Mutch Associates, LLC
Environmental Engineers and Scientists

Technical Memorandum

To: Prashant K. Gupta (Honeywell)
From: Robert D. Mutch, Richard F. Carbonaro
Subject: Technical Approach for Phase 2 CO_2 Sparging, LCP Chemicals Site, Brunswick GA (Revision 1)
Date: September 11, 2014
CC: James M. O'Loughlin (Parsons)

Phase 1 of CO_2 sparging at the LCP Chemicals Site, Brunswick GA (Site), was completed in February 2014. As documented in the Phase 1 final report (Mutch Associates and Parsons, 2014), CO_2 sparging was extremely successful in lowering pH and mercury concentrations in the deep Satilla aquifer. In addition, Phase 1 demonstrated an average 33-foot radius of influence (ROI) to achieve pH < 7.5. Phase 2 of CO_2 sparging is scheduled to commence in Fall of 2014. This work will be performed in accordance with the framework presented in the CO_2 Sparging Work Plan (Work Plan) (Mutch Associates and Parsons, 2013). The purpose of this technical memorandum is to provide the Phase 2 sparge well placement within the Phase 1 footprint and southern area, update the monitoring plan, and address operational changes based upon lesson learned during Phase 1.

Location of Year 2 Sparge Wells Within the Phase 1 Footprint

Phase 1 sparge wells were placed approximately 80 feet apart on a coarse, semi-regular, hexagonal grid pattern (Mutch Associates, Parsons, 2013). This pattern allows for various final sparge well spacings by adding additional sparge wells to the grid. The conceptual layout of Phase 2 sparge wells within the Phase 1 footprint is shown in Figure 1. Phase 1 sparge and Phase 2 sparge wells and their associated ROI form sparge "columns." There is overlap of Phase 1 and Phase 2 sparging radii within each column, and a small amount of non-overlap (i.e. white space) in-between columns. The columns of sparge wells are oriented perpendicular to the direction of groundwater flow. Thus, groundwater within these areas of non-overlap will travel through sparged areas and interact with residual saturation of CO_2 which will continue to treat groundwater. The positioning of the Phase 1 and 2 wells is such that the final sparge well spacing is 69.3 feet (ft) in the x-direction and 40 ft in the y-direction.

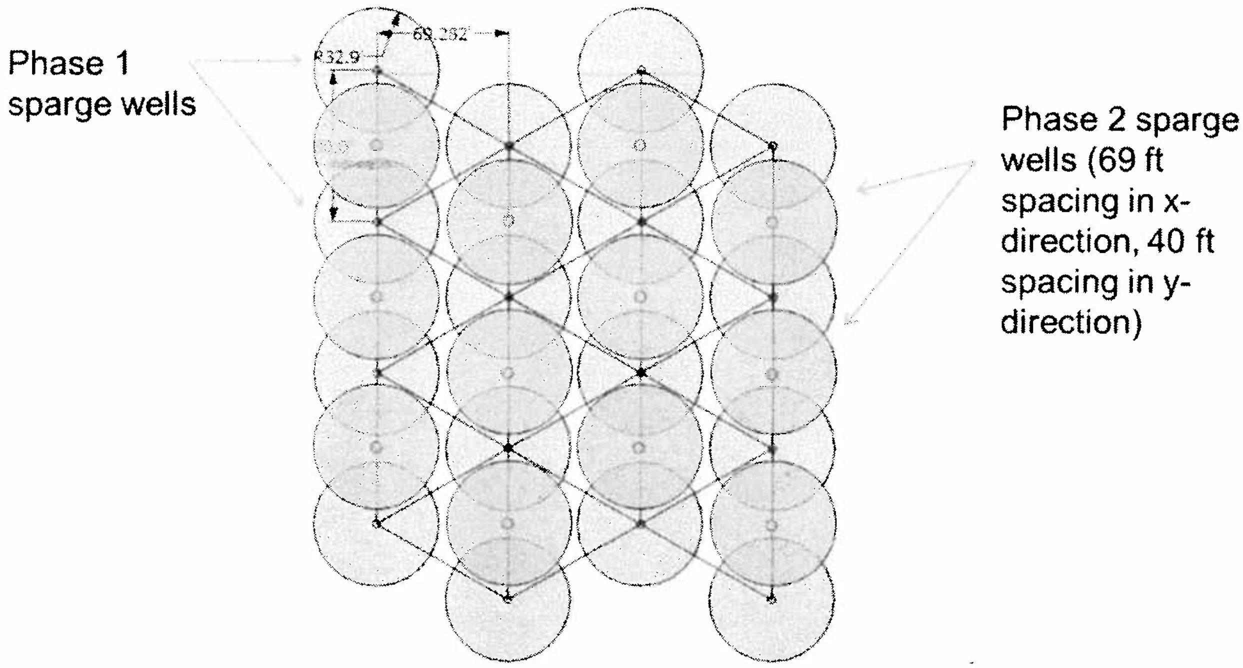

Figure 1. Conceptual Phase 2 sparge well layout for the Phase 1 footprint.

The physical layout of Phase 2 sparge wells within the Phase 1 is shown in Figure 2. A total of 58 Phase 2 sparge wells are shown on Figure 2 (SW-66 through SW-123). Consistent with the conceptual layout, Phase 2 sparge wells (shown in green) are between Phase 1 sparge wells (shown in red). Additional Phase 2 sparge wells were placed to the areas east, south and west of the elevated pad (e.g. SW-111 to SW-113 and SW-116 to SW-118) to treat groundwater underneath the pad. Phase 2 sparge wells were not placed in the area near SW-28 and SW-40 because pre-Phase 1 pH monitoring indicated that this location had pH < 10.5. As was the case during Phase 1 well installation, small modifications to this layout may be required as a result of underground or above ground obstructions such as electrical utilities or groundwater conveyance to the on-site treatment plant.

