CO_2 SPARGING WORK PLAN

LCP CHEMICALS SITE, BRUNSWICK, GA

Prepared for Honeywell

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LIST OF ACRONYMS

bls	Below land surface
btoc	Below top of casing
CBP	Caustic brine pool
CO_2	Carbon dioxide
ESTCP	Environmental Security Technology Certification Program
GaEPD	Georgia Environmental Protection Division
H_2SO_4	Sulfuric acid
Hg	Mercury
IDW	Investigation Derived Waste
LCP	Linden Chemicals and Plastics
NTU	Nepholometric Turbidity Unit
ORP	Oxidation Reduction Potential
psi	Pounds per square inch
psig	Pounds per square inch – gauge
PVC	Poly vinyl chloride
RAO	Remedial Action Operation
RI	Remedial Investigation
ROI	Radius of influence
scfm	Standard cubic feet per minute
SC	Specific conductivity
SOP	Standard Operating Procedure
TDS	Total dissolved solids

1. PURPOSE AND OBJECTIVES

On behalf of Honeywell (formerly AlliedSignal, Inc.), Mutch Associates, LLC, in collaboration with Parsons Corporation (Parsons), have prepared this work plan for implementation of full scale CO_2 sparging of the subsurface caustic brine pool (CBP) at the LCP Chemicals Site in Brunswick, Georgia (Site). The CBP is being addressed under an Administrative Settlement Agreement and Order on Consent (AOC) issued by the U.S. Environmental Protection Agency (EPA) Region 4 on April 18, 2007. The remedial action objectives (RAO) were defined in the AOC - namely, reducing the pH of the CBP to between 10 and 10.5 and reducing the density of the CBP.

1.1. Site Description

The Site is located at 4125 Ross Road,[1] in the City of Brunswick, in Glynn County, Georgia, and is bordered by the Turtle River marshes to the west and south and the urban populations of Brunswick to the north and east. The Site encompasses approximately 813 acres, of which 684 acres are tidally influenced salt marsh. A site location map is provided in Figure 1-1.

Industrial operations were conducted by multiple parties from approximately 1919 until 1994. The site was originally owned and operated by the Atlantic Refining Company (ARCO) who operated a petroleum refinery from 1919 until 1930 and a petroleum storage facility until approximately 1955. Portions of the site were also owned by Georgia Power Company and the Dixie O'Brien Paint Company. In 1955, the property was purchased by Allied Chemical, Inc. From 1956 to 1979, chlorine, hydrochloric acid, and sodium hydroxide were produced by Allied Chemical by the electrolysis of sodium chloride using mercury cells (the chlor-alkali chemical manufacturing process). In 1979, LCP Chemicals purchased the property and continued to operate the chlor-alkali process until they ceased operations in 1994. Honeywell repurchased the property in 1998 and currently owns the property.

During chemical production activities at the Site, a portion of the shallow aquifer was contaminated by residuals of chlor-alkali-manufacturing operations. A subsurface pool of caustic brine formed. The CBP is characterized by elevated pH, total dissolved solids, and concentrations of dissolved metals. This CBP has been defined as groundwater with a pH above 10.5. Figure 1-2 shows the location and extent of the CBP based on pH data collected in 2012[2].

1.2. Purpose and Objectives

In 2012, Mutch Associates LLC, in collaboration with Parsons, evaluated the feasibility of sparging CO_2 into the CBP to lower the pH. These efforts culminated in the implementation of a Proof of Concept Test in October and November of 2012. As described in the Proof of Concept Test Report (Mutch Associates and Parsons, 2013), CO_2 sparging is an effective, innovative technology, suitable for full scale implementation at the Site. This report summarizes key observations from the Proof of Concept

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[1] We understand that a site address was developed as part of the County's upgrade to its 911-emergency system.

[2] The mapping of the CBP (Figure 1-2) was created by kriging pH data from deep Satilla monitoring wells (MW series) from the May/June 2012 monitoring event, supplemented with data from September 2011 for site extraction wells (EW series). For most wells, field pH values were used for the mapping. The only exceptions were MW-357A, MW-357B, MW-512B and MW-516B, where laboratory pH was conservatively used because field pH was considerably lower than historic values. Well MW-113C was not included in kriging because of poor resolution in this area of the site.

Test and presents a work plan for full scale implementation. The report is organized in the following manner:

- Section 2 – Describes the design of the full scale sparging effort.
- Section 3 – Describes Year 1 implementation and reporting.

