as an eyebolt installed in the well casing, to which the cable of the CTD can be attached to achieve a consistent depth for the specific-conductance sensor each time the CTD is deployed (Fig. 12-1).
    A. Install the support in a location that can be easily reached and can accommodate the device as well as the CTD, vent tube, cable and clip (Fig. 12-1).
    B. Measure the vertical distance between the MP and support (length A in Fig. 12-1) and record this in the field data sheet.
    C. Sketch the well casing and CTD support. Label distance between support and MP.
    D. If this CTD support replaces a preexisting CTD support, the cable/vent-tube length (length A in Fig. 12-1) must be adjusted to account for the change in distance between the MP and CTD support. Refer to SOP 7, steps 7 and 8.
12. Replace any cap or cover that was removed from the well.

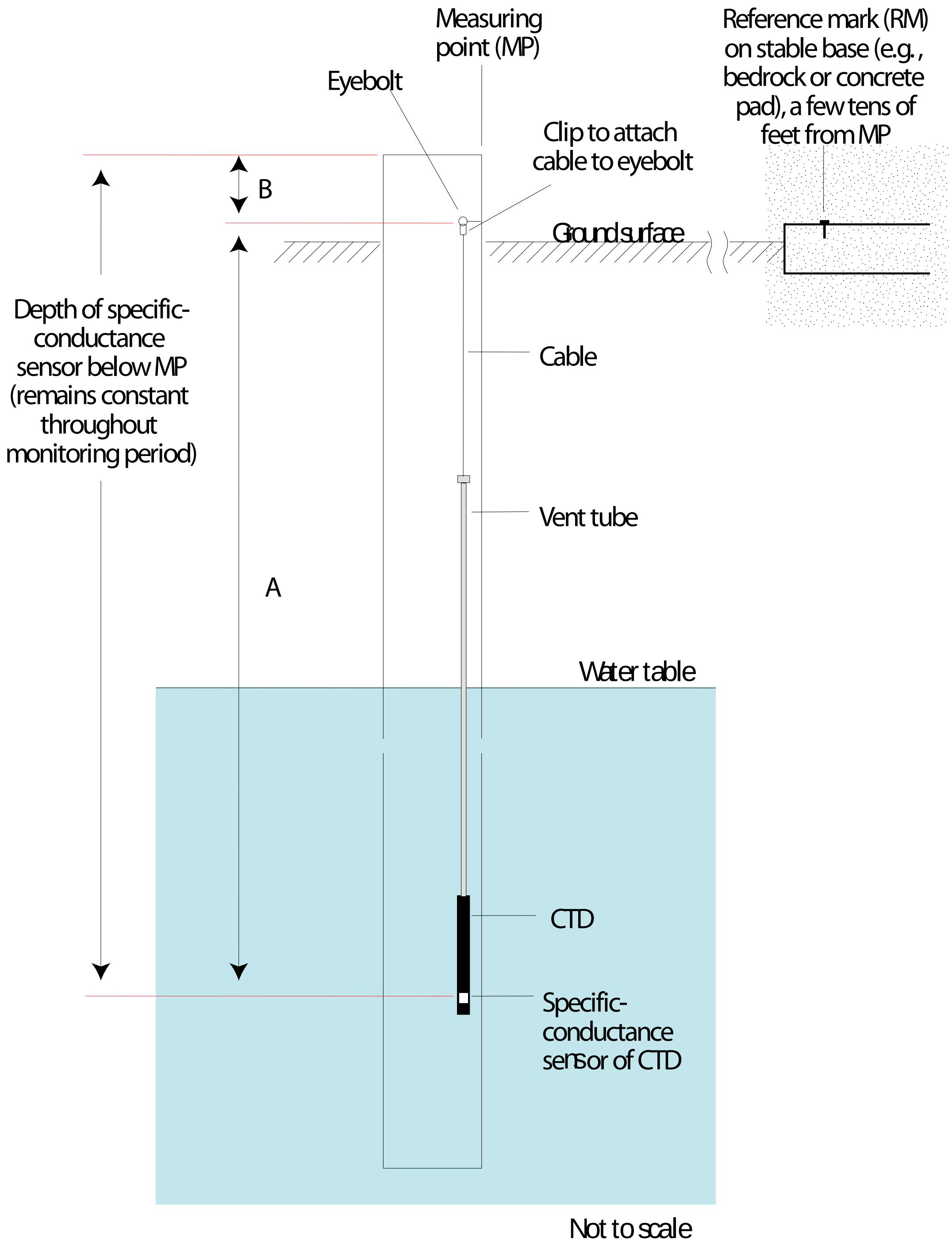

Figure 12-1. Sketch of a conductance-temperature-depth (CTD) probe deployed in a monitoring well. Length A is the distance between the point where the cable attaches to the CTD support (in this case an eyebolt in the well casing) and the point on the CTD where specific conductance is measured. Length B is the distance between the eyebolt and the MP.

Standard Operating Procedure (SOP) # 13: Checking the Measuring Point and Reference Point

Version 1.0 (November 2011)

Change History

Version #	**Date**	**Revised by**	**Changes**	**Justification**

The MP and RMs should be checked annually to ensure that they are in the same position relative to each other. This SOP assumes that personnel doing this task have the knowledge and ability to conduct an accurate rod-and-level survey using standard surveying techniques and are proficient in the operation and maintenance of their equipment. This SOP uses FDS 2.

1. Review SOP 12 regarding the purpose of the MP and RMs and how they were established.
2. Make a photocopy of the field form that describes the latest location and relative elevations of the MP and RMs for the well. Take this copy to the field site, along with blank copies of field data form FDS 2.
3. Conduct a peg test. If the instrument fails the test, make adjustments in accordance with the manufacturer's instructions.
4. Remove any cover, cap or other obstruction to the MP and well.
5. Follow precautions for working near wells.
   A. Avoid holding or placing objects directly over an open well unless absolutely necessary.
   B. When it is necessary to hold a tool over a well momentarily to make a measurement, ensure that the object is held securely or is tethered to something that cannot be pulled into the well if the object is accidentally dropped.
   C. Avoid using anything that may contaminate the water in the aquifer if it is accidentally dropped into the well (for example, lead weights, mercury thermometers, hazardous chemicals)
6. Locate the MP and inspect it for damage that could have affected its elevation. Such damage might be caused, for example, by vandalism, significant spalling due to rusting, or deformation of the casing by heavy equipment. Ideally, there should be no damage. If there is obvious damage, make a note on the field sheet.
7. Locate the RMs and inspect them for damage that could have affected their elevation. If there is obvious damage, make a note on the field sheet. In most cases, there will be no damage.
8. Using standard rod-and-level surveying techniques, determine the elevation of all RMs relative to the MP. Record all data on the field data sheet (FDS 2).
   A. Set the automatic level at a location between the MP and one of the RMs.
   B. Make a back-sight (BS) measurement to the MP and compute the height of instrument (HI).

C. Make a foresight (FS) measurement toward the RM and compute the elevation of the RM.
D. Move the level instrument and repeat setup procedure. The move need not be far, just enough so that the instrument is in a different location.
E. Make a BS measurement to the RM and compute the new HI.
F. Make a FS measurement toward the MP and compute the elevation of the RM. The computed elevation of the MP should be zero. If it is not, the difference is considered the closure error. The closure error must be 0.01 ft or less. If it is not, the procedure (7A thorough 7F) must be repeated.
G. Repeat this procedure for all RMs.

9. Compare the RM elevations computed in this check to the expected RM elevations. Ideally, these should not have changed. If they differ by more than 0.01 ft, it is possible that one or more of the RMs or the MP was moved. If so, it should be apparent from the data which mark was moved. Once it is determined which of the RMs has been moved, or if the MP was moved, it must be reestablished using the techniques described in SOP 12.
10. Replace any cap or cover that was removed from the well.

Standard Operating Procedure (SOP) # 14: Measuring Depth to Water (DTW)

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

This SOP describes the procedures for using the steel tape to measure relative to an established MP on the casing of a well.

1. Remove any covers, caps or other obstruction to the MP and well.
2. Follow precautions for working near wells.
   A. Avoid holding or placing objects directly over an open well unless absolutely necessary.
   B. When it is necessary to hold a tool over a well momentarily to make a measurement, ensure that the object is held securely or is tethered to something that cannot be pulled into the well if the object is accidentally dropped.
   C. Avoid using anything that may contaminate the water in the aquifer if it is accidentally dropped into the well (for example, lead weights, mercury thermometers, hazardous chemicals)
3. Refer to notes from previous site visits to determine approximately what the DTW will likely be.
4. Rub chalk on about 4 feet of the lower end of the steel tape.
5. Make two DTW measurements and check that they agree:
   A. Gently and smoothly lower the chalked end of the steel tape into the well until about 1 ft of the lower end of the tape is submerged (use the estimated DTW from step 3).
   B. Lower the tape very slowly, without pulling up at any time, until the next whole foot mark on the steel tape aligns with the MP. Read the steel tape at the point where it aligns with the MP and record this number as "HOLD" on the field data sheet. Also record the date and time.
   C. Withdraw the steel tape, being careful to wind the tape neatly and flat on the spool. Also avoid letting the tape rub against the well casing.
   D. Find the water-level mark on the chalked interval of the steel tape. The chalk will be dark where it is wet and light where it is dry; the boundary between the dark and light is the water-level mark. Determine the reading on the steel tape indicated by the water-level mark. Record this reading as "CUT" on the field data sheet. (The boundary between wet and dry chalk should be sharp. An indistinct boundary indicates that the chalk may have partially dried or may have been wetted by extraneous moisture. An indistinct boundary is not a reliable mark. To avoid drying effects, read the mark as

quickly as possible after it is brought to the surface. To avoid extraneous moisture, avoid letting the tape rub against the wall of the well, which may be wet.)

E. Compute the DTW:
DTW = HOLD – CUT

F. Begin the second measurement by again, gently and smoothly lowering the chalked end of the steel tape into the well. This time, however, lower the tape until about 2 ft of the lower end of the tape is submerged.

G. Repeat steps B through E.

H. Compare the first and second DTW measurements. They should agree within 0.01 ft. If they do, compute the average and record it on the field data sheet. If they do not agree within 0.01 ft, do the whole procedure over from step 3.

I. Correct the DTW measurement using the calibration table, and record the corrected value on the field data sheet.

J. Wipe the chalk and any water off the tape, and rewind the tape carefully

K. Helpful hints: The boundary between wet and dry chalk should be sharp. An indistinct boundary indicates that the chalk may have partially dried or may have been wetted by extraneous moisture on the well casing. An indistinct boundary is not a reliable mark. To avoid drying effects, read the mark as quickly as possible after it is brought to the surface. To avoid extraneous moisture, avoid letting the tape rub against the wall of the well, which may be wet.

6. Replace any cap or cover that was removed from the well.
7. Check the depth-calibration table (affixed to the spool of the steel tape) to determine if any of the DTW measurements must be corrected. Record the corrections in the appropriate field or column of the field data sheet.

Standard Operating Procedure (SOP) # 15: Calibration of the CTD for specific-conductance

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

The CTD specific-conductance sensor must be calibrated before every field trip and again in the field at each site, prior to making the first measurements at that site. Steps for calibration are as follows.

1. Besides the instrument being calibrated, have the following items on hand:
   A. Two specific-conductance standards that correspond approximately to the range of specific-conductance values that will be encountered. Verify that the date on the standards has not expired. Allow 15 to 30 minutes for the standards to achieve equilibration with the ambient field temperature. Do not allow water to dilute the standard.
   B. A container for holding the standard while the probe is dipped into it. The container should be large enough to allow the sensor in the end of the probe to be submerged in the standard, but not too large that an excessive amount of standard is needed for each calibration.
   C. Enough deionized water (about 500 ml) to thoroughly rinse the sensor, probe, and container three times before and after each reading. A squirt bottle is helpful.
   D. The log book for the instrument, and a pencil.
2. Ensure that the temperature sensor accuracy was checked within the past 12 months.
3. Read manufacturer's instructions for proper use of the instrument.
4. Record the serial number or other identification on the field data sheet.
5. Inspect the instrument, particularly the probe and sensor, for damage. Check the battery voltage. Make sure that all cables are clean and connected properly.
6. Turn the instrument on and allow sufficient time for electronic stabilization.
7. Rinse the sensor (which is usually recessed in the probe for protection) and a container three times with deionized water, discarding the rinse water after each rinse.
8. Select the lower of the two standards as the first standard for calibration. Shake the standard to ensure the liquid is well mixed. Rinse the sensor and container three times with the first standard, discarding the rinse standard after each rinse.
9. Put the sensor into the rinsed container and pour in enough of the first standard to immerse the sensor in the probe. Avoid placing the container and standard where it may be warmed or cooled below the ambient field temperature.

10. Gently agitate the probe sensor up and down in the solution to expel air that may be trapped in the sensor.
11. Read the instrument display. Agitate the sensor up and down in the solution again, and read the display. Be sure that the sensor does not contact the bottom or sides of the container during the reading (in most cases, this will not be a problem because the sensor is recessed in the probe). Repeat the procedure until consecutive readings are the same.
12. Record the display reading and the known value (the value on the standard bottle) in the log book and field data sheets. If the display reading alternates between two consecutive values, record the value ending with an even digit.
13. If the display reading differs from the known value by more than 5 percent, consult the trouble-shooting guide in Table 15-1, then repeat steps 5 through 12.
14. If the display reading still differs from the known value by more than 5 percent, consult the manufacturer's instructions regarding instrument adjustment or repair. Some CTDs allow the user to adjust a correction factor (sometimes called a cell constant). This adjustment should be made rarely and with caution however, because failure to reproduce the stated specific conductance value on a standard can result from a number of reasons other than the cell constant (Table 15-1). Record in the log book any adjustments made or any other relevant information, including the date of the calibration and the names of the persons doing the calibration.
15. Discard the used standard into a waste bottle for later disposal.
16. Repeat steps 6 through 15 with the higher specific-conductance standard.
17. If the instrument passes the check for both standards, rinse the sensor and container thoroughly with deionized water.

Literature Cited

Radtke, D.B., J.V. Davis, and F.D. Wilde. 2005. National water-quality field manual, specific electrical conductance (version 1.2). U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6., section 6.3 Available at http://water.usgs.gov/owq/FieldManual/ Chapter6/6.3_contents.html (accessed 22 October 2007).

Table 15-1. Troubleshooting guide for specific conductance. [Modified from Radtke et al. (2005); HCl, hydrochloric acid; ºC, degrees Celsius]

Symptom	Possible cause and corrective action
Will not calibrate to standards	Standards may be old or contaminated—use fresh standards. Electrodes dirty—clean with a detergent solution, then with 5 percent HCl. Before using any acid solution to remove resistant residues, check manufacturer's guidelines. Air trapped in specific-conductance sensor—agitate sensor up and down to expel trapped air. Weak batteries—replace. Temperature compensation incorrect—ensure that thermometer is operating properly and is calibrated.
Erratic instrument readings	Loose or defective connections—tighten or replace. Broken cables—repair or replace. Air trapped in specific-conductance sensor—agitate sensor up and down to expel trapped air. Rapid changes in water temperature—stabilize temperature. Broken sensor—replace.
Instrument requires frequent recalibration	Temperature compensator not working—measure specific conductance of a solution. Place solution in a water bath and raise solution temperature by about 20ºC. Measure specific conductance again, allowing sufficient time for temperature of specific conductance sensor to equilibrate to temperature of solution. If the two values differ by 5 percent or two values differ by 5 percent or more, replace specific-conductance sensor.