Location of Year 2 Sparging Wells Within Southern Area

In accordance with *Post-sparge pH Monitoring and Geoprobe Transects* technical memorandum, dated June 20, 2014, Geoprobe sampling for pH and mercury (Hg) was conducted in July 7 – 9, 2014 to provide further definition of the CBP in the southwestern area of the Site. A total of ten Geoprobe samples (GP-01 through GP-10) were taken from the base of the Satilla aquifer. In addition, the pH of 38 deep Satilla monitoring wells was also collected. A second round of Geoprobe sampling at nine locations occurred on August 7 – 8, 2014 (GP-11 through GP-19). The results of these two sampling events (Figure 3) indicated that deep Satilla groundwater with pH > 10.5 was present approximately 220 ft W (west) of SW-2, 320 ft SW (southwest) of SW-7, and 350 ft SE (southeast) of SW-36.

In light of these results, a pH 10.5 contour (solid line on Figure 3) was extended into the southern area from MW-515B, through MW-112C and GP-07. East of GP-07, the contour was extended just north of GP-11, GP-15, and GP-19 which all showed pH < 10.5. An approximate boundary of a pH of 10.5 (short dashed line on Figure 3) was extended from just north of GP-19 to SW-49. Mercury concentrations within the 10.5 pH boundary ranged from 5 to 220 µg/L. The pH values above 10.5 and mercury values above 50 µg/L warrant consideration of CO_2 sparging in this southern area.

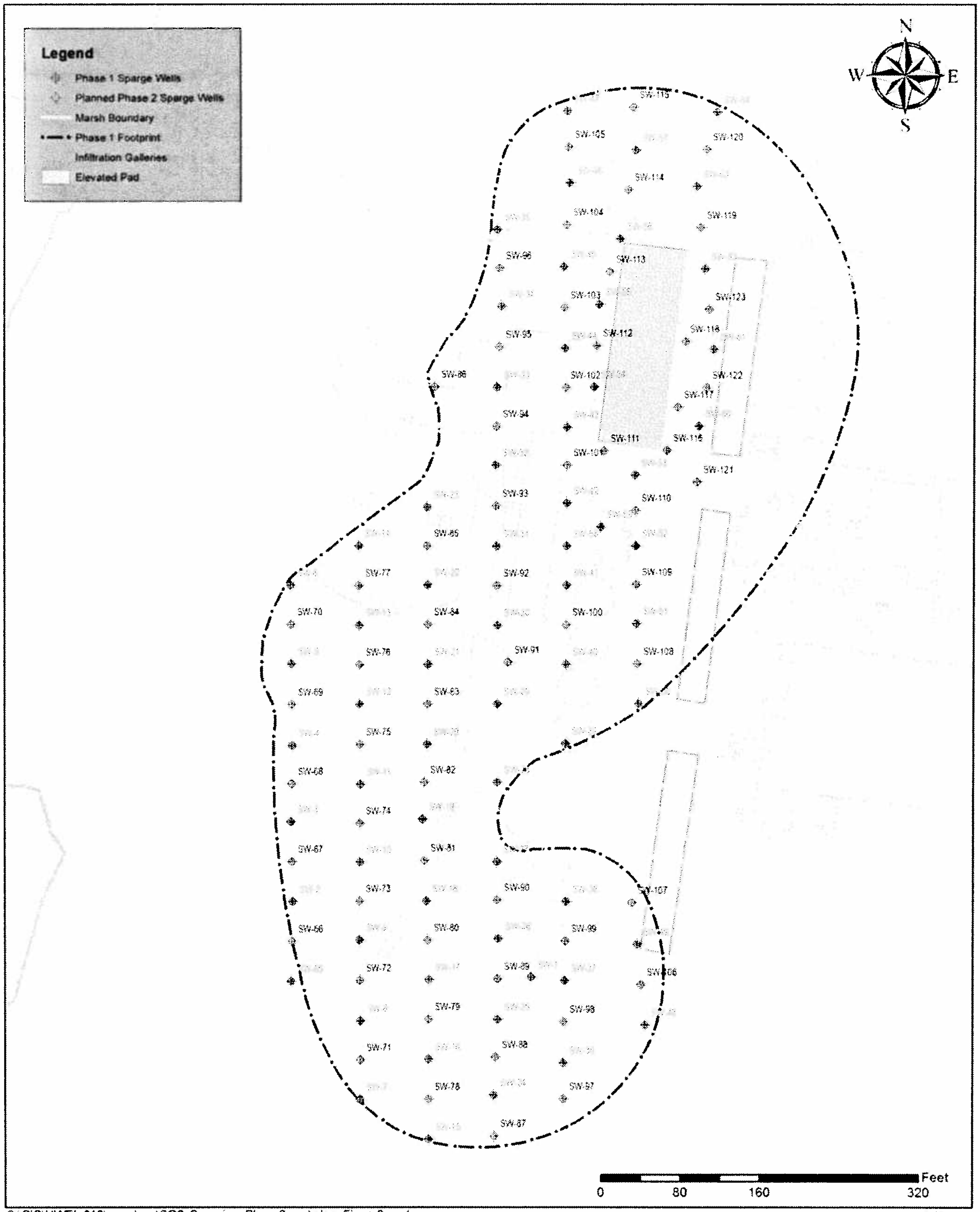

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Figure 2. Phase 2 sparge well layout within the Phase 1 footprint.