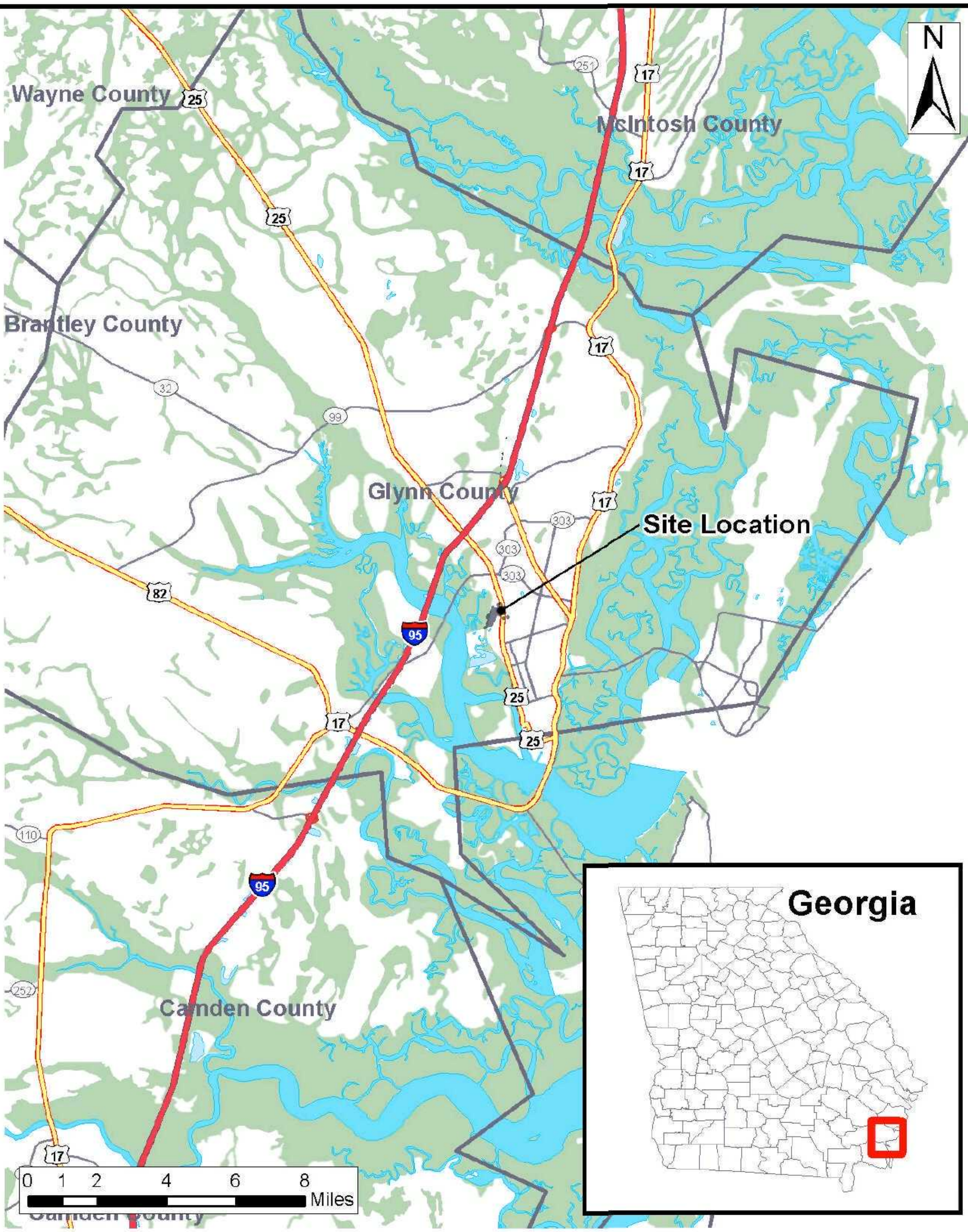

Figure 1-1: Site Location Map

LCP Chemicals Site, Brunswick, GA

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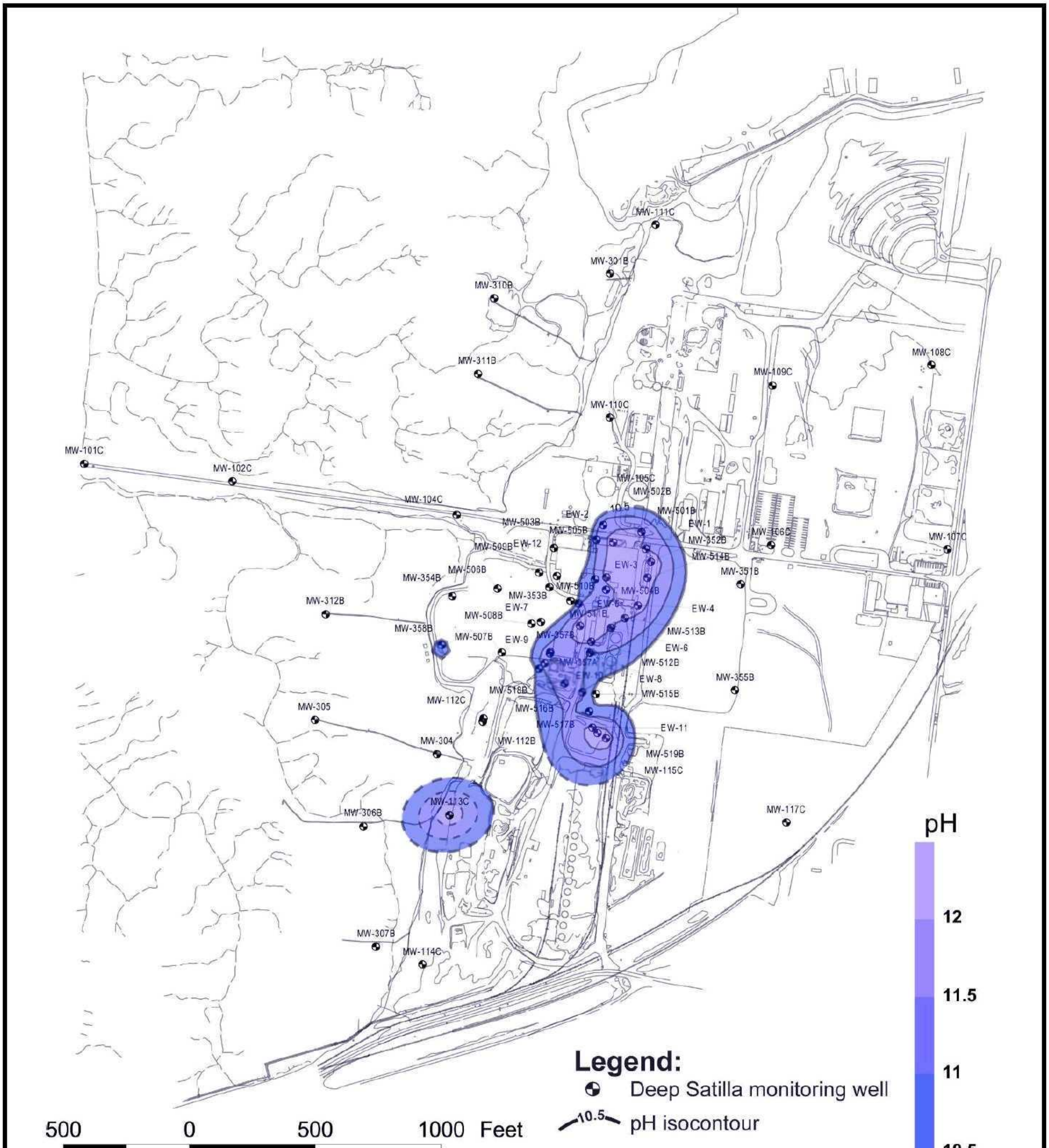

Figure 1-2: Current Location of the CBP

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2. SYSTEM DESIGN

2.1. Basis of Design

The Proof of Concept Test was conducted from October 29, 2012 to November 17, 2012 in accordance with the "Final Work Plan for CO_2 Sparging Proof of Concept Test, LCP Chemicals Site, Brunswick, GA" (Mutch Associates, 2012) dated September 11, 2012. Formal approval of the workplan was granted in a letter from EPA on September 10, 2012. The Proof of Concept Test was designed to evaluate the feasibility of CO_2 sparging to remediate the CBP in order to meet the objectives of the AOC.

Key observations from the Proof of Concept Test that are relevant to the full scale design are:

1. Significant pH reductions from pH 11-12 in the deep Satilla were achievable in 5 to 7 days sparging at circa 50 scfm.
2. A radius of influence of at least 20 feet was achieved in the deep Satilla and greater than 60 feet at the water table surface.
3. Mercury (Hg) levels in the high pH CBP waters fully-impacted by the sparging declined from 110-120 µg/L to 11-33 µg/L (70 to 90% reductions).
4. During sparging, significant mounding of the potentiometric surface was observed. Shallow Satilla wells within the 20 ft radius of sparge wells increased to within 1 foot of the ground surface.
5. Significant rebound of pH or Hg was not observed based on results from groundwater monitoring conducted 3 months after completion of sparging.

The Proof of Concept Test indicated that CO_2 sparging is an effective, innovative technology, suitable for full-scale implementation at the Site. Observations made during testing further indicate that full-scale implementation of CO_2 sparging should be conducted over a multiple-year, sequential effort. The principal drivers for this sequential implementation are:

- Management of groundwater mounding caused by superposition of multiple, closely-spaced sparge wells; and
- Maximization of sparging efficiency.

The Proof of Concept Test indicated that managing groundwater mounding during full scale implementation will be critical as mounding during the test was substantial. The groundwater table rose to within 1 foot of the ground surface during the testing. This potential for mounding will be exacerbated by superposition of mounding from multiple nearby sparging wells and by seasonal rises of the groundwater table. Moreover, in some areas of the CBP, the water table is even closer to the surface than at the test site. These factors impose a practical limit on the spacing of wells and the number of wells that can be sparged simultaneously. Conducting the implementation over multiple years will allow active sparge wells to be further apart, thereby reducing the superposition of groundwater mounding. The optimal time for sparging will be when the groundwater table is at its lowest, during the drier summer and early fall months.

The Proof of Concept Test suggested that CO_2 sparge efficiency can be enhanced by a sparge regimen that emphasizes short bursts of sparging (anywhere from ½ to 4 hrs.) followed by rest periods. The rest periods would allow CO_2 gas residual saturation remaining in the formation to both dissolve and diffuse into the surrounding CBP waters. The Proof of Concept Report concluded that during the first year of sparging, different sparge regimens be tested in an effort to optimize sparge efficiency.

The Proof of Concept results also showed that the pH reached target levels in the deep Satilla at least 20 feet away from sparge well MW-1C (Mutch Associates and Parsons, 2013). This indicates an effective radius of influence (ROI) of at least 20 feet in the deep Satilla. Modest decreases in pH in deep Satilla wells were observed at radial distances greater than 20 feet, indicating some consumption of CO_2 demand, which can be viewed as pre-treatment. The ROI in the intermediate and shallow Satilla was significantly larger than 20 feet. For example, gas channels extended all the way from MW-1C to MW-517A, which is a distance of approximately 100 feet away. Therefore, there is some uncertainty regarding the ROI that will be achieved during full scale implementation. Further evaluation of ROI can be achieved by using an initial coarse grid spacing for sparge wells during the first year of sparging, and then filling in with a denser spacing for Years 2+ based on observed results. There are currently approximately 25 monitoring wells screened in the deep Satilla that are within the areal extent of the CBP that can be used during Year 1 to evaluate ROI.

Taking these factors into consideration, the Proof of Concept Test Report concluded that full scale implementation could be accomplished over approximately 3 years, with 4 to 5 months of sparging during the dryer season followed by a 7- to 8-month period of aquifer relaxation. During the relaxation period, data collected from the site would be analyzed using a three-dimensional visualization program. These analyses would permit planning of the next year of the sparge program.