Standard Operating Procedure (SOP) # 16: Specific-conductance Profile and Pressure-Depth Relation

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

The specific-conductance profile measurement and determination of the slope of pressure-depth relation are done annually. The procedures can be done simultaneously, as both basically require lowering the CTD through the water column and pausing for 30 seconds at 0.5-foot intervals to take readings. This SOP requires FDS 3.

In a CTD, depth is measured by a pressure transducer. The pressure detected by a CTD that is submerged in water but vented to the atmosphere above the water depends on water density and the depth of submergence:

$$P_{\mathrm{CTD}} = g\rho D_{\mathrm{S}} \qquad \text{(eq. 16-1)}$$

where P_{CTD} is pressure measured by the CTD, ρ is water density, g is the acceleration due to gravity (a constant), D_{S} is the depth of submergence. Solving eq. 16-1 for D_{S}, gives the equation for computing submergence depth from pressure:

$$D_{\mathrm{S}} = P_{\mathrm{CTD}}(\rho g)^{-1} \qquad \text{(eq. 16-2)}$$

Most CTD models record both P_{CTD} and D_{S}, where D_{S} is computed from P_{CTD} using eq. 16-2, and allow the user to specify the value of ρ to correspond with the particular water in which the CTD will be deployed. In AMME and KAHO, however, the water density varies with depth because salinity varies with depth, thus, no single number can represent ρ throughout the water column. The procedure in this SOP avoids the need to specify a single value of ρ. Instead, the relationship between the pressure and depth is determined directly in the water column of the monitor well and fitting a regression line – the slope of the regression line ($M_{\mathrm{D/P}}$) is equal to $(\rho g)^{-1}$. The procedure also serves as a means to check that the pressure transducer in the CTD is operating properly.

The specific conductance profile is a log of the variation of specific conductance with depth. In this SOP the specific-conductance profile is measured relative to the MP (established using SOP 12) on the casing of a well.

1. Strong tidal signals in wells can cause rapid water-level changes that affect the accuracy and efficiency of field measurements. This SOP can be scheduled for a time when water-level changes are least rapid, such as near the peak of high tide or the trough of low tide. Important note: the tidal signal in a well usually lags that of the ocean; therefore, the scheduling should be based on the tidal signal of the well, not the ocean. Consult CTD water-level data from previous site visits to help estimate when high and low tides will occur in the well.
2. Prepare the CTD
   A. KAHO – the wells in KAHO have casings that are large enough to accommodate the steel tape and the CTD vent tube. Therefore for KAHO, the steel tape will be attached to the CTD vent tube to provide a means to measure the depth of the CTD during this procedure.
      1) If the cable or vent tube on the CTD is new, they must be allowed to straighten (SOP 7).
      2) Attach the steel tape to the CTD vent tube. The method for doing this differs from one model of CTD to the next. Consult the manufacturer's instructions.
      3) Locate the precise position of the specific-conductance sensor on the CTD. This information may be in the manufacturer's instructions; if not contact the manufacturer.
      4) Measure precisely (to the nearest 0.01 ft) the distance between zero on the steel tape and the location of the specific-conductance sensor. Record this on the field data sheet. This distance must be added to the reading on the steel tape to determine the depth of the CTD sensor during this procedure.
   B. AMME – the steel tape cannot be used for this SOP in AMME because the 1-inch well casings in AMP05 and AMP13 are too small to accommodate both the CTD vent tube and the steel tape side by side. Therefore, the vent tube will be marked in 0.5-foot intervals.
      1) Locate the precise position of the specific-conductance sensor on the CTD. This information may be in the manufacturer's instructions; if not contact the manufacturer.
      2) On a straight and level surface that is sufficiently long (e.g., a hallway floor), lay out the CTD with its vent tube and steel cable attached.
      3) Starting at the specific-conductance sensor, precisely measure and mark the vent tube and cable in 0.5-foot intervals. Use the steel tape for measuring and ensure both the steel tape and the CTD-vent-tube-cable assembly are straight and taught. Use an indelible, immovable medium to make the mark, such as enamel paint or fingernail polish (most "permanent" ink felt-tip markers are not indelible). Near each mark, place a piece of electric tape with the distance between the mark and the specific-conductance sensor.
3. Conduct a field calibration of the CTD for specific conductance (SOP 15).
4. Set the CTD to record at a frequent interval (about 1 second) and start logging. In the AMME, the wells are shallow enough that the CTD can remain connected to a computer during this procedure, the specific conductance and depth can also be monitored on the computer screen as the CTD is lowered.
5. If the DTW was not measured in the last 15 minutes, measure it now (SOP 14).

6. Carefully lower the CTD into the well until it is within a foot above the water surface (but not below it). Ensure that the pressure reading is close to zero (within +/- 0.004 PSI); if the CTD pressure transducer requires adjustment, consult the manufacturer's instructions.
7. Lower the CTD into the well until it is submerged about a foot below the surface of the water and gently agitate to dislodge any air bubbles that may be trapped against the sensors in the CTD housing (air bubbles can cause erroneous readings).
8. Making measurements – to further minimize the tidal effects, all measurements in this step should be completed in 20 minutes.
   A. AMME
      1) Using the latest DTW measurement and ensuring that the CTD's specific-conductance sensor must stay submerged throughout this procedure, find the 0.5-foot vent-tube marking that is closest to the probe but does not cause the sensor to rise out of the water when it is aligned with the MP of the well. Align the marking with the MP and hold for 30 seconds or longer to allow for stabilization. Record the time and the depth of the CTD below the MP on the field data sheet.
      2) Lower the probe until the next 0.5-foot marking on the vent tube is aligned with the MP and hold for 30 seconds. Record the time and the depth of the CTD below the MP on the field data sheet.
      3) Repeat step 11 through the rest of length of the water column in the well, but STOP BEFORE THE TOP OF THE CTD VENT TUBE BECOMES SUBMERGED.
      4) Remove the CTD from the well, being careful not to tangle the cable and vent tube.
   B. KAHO
      1) Using the latest DTW measurement and ensuring that the CTD's specific-conductance sensor must stay submerged throughout this procedure, find the 0.5-foot mark on the steel tape that is closest to the probe but does not cause the sensor to rise out of the water when it is aligned with the MP of the well. Align the mark with the MP and hold for 30 seconds. Record the time and the depth of the CTD below the MP on the field data sheet.
      2) Lower the probe until the next 0.5-foot mark on the steel tape is aligned with the MP and hold for 30 seconds. Record the time and the depth of the CTD below the MP on the field data sheet.
      3) Repeat step 11 through the rest of length of the water column in the well, but stop before the top of the CTD vent tube becomes submerged.
      4) Remove the CTD from the well, being careful not to tangle the cable and vent tube.
9. Measure DTW again; record the DTW and time on the field data sheet.
10. Check the depth-calibration table (affixed to the spool of the steel tape) to determine if any of the DTW measurements must be corrected. Record the corrections in the appropriate field or column of the field data sheet.
11. Upload the data from the CTD to a field computer.
12. Create a backup copy of the data on a compact disk or other device that can be physically detached from the computer.
13. Import the data into a spreadsheet.
14. Compute the relation between the pressure measured by the CTD (P_{CTD}) and depth of the CTD (D_{CTD}) indicated by the cable markings (AMME) or steel tape (KAHO).

A. Plot P_{CTD} versus time. The plot should have steps corresponding to each time the CTD was lowered by a 0.5 ft and held for 30 seconds. Use the graph and spreadsheet data to determine the values of P_{CTD} for each value of D_C.
B. Plot P_{CTD} and D_{CTD} on another graph, with P_{CTD} on the x-axis and D_{CTD} on the y-axis.
C. Using straight-line linear regression, determine the equation of the best-fit line through the P_{CTD} and D_{CTD} data. The data should plot as a straight line, although the line may or may not pass through the origin. The R^2 value should be greater than 0.97; if it is not, the depth SOP should be redone.
D. If the procedure is successful, the resulting regression equation has the form of a straight-line equation:

$$D_{CTD} = M_{D/P} \times P_{CTD} + B \quad \text{(eq. 16-4)}$$

where the intercept (B) is irrelevant, and $M_{D/P}$ is the slope of relation between D_{CTD} and P_{CTD}, which will be used later (SOP 19) to compute DTW from the CTD pressure readings (Figure 16-1).
E. Record the computed value of $M_{D/P}$ on the field data sheets.

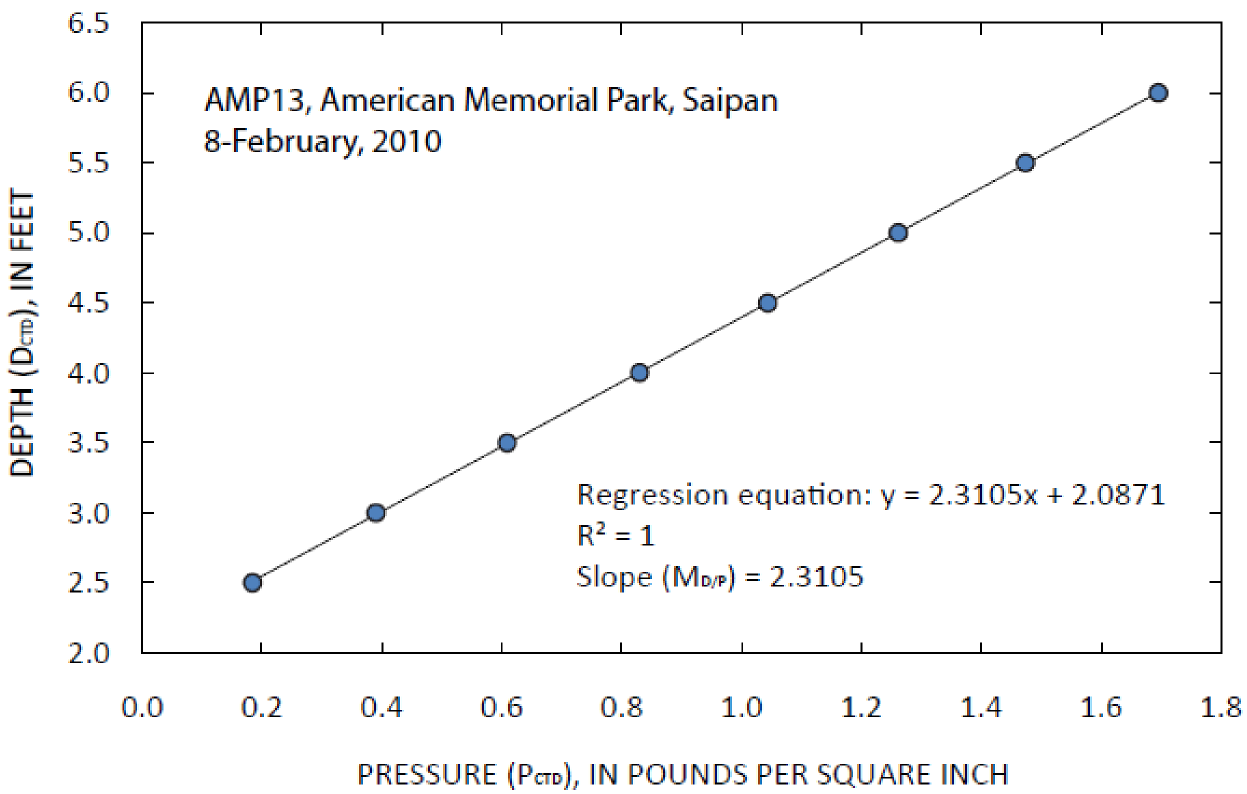

Figure 16-1. Example plot of pressure measured by the CTD (P_{CTD}) versus depth of CTD submergence (D_{CTD}) and regression line used to determine $M_{D/P}$. Data collected at American Memorial Park, January 2010.

Data Handling and Reporting

This section contains SOPs (17 – 26) that provide specific procedures for data handling. Data collected during field visits must be processed as soon as possible after returning from the field to ensure that details of the field visit are fresh in the memories of the field personnel and to avoid accidental loss or misplacement of data.

Standard Operating Procedure (SOP) # 17: Workspace Set-up and Records Management

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

Setup of Project Workspace

A section of the networked PACN file server is reserved for this project, and access permissions are established so that project staff members have access to needed files within this workspace. Prior to each season, the Project Lead should make sure that network accounts are established for each new staff member, and that the Data Manager is notified to ensure access to the project workspace and databases. If network connections are too slow for efficient data entry and processing, individual staff members may set up a workspace on their own workstation, with periodic data transfer to the PACN server. Daily back-ups of the workstation to an external hard drive will ensure that no data is lost.

The recommended file structure within this workspace is shown in Figure 17-1. Certain subfolders, especially those for GPS data and images, should be retained in separate folders for each calendar year. This will make it easier to identify and move these files to the project archives at the end of each season.

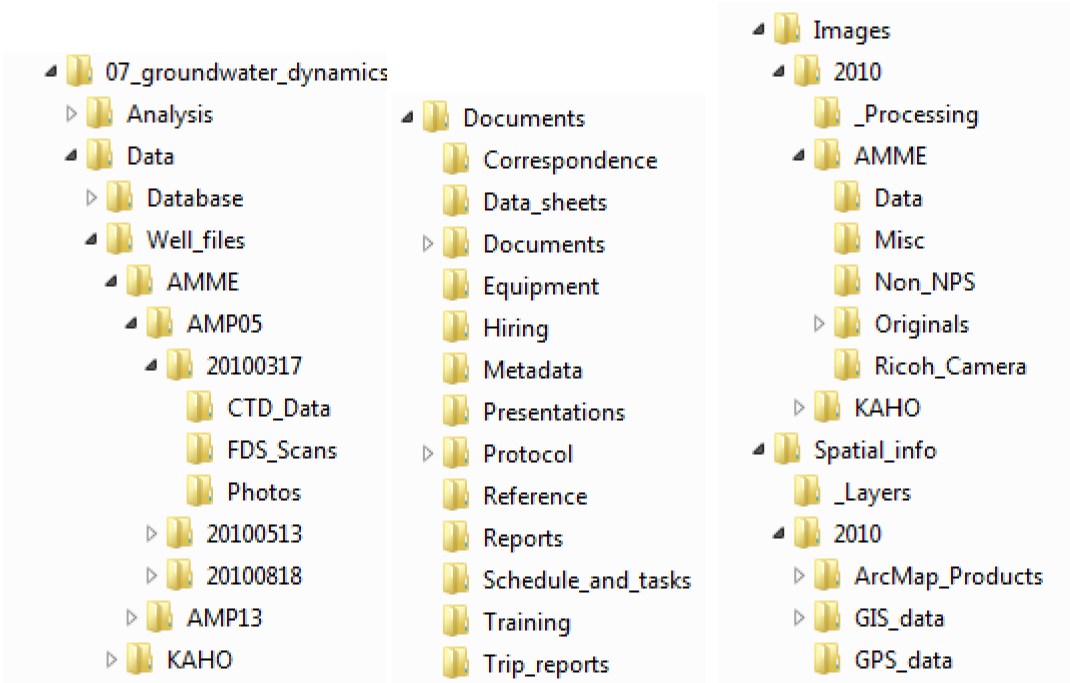

Figure 17-1. Recommended file structure for project workspace.