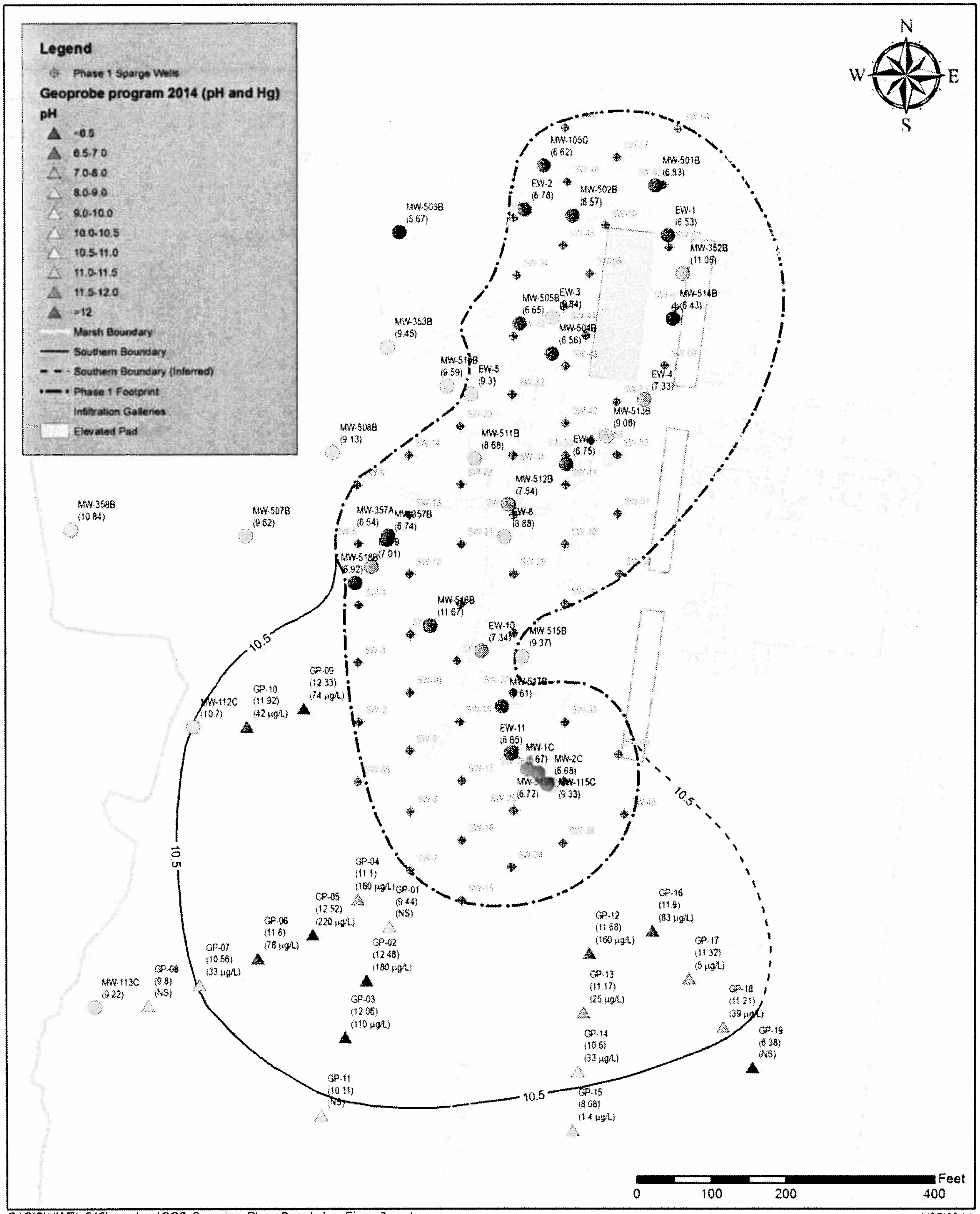

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Figure 3. Pre-Phase 2 Geoprobe and monitoring well sampling results. Data for Hg shown for Geoprobe locations only. NS indicates not sampled for Hg.

The conceptual layout for the southern area is shown in Figure 4. This layout features a coarse hexagonal grid pattern, similar to what was employed in Phase 1. Sparge wells on this coarse grid are 114.3 ft apart. Management of shallow Satilla groundwater mounding is more challenging in the southern area relative to the uplands because the depth of the unsaturated zone is smaller. The coarse grid provides more separation between sparge wells and helps mitigate excessive mounding and surfacing. Initially, adjacent wells will not be sparged simultaneously until the effect of sparging on mounding is understood in the southern area. In addition, flow rates can be decreased and/or sparge pulse durations can be shortened to mitigate the risk of excessive groundwater rise.

The coarse layout will allow for placement of additional sparge wells on the hexagonal grid in future phases, pending the results of Phase 2 sparging. The spacing of 114.3 ft was selected because it results in a final spacing of 66 ft when additional sparge wells (shown as the grey circles on Figure 4) are placed at the geometric center of tringles formed by the Phase 2 wells.