2.2. Sparge Well System

2.2.1. Sparge Well Design

The objective of the well development will be to screen sparge wells as close to the base of the Satilla Aquifer as possible. In some areas, the base of the aquifer is delimited by a clay stratum overlying the variably cemented sandstone of the Coosawhatchie formation. In other areas, the clay is absent and the variably cemented sandstone defines the base of the aquifer. The specific lithology at each sparge well location will be defined by drilling and soil sampling. The soil cores will be analyzed on Site by a geologist or engineer to determine the appropriate screened interval for each sparge well. Drilling will be conducted by sonic drilling or other means to permit sampling and logging of the lithology of the Satilla Aquifer. The number and positioning of the sparge wells is discussed in Section 2.2.3

Structural contours of the top of the clay or the variably-cemented sandstone, if the clay is absent, along with a topographic map of the CBP area will for estimation of depths to either the clay or the variably-cemented sandstone. The depth to the expected contact with the clay or the variably-cemented sandstone will be approached gradually, advancing the sampling tool only a foot or two at a time until contact is made. Some penetration of the clay or variably-cemented sandstone is inevitable and will be plugged with bentonite pellets or the equivalent before constructing the sparge well at the appropriate overlying depth. The information on the depth to the clay or the variably-cemented sandstone from each successive sparge well will be input to a structural contour mapping program such as Surfer® (Golden Software). In this way, the contour mapping can be adjusted in real time to reflect the spatial data gained from the drilling of each sparge well. This spatial information will then be used to assist the drilling of the next well.

Sparge wells will be constructed of 2-inch PVC. Sparge well screens will be 2 feet in length unless hydrogeologic conditions dictate otherwise. This relatively small screen will aid in getting the CO_2 sparging as close to the base of the aquifer as possible, recognizing that the CO_2 gas tends to preferentially exit the well screen near the top of the screened interval. An example of a hydrogeologic scenario where a longer screen may be warranted is a basal transmissive sand subdivided by a one-foot or slightly thicker clay stratum. In such a case, a slightly longer screen will be used to attempt to sparge CO_2 both below and above the thin clay stratum.

Following installation, the wells will be developed to remove material which may have settled in and around the well screen. Development will consist of the removal of ten well volumes or achieving a turbidity reading of less than 50 NTUs. During this development, the approximate maximum yield and specific capacity of the well will be determined.

Drill cuttings and other investigation derived waste (IDW) will be temporarily drummed, labeled, transported, and staged at a waste accumulation area. IDW will be characterized and disposed at an appropriate off-site repository.

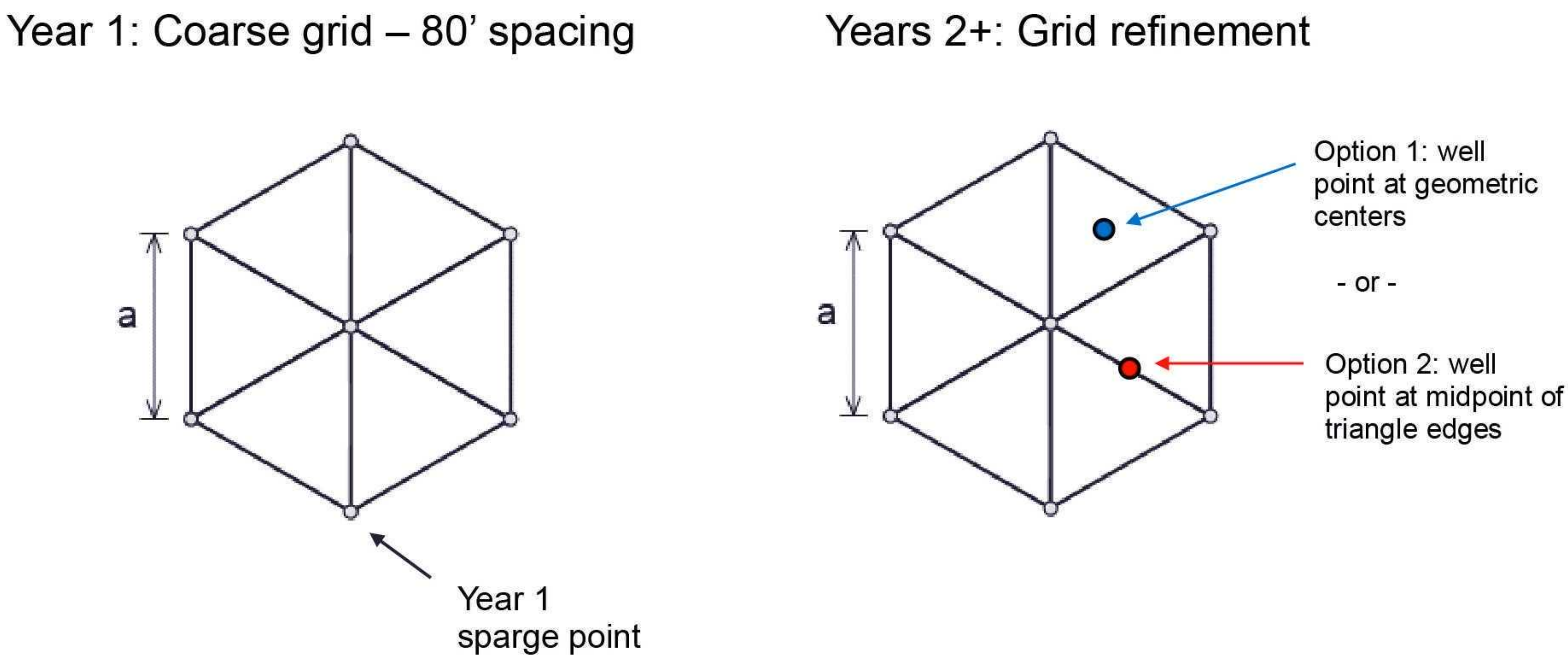

Figure 2-1: Conceptual coarse sparge well layout

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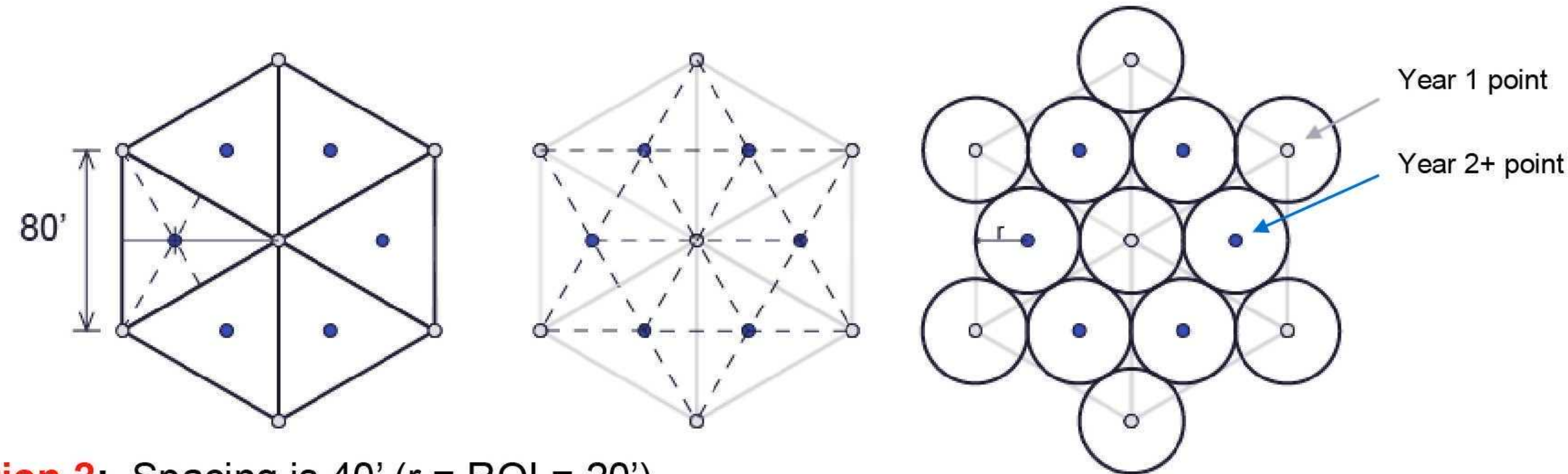
Option 1: Spacing is 46.2’ (r = ROI = 23.1’)