After each quarterly field visit, field data sheets are to be scanned as PDF documents. The PDF documents should be stored in the Data\Scanned_datasheets folder in the PACN project workspace, and the hard copy data sheets stored along with original field notes in the designated filing cabinet for retention. The PDF files may then serve as a convenient digital reference of the original if needed.

Within the Database folder there should be a folder called “Database_images” (see Figure 17-2). Within this folder should be a folder for the current monitoring year. Each of the year folders will have a folder for each park. Images for stations and sampling event (quarterly field visit) images that are to be linked to the database should go into the appropriate folder for the year and park. All other images should go into the image folder in the main directory.

For CTD files that will be imported into the database, create a folder for each sampling event for each park. Place clean CTD text files in these sampling event folders before importing to the database.

Following these steps will ensure that the files will be re-linked to the database upon moving as long as the structure is maintained.

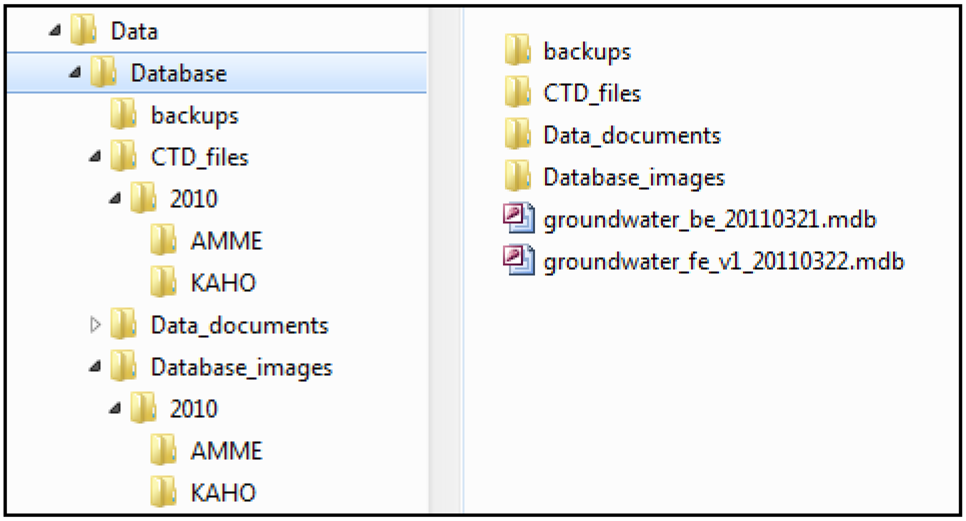

Figure 17-2. Required file structure for images linked to the water quality database.

Each major subfolder is described as follows:

- Analysis: Contains working files associated with data analysis
- Data: Contains the raw CTD data files, scanned field data sheets, working database files for the season, the folder for linked images, and the folder for imported cleaned CTD files. The master database for the project is stored in the PACN Digital Library.
- Documents: Contains subfolders to categorize documents as needed for various stages of project implementation.
- Images: For storing images associated with the project (refer to SOP 18). Note that this folder contains subfolders to arrange files by year.
- Spatial info: Contains files related to visualizing and interacting with GIS data.
  - ArcMap_Products: Map composition files (.mxd) and PDFs.
  - GIS data: New working shapefiles and geodatabases specific to the project.
  - GPS_data: GPS data dictionaries, and raw and processed GPS data files.

Naming Conventions

Folder Naming Standards

In all cases, folder names should follow these guidelines:

- No spaces or special characters in the folder name.
- Use the underbar ("_") character to separate words in folder names.
- Try to limit folder names to 20 characters or fewer.
- Dates should be formatted as YYYYMMDD.

File Naming Standards

In all cases, file names should follow these guidelines:

- No spaces or special characters in the file name.
- Use the underbar ("_") character to separate file name components.
- Try to limit file names to 30 characters or fewer, up to a maximum of 50 characters.
- Dates should be formatted as YYYYMMDD.
- All files should be named as YYYYMMDD_AuthorName_subject.ext where applicable. Modify the file name based on the subject. Date stamps should always be at the beginning of a file name.

Archival and Records Management

All project files should be reviewed, cleaned up and organized by the Project Lead on a regular basis (e.g., annually in January). Decisions on what to retain and what to destroy should be made following guidelines stipulated in [NPS Director's Order 19](http://www.nps.gov/refdesk/DOrders/DOrder19.html) (http://www.nps.gov/refdesk/DOrders/DOrder19.html), which provides a schedule indicating the amount of time that the various kinds of records should be retained. Although many of the files for this project may be scheduled for permanent retention, it is important to isolate and protect these important files and not lose them in the midst of a large, disordered array of miscellaneous project files. Because this is a long-term monitoring project, good records management practices are critical for ensuring the continuity of project information. Files will be more useful to others if they are well organized, well named, and stored in a common format. Hard copies of field data forms should be stored in the designated water quality filing cabinet for three years as specified by NPS Director's Order 19.

To help ensure safe and organized electronic file management, PACN has implemented a system called the PACN Digital Library, which is a hierarchical digital filing system stored on the PACN file servers. The typical arrangement is by project, then by year to facilitate easy access. Network users have read-only access to these files, except where information sensitivity may preclude general access. Submission of certified products occurs in the PACN Digital Library by uploading the certified products in the "Submissions" folder and notifying the Data Manager.

As digital products are delivered for long-term storage, according to the schedule in SOP 24 (Product Delivery Specifications), they will be catalogued in the PACN project tracking database and filed within the PACN Digital Library by the Data Manager. The master versions of all digital files relating to the Groundwater Monitoring protocol are stored within the PACN Digital Library, with regular file backups accomplished automatically. Presently, the master protocol files include the protocol narrative, the protocol appendixes, the SOPs, and the groundwater monitoring database files. Analog (non-digital) materials are to be handled according to current practices of the individual park collections.

Maintenance of Archived Data

Any editing of archived data is accomplished jointly by the Project Lead or designee and PACN Data Manager. Prior to any major changes of a dataset, a copy is stored with the appropriate version number to allow for tracking of changes over time. Likewise, any time a revision of the protocol requires a revision to the database, a complete copy of the database will be made and stored in an archive directory. In addition to this copy in its native database format, all tables will be archived in a comma-delimited ASCII format that is platform-independent by using the Access_to_ascii.mdb utility developed by Northern Colorado Plateau Network.

Versioning of archived datasets is handled by adding a three digit number to the file name, with the first version being numbered 001 (e.g., groundwater_be_2010_validated_v001, for the first version of a back-end data file validated by the Project Lead and Data Manager at the end of the 2010 field season). The two text files generated by the Access_to_ascii.mdb utility, FieldDef.txt and TableDef.txt, will be stored in a similarly named folder (e.g., groundwater_be_2010_validated_v001_text). Each additional version is assigned a sequentially higher number. Frequent users of the data are notified of the updates, and provided with a copy of the most recently archived version.

Every change must be documented in the edit log and accompanied by an explanation that includes pre- and post-edit data descriptions. All data collected using this protocol is subject to the following three caveats:

- Only make changes that improve or update the data while maintaining data integrity.
- Once archived, document any changes made to the dataset through an edit log. At end of each fiscal year, the database manager will update the central database and will post read-only versions.
- Mistakes can be made during editing so updates must be compared with the original data form prior to validating the data.

Standard Operating Procedure (SOP) # 18: Managing Photographic Images

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

Care should be taken to distinguish data photos from incidental or opportunistic photos taken by project staff. Data photos are those taken for at least one of the following reasons:

- To document a particular feature or perspective for the purpose of site relocation
- To capture site habitat characteristics and possibly to indicate gross structural changes over time

Data photos are linked to specific records within the database, and are stored in a manner that permits the preservation of those database links. Other photos—e.g., of field crew members at work—may also be retained but are not necessarily linked with database records.

Effectively managing hundreds of photographic images requires a consistent method for downloading, naming, editing, and documenting. The general process for managing data photos proceeds as follows:

1. File Structure Setup: Set up the file organization for images prior to acquisition
2. Image Acquisition
3. Download and Process
    - Download the files from the camera.
    - Rename the image files according to convention.
    - Copy and store the original, unedited versions
    - Review and edit or delete the photos
    - Move files into appropriate folders for storage
4. Establish Database Links
5. Deliver Image Files for Final Storage

File Structure Setup

Prior to data collection for any given year, project staff will need to set up a new folder under the Images folder in the project workspace as follows:

[Year]	The appropriate year – 2010, 2011, etc.
_Processing	Processing workspace
[Park code]	Arrange files by park – AMME, KAHO, etc.
Data	Data images
[Site_code]	Arranged by sampling locations, or
[Date]	by date, for images not taken at sampling locations
Miscellaneous	Non-data images taken by project staff
[Site_code]	Arranged by sampling locations, or
[Date]	by date, for images not taken at sampling locations
Originals	Renamed but otherwise unedited image file copies
[Site_code]	Arranged by sampling locations, or
[Date]	by date, for images not taken at sampling locations
Non-NPS	Images acquired from other sources

This folder structure permits data images to be stored and managed separately from non-record and miscellaneous images collected during the course of the project. It also provides separate space for image processing and storage of originals. For all images that are to be linked to the database, the image files will need to be copied to the appropriate image folder under the database folder, as shown below. This will ensure that the links to the database are preserved at all times. See below for database image workspace structure. Note: For additional information about the project workspace, refer to SOP 17 (Workspace Set-up and Records Management).

Database
  Database_images
    [Year]
      [Park code]

Folder Naming Standards

In all cases, folder names should follow these guidelines:

- No spaces or special characters in the folder name
- Use the underscore ("_") character to separate words in folder names.
- Try to limit folder names to 20 characters or fewer.
- Dates within folder names should be formatted as YYYYMMDD (for better sorting).

Image Acquisition

Capture images at an appropriate resolution that balances space limitations with the intended use of the images. Although photographs taken to facilitate future navigation to the site do not need to be stored at the same resolution as those that may be used to indicate gross environmental change at the site, it may be more efficient to capture all images at the same resolution initially. A recommended minimum raw resolution is 1,600 x 1,200 pixels (approximately 2 megapixels).

Downloading and Processing Procedures

1. Download the raw, unedited images from the camera into the appropriate "_Processing" folder.
2. Rename the images according to convention (refer to the image file naming standards section below. If image file names were noted on the field data forms, be sure to update these to reflect the new image file name prior to data entry.
3. Process the images in the _Processing folder. At a minimum, the following processing steps should be performed on all image files:
    - Copy the images to the "Originals" folder and set the contents as read-only by right-clicking in Windows Explorer and checking the appropriate box. These originals are the image backup to be referred to in case of unintended file alteration or deletion.
    - Delete any poor quality photos, repeats, blurred or otherwise unnecessary photos. Low quality photos might be retained if the subject is highly unique, or the photo is an irreplaceable data photo.
    - Rotate the image to make the horizon level.
    - Photos of people should have 'red-eye' glare removed.
    - Photos should be cropped to remove edge areas that grossly distract from the subject.
4. When finished, move the image files that are to be retained and possibly linked in the database to the appropriate folder; data images under the "Data" folder, other images under the "Miscellaneous" folder. Photos of interest to a greater audience should be copied to the park Digital Image Library. To minimize the chance for accidental deletion or overwriting of needed files, no stray files should remain in the processing folder between downloads.
5. Images that are to be linked to the database should be moved into the appropriate image folder within the database folder.
6. Depending on the size of the files and storage limitations, contents of the "Originals" folder may be deleted if all desired files are accounted for after processing.

Large groups of photos acquired under sub-optimal exposure or lighting can be batch processed to enhance contrast or brightness. Batch processing can also be used to resize groups of photos for use on the web. Batch processing may be done in ThumbsPlus, Extensis Portfolio, or a similar image software package.

Image File Naming Standards

In all cases, image names should follow these guidelines:

- No spaces or special characters in the file name
- Use the underscore ("_") character to separate file name components
- Try to limit file names to 30 characters or fewer, up to a maximum of 50 characters
- Park code and year should either be included in the file name or conclusive by the directory structure

The image file name should consist of the following parts:

- The date of data capture (formatted as YYYYMMDD)
- The sampling location (if recorded at a sampling location)
- Optional: a brief descriptive word or phrase

- Optional: a sequential number if multiple images were captured
- Optional: time (formatted as HHMM)

Examples:

- 20100621_Waihanau_habitat_001.jpg: The habitat at Waihanau Valley taken on June 21, 2010
- 20100518_training_004.jpg: 4th photo taken during training on May 18, 2010

In cases where there are small quantities of photos it is practical to individually rename these files. However, for larger numbers it may be useful to rename files in batches. This may be done in ThumbsPlus, Extensis Portfolio or a similar image software package. A somewhat less sophisticated alternative is to batch rename files in Windows Explorer, by first selecting the files to be renamed and then selecting File > Rename. The edits made to one file will be made to all others, although with the unpleasant side effect of often adding spaces and special characters (e.g., parentheses) which will then need to be removed manually.

Renaming photos may be most efficient as a two-part event: one step performed as a batch process which inserts the date and transect number at the beginning of the photo name, and a second step in which a descriptive component is manually added to each file name.

Establishing Database Links

During data entry and processing, the database application will provide the functionality required to establish a link between each database record and the appropriate image file(s). To establish the link, the database will obtain the root project workspace directory path, the specific image folder within the project workspace, and the specific file name from the image file the user chooses to link. This way, the entire workspace may be later moved to a different directory (i.e., the PACN Digital Library) and the links will still be valid after changing only the root path. For additional details on establishing these links, refer to SOP 20 (Data Entry and Verification).

Note: It is important that the files keep the same name and relative organization, once these database links have been established. Users should not rename or reorganize the directory structure for linked image files without first consulting with the Data Manager.

Delivering Image Files for Final Storage

Note: Please refer to SOP 24 (Product Delivery Specifications).

At the end of the season, and once the year's data are certified, data images for the year may be delivered along with the working copy of the database to the Data Manager on a CD or DVD. To do this, simply copy the folder for the appropriate year(s) and all associated subfolders and images onto the disk. These files will be loaded into the project section of the PACN Digital Library, and the database links to data images will be updated accordingly.

Prior to delivery, make sure that all processing folders are empty. Upon delivery, the delivered folders should be made read-only to prevent unintended changes.

Standard Operating Procedure (SOP) # 19: Initial Data Processing

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

1. Within 24 hours after returning from the field:
   A. Electronically scan all hand-written data, including field notes and completed field data sheets, into the electronic subcomponent of the well files.
   B. Place the original handwritten data in the paper subcomponent of the well file (see SOP 17); use copies for all further data processing, including data entry and data-entry verification.
   C. Place backup media (e.g., disks, flash memory) in paper subcomponent of well file.
   D. Transfer the raw (unaltered) CTD data from the field laptop computer to the electronic component of the well file.
   E. Upload digital photographs from camera or flash storage device. Place photograph files in the electronic component of the well file. Create an electronic photographic log (text file) describing for each photograph (1) the filename, (2) date and time taken, photographer, and subject of the photograph. A set of representative photographs and their descriptions may be printed and placed in the paper component of the well file.
2. Enter hand-written data from the field data sheets into the appropriate form in the groundwater database (see SOP 20). In the "status" field of the database, designate the data "provisional."
3. Create a metadata file for the CTD data using a text editor. At the top of the metadata document provide (1) the well name, (2) latitude and longitude; (3) beginning and end dates and times of the data to which the metadata pertain; (4) the model and serial number of the CTD; (5) and the name of the person who uploaded the data from the field computer. All significant processing steps, including screening, checking and review, should be logged in the metadata, along with the name of the person completing the steps.
4. Screen the CTD data and archive the screened file.
   A. Make a copy of the raw file for screening purposes.
   B. Import the CTD data into a spreadsheet. Plot each parameter (pressure, temperature, and specific conductance) versus time (for example, see Fig. 18, in narrative). Plot time on the horizontal axis and the parameter values on the vertical axis.
   C. Check the data against the field data sheets to ensure that they are in agreement. For example, the time of CTD submergence or withdrawal recorded on the field data sheets, should correspond with pressure changes recorded by the CTD. If the data agree with the field data sheets, go to step E. If there is a discrepancy, try to resolve it by looking at all

evidence and data available, such as dates and times the files were created. If the discrepancy cannot be resolved, make a note in the Station Analysis and continue to step E.