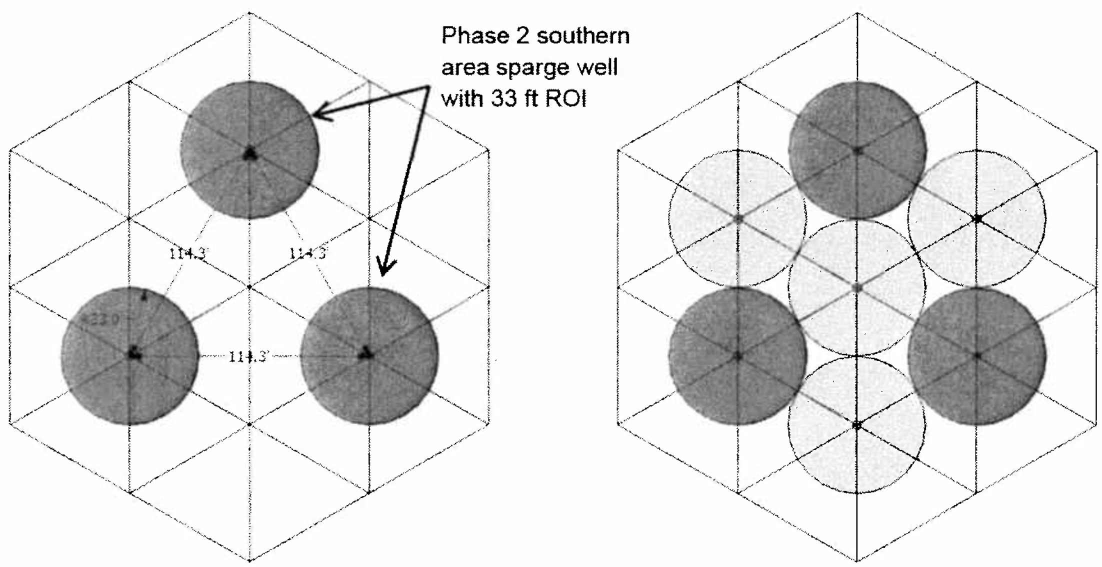

Figure 4. Conceptual layout of sparge wells in the southern area.

The tentative physical layout of sparge wells in the southern area is shown in Figure 5. A total of 22 wells are planned (SW-124 through SW-145). Consistent with the conceptual layout, Phase 2 sparge wells in the southern area are on a coarse grid, 114.3 ft on center. As discussed earlier for the Phase 1 footprint, small modifications to this layout may be required as a result of underground or above-ground obstructions.

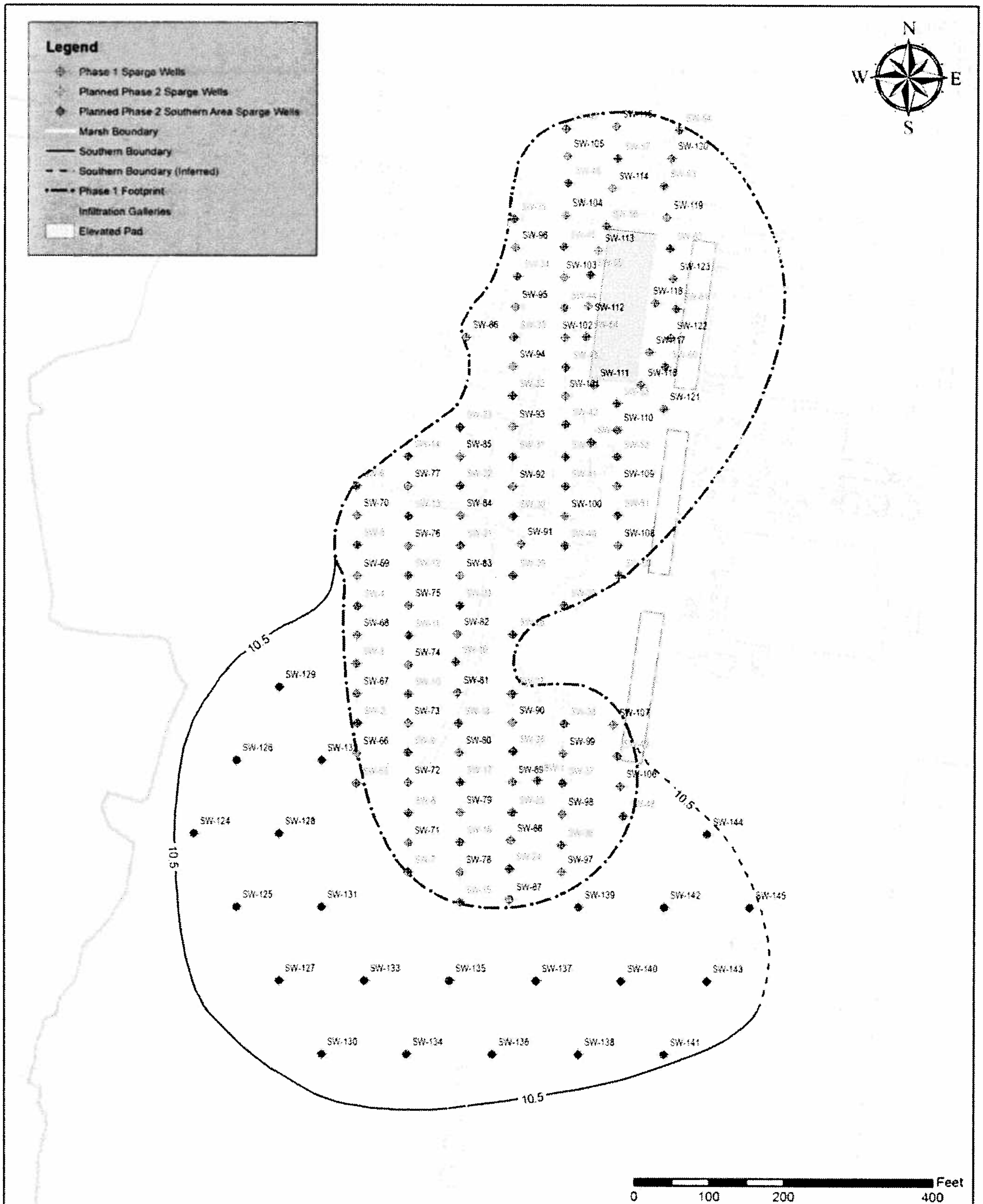

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Figure 5. Phase 2 sparge well layout within the southern area.