Option 2: Spacing is 40’ (r = ROI = 20’)

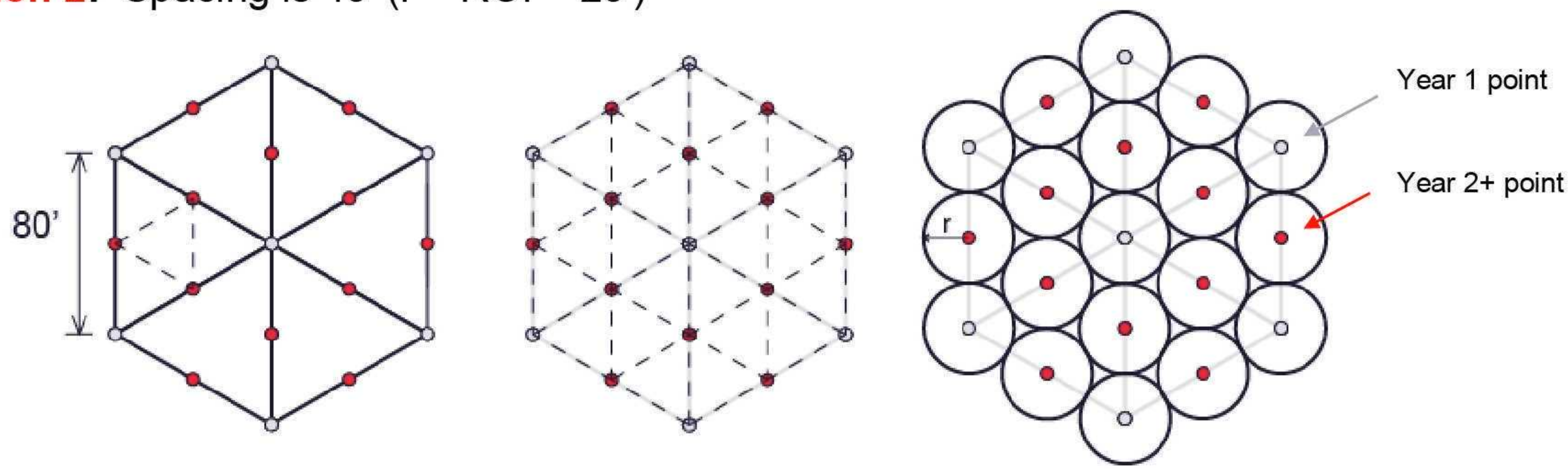


Figure 2-2: Conceptual flexible sparge well layout

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2.2.2. Design ROI and Well Spacing

An initial coarse sparge well grid spacing of 80 feet will be used for the first year of full scale implementation. A hexagonal unit cell containing seven sparge wells with an 80-foot spacing is presented in Figure 2-1. The initial coarse grid provides flexibility for well placement in the following years; additional wells will be installed as required in Years 2+ to achieve a denser sparge well spacing.

As shown on Figure 2-1, there are two denser sparge well spacings that are achievable using this approach. Sparge wells can be placed either at the geometric centers of triangles within the unit cell (Option 1) or at the midpoint of triangle edges (Option 2). These two options result in different final sparge well spacings (Figure 2-2). Options 1 and 2 yield a final sparge well spacing of 46 and 40 feet, respectively.

The determination of sparge well spacing in Years 2+ will be made based on pH monitoring data obtained from the existing monitoring well network. Areas at the site with especially high CO_2 demand (such as the EW-6 area) may require the closer 40-foot spacing. This can be accommodated by transitioning the grid spacing from 46-foot to 40-foot spacing as necessary over portions of the treatment area.

2.2.3. Sparge Well Grid/Treatment Area

The most recent mapping of the CBP (Figure 1-2) was used to create a conceptual layout of sparge points shown on Figure 2-3. A total of 64 wells are required at the initial 80-ft spacing to cover the extent of the CBP. In Years 2+ of full scale implementation, the sparge well network will be supplemented to achieve a 46-foot or 40-foot spacing. If a final 46-foot spacing is selected site-wide (Option 1), 128 additional sparge points are required in Years 2+. If a final 40-foot spacing is selected site-wide, 192 additional sparge points would be required in Years 2+. Water quality monitoring data collected at the end of Year 1 may indicate that portions of the site require closer spacing. In this case, the sparge well grid can be transitioned from the 46-foot spacing to the 40-foot spacing where necessary. The total number of sparge points for full scale could be somewhere between 192 and 256.

The conceptual layout shown in Figure 2-3 treats only the main body of the CBP as mapped using the 2012 dataset. There is some uncertainty as to the extent of the CBP at its southern boundary. Sparge points in this area (e.g. points 6, 7, 14, etc.) will be sampled for pH and conductivity as part of pre-sparge monitoring (Section 2.4.1). This data will provide additional points to better delineate the CBP in this area. Additional sparge wells could be installed in Years 2+ if the CBP is determined to be larger in areal extent. Final sparge well placement will be provided to the driller prior to well installation.

Table 2-1: Summary of number of sparge points required for full scale treatment

	Option 1	**Option 2**
Year 1	64	64
Years 2+	128	192
Total	192	256

2.2.4. Monitoring Well Network

The Year 1 sparge well layout shown in Figure 2-3 was designed to provide coverage for the CBP as well as to provide the maximum number of deep Satilla monitoring points (either as monitoring wells or extraction wells) within 15 to 30 feet of a sparge well. This was accomplished by translating the 64 sparge points in the X-Y plane within the pH 10.5 isocontour boundary until a maximum number of monitoring points was obtained. The resulting distribution of monitoring point to sparge point distances is shown in Figure 2-4 for the smallest 30 distances. There are 16 monitoring point to sparge point pairs that have distances between 15 to 30 feet. There are an additional 13 monitoring points that are between 30 and 40 feet from a sparge point. Note that each monitoring/extraction well shown on Figure 2-4 serves as a monitoring point for only 1 sparge well since the intra-sparge well distance is 80 feet. As described in Section 2.4.2, these deep Satilla monitoring and extraction wells will be monitored for pH during sparging. These 16 monitoring points will be used to provide the data to define effectiveness and the well spacings that will be used during Years 2+ of implementation.

The location of wells that will be used for monitoring during full scale sparging is shown in Figure 2-5. Specific deep Satilla wells outside of the CBP will also be monitored for pH during sparging to confirm that the CBP is not being displaced during sparging. Approximately 16 shallow piezometers will be installed prior to the start of sparging. These piezometers will supplement the existing shallow Satilla monitoring wells to measure water table depth during sparging. The final location of these piezometers will be provided to the driller prior to well construction.

2.2.5. Well Preparation

To minimize the potential for groundwater surfacing, 5-foot extensions will be installed on all the monitoring wells to contain the rise of water. The attachment will be fixed to the well using PVC compression couplings. Fittings and ports will be attached to the top of the extensions to allow for instrumentation cables and manual pressure measurements. The well extensions and fittings will be sealed to prevent CO_2 gas from preferentially flowing up though the wells. A picture of the extensions and fittings employed in the Proof of Concept Test is provided as Figure 2-5.