E. The CTD may have recorded spurious data while being lowered into place or withdrawn from the well. The data may also include invalid measurements that were made while a new cable or vent tube was stretching (see SOP 7). Remove any data that are known to have been recorded at these times. Describe any deletions and reasons for the deletion in the metadata.

F. Search the plot for anomalies that may indicate instrument malfunction. Not all anomalies are due to instrument error, however. Some anomalies might arise as a result of episodic events, such as pulses of groundwater recharge following a rainstorm. These "anomalies" should not be removed from the data set. An anomaly should be investigated thoroughly and all possible real causes exhausted before the data are deemed to be due to instrument malfunction. If the anomalies are truly due to instrument malfunction, the erroneous data should be removed from the screened data set and a note added to the metadata explaining the section (period of time) of the deleted data and the reasons for the deletion.

G. If there are observations or known events that have the potential to cause errors in the CTD data (e.g., vandalism), search the plots for these periods and ascertain whether the data have been compromised. If so, remove the data from the screened file. Describe any deletions and reasons for the deletion in the metadata.

H. If the CTD data are replete with spurious values, make a note in the Station Analysis and metadata, check the instrument, and repair or replace the instrument as necessary.

5. Compute DTW from CTD pressure measurements:

A. Make a copy of the screened file.

B. Using the following formula and $M_{D/P}$ from the most recent determination of the pressure-depth relation (see SOP 16), convert the CTD pressure data to depth of submergence of the CTD (D_S):

$$D_S = P_{CTD} M_{D/P} \qquad \text{(eq. 19-1)}$$

C. From the field data sheets, look up the time and value of the DTW measurement made immediately after the CTD was recovered.

D. Determine the depth of submergence at the exact time the DTW measurement was made immediately after the CTD was recovered (this submergence depth will be called D_{DTW}). The determination must be done by extrapolation because the DTW was measured after the CTD was removed from the well. The procedure is illustrated in Fig. 19-1 and described below:

(1) Create a plot with depth of submergence (D_S) on the y-axis and time on the x-axis.

(2) Using the trend of the antecedent data, extrapolate a short distance (at least including the time of the DTW reading) beyond the end of the CTD data. Note: the trend of the graph will mimic waves in tidally affected wells such as those in AMME and KAHO. Looking at the shape and periodicity of the waves in the antecedent CTD data is essential to extrapolating the trend.

(3) Find the time of the DTW reading on the x-axis. Trace vertically to the extrapolated trend and then horizontally back to the y-axis to find the corresponding value of D_{DTW} (see red dashed line in Fig. 19-1).

E. Compute DTW for each value of D_S using the following formula:

$$DTW_t = DTW_0 + D_{DTW} - D_S \qquad \text{(eq. 19-2)}$$

where DTW_t is the computed depth to water at a given time t; DTW_0 is the depth to water measured immediately after the CTD was recovered; D_{DTW} is the depth of submergence at the exact time DTW_0 was measured; and D_S is the depth of submergence at time t.

   F. The value of $DTW_0 + D_{DTW}$ is equal to the depth of the CTD pressure sensor below the MP. This value should be the same each time the CTD is deployed. Compare the value of $DTW_0 + D_{DTW}$ from this data set with that from the previous data set. If the difference is greater than 0.02 ft, check the field data sheets to ensure that the CTD is being set at a consistent depth. If so, the difference may indicate CTD drift or malfunction. If the difference is greater than the manufacturer's accuracy specification of the instrument, the CTD should be sent for repair or replacement.
   G. In the metadata, make a note that the pressure was converted to DTW, and record the values for DTW_0, $M_{D/P}$, and P_0 that were used.
6. Archive the CTD data and computations as provisional.
   A. Create a text version of the spreadsheet, including all data and computed values, and place copies of both the spreadsheet and the text version into the electronic subcomponent of the well file.
   B. Import the contents of the spreadsheet, including all data and computed values, into the groundwater database (see SOP 20). In the "status" field of the database, enter "provisional."
7. Update the Station Analysis (Appendix B) with relevant information including:
   A. Dates of field visit.
   B. Significant observations made during field visit or during data processing, such as vandalism, storm damage, etc.
   C. Summary of standard procedures done during field visit.
   D. Significant changes, such as establishing new RMs or MP, changing or repairing instruments, changes in the surrounding land use.
   E. Any other data or observations that may have a bearing on groundwater monitoring.
8. Print a paper copy of the updates and insert it into the paper component of the well file.
9. Submit data for checking, the next step in review process (see SOP 20).

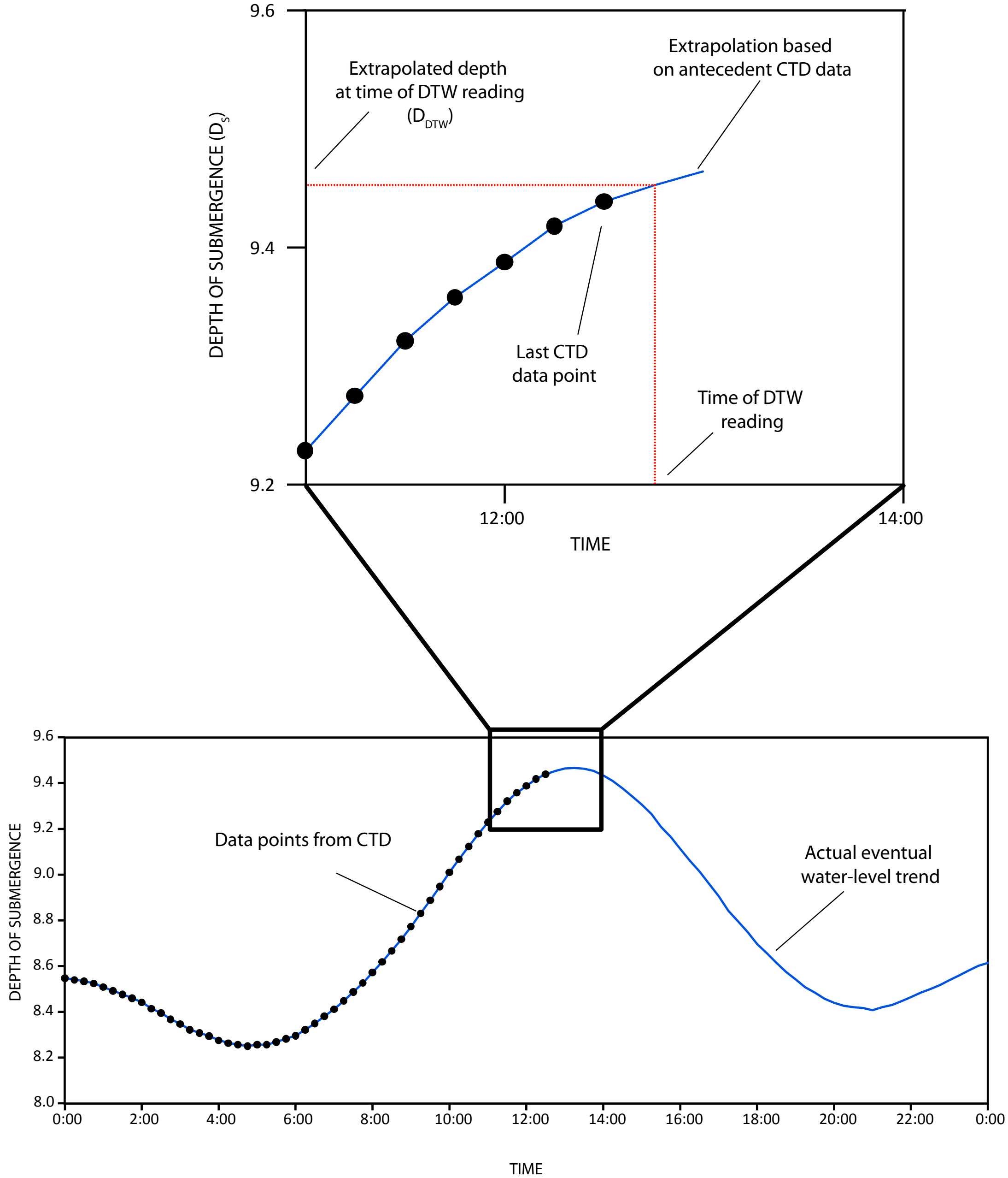

Figure 19-1. Extrapolation to estimate the depth of submergence (D_S) that would have occurred at the time of the depth to water (DTW) reading.

Standard Operating Procedure (SOP) # 20: Data Entry and Verification

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

The PACN groundwater monitoring database was created based on the NPSTORET desktop database application, but is modified and condensed to deal specifically with PACN groundwater monitoring needs. NPSTORET is a Microsoft Access application designed around a series of templates that allow users to describe physical, chemical, and biological water quality monitoring activities.

NPSTORET is a subset of the STORET database developed and maintained by the U.S. Environmental Protection Agency (EPA) as a database to house ambient water quality data collected by states, federal agencies, volunteer monitoring groups, and other entities (www.epa.gov/storet). The NPSTORET database is maintained by the NPS Water Resources Division (WRD) (more information at http://www.nature.nps.gov/water/infoanddata/index.cfm). PACN's NPSTORET data will be transferred annually to WRD for uploads to the STORET National Data Warehouse.

PACN data management staff designed the PACN groundwater monitoring database following the hierarchical data table organization of the Natural Resource Database Template (http://science.nature.nps.gov/im/apps/template/index.cfm [last accessed 02 August 2010]; see the data dictionary and other documentation in Appendix X. The PACN data management staff is responsible for development and maintenance of the database, including customization of data summarization and export routines. The PACN groundwater monitoring database has built in functionality for converting data into the correct format for importation into NPSTORET.

This Standard Operating Procedure document describes the general procedures for entry and verification of field data in the working project database. The following are general guidelines to keep in mind:

1. Data entry will be conducted by the Field Lead at their duty station.
2. Data entry should occur as soon after data collection as possible so that field crews keep current with data entry tasks, and catch any errors or problems as close to the time of data collection as possible.

3. The working database application will be found in the project workspace. If the workspace resides on the networked server, it is recommended that users copy the front-end database onto their workstation hard drives and open it there for enhanced performance. This front-end copy may be considered "disposable" because it does not contain any data, but rather acts as an interface with data residing in the back-end working database. The database may be in the project workspace on the user's computer if the connection to the networked server is too slow (see SOP 17), with periodic uploads to the network server.
4. Each data entry form is patterned after the layout of the field form, and has built-in quality assurance components such as pick lists and validation rules to test for missing data or illogical combinations. The database allows the users to view only the pre-built forms and does not permit users to view the raw data tables and other database objects as a way of ensuring the maximum level of quality assurance.
5. As data are being entered or imported, the person entering the data should visually review each data form to make sure that the data on screen match the field forms. This should be done for each record prior to moving to the next form for data entry.
6. At regular intervals and at the end of the field season the Field Lead should inspect the data that have been entered to check for completeness and perhaps catch avoidable errors.
7. After each data entry session for a tour, the Field Lead should upload the working copy of the database onto the networked server if the database has been stored on their computer.

Database Instructions

Getting Started

The first action to be taken is to make sure the data entry workspace is set up properly either on a networked drive or the user's computer if networked server connections are too slow for efficient data entry. If you are unclear about where the data entry workspace should be contact the Data Manager (see SOP 17 for more information).

- Store the back-end database file in the database folder in the project workspace. The back-end file has "_be_" as part of its name.
- The user's copy of the front-end database should also be stored in the same folder.
- If it doesn't already exist, also create a folder in the same network folder named "backups" for storing daily backups of the back-end database file. If this step is neglected, a backup folder will automatically be created during the first back up.
- Open the front-end database. The first thing it will do is to ask to update the links to the back-end database file. This will only need to be done once for each new issue of the front-end database.

Important Reminders for Daily Database Use

- A copy of the front-end will need to be copied to your workstation if the project workspace is set up on the networked server. <u>Do not open up and use the front-end on the network</u> as this 'bloats' the database file and makes it run more slowly.

- The front-end application will automatically prompt you to make a backup upon initially opening the application.
- To save drive space and network resources, backup files should be compacted by right-clicking on the backup file in Windows Explorer and selecting the option: "Add to Zip file". Older files may be deleted at the discretion of the project crew lead.
- New issues of the front-end application may be released as needed through the course of the field season. If this happens, there should be no need to move or alter the back-end file. Instead, the front-end file may be deleted and replaced with the new version, which will be named in a manner reflecting the update (e.g., groundwater_20100803_v2.mdb).
- If the front-end database gets bigger and slower, compact it periodically by selecting Tools > Database Utilities > Compact and Repair Database.

Standard Operating Procedure (SOP) # 21: Checking Data for Accuracy

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

After initial data processing, data must be checked for accuracy. Checking must be done by a person other than the person who did the initial processing and should be done using copies (whether electronic or paper), not the originals. The person doing the checking may make minor corrections provided the corrections are noted in the metadata. Substantial errors should be brought to the attention of the project lead, who will determine whether the data files should be returned to the person who entered or computed the data. Corrections to original field data sheets should be rare, but if needed, they will be made by drawing a line through the error and writing the correction nearby, along with the date and the initials of the person making the correction. Under no circumstances shall any hand-written entry be erased.

1. Check the paper subcomponent of the well file to ensure that the following items are present, complete, accurate, and meet the requirements of this protocol:
   A. Field data sheets – check that all the appropriate field sheets required for the field visit are present and complete. After checking, place your initials and date in the "checked by" field on the field data sheets.
   B. Backup copy (on disk or other storage media) of the CTD data (if a CTD is being used for monitoring).
   C. Prints of significant digital photographs (not every field visit will have significant photographs).
2. Check the electronic subcomponent of the well file to ensure that the following items are present, complete, and meet the requirements of this protocol:
   A. Scans of the handwritten field notes and field data sheets.
   B. Digital photographs and photograph log.
   C. Raw data from the CTD
   D. Spreadsheet of screened CTD data, including plots used for screening – review the screened data and metadata to ensure that spurious data were removed, and that any data removal during screening was appropriate.
   E. Text file of screened data – check that it agrees with spreadsheet.
   F. Spreadsheet of computed and adjusted CTD data – check that the computations and adjustments were made correctly.
   G. Text file of computed and adjusted CTD data – check that it agrees with spreadsheet.

H. Metadata text file – check that this file contains descriptions of all CTD data-processing steps to this point. After checking, place your name or initials in the "checked by" field of the metadata.