Well Drilling and Completion

The objectives of well drilling for Phase 2 are the same as that for Phase 1: to set the sparge well screens as close to the base of the Satilla Aquifer as practicable and minimize any penetrations of the variably-cemented sandstone aquitard or the clay strata that directly overlies it in some areas. To help meet these objectives, a structural contour map (Figure 6)[1] and clay isopach map (Figure 7)[2] were created using information from historical boring logs and the recent Geoprobe program. In areas where the expected screen elevation can be triangulated accurately using the structural contour map, split-spoon sampling will commence from 6 ft above the expected elevation of the top of the variably-cemented sandstone. Well locations that do not have sufficient data to confidently determine likely screen elevation or indicate clay near the expected screen setting, split-spoon sampling will proceed from 40 ft below ground surface as was performed during Phase 1. In addition, a total of 20 new shallow piezometers will be placed within the Year 2 sparging footprint to monitor for shallow groundwater rise. All other details of well drilling are the same as in Phase 1 and can be found in the Work Plan.

Sparge wells will be completed as described in the Phase 1 Work Plan. All new sparge wells will be monitored for pH and conductivity after development. In addition, one-half of the new sparge wells within the Phase 1 footprint and all new sparge wells in the southern area will be sampled pre-sparge and analyzed for alkalinity to assist in decisions for CO_2 dosing (Table 1). A total of 16 sparge wells (eight in the Phase 1 footprint, eight in the southern area) will be sampled and analyzed for dissolved mercury pre and post sparging (see wells in bold-italics in Table 1). This information will provide baseline mercury concentrations and percent removals post-treatment.

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[1] Contour map was created using the Simple Kriging method within the Geostatistical Analyst package in ArcGIS (v 10.2.2). The dataset (n = 162) was detrended using a second order local polynomial interpolation prior to Kriging. The experimental semivariogram was fit using an isotropic spherical model with (range = 1043 ft, partial sill = 0.65 ft^2). A nugget of 1.85 ft was used to account for the spatial sources of variation at distances smaller than the sampling interval (i.e. data points that are next to each other that show a large difference in depth to sandstone). The data was gridded using 10 ft by 10 ft cells.

[2] Clay isopach map was created using the Inverse Distance Weighting method within the Geostatistical Analyst package in ArcGIS (v 10.2.2). IDW was used because it is an exact interpolator and it does not predict values outside the bounds of the data thereby preventing prediction of negative clay thicknesses. A power of 3 was used because of the high density of the data provided by the sparge well locations. The dataset (n = 149) was using 10 ft by 10 ft cells.

Table 1: Summary of Sparge Well Sampling and Analysis[(a)]	
Phase 1 Footprint:	SW-67, ***SW-68***, SW-70, ***SW-71***, SW-72, ***SW-73***, SW-74, SW-77, SW-78, SW-79, SW-80, SW-83, ***SW-87***, SW-88, SW-94, SW-97, SW-100, SW-101, ***SW-106***, SW-107, ***SW-108***, SW-109, SW-111, SW-112, ***SW-113***, ***SW-115***, SW-117, SW-118, SW-123
Southern Area:	***SW-124***, SW-125, SW-126, SW-127, ***SW-128***, SW-129, SW-130, SW-131, SW-132, SW-133, ***SW-134***, ***SW-135***, ***SW-136***, ***SW-137***, SW-138, SW-139, SW-140, ***SW-141***, SW-142, SW-143, SW-144, ***SW-145***
(a) Sparge wells in ***bold-italics*** are will be measured for mercury in addition to alkalinity as described in the text.	

Operations

Phase 1 of CO_2 sparging tested four sparging regimens to optimize CO_2 efficiency (Mutch Associates and Parsons, 2014). The Phase 1 final report recommended a once per week regimen with a 4-hour duration (Regimen A) to start, with adaptive management to optimize well-specific performance. For example, wells may be sparged at longer intervals (e.g. 8 hours or 24-hours) where necessary to provide adequate mass flows of CO_2. An overall mass of at least 8,000 to 9,000 lb of CO_2 per sparge well is required in moderate alkalinity areas, and 1.5-times this amount in high alkalinity area is estimated to be required to meet treatment objectives.