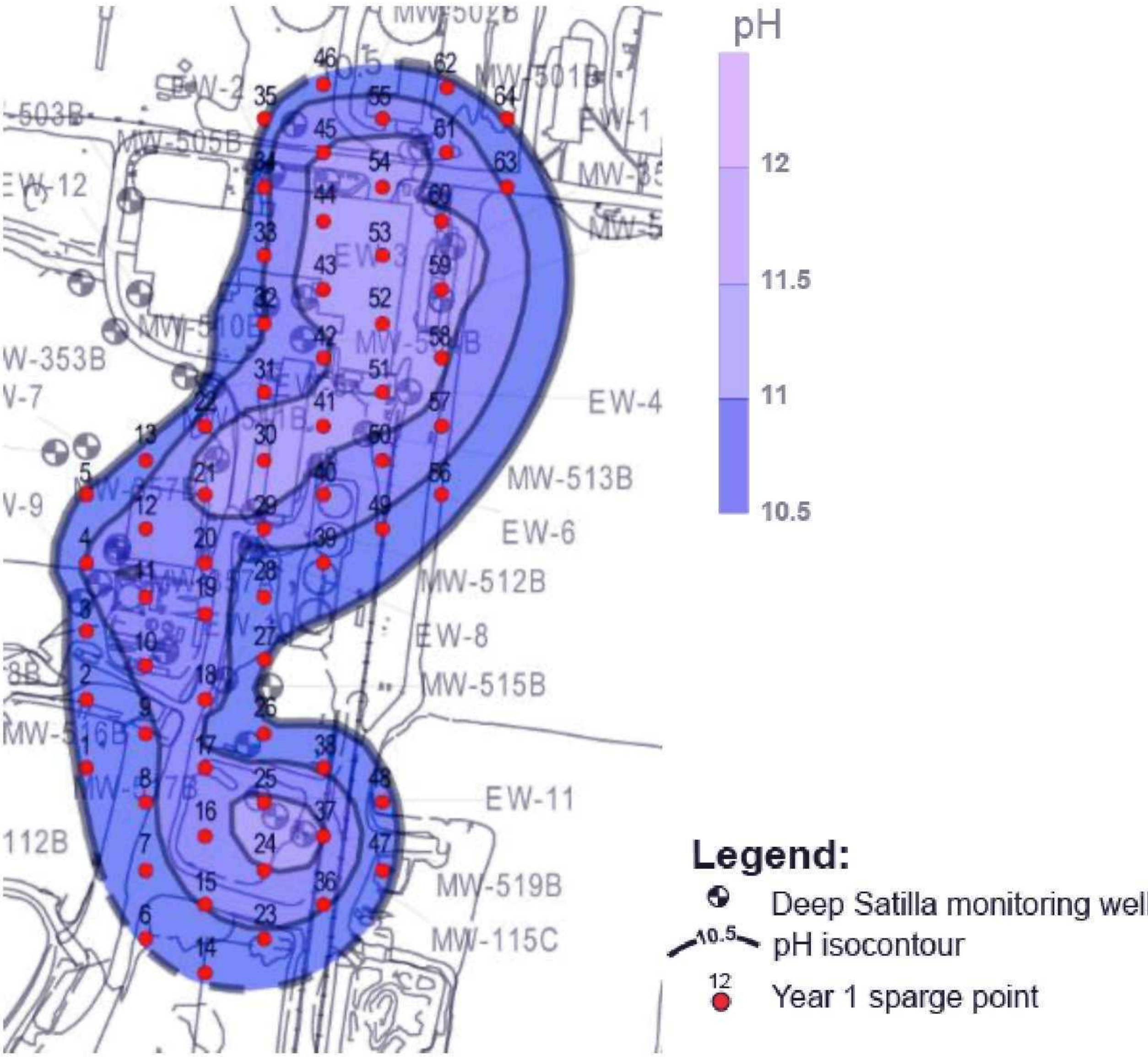

Figure 2-3: Layout of 64 sparge wells (80' on center) and pH isocontours

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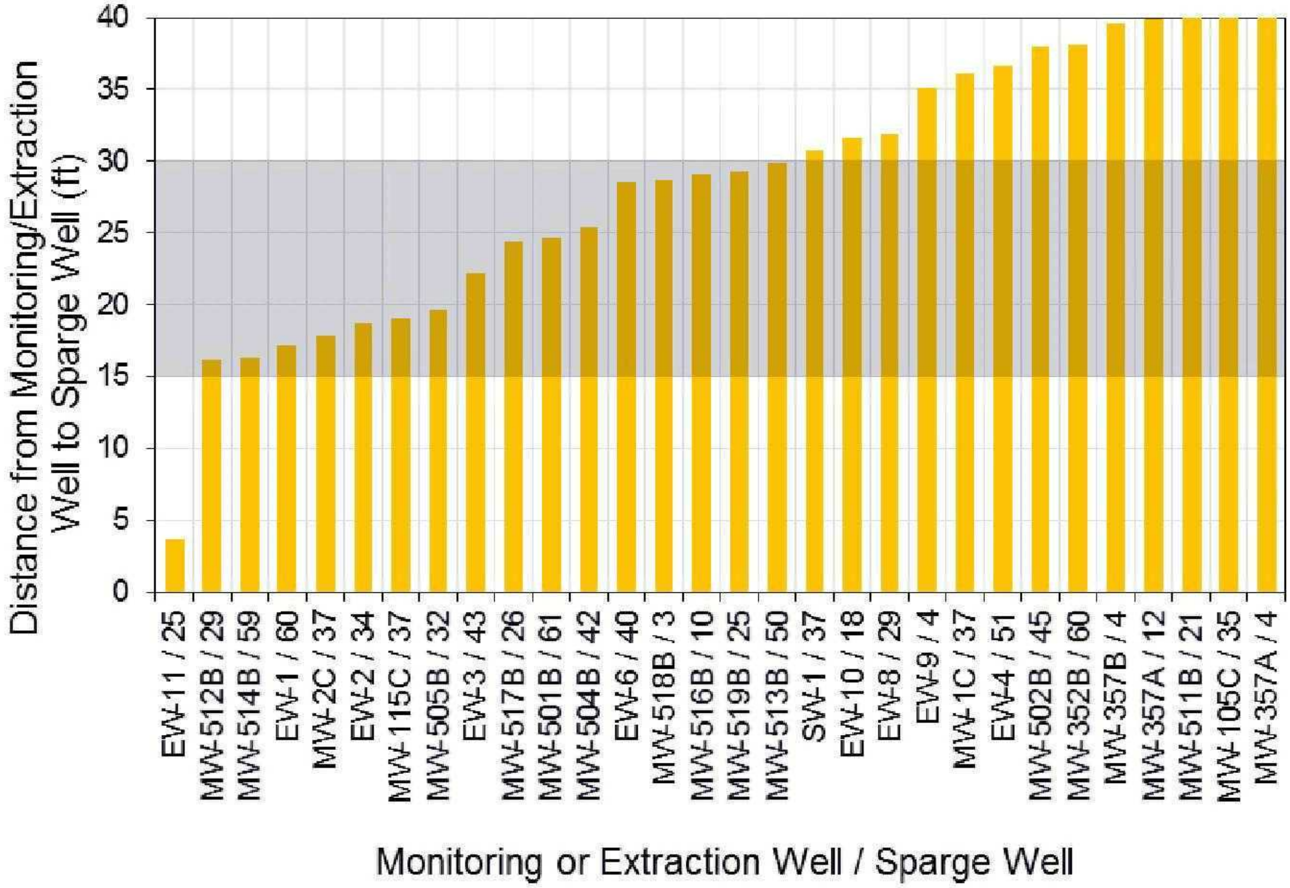

Figure 2-4: Distances from sparge points to deep Satilla monitoring wells and extraction wells