3. Check the groundwater database to ensure that the following items are present and meet the requirements of this protocol:
   A. Data transcribed from the field data sheets into the appropriate form in the groundwater database. Check that all entries agree with data in printed copies of the scanned field sheets.
   B. Data from the CTD (if CTD is used) imported from the spreadsheet of computed and adjusted CTD data. Cross check to ensure that the database entries agree with the spreadsheet (data are entered in the appropriate columns and all data in the spreadsheet are present in the database).
   C. Check that the "status" field of the database indicates the data are "provisional."
   D. Check that the "computed/entered by" field of the database contains the name or initials of the person who did the initial data processing.
   E. After checking, enter your name or initials in the "checked by" field of the database.
4. If any corrections were made during this checking step, ensure that they are noted in the appropriate metadata, along with your initials or name.
5. Check the Station Analysis to ensure that appropriate updates have been made.
6. Submit data for final review, the next step in the review process (see SOP 22).

Standard Operating Procedure (SOP) # 22: Data Quality Review and Certification

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

After the season's field data have been entered and processed, they need to be reviewed and certified by the Project Lead for quality, completeness and logical consistency. Data validation is the process of checking data for completeness, structural integrity, and logical consistency.

Once the data have been through the validation process and metadata have been developed for them, they are to be certified by completing the PACN Project Data Certification Form (PACN 2007, *http://science.nature.nps.gov/im/units/pacn/data/data_sop/PACN_Project_Data_Certification_Form.doc*), available on the PACN website. The completed form, certified data, and updated metadata may then be delivered to the Data Manager according.

Data Quality Review

At the end of each field season, the Project Lead and the PACN data management staff are collectively responsible for finalizing a validated dataset for that field season. The Project Lead or Aquatic Biological Technician will complete all data validation. Some validation (ensuring that the data make sense) methods have been incorporated into the groundwater monitoring database. Other, more specific validation routines will be worked out with the protocol Project Lead and/or project staff and incorporated into the database as appropriate. These modifications will be described in the edit log and the functionality of the validation routines will be explained in detail in the groundwater monitoring database user manual (in development).

Completing Data Certification

Data certification is a benchmark in the project information management process that indicates that:

1. The data are complete for the period of record.
2. They have undergone and passed the quality assurance checks.
3. That they are appropriately documented and in a condition for archiving, posting and distribution as appropriate. Certification is not intended to imply that the data are completely free of errors or inconsistencies which may or may not have been detected during quality assurance reviews.

To ensure that only quality data are included in reports and other project deliverables, the data certification step is an annual requirement for all tabular and spatial data. The Project Lead is primarily responsible for completing a PACN Project Data Certification Form, available on the PACN website. Refer to SOP 24 (Product Delivery Specifications) for delivery instructions.

Data Review Steps

1. Be knowledgeable about all SOPs relevant to the monitoring approach being used at the well. Review as necessary.
2. Check that protocols for initial processing have been followed:
   A. Data were processed promptly after field runs.
   B. Data have been checked by a person other than the one who did the initial data processing.
   C. All electronic and handwritten data have undergone all stages of checking and screening, and that all stages of the data processing are properly archived in the well file and groundwater database.
3. Check the accuracy of the data:
   A. Check that data from field data sheets agree with the provisional electronic data.
   B. Check the screened CTD data to ensure that erroneous data have been properly removed. Compare the screened data to the raw data to ensure that any data that have been removed from the screened data were indeed erroneous.
   C. Check the computed and adjusted DTW values in the provisional CTD data to ensure that values were properly computed.
4. Check that the Station Analysis has been properly updated and is consistent with all relevant information in the field data sheets and metadata.
5. Cross-check handwritten and electronic data to ensure that they are consistent with each other and what is known about the well.
6. If there are any errors or discrepancies in the data, discuss and try to resolve them with the field technicians; make appropriate corrections to affected data sets.
7. If one or more data-processing SOPs were not followed, send the data back to the technicians for processing according to the SOP.
8. If it is not possible to retroactively follow the SOP, as may be the case if the field SOPs were not followed, assess whether the failure to follow the SOP has compromised the reliability of the data and if so, remove the affected data values from the final data set and make a note in the metadata and Station Analysis. Ensure that the appropriate SOPs will be followed in the future.
9. After the review is completed, all necessary corrective actions have been taken, and the data appear to be accurate:
   A. Place a note indicating the completion of review (including reviewer's name) in the metadata in the electronic subcomponent of the well folder.
   B. Change the status of the data in the groundwater database to "final."

Standard Operating Procedure (SOP) # 23: Metadata Development

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

Metadata Documentation

Data documentation is a critical step toward ensuring that data sets are usable for their intended purposes well into the future. This involves the development of metadata, which can be defined as structured information about the content, quality, condition and other characteristics of a given data set. Additionally, metadata provide the means to catalog and search among data sets, thus making them available to a broad range of potential data users. Metadata for all PACN monitoring data will conform to Federal Geographic Data Committee (FGDC) guidelines and will contain all components of supporting information such that the data may be confidently manipulated, analyzed and synthesized.

Updated metadata is a required deliverable that should accompany each season's certified data. For long-term projects such as this one, metadata creation is most time consuming the first time it is developed; after which most information remains static from one year to the next. Metadata records in subsequent years then only need to be updated to reflect changes in contact information and taxonomic conventions, to include recent publications, to update data disposition and quality descriptions, and to describe any changes in collection methods, analysis approaches or quality assurance for the project.

Specific procedures for creating, parsing, and posting the metadata record are found in PACN Metadata Development Guidelines (*http://science.nature.nps.gov/im/units/pacn/data/data_sop/PACN_Metadata_Guidelines.pdf*). The general flow is as follows:

1. After the annual data quality review has been performed and the data are ready for certification, the Project Lead (or a designee) updates the PACN Metadata Interview Form (*http://science.nature.nps.gov/im/units/pacn/data/data_sop/PACN_Metadata_Interview_Form.doc*).
    a. The metadata interview form greatly facilitates metadata creation by structuring the required information into a logical arrangement of 15 main questions, many with additional sub-questions.
    b. The first year, a new copy of the metadata interview form should be downloaded. Otherwise the form from the previous year can be used as a starting point, in which case

the Track Changes tool in MS Word should be activated in order to make edits obvious to the person who will be updating the XML record.

c. Complete the metadata interview form and maintain it in the project workspace. Much of the interview form can be filled out by cutting and pasting material from other documents (e.g., reports, protocol narrative sections, and SOPs).
d. The Data Manager can help answer questions about the metadata interview form.

2. Deliver the completed interview form to the Data Manager according to SOP 24 (Product Delivery Specifications).

3. The Data Manager (or GIS Specialist for spatial data) will then extract the information from the interview form and use it to create and update an FGDC- and NPS-compliant metadata record in XML format. Specific guidance for creating the XML record is contained in PACN Metadata Development Guidelines.

4. The Data Manager will post the record and the certified data to the Integrated Resource Management Application (IRMA Portal; *https://irma.nps.gov/App/Portal/Home*), and maintain a local copy of the XML file for subsequent updates. The IRMA Portal has help files to guide the upload process.

5. The Project Lead should update the metadata interview content as changes to the protocol are made, and each year as additional data are accumulated.

Standard Operating Procedure (SOP) # 24: Product Delivery Specifications

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

This Standard Operating Procedure document provides details on the process of submitting completed data sets, reports and other project deliverables. Prior to submitting digital products, files should be named according to the naming conventions appropriate to each product type (see below for general naming conventions).

All digital file submissions that are sent by email should be accompanied by a Product Submission Form (*http://science.nature.nps.gov/im/units/pacn/data/data_sop/PACN_Product_Submissions_Form.doc*), which briefly captures the following information about the products:

- Submission date
- Name of the person submitting the product(s)
- Name and file format of each product

This form can be obtained from the Data Manager. Upon notification and/or receipt of the completed products, the Data Manager or GIS Specialist will check them into the PACN project tracking application.

Table 24-1. Product delivery schedule and specifications.

Deliverable Product	Primary Responsibility	Target Date	Instructions
Field season report	Project Lead	December 15 of the same year	Upload digital file in MS Word format to the PACN Digital Library[1] submissions folder.
Raw GPS data files	Field Crew Lead	After each sampling event	Zip and send all digital files to the GIS Specialist who will post it to the PACN Digital Library[1].
Processed GPS data files	GIS Specialist	September 15 of the same year	Zip and upload files to the PACN Digital Library[1].

Table 24-1. Product delivery schedule and specifications (continued).

Digital photographs	Field Crew Lead	After each sampling event	Organize, name and maintain photographic images in the project workspace according to SOP 18.
Field data forms	Field Crew Lead and Project Lead	After each sampling event. No later than November 30 of the same year	Scan original, marked-up field forms as PDF files and upload these to the PACN Digital Library[1] submissions folder. Originals go to the Park Curator for archival.
Certified working database	Project Lead	November 30 of the same year	Refer to the following section on delivering certified data and related materials. Data will be uploaded to the Integrated Resource Management Application Portal[2], and stored in the PACN Digital Library[1].
Certified geospatial data	Project Lead with GIS Specialist		
Data certification report	Project Lead		
Metadata interview form	Project Lead		
Full metadata (parsed XML)	Data Manager and GIS Specialist	March 15 of the following year	Upload the parsed XML record to the Integrated Resource Management Application Portal [2], and store in the PACN Digital Library[1].
Annual I&M report	Project Lead	April 30 of the following year	Refer to the following section on reports and publications. Final reports will be entered in Integrated Resource Management Application Portal [2], and stored in the PACN Digital Library[1].
5-year analysis report	Project Lead, Data Analyst	Every 5 years by April 30	
Other publications	Project Lead, Data Analyst	as completed	
Other records	Project Lead	review for retention every January	Organize and send analog files to Park Curator for archival. Digital files that are slated for permanent retention should be uploaded to the PACN Digital Library. Retain or dispose of records following NPS Director's Order #19[3].

[1]The PACN Digital Library is a hierarchical digital filing system stored on the PACN file servers. Network users have read-only access to these files, except where information sensitivity may preclude general access.
[2]The Integrated Resource Management Application Portal is a clearinghouse for natural resource data, metadata, bibliographic records, and park species information (*https://irma.nps.gov/App/Portal/Home*). Only non-sensitive information is posted to the Integrated Resource Management Application Portal. Refer to the protocol section on sensitive information for details.
[3]NPS Director's Order 19 (NPS 2001) provides a schedule indicating the amount of time that the various kinds of records should be retained. Available at: http://data2.itc.nps.gov/npspolicy/DOrders.cfm

Specific Instructions for Delivering Certified Data and Related Materials

Data certification is a benchmark in the project information management process that indicates that: 1) the data are complete for the period of record; 2) they have undergone and passed the quality assurance checks; and 3) that they are appropriately documented and in a condition for archiving, posting and distribution as appropriate. To ensure that only quality data are included in reports and other project deliverables, the data certification step is an annual requirement for all tabular and spatial data. For more information refer to SOP 22 (Data Quality Review and Certification).

The following deliverables should be delivered as a package:

- *Certified Working Database*: Database in MS Access format containing data for the current season that has been through the quality assurance checks documented in SOP 22 (Data Quality Review and Certification).
- *Certified Geospatial Data*: GIS themes in ESRI coverage or shapefile format.
- *Data Certification Form*: A brief questionnaire in MS Word that describes the certified data product(s) being submitted (http://science.nature.nps.gov/im/units/pacn/data/data_sop/PACN_Project_Data_Certification_Form.doc).
- *Metadata Interview Form*: The metadata interview form is an MS Word questionnaire that greatly facilitates metadata creation (http://science.nature.nps.gov/im/units/pacn/data/data_sop/PACN_Metadata_Interview_Form.doc. For more details, refer to SOP 23 (Metadata Development).

After the quality review is completed, the Project Lead should package the certification materials for delivery as follows:

1. Open the certified back-end database file and compact it (in Microsoft Access, Tools > Database Utilities > Compact and Repair Database). This will make the file size much smaller. Back-end files are typically indicated with the letters "_be" in the name (e.g., groundwater_be_2010.mdb).
2. Rename the certified back-end file with the project name ("groundwater"), the year or span of years for the data being certified, and the word "certified". For example: groundwater_2010_certified.mdb.
3. Create a compressed file (using WinZip® or similar software) and add the back-end database file to that file. Note: The front-end application does not contain project data and as such should not be included in the delivery file.
4. Add the completed metadata interview and data certification forms to the compressed file. Both files should be named in a manner consistent with the naming conventions described elsewhere in this document.
5. Add any geospatial data files that aren't already in the possession of the GIS Specialist. Geospatial data files should be developed and named according to PACN GIS Naming Conventions.
6. Upload the compressed file containing all certification materials to the submissions folder of the PACN Digital Library. If the Project Lead does not have access to the PACN Digital Library, then certification materials should be delivered as follows:
    a. If the compressed file is under 5 mb in size, it may be delivered directly to the NPS Lead and Data Manager by email.
    b. If the compressed file is larger than 5 mb, it should be copied to a CD or DVD and delivered in this manner.
7. Notify the Data Manager by email that the certification materials have been uploaded or otherwise sent.

Upon receiving the certification materials, the Data Manager will:

1. Review them for completeness and work with the Project Lead if there are any questions.
2. Notify the GIS Specialist if any geospatial data are submitted. The GIS Specialist will then review the data, and update any project GIS data sets and metadata accordingly.
3. Check in the delivered products using the PACN project tracking application.
4. Store the certified products together in the PACN Digital Library.
5. Upload the certified data to the master project database.
6. Notify the Project Lead that the year's data have been uploaded and processed successfully. The Project Lead may then proceed with uploading data to IRMA, data summarization, analysis, and reporting.
7. Develop, parse and post the XML metadata record to the Integrated Resource Management Application Portal.
8. After a holding period of 2 years, the Data Manager will upload the certified data to the Integrated Resource Management Application Portal. This holding period is to protect professional authorship priority and to provide sufficient time to catch any undetected quality assurance problems (see SOP 25).

Specific Instructions for Reports and Publications

Annual reports and trend analysis reports will use the NPS Natural Resource Publications template, a pre-formatted Microsoft Word template document based on current NPS formatting standards. Annual reports will use the Natural Resource Report template (*http://www.nature.nps.gov/publications/nrpm/docs/templates/NRR_Template_v3.dot*), and trend analysis and other peer-reviewed technical reports will use the Natural Resource Technical Report template (*http://www.nature.nps.gov/publications/nrpm/docs/templates/NRTR_Template_v3.dot*). Instructions for acquiring a series number and other information about NPS publication standards can be found at the NPS Natural Resources Publications website (*http://www.nature.nps.gov/publications/NRPM/index.cfm*). In general, the procedures for reports and publications are as follows:

1. The document should be formatted using the NPS Natural Resource Publications template. Formatting according to NPS standards is easiest when using the template from the very beginning, as opposed to reformatting an existing document.
2. The document should be peer reviewed at the appropriate level. For example, I&M Annual Reports should be reviewed by other members of the appropriate project work group. The Program Manager will also review all annual reports for completeness and compliance with I&M standards and expectations.
3. Upon completing the peer review, acquire a publication series number from the NPS Key Official (currently the Regional I&M Coordinator).
4. Upload the file in PDF and MS Word formats to the PACN Digital Library submissions folder.
5. Send a printout to each Park Curator.

6. The Data Manager or a designee will create a bibliographic record and upload the PDF document to the Integrated Resource Management Application Portal according to document sensitivity.

