Section 2 Field Methods

2.1 GPR Technology and Limitations

Ground-penetrating radar data are acquired by transmitting pulses of electromagnetic energy, in the radar frequency range, into the ground via a sending antenna. Each time a radar pulse encounters a material with a different density, electrical conductivity, or chemical composition, a portion of the radar energy will reflect back to the surface and be recorded via a receiving antenna. The remaining radar energy will continue to pass into the ground to be further reflected, until it finally dissipates with depth. Reflection features may include discrete objects, stratigraphic layering, or other subsurface anomalies such as subsurface disturbances associated with utility installation or human interment.

The effectiveness of GPR is highly dependent on local soil conditions. The penetration depth of GPR is determined by antenna frequency and the electrical conductivity of the earthen materials being profiled (Daniels 2004). Soils having high electrical conductivity rapidly attenuate radar energy, restrict penetration depths, and severely limit the effectiveness of GPR (USDA NRCS GPR Methodology n. d.). The electrical conductivity of soils increases with increasing water, clay and soluble salt contents.

GPR suitability maps created by the National Resource Conservation Service (NRCS) were reviewed in an attempt to anticipate the predominant soil matrix within the project area and to assess the relative suitability of GPR application. Figure 1 shows the project area on the NRCS GPR Suitability Map for Hawai'i. The project area is shown to predominantly traverse lands within the low to very low GPR suitability range. The NRCS provides the following discussion when defining their GPR suitability categories:

> Areas dominated by mineral soil materials with less than 10 percent clay or very deep organic soils with pH values < 4.5 in all layers have very high potential for GPR applications. Areas with very high potential afford the greatest possibility for deep, high resolution profiling with GPR. However, depending on the ionic concentration of the soil solution and the amounts and types of clay minerals in the soil matrix, signal attenuation and penetration depths will vary. With a 200 MHz antenna, in soils with very high potential for GPR, the effective penetration depth has averaged about 16.5 feet. However, because of variations in textural layering, mineralogy, soil water content, and the ionic concentration of the soil water, the depth of penetration can range from 3.3 to greater than 50 feet.
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> Areas dominated by mineral soils with 18 to 35 percent clay or with 35 to 60 percent clay that are mostly low-activity clay minerals have moderate potential for GPR. Low activity clays are principally associated with older, more intensely weathered soils. In soils with moderate potential for GPR, the effective penetration depth with a 200 MHz antenna has averaged about 7 feet with a range of about 1.6 to 16 feet. Though penetration depths are restricted, soil polygons with moderate potential are suited to many GPR applications.
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> Mineral soils with 35 to 60 percent clay, or calcareous and/or gypsiferous soils with 18 to 35 percent clay have low potential for GPR. Areas with low potential are very depth restrictive to GPR. In soils with low potential for GPR, the depth of penetration with a 200 MHz antenna has averaged about 1.6 feet with a range of about 0.8 to 6.5 feet. Areas that are unsuited to GPR consist of saline and sodic soils. These soil map units are principally restricted to arid and semiarid regions and coastal areas of the United States. (USDA NRCS GPR Methodology n. d.)