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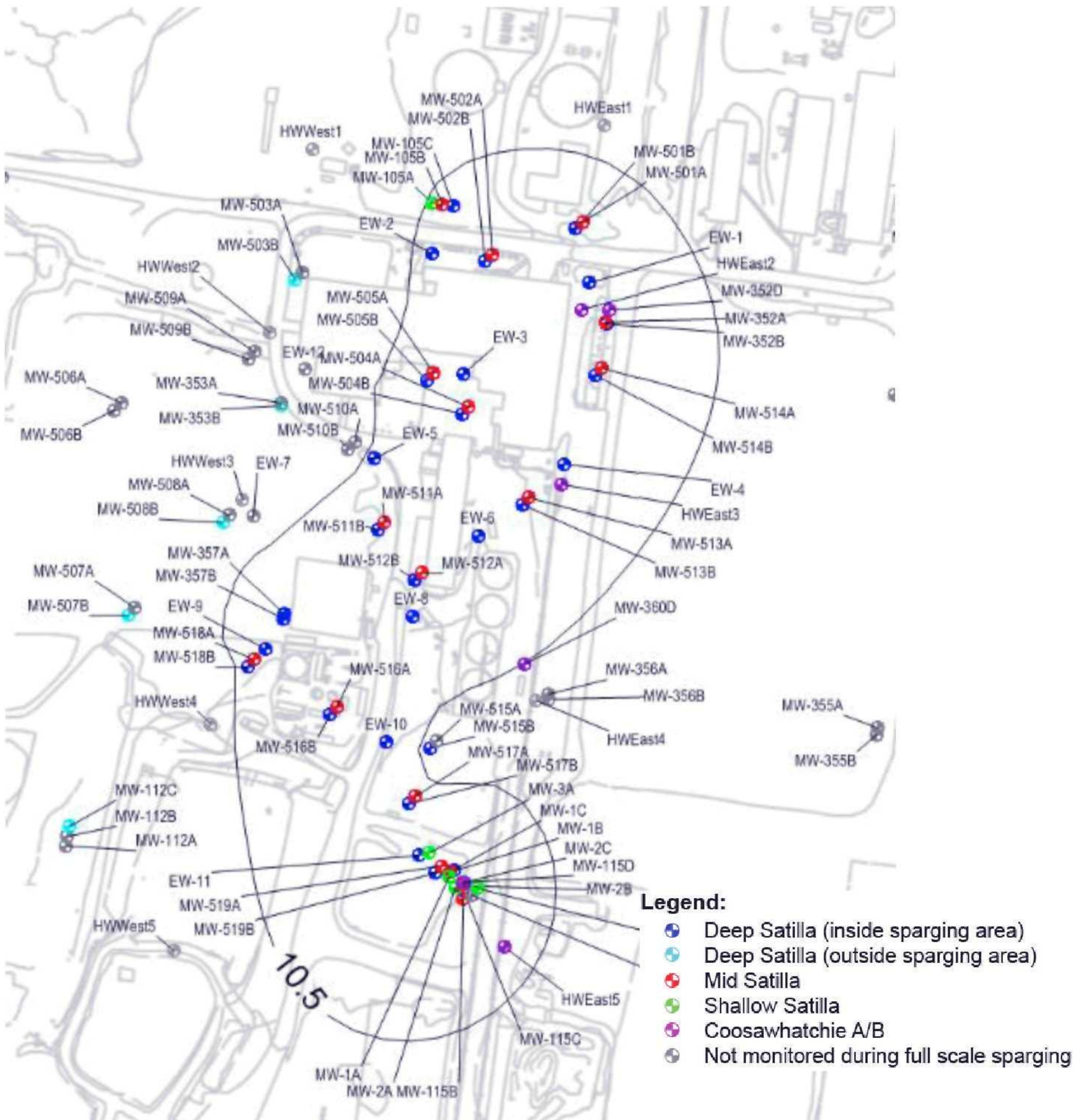

Figure 2-5: Location of monitoring wells during full scale sparging

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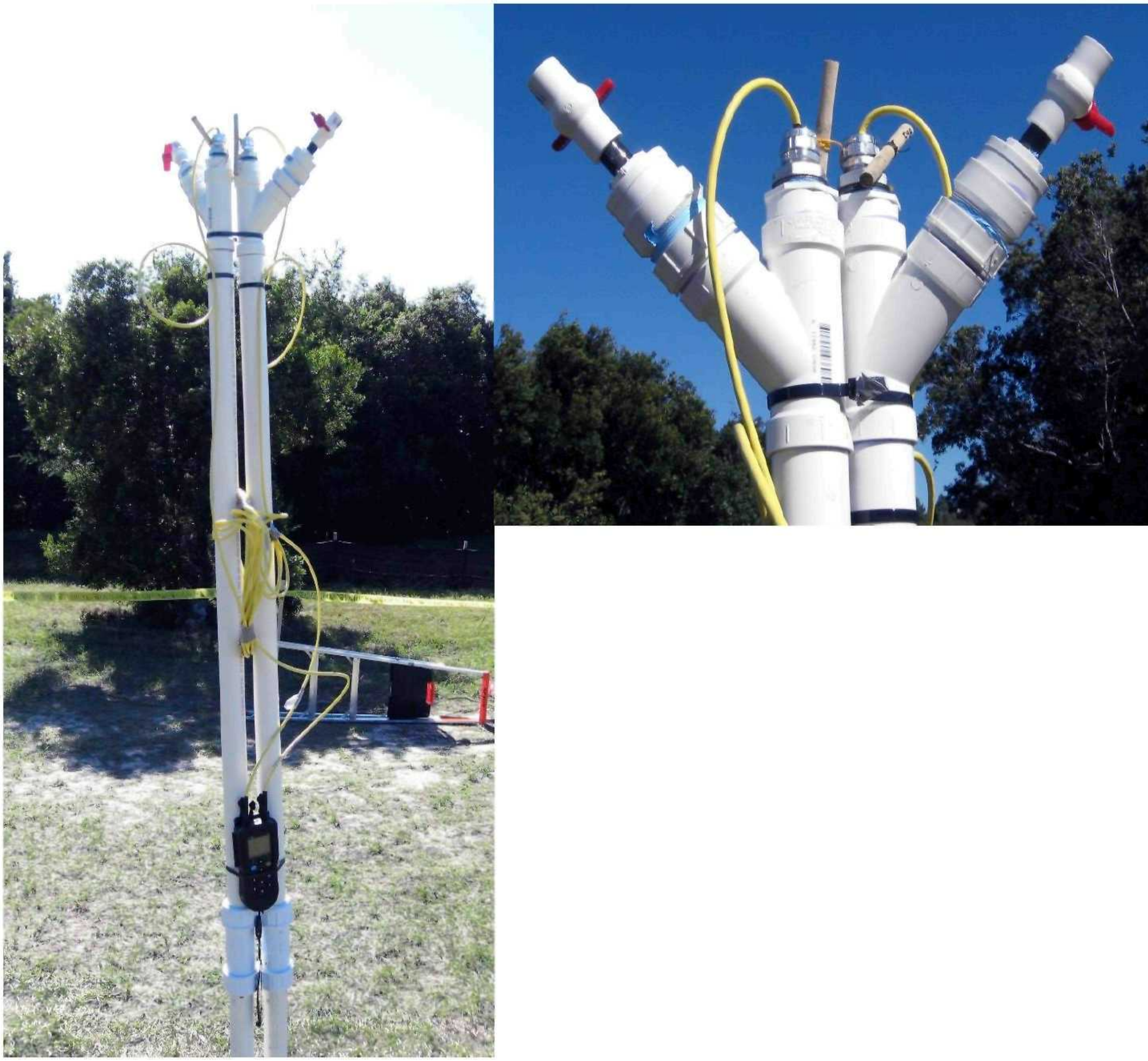

Figure 2-6: Monitoring well extensions and fittings

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2.3. CO_2 Storage and Distribution System

2.3.1. CO_2 Sparging Pressure

Fractures can be generated in geologic formations if air or any other gas is injected at a pressure that exceeds the sum of the natural strength of the formation and the in-situ stresses present (Suthersan, 1997). The pressure required to fracture a consolidated geologic formation is a function of the cohesive or tensile strength of the formation and the pressure exerted by the weight of soil and water. Ignoring the cohesion of the soil, and considering only the weight of the water and soil, the minimum pneumatic fracture initiation pressure, P_i is:

$$P_i > d_w(\gamma_w \eta + \gamma_{soil}(1-\eta)) + (d_{tot} - d_w)\gamma_{soil}(1-\eta) \qquad (2\text{-}1)$$

where d_w is the depth of water (saturated thickness), d_{tot} is the total depth of soil, η is the soil porosity, γ_w is the specific weight of water (62.4 lb/ft^3) and γ_{soil} is the specific weight of soil. The minimum pneumatic fracture initiation pressure for a sparge well 40 feet below ground surface was calculated to be 30 psig assuming a saturated thickness of 35 feet, 40 feet of soil, porosity of 0.30, and a specific gravity of soil equal to 2.65 (specific weight of soil equal to 116 lb/ft^3). As a result, the upper limit of injection pressures will be 25 psig to prevent fracturing of the Satilla.