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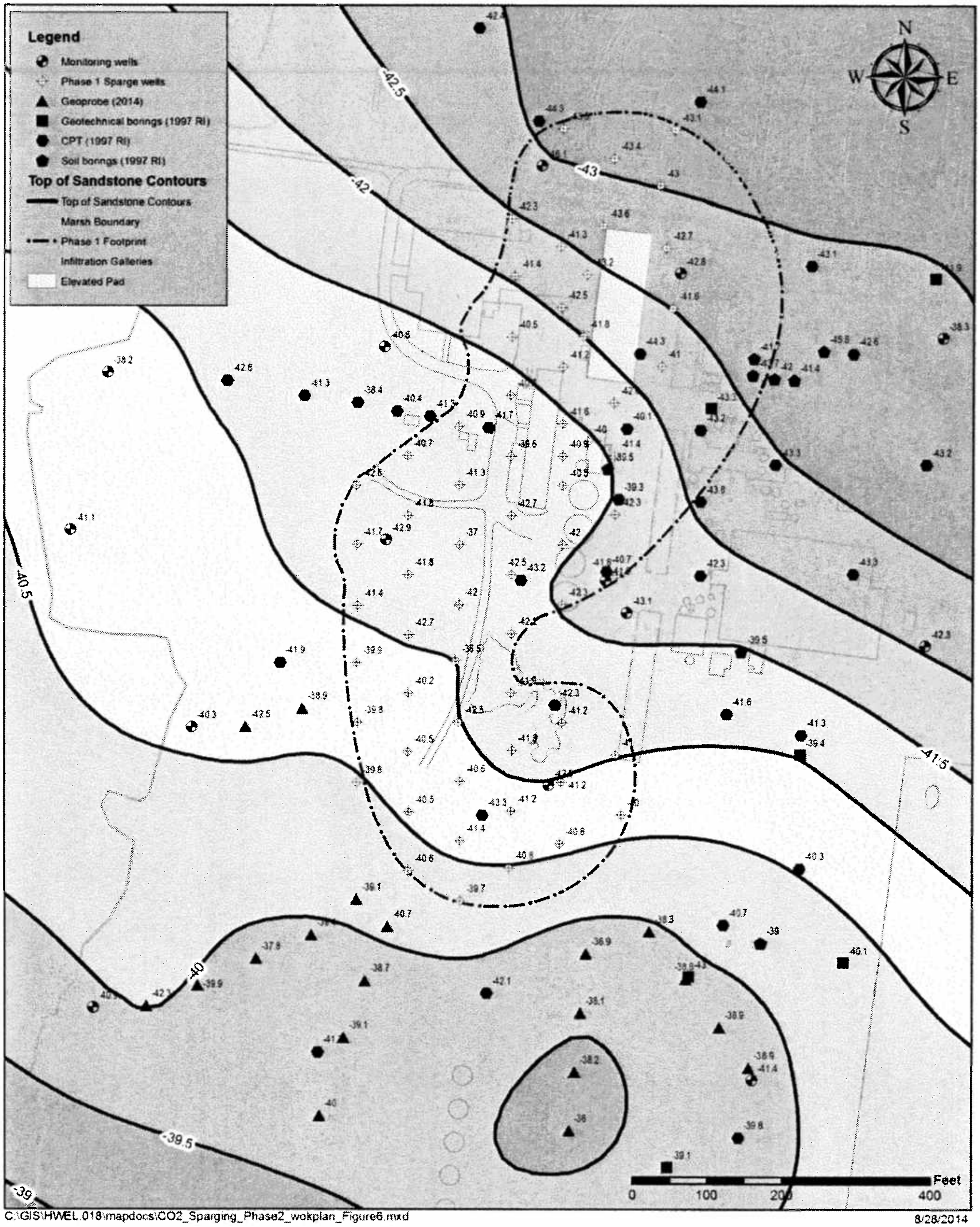

Figure 6. Structural contours of top of variable-cemented sandstone.