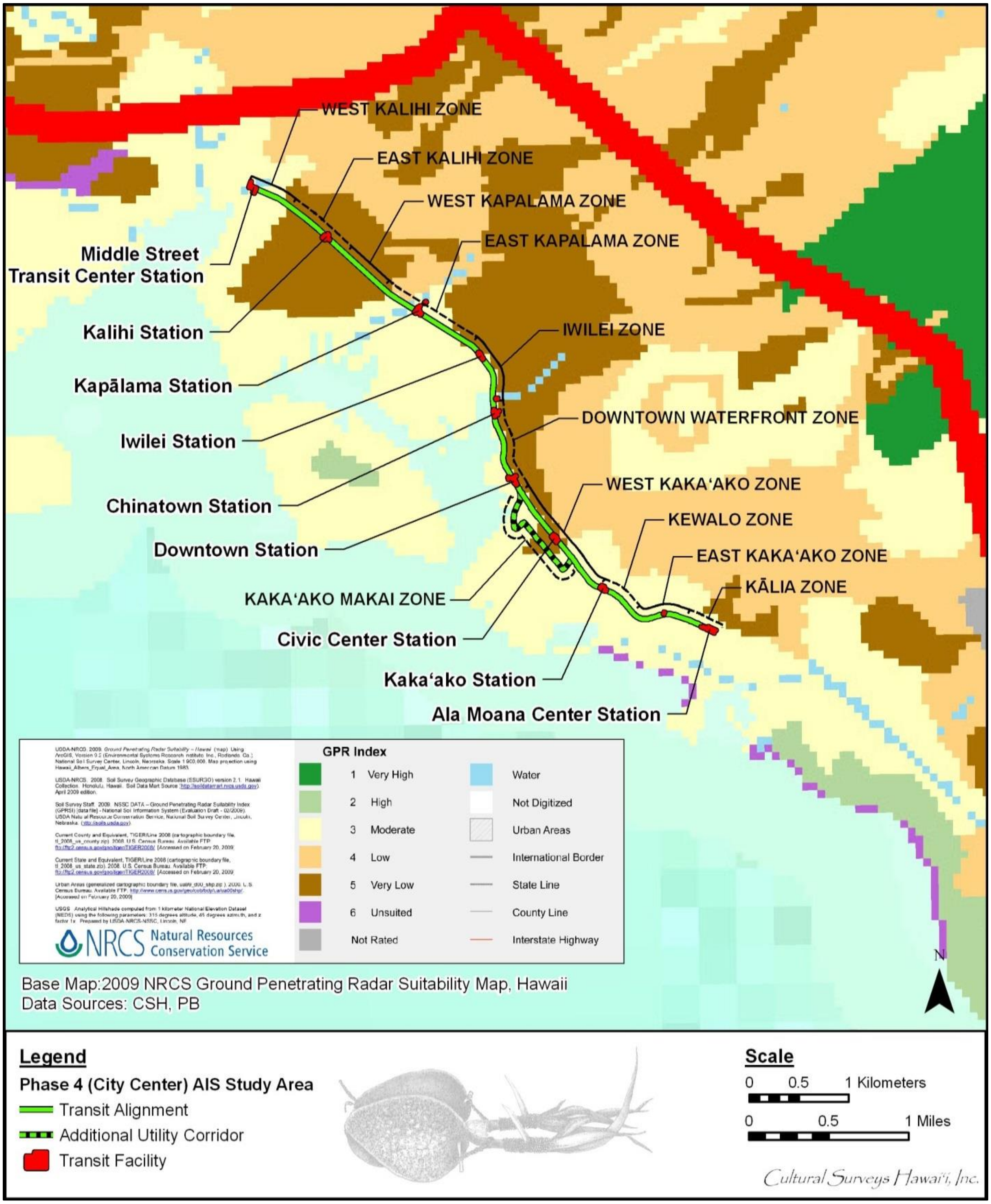

Figure 1. GPR suitability map (source: National Resource Conservation Service) showing the location of the study area

Note that the estimated depth penetration by the NRCS is based on the use of a 200MHz antenna. The current survey utilizes a 400MHz antenna, which balances radar penetration depth with image resolution, so all projected depth estimates by the NRCS must be cut in half. Thus average depth penetration would be 3.5 feet (1.0 m) in moderate suitability areas and 0.8 feet (0.2 m) in low suitability areas.

2.2 Survey Methodology

A total of 251 test excavations were surveyed and excavated during HHCTCP Section 4 AIS. GPR surveys were conducted on all test excavations with the exception of a bore-hole excavation (T-124A) and a test excavation (T-206) that was located in a planter inaccessible to the GPR equipment. The excavations tested two elements of subsurface construction associated with the project: support columns and utility relocation corridors. The test excavation size for the support columns was generally 0.90 m by 3 m, while utility corridor test excavations measured 0.60 m by 6 m. GPR survey grids were created to accommodate for test excavation size and designed to balance maximum coverage and safety. Many of the test excavations were located in busy streets and required traffic control, which limited the size of the GPR grids. The size of the GPR grids was dictated by obstacles near the surveyed excavation margins including: trees, signs, curbs, etc. GPR grids were also designed to be large enough to accommodate for potential test excavation relocations needed to avoid utilities or other obstacles.