File naming conventions

- In all cases, digital file names should follow these guidelines:
- No spaces or special characters in the file name
- Use the underscore ("_") character to separate file name components
- Try to limit file names to 30 characters or fewer, up to a maximum of 50 characters
- As appropriate, include the project name (e.g., "Anchialine Pools"), network code ("PACN") or park code, and year in the file name.

Standard Operating Procedure (SOP) # 25: Product Posting and Delivery

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

Once digital products have been delivered and processed, the Data Manager will post the products to the Integrated Resource Management Application Portal (*https://irma.nps.gov/App/Portal/Home*). The Integrated Resource Management Application Portal is the NPS clearinghouse for natural resource products that are available to the public. The following sets of products are available in the Integrated Resource Management Application Portal:

1. Full metadata records and datasets will be posted to the References service within the Integrated Resource Management Application Portal and made available to the public.
2. A record for reports and other publications will be created in the Reference service. The digital report file in PDF format will then be uploaded and linked to the reference record.
3. Species observations will be extracted from the database and entered into the Biology service which is the NPS database and application for maintaining park-specific species lists and observation data.

The Integrated Resource Management Application Portal serves as the primary mechanism for sharing reports, data, and other project deliverables with other agencies, organizations, and the general public..

Holding period for project data

To protect professional authorship priority and to provide sufficient time to complete quality assurance measures, there is a two-year holding period before posting or otherwise distributing finalized data. This means that certified data sets are first posted to publicly accessible websites (i.e., the Integrated Resource Management Application Portal) approximately 24 months after they are collected (e.g., data collected in June 2008 becomes generally available through the Integrated Resource Management Application Portal in June 2010). In certain circumstances, and at the discretion of the NPS Lead and Park Biologists, data may be shared before a full 2 years have elapsed.

Note: This hold only applies to raw data; all metadata, reports or other products are to be posted to NPS clearinghouses in a timely manner as they are received and processed.

Responding to Data Requests

Occasionally, a park or project staff member may be contacted directly regarding a specific data request from another agency, organization, scientist, or from a member of the general public. The following points should be considered when responding to data requests:

- NPS is the originator and steward of the data, and the NPS Inventory and Monitoring Program should be acknowledged in any professional publication using the data.
- NPS retains distribution rights; copies of the data should not be redistributed by anyone but NPS.
- The data that project staff members and cooperators collect using public funds are public records and as such cannot be considered personal or professional intellectual property.
- No sensitive information (e.g., information about the specific nature or location of protected resources) may be posted to the Integrated Resource Management Application Portal or another publicly accessible website, or otherwise shared or distributed outside NPS without a confidentiality agreement between NPS and the agency, organization, or person(s) with whom the sensitive information is to be shared.
- For quality assurance, only the certified, finalized versions of data sets should be shared with others.

The Project Lead will handle all data requests as follows:

1. Discuss the request with other Park Biologists as necessary to make those with a need to know aware of the request and, if necessary, to work together on a response.
2. Notify the Data Manager of the request if s/he is needed to facilitate fulfilling the request in some manner.
3. Respond to the request in an official email or memo.
4. In the response, refer the requestor to the Integrated Resource Management Application Portal (*https://irma.nps.gov/App/Portal/Home*), so they may download the necessary data and/or metadata. If the request cannot be fulfilled in that manner—either because the data products have not been posted yet, or because the requested data include sensitive information—work with the Data Manager to discuss options for fulfilling the request directly (e.g., burning data to CD or DVD). Ordinarily, only certified data sets should be shared outside NPS.
5. If the request is for a document, it is recommended that documents be converted to PDF format prior to distributing it.
6. After responding, provide the following information to the Data Manager, who will maintain a log of all requests in the PACN Project Tracking database:
    a. Name and affiliation of requestor
    b. Request date
    c. Nature of request
    d. Responder
    e. Response date
    f. Nature of response

g. List of specific data sets and products sent (if any)

All official FOIA requests will be handled according to NPS policy. The NPS Lead will work with the Data Manager and the park FOIA representative(s) of the park(s) for which the request applies.

Standard Operating Procedure (SOP) # 26: Annual Data Analyses and Reporting for the Long-Term Monitoring

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

The results and analyses of the groundwater monitoring protocol will be described in an annual summary report. All analyses will be done using only final data (as determined by SOP 22). The two SOPs for data analysis and reporting include report outlines which indicate the type of data and analysis needed.

A summary report of the final water-level and specific-conductance data will be published annually. In addition to summarizing the data collected in a year, the annual summary also provides an opportunity to compare data collected in one year to that collected in previous years. For further information on trend analysis, please see Hirsch (2005) and Helsel and Hirsch (2002). These references give detailed instructions on conducting trend analyses, including which analyses are appropriate and links to a computer program that can be used to run the trend analyses. Use these guides as directions in determining the type and proper method of conducting trend analyses based on park requirements, which may change over time.

1. Use the format for the NPS Natural Resources Report series (National Park Service, 2008).
2. Prepare the report using the following outline:
   A. Introduction
      (1) Background information about the monitoring, purpose, scope
      (2) Year of the report and period of data collection covered in the report.
   B. Study area
      (1) General setting, including park name, geology, and potential natural and anthropogenic stresses to the water system, and other useful information.
      (2) Well name, geographic coordinates.
      (3) Measuring-point and reference-point locations
      (4) Well-construction details, such as depth and diameter of the original boring, lengths of the various solid casing types (e.g., solid, perforated, slotted, etc.); length of open hole, if any; gravel packing, if any.
   C. Methods
      (1) Parameters monitored – DTW, specific conductance, temperature
      (2) Instruments, sampling intervals

(3) Field methods -- quarterly field visits, annual tasks
(4) Data processing

D. Results (all data must be in final status)

(1) Compute daily means from 15-minute CTD data:

$$\boldsymbol{m}_{\mathrm{d}} = \left(\sum_{t=1}^{t=96} v_t\right) / n \qquad \text{(eq. 26-1)}$$

where $\boldsymbol{m}_{\mathrm{d}}$ is the daily mean value, t=1 is the first reading at midnight at the beginning of the day, t = 96 is the time of the last (96th) reading for the day (at 2345 h), v_{t} is the value whose daily mean is being computed, and n is the number of values in the average. (Note that the midnight value belongs to the day to come, not the day that has passed.) Compute daily mean values only for days having at least 87 of the 15-minute measurements (i.e., missing no more than nine of the 15-minute measurements).

(2) Present data as follows:

(a) Table of the manual DTW measurements for the year, including date and time of measurement (Table 26-1).
(a) Table of the daily mean DTW and specific conductance (Table 26-2).
(b) Graphs of DTW, specific conductance, and temperature versus time (time on the horizontal axis, Fig. 26-1). These graphs should show all data, from the start of monitoring through the current year. Plot each parameter on a separate graph. Plot the DTW in reverse order (lowest value on top, highest value on bottom) so that a rising water-level trend will display as an upward trend on the graph.
(c) Graphs of daily mean values for DTW, specific conductance, and temperature versus time (time on the horizontal axis, Fig. 26-2). These graphs should show all data, from the start of monitoring through the current year. Plot each parameter on a separate graph. Plot the DTW in reverse order (lowest value on top, highest value on bottom) so that a rising water-level trend will be upward on the graph.
(d) Tables of the specific-conductance profiles, including date and time, depth relative to MP, specific conductance value (Table 26-3).
(e) Graph of the specific-conductance profile (specific conductance on the horizontal axis, depth below MP on the vertical axis with depth increasing downward, Fig 26-3).

E. Discussion.

(1) Examine the graphs for shifts and trends. A shift is a relatively sudden change in water level or specific conductance with time, whereas trend is a gradual change with time. Shifts and trends can be a consequence of the monitoring procedure or indicate actual hydrologic changes with time. If shifts or trends are apparent, re-examine the data collection, instrumentation, calibration, and data entry to ensure that the shift or trend is not an artificial consequence of the monitoring procedure.

(2) If the shift or trend is not artificial, describe them and discuss possible causes. For the purposes of this protocol, the trend analysis is simply a visual examination of the time-series data. If visual examination indicates a persistent trend, the trend can be further examined for statistical significance.

(3) If the data indicate that the transition zone has moved so far that the CTD is no longer within it, the position of the CTD should be reassessed using the following criteria:

(a) Goal is to set the CTD where it will be most sensitive to changes in the groundwater system, with some limitations.

(b) To prevent damage to the CTD, the maximum expected depth, considering possible changes in water level, cannot exceed limitations of the vent tube or the pressure transducer in the CTD. Refer to manufacturer's instructions.
(c) Sensor end of the CTD should remain submerged at all times.
(d) Changes in specific conductance are likely to be most readily apparent by monitoring the transition zone. Use the plot of the specific conductance profile to identify the transition zone (Fig. 26-3, 26-4). Within limitations imposed by items (b) and (c) above, the CDT should be placed at the middle of the transition zone (where the specific conductance is about 25,000 µS/cm at 25˚ C).
(e) If the entire water column of the well is fresh (less than 1,000 µS/cm), or only the upper part of the transition zone (less than 25,000 µS/cm at 25˚ C) is present, place the CTD as deep as possible within the limitations of the instrument and without allowing the CTD to touch the bottom of the well.
(f) If the entire water column of the well has the salinity of seawater (greater than 50,000 µS/cm), or only the lower part of the transition zone (greater than 25,000 µS/cm) is present, place the CTD near the top of the water column but deep enough that it will remain submerged even if there is a change in water level.

3. Submit report for peer review and publication following the NPS Natural Resource Publications guidelines (National Park Service, 2008).

Literature Cited

National Park Service. 2008. Natural resource publications management. Available at http://www.nature.nps.gov/publications/NRPM/index.cfm (accessed 17 June 2008).

Helsel D. R., D. K. Mueller and J. R. Slack. 2006. Computer program for the Kendall family of trend tests. U.S. Geological Survey Scientific Investigations Report 2005-5275. U. S. Geological Survey, Reston, Virginia

Helsel, D. R. and R. M. Hirsch. 2002. Trend analysis *in* Statistical Methods in Water Resources. Techniques of Water-Resources Investigations of the United States Geological Survey. Book 4 Chapter A3. U. S. Geological Survey. Reston, Virginia.

Table 26-1. Example of table showing manual depth to water measurements made in the year. The table title should give the well number, park name, and location.

Date	Time	Depth to water (feet)
January 30, 2008	9:58	22.52
January 30, 2008	10:32	22.54
April 29, 2008	10:58	22.73
April 29, 2008	11:33	22.68
July 30, 2008	8:27	23.20
July 31, 2008	9:48	23.22
October 31, 2008	10:13	22.35
October 31, 2008	10:47	22.46

Table 26-2. Example of table showing daily mean depth to water and specific conductance. The example below is abbreviated; the table in the actual report should show all the data for the year. The table title should give the well number, park name, and location. [MP, measuring point; □S/cm, microsiemens per centimeter at 25 degrees Celsius]

Date	Daily mean		
	Depth to water (feet relative to MP)	**Specific conductance (□S/cm)**	**Temperature (degrees Celsius)**
January 30, 2008	22.69	12972	18.88
January 31, 2008	22.59	12977	18.87
February 1, 2008	22.62	12937	18.87
February 2, 2008	22.64	12928	18.87
February 3, 2008	22.66	12938	18.87
February 4, 2008	22.66	12967	18.87
February 5, 2008	22.63	12992	18.86
February 6, 2008	22.62	13032	18.86
February 7, 2008	22.59	13058	18.86
February 8, 2008	22.57	13087	18.86
February 9, 2008	22.59	13077	18.86
February 10, 2008	22.58	13076	18.86
February 11, 2008	22.63	13059	18.86
February 12, 2008	22.68	13037	18.86
February 13, 2008	22.72	12975	18.86
February 14, 2008	22.73	12935	18.86
February 15, 2008	22.68	12910	18.86
February 16, 2008	22.72	12876	18.86
February 17, 2008	22.72	12925	18.86
February 18, 2008	22.70	12952	18.86
February 19, 2008	22.65	12993	18.86
February 20, 2008	22.60	13022	18.86
February 21, 2008	22.59	13042	18.85
February 22, 2008	22.57	13063	18.85
February 23, 2008	22.57	13052	18.85
February 24, 2008	22.55	13063	18.85
February 25, 2008	22.58	13049	18.85
February 26, 2008	22.61	13021	18.85
February 27, 2008	22.70	12932	18.85
February 28, 2008	22.76	12865	18.85
February 29, 2008	22.73	12833	18.85
March 1, 2008	22.76	12788	18.85
March 2, 2008	22.76	12775	18.85
March 3, 2008	22.73	12800	18.85
March 4, 2008	22.72	12806	18.85
March 5, 2008	22.67	12829	18.85
March 6, 2008	22.61	12859	18.84
March 7, 2008	22.56	12901	18.84
March 8, 2008	22.57	12920	18.84
March 9, 2008	22.61	12935	18.84
Continue table to include entire year.			

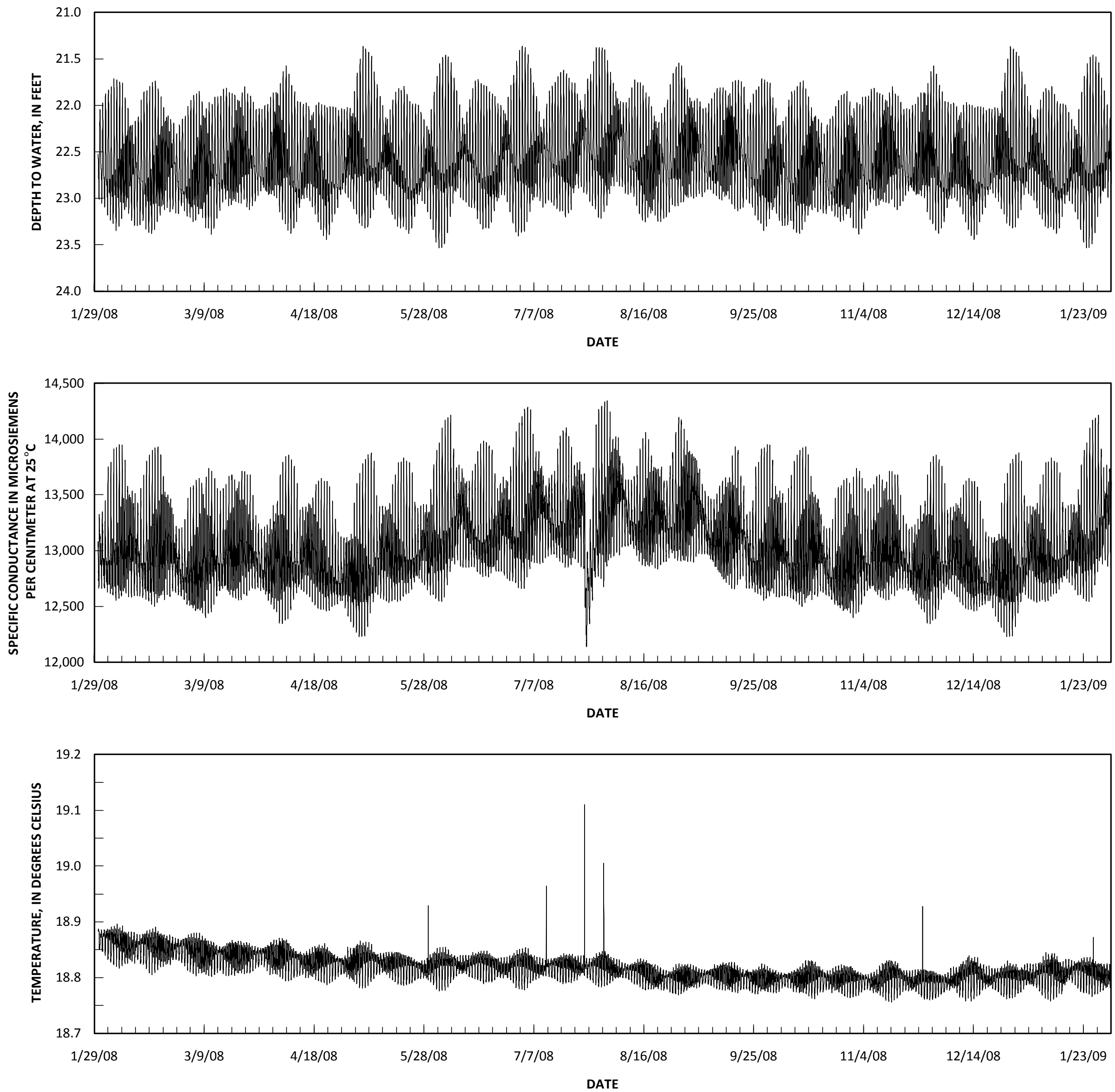

Figure 26-1. Example time-series graphs of depth to water (DTW), specific conductance, and temperature for the annual summary report.