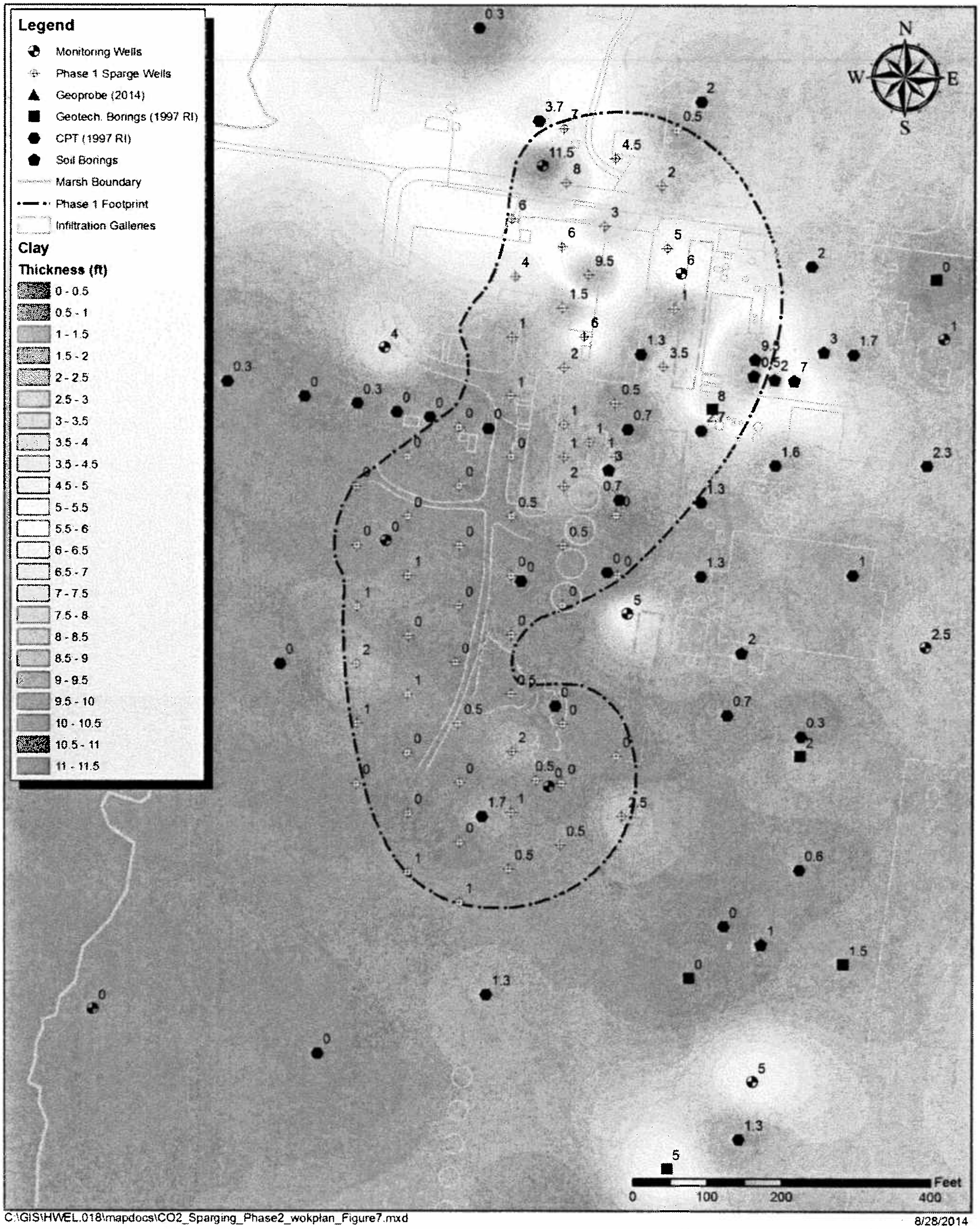

Figure 7. Clay isopach map. Measured clay thicknesses (in ft) at specific locations are provided on the map.

Monitoring Plan

Pre-and Post- Sparge Monitoring

Pre-sparge groundwater monitoring will be performed in a sub-set of monitoring points (monitoring wells and extraction wells) within the sparging footprint (Table 2). The criteria used for monitoring point selection was all deep wells, and any well prior to Phase 1 sparging that had pH > 10 or Hg > 20 µg/L. The majority of these points are in the deep Satilla with a small number in the mid Satilla. These wells will be purged and sampled using the low flow "Tubing-in-Screened-Interval" method, pursuant to US EPA Region IV Environmental Investigations Standard Operating Procedure (SOP). Groundwater pH, specific conductivity (SC), dissolved oxygen (DO), temperature, and oxidation-reduction potential (ORP) will be measured in the field as part of this procedure. Specific gravity will be measured in a subset of Satilla wells (see wells in bold italics, Table 2) using a field hydrometer. The specific wells selected for specific gravity include a subset of the wells monitored during Phase 1 and some additional monitoring wells in the southern area (i.e. MW-112C and MW-113C).

Table 2: Monitoring points selected for Phase 2 sampling and analysis[(a)]

Extraction wells (10)	EW-1, EW-2, EW-3, EW-4, EW-5, EW-6, EW-8, EW-9, EW-10, EW-11
Deep Satilla monitoring wells (28)	***MW-105C, MW-112C, MW-113C, MW-115C,*** MW-1C, MW-2C, MW-352B, MW-353B, MW-357A, MW-357B, MW-358B, ***MW-501B, MW-502B, MW-503B, MW-504B,*** MW-505B, MW-507B, MW-508B, MW-510B, ***MW-511B, MW-512B, MW-513B, MW-514B,*** MW-515B, ***MW-516B,*** MW-517B, ***MW-518B,*** MW-519B
Mid Satilla monitoring wells (7)	MW-352A, MW-502A, MW-504A, MW-505A, MW-513A, MW-514A, MW-517A
(a) Wells in ***bold-italics*** are will be measured for specific gravity pre and post sparging as described in the text	

The groundwater samples will be submitted for analysis by TestAmerica (Savannah, GA) for the analytical parameters listed in Table 3. Approximately one week after completion of Phase 2 sparging, these same wells will be resampled and analyzed for the parameters listed in Table 3. An additional monitoring event will occur 4 to 8 months after the end of Phase 2 sparging to assess longer-term changes in water quality after sparging. Since the Southern area has very few monitoring wells, Geoprobe sampling of deep Satilla groundwater for analysis of pH and Hg will be conducted a few weeks after the conclusion of sparging. A total of fifteen samples will be taken within the 10.5 boundary along the same transects (Figure 3) performed in July and August of 2014.

Table 3: Water Quality Analytes and Associated Laboratory Methods

Analyte	Method	Description
pH	EPA SW-846 9040B	Ion selective electrode
Alkalinity	SM 2320B	Potentiometric titration
Total mercury	EPA SW-846 7470A	Cold-vapor atomic absorption spectrophotometry
Total dissolved solids	SM 2540C	Gravimetric
Total metals & silica[(a)]	EPA SW-846 6010B	Inductively Coupled Plasma – Atomic Emission Spectroscopy
(a) Total metals included aluminum, barium, beryllium, calcium, cobalt, chromium, iron, potassium, magnesium, manganese, sodium, nickel, selenium, vanadium, zinc.		

Field Measurements During Sparging

Field measurements of pH and conductivity will occur at a frequency of approximately one time per week at the monitoring points listed in Table 2. All other details of sampling are the same as in the Work Plan except that a YSI Professional Plus multi-parameter meter will be employed instead of separate Hach pH and conductivity meters.

Groundwater Monitoring

Groundwater levels within the Satilla wells will be monitoring via a combination of automatic data loggers and manual water level readings. Solinst Level Loggers (or equivalent) will be employed for automatic data logging. The data logger will be set at a designated depth within the well. The automatic data loggers will be synchronized for time and will be programmed to record water levels at 5-minute intervals during the CO_2 sparging period and for one day after conclusion of the sparging. The manual depth to water measurement and time of collection will be recorded in a field book.