The GPR survey was conducted using a Geophysical Survey Systems, Inc. (GSSI) SIR-3000 system equipped with 400 MHz radar antenna, which was moved along transects within a survey grid (Figure 2). Transects were collected in both the Y and X directions, originating from the southwest corner (Figure 3). Most transect spacing for the Y transects were set at an interval of 0.25 m between scans and X transects were collected every meter (A few early grids used 0.50 m intervals). Due to computer interpolation software (Radan 7; see Post-processing section below), it was only necessary to collect Y axis transects for graphic interpretation of the data for sediment analysis. However, to better identify utilities running parallel to the excavation long-axis that may fall between the Y axis scans, it was necessary to collect X axis transects. GPS points were taken at the corners of the GPR grid using a Trimble Pathfinder Pro XH (with sub-meter post-processed horizontal accuracy). Plan views were also drafted which include: GPR grid locations, surveyed test excavation locations, marked or potential utilities (designated through the “One-call” utility notification process), and any other objects that may affect analysis.

Figure 2. Photograph showing the GPR grid and antenna

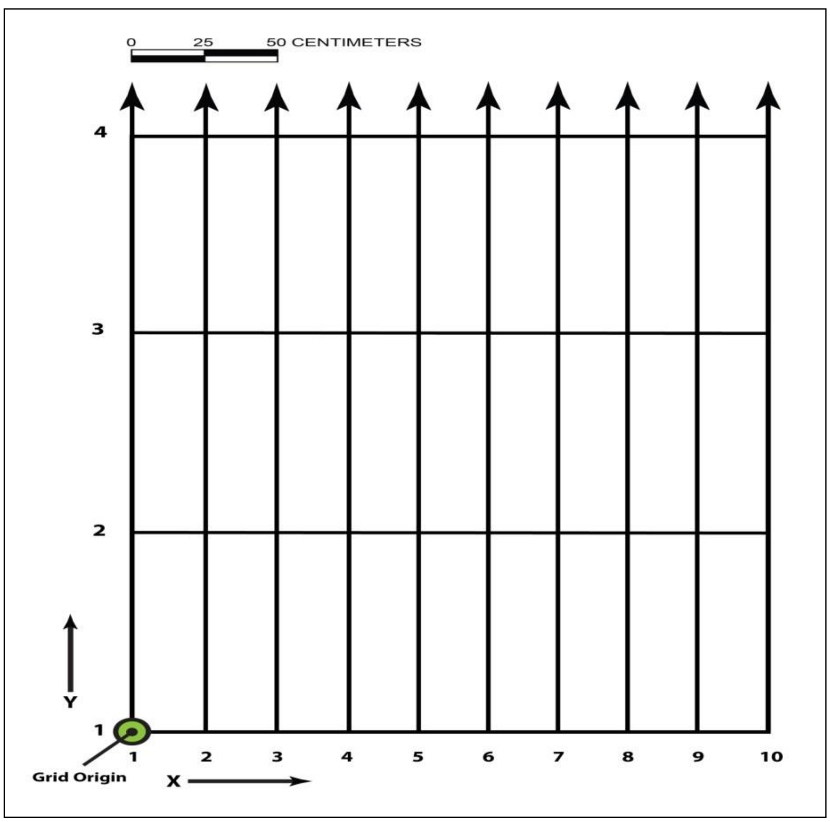

Figure 3. Transect alignment and spacing

2.3 Data Collection Parameters

GPR data collection parameters were held constant throughout the survey (Table 1). However, a varying dielectric constant (a mathematical constant applied to the signal return to determine depth) was used in anticipation of complex stratigraphic sequences within the project area. USDA soil survey data indicate that the project area consists of three predominate sediment types including: Ewa Series silty clay loam (alluvium derived from decomposed basalt), Pearl Harbor soil series (alluvial soils derived from decomposed basalt deposited over and mixed with muck), and Fill land (fill sediments consisting of “material dredged from the ocean or hauled from nearby areas, garbage, and general material from other sources” are located within the project area) (Foote et al. 1972: 31). The dielectric constant was adjusted during post-processing once known depths are determined as a form of signal calibration. A dielectric range of 10.0 to 15.0 was used throughout the project area.