It was observed during the Proof of Concept Test that after the static well head and capillary pressures are exceeded, sparging flow rate increases dramatically with small increases in pressure. This threshold pressure was approximately 22 psig for SW-1 and MW-1C. Flow rates of 20 to 60 standard cubic feet per minute (scfm) were easily achievable in SW-1 from pressures ranging from 22.0 and 25.0 psig. After switching to MW-1C for sparging, flow rates of 50 to 60 scfm were achievable at pressures up to 25 psig.

Based on the results of the Proof of Concept Test, it is expected that pressures will be maintained between 22 and 25 psig at the well head. Start-up will involve slowly increasing the pressure at injection wells over a 15 to 30 minute period as was performed in the Proof of Concept Test.

2.3.2. CO_2 Sparging Flow Rate

The target flow rate for the Proof of Concept Test was 20 scfm (Mutch Associates, 2012). This flow rate was selected based upon guidance from ESTCP (Leeson et al., 2002), USEPA (2004) and the Army Corps of Engineers Design Manual (2008). During sparging into SW-1, it was observed that flow rates greater than 20 scfm were required to lower the pH in deep Satilla monitoring wells[3]. As a result, the average flow rate during sparging into SW-1 and MW-1C were 50.5 and 57.6 scfm respectively. The average flow rate for the entire Proof of Concept Test was 53.3 scfm (Mutch Associates & Parsons, 2013).

A design flow rate of 50 scfm per well will be used for Year 1 of full scale implementation. This is based upon i) the success of the Proof of Concept Test results in lowering pH and ii) the observation that larger flow rates achieved larger decreases in deep Satilla wells during sparging. If sparging at 50

[3] This can be seen most clearly for MW-2C which was 13.1 ft from SW-1. During the first week of sparging, the largest decreases in pH during the sparge period occurred when the flow rate was greater than or equal to 45 scfm (e.g. on 10/29, 10/31 and 11/1). Decreases in pH during sparging into SW-1 were more modest when sparge flow rates were between 20 and 40 scfm (e.g. on 10/30 and 11/2).

scfm is not successful in lowering pH in monitoring wells in the deep Satilla, the flow rate may be increased to up to 70 scfm per well[4], which was the maximum sparge rate employed in the Proof of Concept Test.

2.3.3. CO_2 Demand and Sparging Duration

During the Proof of Concept Test, the pH of deep Satilla monitoring wells (MW-2C and MW-519B) was lowered only after sparging was switched from SW-1 to MW-1C. Sparging into MW-1C occurred for six continuous days at an average duration of 9.1 hours per day resulting a total duration of sparging of 54.5 hrs. and a flow rate of 57.6 scfm (Mutch Associates and Parsons, 2013). The total mass of CO_2 injected was approximately 21,800 lbs. The calculated CO_2-utilization efficiency was approximately 10%, which was consistent with the efficiency anticipated in the Proof of Concept Work Plan (Mutch Associates, 2012).

Sulfuric acid titration curves of water from the extraction well system (CH2M Hill, 2010) provide useful information for evaluating the expected CO_2 demand for the rest of the treatment area (Figure 2-7). With the exception of the EW-6 area, titration curves indicate that some areas of the CBP will require slightly less CO_2 than EW-11 (e.g. water near EW-8 and EW-9) and other areas may require slightly more CO_2 (e.g. water near EW-3 and EW-5). Since EW-11 water is generally representative of the entire CBP (with the exception of EW-6), sparging for a similar duration as performed in the Proof of Concept Test will be suitable to lower pH over much of the area. The titration curves indicate that the demand of water from EW-6 is approximately 4-times higher than that of water from EW-11. The EW-6 area could therefore require a sparging period that is 4-times longer than the rest of the area.

Based on the Proof of Concept results and the titration data from CH2M Hill (2010), the initially assumed sparging duration used for full scale implementation will be 56 hours of sparging at 50 scfm. This results in 19,400 lbs of CO_2 per sparge well. As discussed in Section 2.3.2, the flow rate may be increased to 70 scfm as necessary. At 70 scfm, this results in 27,200 lbs of CO_2 per well. The sparging duration used for sparge wells in the EW-6 area will be $56 \times 4 = 224$ hrs at the rate of 50 scfm.

The sparing durations discussed above assume that full scale implementation will achieve the same 10% CO_2 utilization efficiency achieved in the Proof of Concept Test. However, it is believed that increased utilization efficiency can be attained by sparging for shorter bursts of ½ to 4 hours, followed by longer rest periods. This will be evaluated using the existing monitoring well network in the deep Satilla. Decreases in pH to target levels in the deep Satilla monitoring before 56 hours of sparging is reached will be evidence of improved CO_2 utilization efficiency. If there is evidence of improved efficiency, a shorter sparging duration will be employed for the remainder of Year 1. These results will also be incorporated into implementation in the following year.

[4] The flow rate will be increased to 70 scfm provided that the maximum pressure of 25 psig is not exceeded.

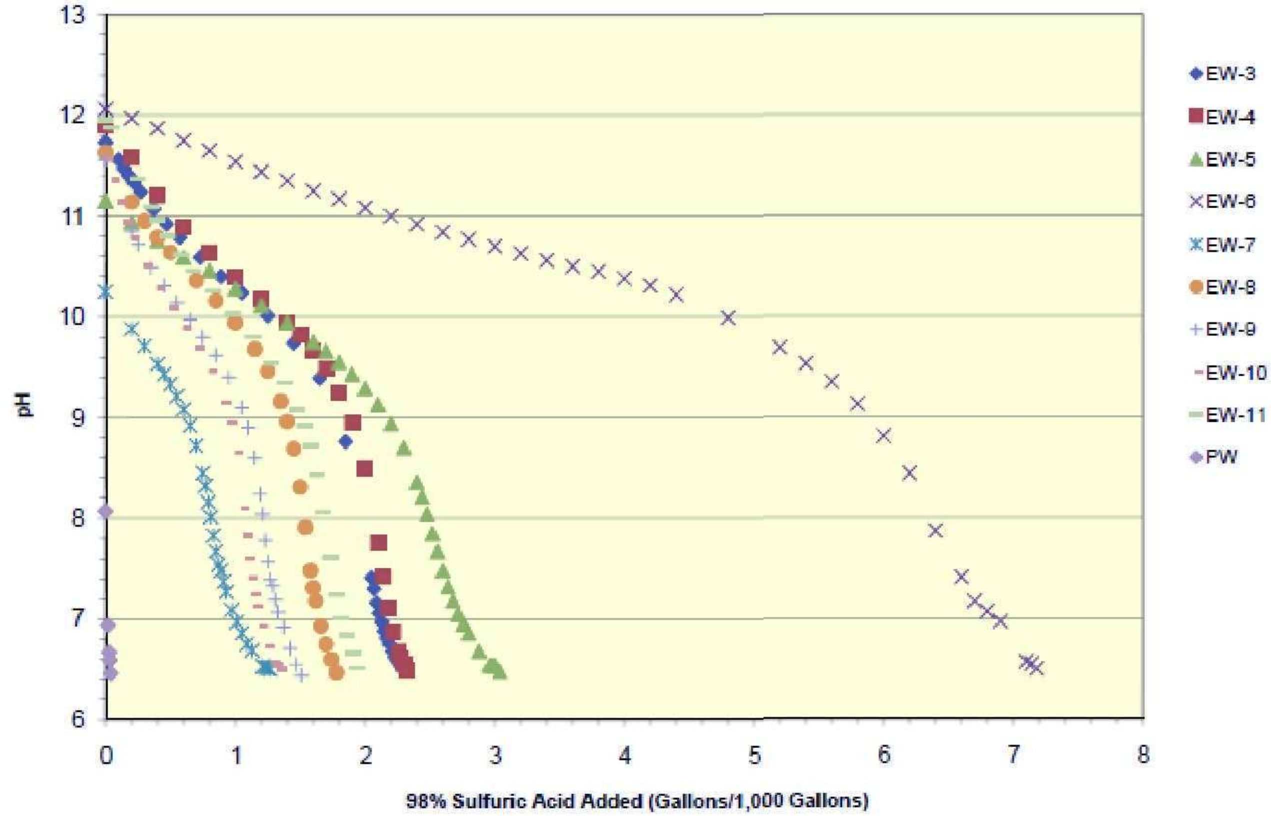

FIGURE 2
Extraction Well Titration Curves
LCP Chemicals, Brunswick, Georgia

CH2M Hill, 2009

Figure 2-7: CBP Sulfuric Acid Titration Curves

LCP Chemicals Site, Brunswick, GA

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2.3.4. CO_2 Storage and Distribution