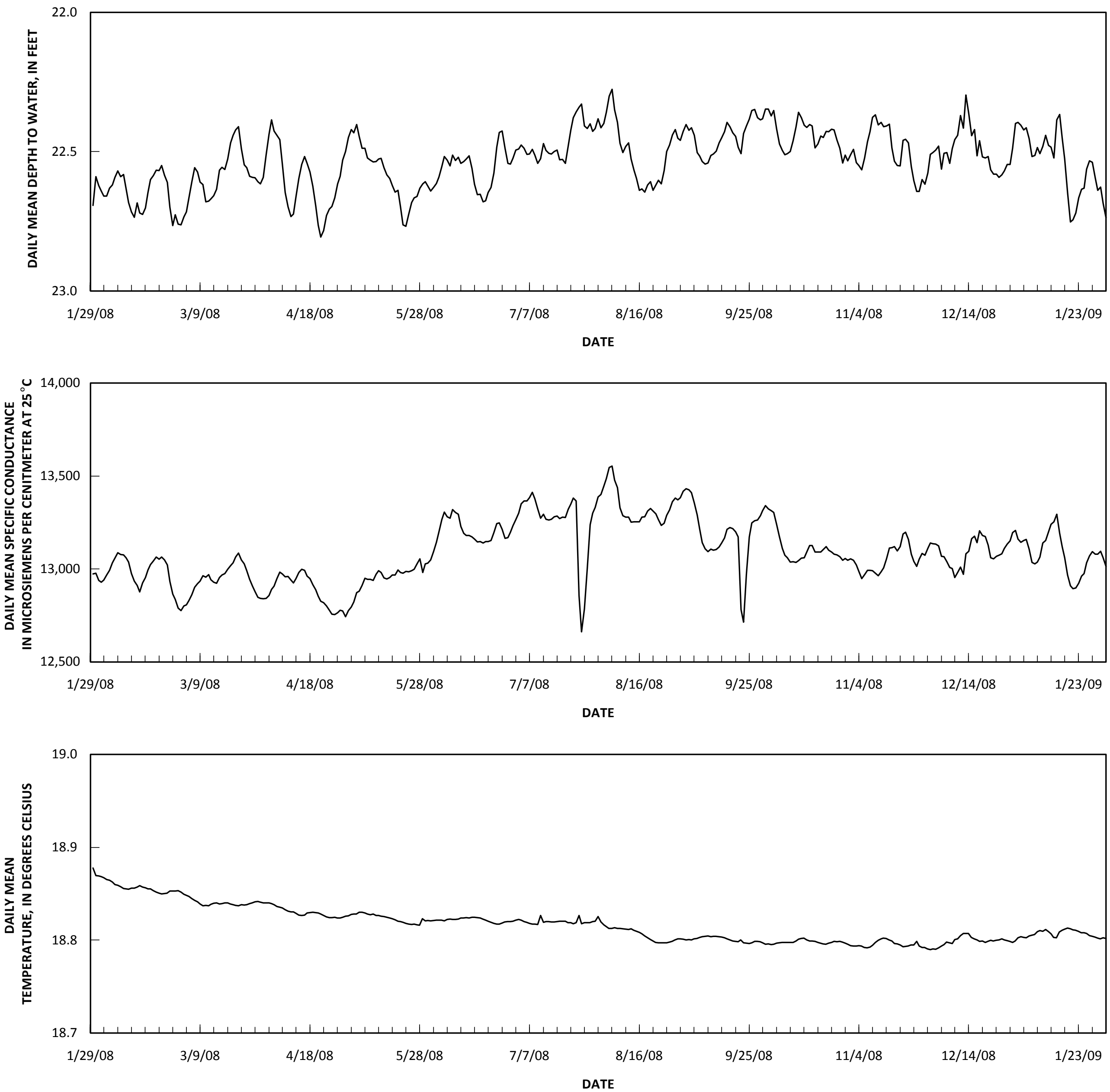

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Figure 26-2. Example time-series graphs of daily mean depth to water (DTW), specific conductance, and temperature for the annual summary report

Table 26-3. Example of table showing data from annual specific-conductance profile. The table title should give the well number, park, mbv name, and location. [MP, measuring point; µS/cm, microsiemens per centimeter at 25 degrees Celsius].

Date	Time		Depth (feet below MP)	Specific conductance (µS/cm)
	From	To		
February 8, 2010	11:35:42	11:36:12	2.50	8773
February 8, 2010	11:36:47	11:37:17	3.00	8872
February 8, 2010	11:38:17	11:38:47	3.50	8901
February 8, 2010	11:39:22	11:39:52	4.00	8931
February 8, 2010	11:40:12	11:40:42	4.50	8939
February 8, 2010	11:41:12	11:41:42	5.00	8970
February 8, 2010	11:41:57	11:42:27	5.50	9025
February 8, 2010	11:42:47	11:43:17	6.00	9152

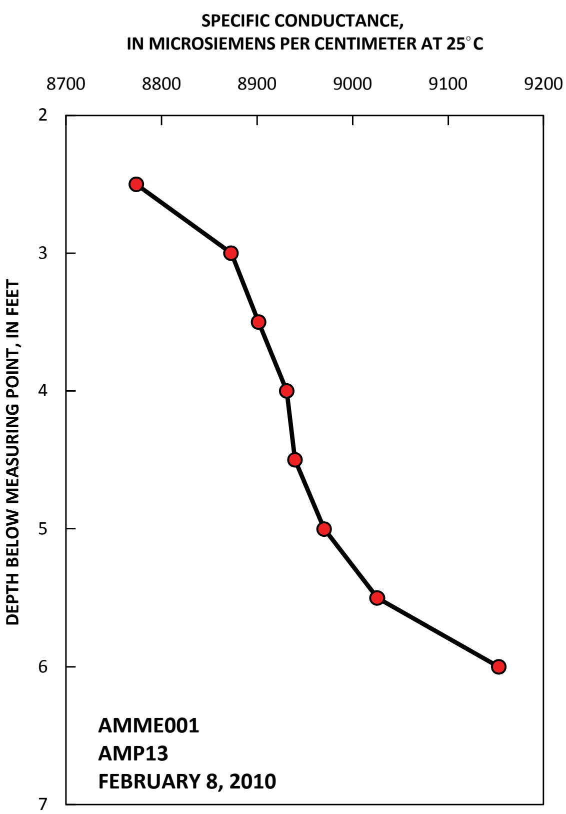

Figure 26-3. Example graph of the specific-conductance profile for the annual summary report.

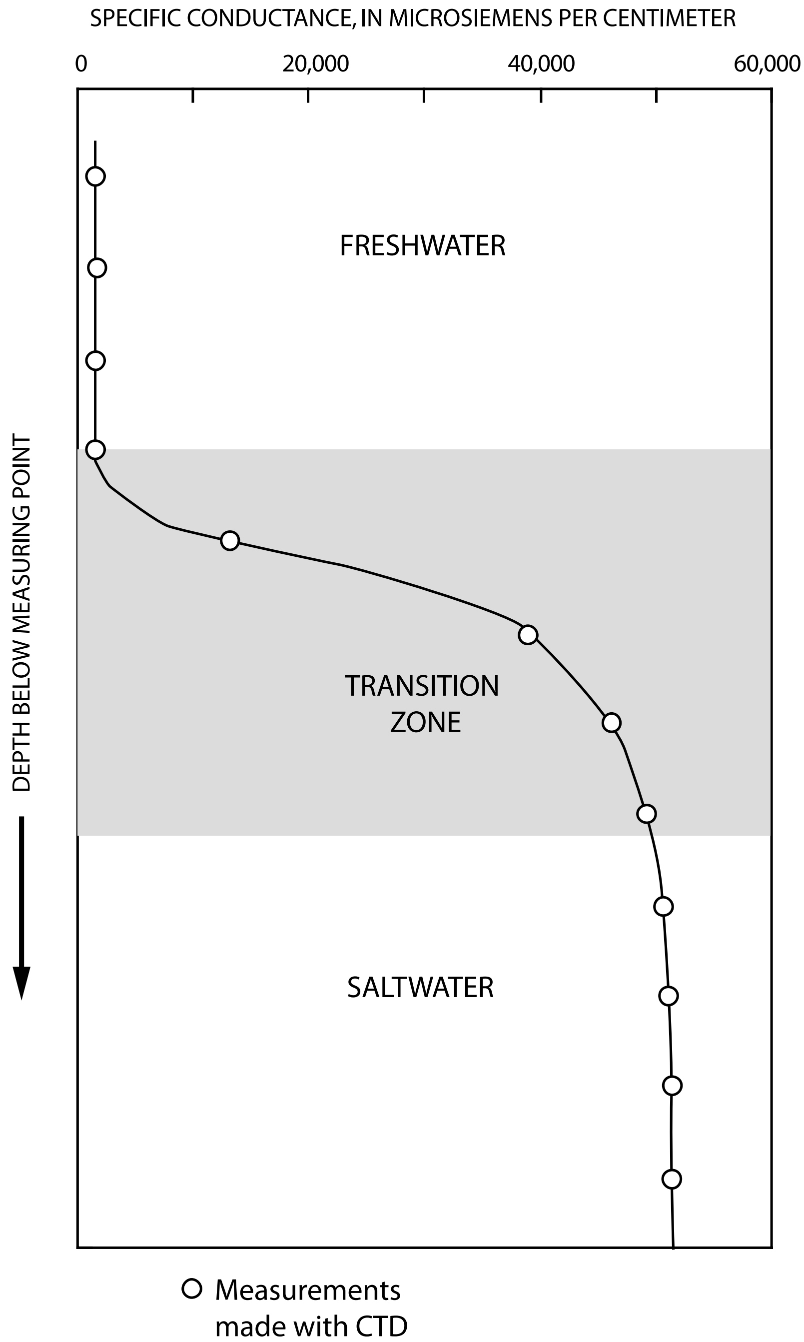

Figure 26-4. Specific-conductance profile in relation to the transition zone.

Standard Operating Procedure (SOP) # 27: Safety

Version 1.0 (November 2011)

Change History

Version #	Date	Revised by	Changes	Justification

This SOP explains the safety protocol for the Groundwater Vital Signs Monitoring Protocol and associated SOPs for the Pacific Island Network. This document outlines safety considerations for conducting any aspect of the protocol. All observers should be familiar with this SOP in order to identify and use the most current procedures and ensure optimum safety.

Prior to conducting field work, observers are required to review this entire protocol, including all SOPs. In particular, all participants should be thoroughly familiar with the NPS Occupational Safety and Health Policies.

The USGS National Field Manual (USGS variously dated, (http://water.usgs.gov/owq/FieldManual/Chap9/content.html) is another recommended reference for safety procedures. Table SOP 3.1 provides a partial list of reference material and websites with information on specific safety topics.

Table 27-1. Safety topics, policies, and information locations for safety issues that may arise during the implementation of groundwater monitoring in the Pacific Islands National Parks.

Safety Topic	Guidance	Website
Safety policies, regulations and requirements	DRAFT NPS RM 50B Occupational Safety & Health Program	http://inside.nps.gov/waso/custommenu.cfm?lv=2&prg=46&id=5898
	Safety Smart!	http://safetysmarts.smis.doi.gov/
	USGS National Field Manual Section 9.1 (Lane and Fay 1997).	http://water.usgs.gov/owq/FieldManual/Chap9/content.html
	29 CFR, Part 1960, "Elements for Federal Employee Occupational Safety and Health Programs," Subpart C	
	Departmental Manual (DM), Part 485, "Safety and Health Handbook," Chapter 4	

Table 27-1. Safety topics, policies, and information locations for safety issues that may arise during the implementation of groundwater monitoring in the Pacific Islands National Parks (continued).

Safety training guidelines	SMIS Training Materials	https://www.smis.doi.gov/SMISReference/homepage.htm
	DOI Office of Occupational Health and Safety	http://www.doi.gov/ohs/index.html
	29 CFR, Part 1960, "Elements for Federal Employee Occupational Safety and Health Programs," Subpart H	
	Departmental Manual (DM), Part 485, "Safety and Health Handbook," Chapter 13	
Transportation	NPS Reference Manual 50B, Section 6.0 Motor Vehicles	http://www.inside.nps.gov/waso/custommenu.cfm?lv=3&prg=704&id=2860
	USGS National Field Manual Section 9.3	http://water.usgs.gov/owq/FieldManual/Chap9/A9.3.html
	State, Territory, and Commonwealth traffic laws	
Inclement weather and water activities	USGS National Field Manual Section 9.4	http://water.usgs.gov/owq/FieldManual/Chap9/A9.4.html
	National Weather Service	http://www.prh.noaa.gov
Environmental conditions	USGS National Field Manual Section 9.8	http://water.usgs.gov/owq/FieldManual/Chap9/A9.8.html
	1992. USDHHS. CDC. HIOSH. "Working in Hot Environments"	
Chemical handling and storage	USGS National Field Manual Section 9.6	http://water.usgs.gov/owq/FieldManual/Chap9/A9.6.html
	MSDS file, right to know	
Animals and disease vectors	NPS Reference Manual 83G Vectorborne and Zoonotic Diseases	http://www.nps.gov/public_health/inter/info/rms/rm83g.pdf

Safety is "the condition of averting or not causing injury, danger, or loss" (Lane and Fay 1997). As a Federal employee, partner, or cooperator, you are required to know and follow safety policies and requirements documented in Reference Manual 50 B Occupational Safety and Health Program (http://inside.nps.gov/waso/custommenu.cfm?lv=2&prg=46&id=5898). In addition, individual parks also have park specific safety procedures, and operational protocols. This SOP recommends that these and all other available reference materials be used to address the topics below.