Table 1. GPR Data Collection Parameters

Parameter	Settings
Antenna	400 MHz
Transmission rate	120KHz
Samples	512
Format	16-bit
Range	47 nanoseconds
Dielectric	10.00 – 15.00
Rate	120
Scans per unit	75 per meter
Low Pass Filter	750MHz
High Pass Filter	200MHz

2.4 Post-processing

All collected radar data were post-processed using *RADAN 7*, which is an industry standard for GPR data processing.

RADAN 7 was utilized to generate two-dimensional depth profiles from the collected GPR data. These profiles illustrate the geometry of the reflections recorded during data collection. An analysis of these profiles can determine whether the radar energy is reflecting from a flat stratigraphic layer (seen as a distinct horizontal band on a profile), a discrete buried object (seen as a hyperbola in profile), or from stratigraphic irregularities such as subsurface disturbances associated with utility installation or human interment (also seen as hyperbolas, but usually are more ephemeral and consist of clustered reflections).

Position correction was utilized to remove unwanted surface “noise” from GPR profiles. High and low pass filters were applied to remove any excess background “noise” generated from nearby power lines, radio frequencies, etc. during data collection. Gain (signal amplification) was also applied to accent poorly defined or ephemeral reflection that are typically associated with subsurface cultural deposits.

RADAN 7 was also used to generate amplitude slice maps from the collected GPR data. Amplitude slice-maps are a three-dimensional tool for viewing differences in radar reflection amplitudes across a given surface at various depths. Amplitude slice-maps can be thought of as plan view maps or excavation level records that display GPR data at user defined depth intervals. Reflected radar amplitudes are of interest because they measure the degree of physical and chemical differences in buried materials, which in turn can indicate the presence of stratigraphic interfaces, descrete buried objects (i.e., basalt boulders, utility lines, burial caskets, etc.), or stratigraphic irregularties (i.e., subsurfaces anomalies associated with burial pits, fire pits, buried irrigation ditches, etc.). The amplitude slice maps are also important because they allow the visulization of radar reflections throughout the entire data set collected at a survey area at a given depth. This gives size and shape to collected radar reflections, which can aid in the interpretation of identified subsurface anomalies.

Amplitude slice-maps are generated through the comparison of radar reflection amplitudes recorded in vertical depth profiles, which corespond to individual transects collected within a survey grid along the X-axis (Note that while transects are collected in the Y-direction, they are actually located within the X-axis.). In this method, amplitude variations are analyzed at each location where a radar reflection was recorded. Reflection amplitude data from the X-axis is then use to interpolate reflection data on to the Y-axis.

2.5 Ground-truthing

GPR interpretations, including slice maps and profiles, were provided to field crews prior to excavation of test excavations. It was intended that the GPR analysis be used to aide excavation in anticipation of stratigraphic changes, utilities, or anomalies that may represent a buried discrete object. A GPR Interpretation form was included in the test excavation documentation packets and field crews were tasked with checking the accuracy of the pre-excavation GPR analysis. Ground-truthing GPR data with test excavations consisted of:

- *Were there factors that limited GPR depth penetration or caused image distortion?*
- *Were there GPR anomalies that corresponded to utility lines (metal or plastic), construction debris, boulders (basalt or limestone), previously backfilled excavations, concrete slabs, trash pits, coffin burials, traditional Hawaiian burials, etc.?*
- *How accurate were pre-excavation GPR interpretations? (Provide specific discussions in relation to both slice maps and profiles.) Were subsurface features present where indicated? Were indicated depths accurate? If initial analysis was inaccurate, try to provide an explanation for the documented anomalies.*
- *Were any subsurface features or sediment transitions present that were not recorded by the GPR? (i.e., utility lines, trash pits, burials, drastic stratigraphic transitions, etc...)*

The completed interpretation forms were then used to compile an excavation by excavation analysis detailing the GPR results, usefulness, and accuracy of the GPR data. The excavation by excavation analysis includes: geospatial referencing of the excavation, proximity to utilities, a brief review of both slice and profile maps, and a visual comparison of excavated profiles and GPR signal profiles. For reporting purposes, this GPR report and the archaeological inventory survey (AIS) for the City Center Section 4 of the Honolulu High-Capacity Transit Corridor Project (HHCTCP) has been divided into 11 zones based on geographic and cultural boundaries. GPR results for 249 test excavations conducted during HHCTCP Section 4 are presented following the GPR Human Remains Report section.