The following wells along the marsh will be monitored with pressure transducers: MW-112C, MW-353B, MW-503B, MW-507B, and MW-508B. An additional five monitoring points within the Phase 1 sparging footprint will be outfitted with pressure transducers. The transducers will be connected to a reader where the data can be viewed and downloaded. The piezometers along with shallow Satilla wells will be monitored for water level rise via manual measurement with an electronic water level meter.

Aquifer Testing

The Phase 1 pre- and post-sparge aquifer tests were precluded from direct analysis of aquifer properties using conventional methods (e.g. drawdown monitoring) due to the presence of residual CO_2. As a result, Phase 2 pre- and post- aquifer tests will not be performed. As the CO_2 residual saturation dissolves into the surrounding groundwater, a process that could take months or years, aquifer properties such as hydraulic conductivity and storativity should concomitantly approach pre-sparge levels, except for whatever impact the minimal reduction in porosity may have on these properties.

Schedule

The schedule for Phase 2 CO_2 sparging is shown in Figure 8. The sparging effort is expected to last approximately 18 weeks, beginning in late October 2014 and extending through late-February 2015.

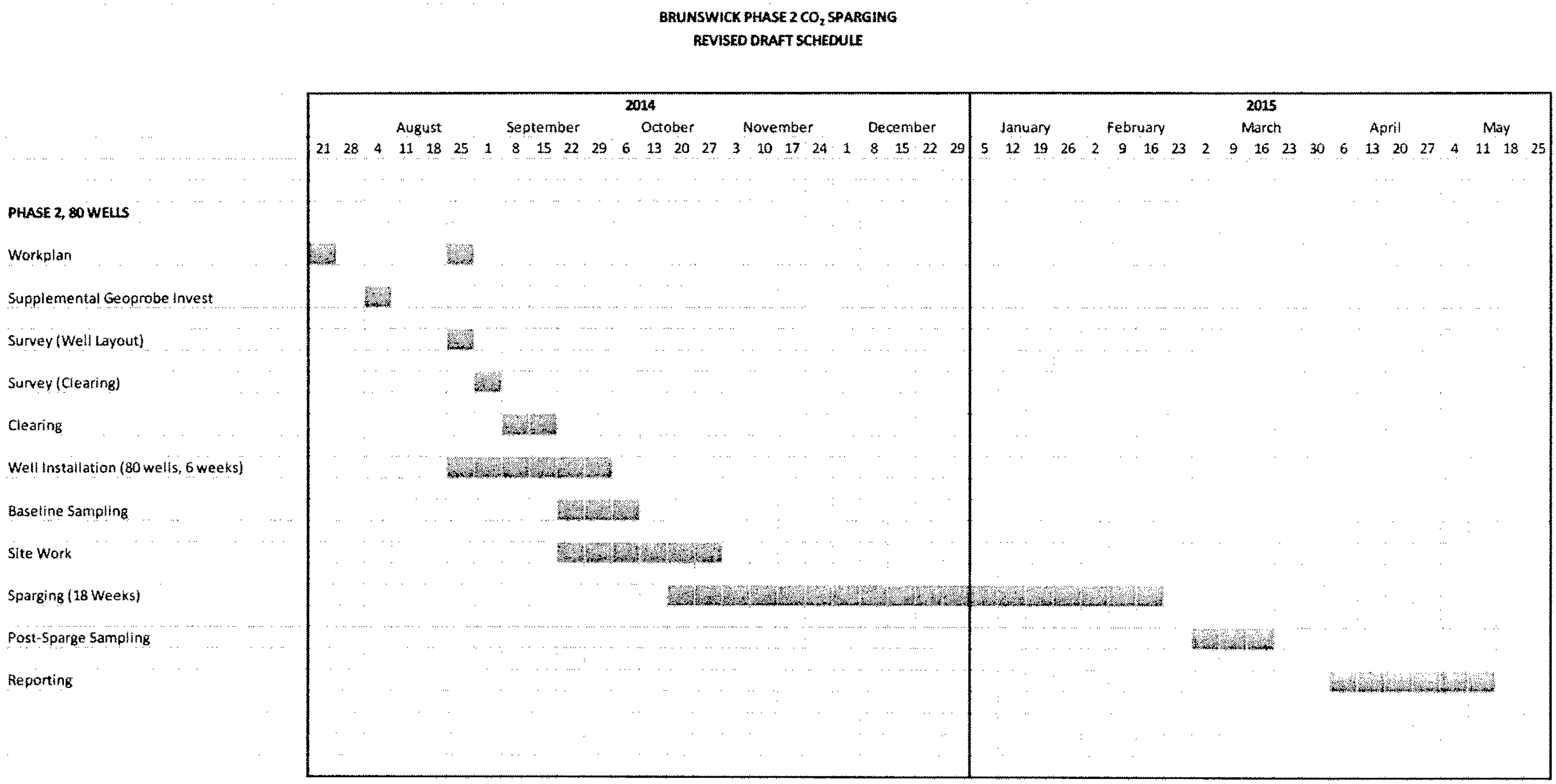

Figure 8. Schedule for Phase 2 sparging

References

Mutch Associates, Parsons (2013). CO_2 Sparging Work Plan, LCP Chemicals Site, Brunswick, GA.

Mutch Associates, Parsons (2014). CO_2 Sparging Phase 1 Full-Scale Implementation and Monitoring Report, Revision 1 LCP Chemicals Site, Brunswick, GA.