Safety Policies Regulations and Requirements

All individuals participating in activities related to this Vital Signs must adhere to applicable safety policies, regulations, and requirements outlined in RM 50 B Occupational Safety and Health Program. This includes both field and office activities and applies equally to NPS staff, cooperators, partners, volunteers, and others. The applicable policies, regulations, and requirements of each participating agency should be compiled and reviewed each year as part of this SOP. Ensure that all field personnel obtain First Aid, CPR training, and oxygen administration. This is also highly recommended for office personnel. Supervisory staff should ensure that all field staff are well trained in the safety guidelines and policies outlined below.

Transportation

Safety considerations for vehicles used to reach sampling sites should be considered for each park and field location. It is very important to inspect the vehicle before going into the field. Ensure that safety equipment required for the scheduled activity is stowed securely in the vehicle. During driving to and from sampling areas, it is particularly important to consider issues such as night-time driving, fatigue, storms, road flooding, driving in unfamiliar areas, and remote areas where large animals may be crossing the road. Additional details regarding transportation safety procedures and policies are listed in NPS Reference Manual 50B Section 6.0 Motor Vehicles (http://www.inside.nps.gov/waso/custommenu.cfm?lv=3&prg=704&id=2860and the USGS National Field Manual Section 9.3 (USGS, http://water.usgs.gov/owq/FieldManual/Chap9/content.html).

Weather

Sampling during inclement weather is of particular concern. Prior to departure, it is the responsibility of all personnel to be aware of the appropriate local weather and tide forecast for the day and to decide whether sampling should commence. Consult the USGS National Field Manual Section 9.4 (http://water.usgs.gov/owq/FieldManual/Chap9/content.html) for more weather related safety considerations.

Sampling should be conducted during periods of little rain and mild wind. If thunder is heard and lightning seen, sampling will be suspended and personnel should seek shelter for at least 30 minutes. Do not stay out during a lightning storm. During intense rainfall events, visibility may drop and appropriate precautions should be taken to ensure safe travel conditions. At any point during sampling, any personnel involved have the right and responsibility to abort a sampling trip if hazardous conditions develop.

Environmental Conditions

Individual parks have occupant emergency plans which cover safety procedures for medical emergencies, earthquakes, floods, fires, tsunamis, and bomb threats. Be familiar with the procedures and emergency contact numbers of your duty station park as well as other parks you may visit during field sampling activities. Overall, be aware of your environment, use common sense, do not exceed your limits (for example, operation of equipment; lifting heavy objects and equipment; physical tolerance to exertion, heat, and cold), and trust your instincts (Lane and Fay 1997). The USGS National Field Manual Section 9.8 (http://water.usgs.gov/owq/FieldManual/Chap9/content.html) covers environmental hazards in more detail.

Rough and slippery terrain as well as hiking over very rough and unstable terrain in hot and arid conditions will be encountered when conducting field work necessary for this protocol. Special care needs to be taken to protect field personnel from injuries as well as dehydration and exposure in these environments. Appropriate footwear should be worn to protect field personnel from foot and leg injuries and a sufficient supply of drinkable liquid (two quarts minimum) should be taken and used. Field conditions in the region are likely to expose crews to intense tropical sunlight, wind, and rain. Flash flooding should always be a concern in wetlands (i.e. AMME). High topographical relief in the region combined with the episodic nature of rainfall in the tropics can lead to extreme flood events with little or no warning.

Chemical and Material Safety Considerations

All chemicals should be handled and stored according to the recommendations found in the Material Safety and Data Sheet (MSDS) provided by the supplier. All persons using or exposed to hazardous substances must be fully informed of the properties and potential hazards of the material in use as well as proper handling and disposal procedures. Park staff should always be consulted about local considerations when handling any chemicals of concern. Chemical users should also consult the park-specific Chemical Hygiene Plan. Other chemical handling procedures can be found in the USGS National Field Manual Section 9.6 (http://water.usgs.gov/owq/FieldManual/Chap9/content.html).

Contaminated Water

Well water born pathogens that may survive or be transmitted include *Enterococci* and *Staphylococci* bacteria. Never consume well water. Well water may also be contaminated with other pathogens or harmful chemicals. As a general rule, when conducting sampling, use precautions such as cleaning hands with sanitizer before eating or drinking while sampling. Consuming untreated or unfiltered well water may result in the contraction of bacterial diseases or parasites (i.e. *Leptospirosis*, *Giardia*.) In particular, keep hands away from nose, ears and mouth and wash hands thoroughly before eating. If no soap and water are available, use of an antibacterial hand cleanser is highly recommended after handling water sampling equipment. Consult NPS Reference Manual 83D1 Bathing Beaches (http://www.nps.gov/public_health/inter/info/rms/rm83d1.pdf) and the USGS National Field Manual Section 9.7 (http://water.usgs.gov/owq/FieldManual/Chap9/A9.7.html) for complete recommended safety procedures concerning contaminated water.

Animal Hazards and Disease Vectors

Any open cut has a high likelihood of becoming infected and all cuts should be carefully tended and monitored. Terrestrial areas of the PACN are relatively free of pests, although the brown tree snake is a potential concern on Saipan. Mosquitoes, possible vectors, are likely to be encountered in the freshwater and brackish water environments near wells. Personnel should also be aware of spiders and other insects that can bite or sting. Of particular medical concern are the black widow spider and the brown violin spider. Though bites are not common, if they occur, personnel should seek immediate medical attention (Kuwaye, 2002). Appropriate first aid should be administered and professional medical attention sought if necessary. It is the responsibility of all personnel to be familiar with the local hazardous flora and fauna and to understand the appropriate treatment methods.

Field Trip Preparations and Emergency Contacts

Basic planning is required before each field sampling event. A large component of the planning effort involves gathering safety information and documenting all aspects of field sampling trip plans in advance. All field personnel should complete an Emergency Contact Form (Appendix SOP 3A) and a Medical Information Form (Appendix SOP 3B) prior to conducting field work. A trip plan must be completed. One copy should be left at the office, and additional copies should be given to the park safety officer and field personnel involved in the trip. Weather forecasts should be obtained prior to departure. Upon completion of the field work it is imperative that personnel check in with the park safety officer at the specified time noted on the plan.

It is the responsibility of all personnel to ensure that the appropriate safety equipment is present and in working condition. Examples of safety equipment checklists are provided below. These lists should be customized according to the specific field conditions and the needs of personnel. Additional safety equipment may be required at some parks, and the Park Safety Officer and PDO must be consulted prior to commencing sampling activities. No sampling activities will be conducted without all necessary safety equipment present and in proper working condition.

Emergency Procedure

In the event of an emergency, the first action is ALWAYS to take care of the injured person and seek help. Once help is on the way and the situation is under control, the team leader or crew member should contact, or have someone else contact, the supervisor to inform them of the incident. The person that sustained the injury, or (if necessary) another team member who was witness to the accident must fill out report forms as soon as feasibly possible. The forms are available online on The United States Department of the Interior Safety Management Information System (SMIS) at https://www.smis.doi.gov/. This website contains online accident reports and other documentation to be filled out by the injured crew member, witnesses, and supervisor. These documents must be completed as soon a possible, no later than 24 hours from the time of the accident.

JOB HAZARD ANALYSIS (JHA)

JOB HAZARD ANALYSIS (JHA)		Date: 2/24/2011	■ New JHA ☐ Revised JHA
Park Unit: PACN	Division: Aquatic Resources	Branch: Q22-Oubliette	Location: KAHO and AMME
TASK TITLE: Groundwater Monitoring		JHA Number: 001	Page ___1___of __3____
Job Performed By: PACN Aquatic Staff	Analysis By: Tahzay Jones	Supervisor: Greg Kudray	Approved By: Greg Kudray
Required Standards and General Notes:	All work should be performed according to the Pacific Islands Network Groundwater Monitoring Protocol and SOPs. There is a safety protocol included in the SOP's that should be followed while conducting monitoring for this work.		
Required Training:	On the job training through the USGS or through the Pacific Islands Network Aquatic Ecologist is required to conduct this work.		
Required Personal Protective Equipment:	Sunscreen, hat, close toed shoes, gloves, water		
Tools and Equipment:	**Groundwater probe, charged laptop, connector cables, conductivity standard, deionized water, steel tape, chalk, paper, pencil, clipboard.**		

Sequence of Job Steps	Potential Hazards	Safe Action or Procedure
• Collect monitoring equipment from office.	Weight of equipment (approx 15 lbs.)	Lift with legs
• Walk to well.	Sunburn, dehydration	Wear hat and sunscreen. Carry plenty of water.
• Open well.	Pinched fingers, sunburn	Take time to open well carefully, wear hat and sunscreen.
• Remove groundwater probe	Sunburn, dropping things in well	Wear hat and sunscreen, do not lean over well.
• Measure depth to water	Sunburn, dropping things in well, cut from steel tape.	Wear hat and sunscreen, do not lean over well, avoid gripping steel tape tightly when using and move tape slowly.
• Download data from probe	Sunburn, battery heat	Wear hat and sunscreen, wear pants that cover thighs, or place computer on ground.
• Recalibrate the probe	Sunburn, swinging motion with arm	Wear hat and sunscreen, swing probe gently, avoid other personnel in area while swinging.
• Measure depth to water	Sunburn, dropping things in well, cut from steel tape.	Wear hat and sunscreen, do not lean over well, avoid gripping steel tape tightly when using and move tape slowly.

JHA - CONTINUATION SHEET	JHA Number: 001	Page 2 of 3
Sequence of Job Steps	Potential Hazards	Safe Action or Procedure
• Conduct a well profile	Sunburn, dropping things in well, dehydration	Wear hat and sun screen, do not lean over well, drink water if/when necessary.
• Prepare groundwater sonde for deployment.	Sunburn, battery heat	Wear hat and sunscreen, wear pants that cover thighs, or place computer on ground.
• Measure depth to water	Sunburn, dropping things in well, cut from steel tape.	Wear hat and sunscreen, do not lean over well, avoid gripping steel tape tightly when using and move tape slowly.
• Place groundwater probe in well	Sunburn, dropping things in well	Wear hat and sunscreen, do not lean over well.
• Cover well	Pinched fingers, sunburn	Take time to close well carefully, Wear hat and sunscreen.
• Return monitoring equipment to office.	Weight of equipment (approx 15 lbs.)	Lift with legs.

JHA - CONTINUATION SHEET	JHA Number: 001	Page __3___of ___3__
Text Description of Task When it is Done Safely		
Personnel go to office and pick up equipment, then walk to the well site. The well cap is removed (well opening is 1 inch diameter in AMME and 2 inch diameter in KAHO.) and the groundwater instrument is retrieved from the well by a gentle pulling motion until the instrument emerges. The steel tape is then chalked and slowly lowered into the well to determine the depth to water. The tape is removed, interpreted, and the information recorded. The groundwater instrument is then downloaded, memory cleared and the instrument recalibrated using a conductivity solution (salt water of known conductivity) and deionized water. The depth to water is then measured again using steel tape and chalk. The groundwater probe is the slowly lowered into the well, stopping every 6 inches for the probe to stabilize once the probe reaches the water. The values of the instrument are recorded at each stop. The instrument is then retrieved and the computer used to reset the instrument. The depth to water is measured again. Once the new depth to water reading is obtained, the groundwater instrument is replaced in the well and begins monitoring unattended. The groundwater well is covered and the other equipment is then returned to the office.		

Authorized Employee Information			
Employee ID	Last Name	First Name	Qualifications/Remarks
	Farahi	Anne	USGS training
	deVillers	Amanda	NPS training
	Gawel	Mike	NPS training

Literature Cited

Lane, S. L., and R. G. Fay. 1997, Safety in field activities. U.S. Geological Survey techniques of water-resources investigations. Book 9, Chapter A9. University of Hawai‘i John A. Burns School of Medicine, Department of Pediatrics, Honolulu, Hawai‘i. Available at http://water.usgs.gov/owq/FieldManual/Chap9/content.html (accessed 4 January 2010).

Kuwaye, T. T. 2002. Case based pediatrics for medical students and residents. Chapter XXI.5, Bites and Stings. Available at http://www.Hawai‘i.edu/medicine/pediatrics/pedtext/s21c05.html. (accessed 8 January 2009).

U.S. Geological Survey (USGS). Variously dated. National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations. Book 9, Chapters A1–A9. USGS, Reston, Virginia. Available at http://water.usgs.gov/owq/FieldManual/ (accessed 4 January 2010).

Table 27-2 List of Basic Field Survival Equipment for the Groundwater Protocol.

Equipment (#/quantity)	**Preparation & Maintenance**
First Aid Kit	Keep stocked (see SOP 3: Safety Protocol)
Sunscreen (non-toxic)	Ensure that the proper quantities are available.
Insect repellant (non-toxic)	Ensure that the proper quantities are available.
Sunglasses (polarized)	Ensure that this equipment is available.
Appropriate raingear, clothing and footwear	Ensure this equipment is available.
Personal items	Ensure this equipment is available.

Note that a master gear list is located in SOP 1 (General Preparations for Field Work). If any changes are made with regard to equipment type, quantity, or required items, please update SOP 1 simultaneously.

Table 27-3 Emergency Contact Form (Modified from USGS National Field Manual, Chapter A9).

Emergency Contact Form					
Employee Name:					
Personal contacts					
Name:					
Phone (home) (work):					
Name:					
Phone (home) (work):					
PACN contacts:					
WAPA:					
NPSA:					
KALA:					
KAHO:					
Local emergency contacts (or call 911):					
Hospital / Phone:					
Address:					
Walk-in clinic / Phone:					
Address:					
Police:					
Fire:					
Utility:					
Health Information Centers:					
Center Disease Control:					
Information Hotline:					
Fax: Disease Directory:					
Other:					

Table 27-4 Medical form for Office Personnel (Modified from USGS National Field Manual, Chapter A9).

Medical Information for Office Personnel						
Employee Name:						
Home Phone:						
Treatment preference:						
	Medical:					
	other:					
Doctor						
	Name:					
	Phone:					
Other Emergency Contact:						
	Name:					
	Phone:					
Relevant Medical History:						
Allergies & Medical Conditions:						
	Allergies:					
	Conditions:					
Medications:						
	Current:					
	To avoid:					
Special Instructions:						

Table 27-5 Example of a Standard Safety Checklist.

Standard Safety Checklist		
Item:		Check:
Climatic and UV protection		
	Boots	
	Fluids (e.g., water, electrolyte drink)	
	Hat, wide-brimmed	
	Insect repellent (unscented)	
	Rain gear	
	Sunglasses	
	Sunscreen	
	Antibacterial soap or hand lotion	
	Temperature-modifying clothing	
Items for Vehicles		
	Vests and jackets w/reflective protection	
	First aid kit (see below)	
	Flares	
Chemical Protection and Storage		
	Chemical spill kit	
	Eye wash kit (replace old/expired solution)	
	Material Safety Data Sheets (MSDS)	
	Chemical reagents (stored appropriately)	
	Flammable solvents (stored appropriately)	
	Pressurized gases (stored appropriately)	
First Aid and Protective Equipment		
	Complete change of clothes (stored dry)	
	Fire extinguisher (safely secured)	
	First aid kit and manual (ensure full/updated)	
	Orange reflective vest	
Communications		
	Cellular phone/communication equipment	
	Field folder (see below)	
Field Folder:		
	Maps	
	Medical facility numbers/location	
	Emergency contact numbers	
Miscellaneous Equipment		
	Bungie cords (to secure loose articles)	
	District flood plan (most current)	
	Flagging	
	Safety cones	
	Tool kit	

NPS 483/111853, 466/11185, December 2011

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