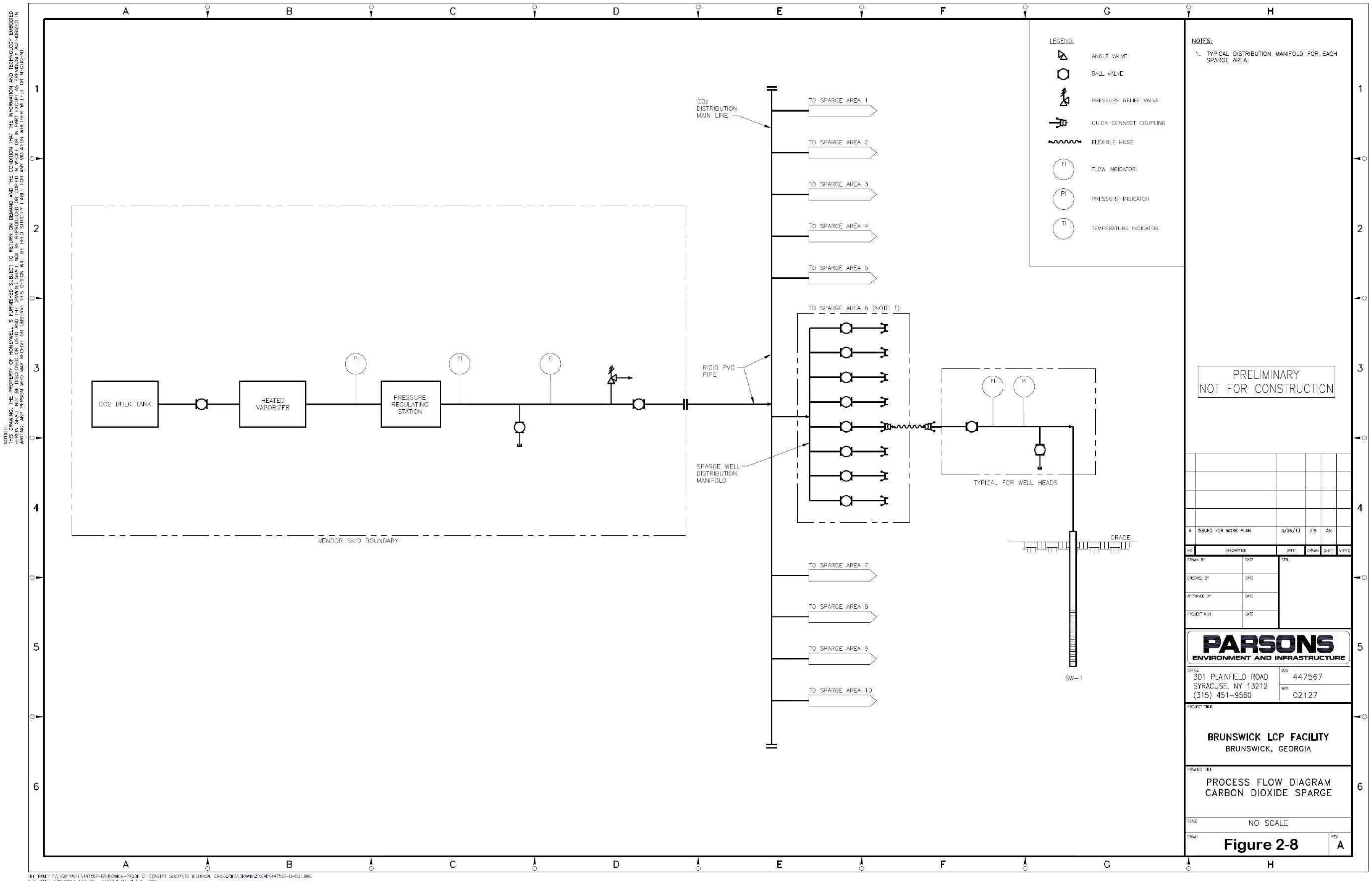
As described above, the per well design flow rate for full scale sparging is 50 scfm, 70 scfm maximum. Over an 8-hr sparging duration, this equates to a per-well demand of 2,800 lbs (3,900 lbs maximum). For a 500 scfm system, 7 to 10 wells could be sparged simultaneously, with a daily usage of approximately 14 tons.

A process flow diagram for the CO_2 storage and distribution system and the potential area where the CO_2 bulk storage tank will be located is provided in Figure 2-8 and Figure 2-9. The CO_2 system will be a vendor-provided system that will include bulk storage tank(s), heated vaporizer(s), and pressure regulating system designed in accordance with Compressed Gas Association (CGA) guidelines. Power for the CO_2 system is anticipated to be sourced from the existing treatment facility at the Site.

Approximately 50 to 100 tons of liquid CO_2 storage would be provided at a location central to the CBP, using one or more bulk refrigerated storage tanks. The number and size of tanks will be dependent on available vendor inventory. Heated vaporizer(s) would be provided and sized for a design flow of 500 scfm. A pressure regulating station will maintain downstream supply pressure to a distribution manifold.

The distribution system will consist of a main pipeline that will run north / south within the CBP. Pipe connections will be made to the main line which will supply CO_2 to individual sparging areas across the treatment area. The supply pipeline into each area will terminate into a discharge manifold which will have hose connections to wells within that area to be sparged. Flow and pressure control and monitoring devices will be used to regulate flow and pressure to each well. It is anticipated that flow will be diverted manually from one well to another in a given area. Secondary securing mechanisms (e.g., whipcheck safety cables) will be provided at quick-connect hose connections in accordance with applicable safety guidelines.

It is anticipated that a total of 64 wells across the treatment area will be sparged during the Year 1 of sparging as indicated in Section 2.2; as a starting point, it is assumed that eight areas would be established with eight wells in each area. The number of areas and wells within each area may vary based on area-specific considerations and observations made during Year 1.



LEGEND:
ANGLE VALVE
BALL VALVE
PRESSURE RELIEF VALVE
QUICK CONNECT COUPLING
FLEXIBLE HOSE
FLOW INDICATOR
PRESSURE INDICATOR
TEMPERATURE INDICATOR
NOTES:
1. TYPICAL DISTRIBUTION MANIFOLD FOR EACH SPARGE AREA.
CO2 BULK TANK
HEATED VAPORIZER
PRESSURE REGULATING STATION
PI
TI
FI
VENDOR SKID BOUNDARY
CO2 DISTRIBUTION MAIN LINE
RIGID PVC PIPE
SPARGE WELL DISTRIBUTION MANIFOLD
TO SPARGE AREA 1
TO SPARGE AREA 2
TO SPARGE AREA 3
TO SPARGE AREA 4
TO SPARGE AREA 5
TO SPARGE AREA 6 (NOTE 1)
TO SPARGE AREA 7
TO SPARGE AREA 8
TO SPARGE AREA 9
TO SPARGE AREA 10
TYPICAL FOR WELL HEADS
GRADE
SW-1
PRELIMINARY NOT FOR CONSTRUCTION
A ISSUED FOR WORK PLAN 3/26/13 JTS AN
NO. DESCRIPTION DATE DRAWN CHK'D APPV'D
PARSONS
ENVIRONMENT AND INFRASTRUCTURE
301 PLAINFIELD ROAD
SYRACUSE, NY 13212
(315) 451-9560
447567
02127
BRUNSWICK LCP FACILITY
BRUNSWICK, GEORGIA
PROCESS FLOW DIAGRAM
CARBON DIOXIDE SPARGE
NO SCALE
Figure 2-8
A

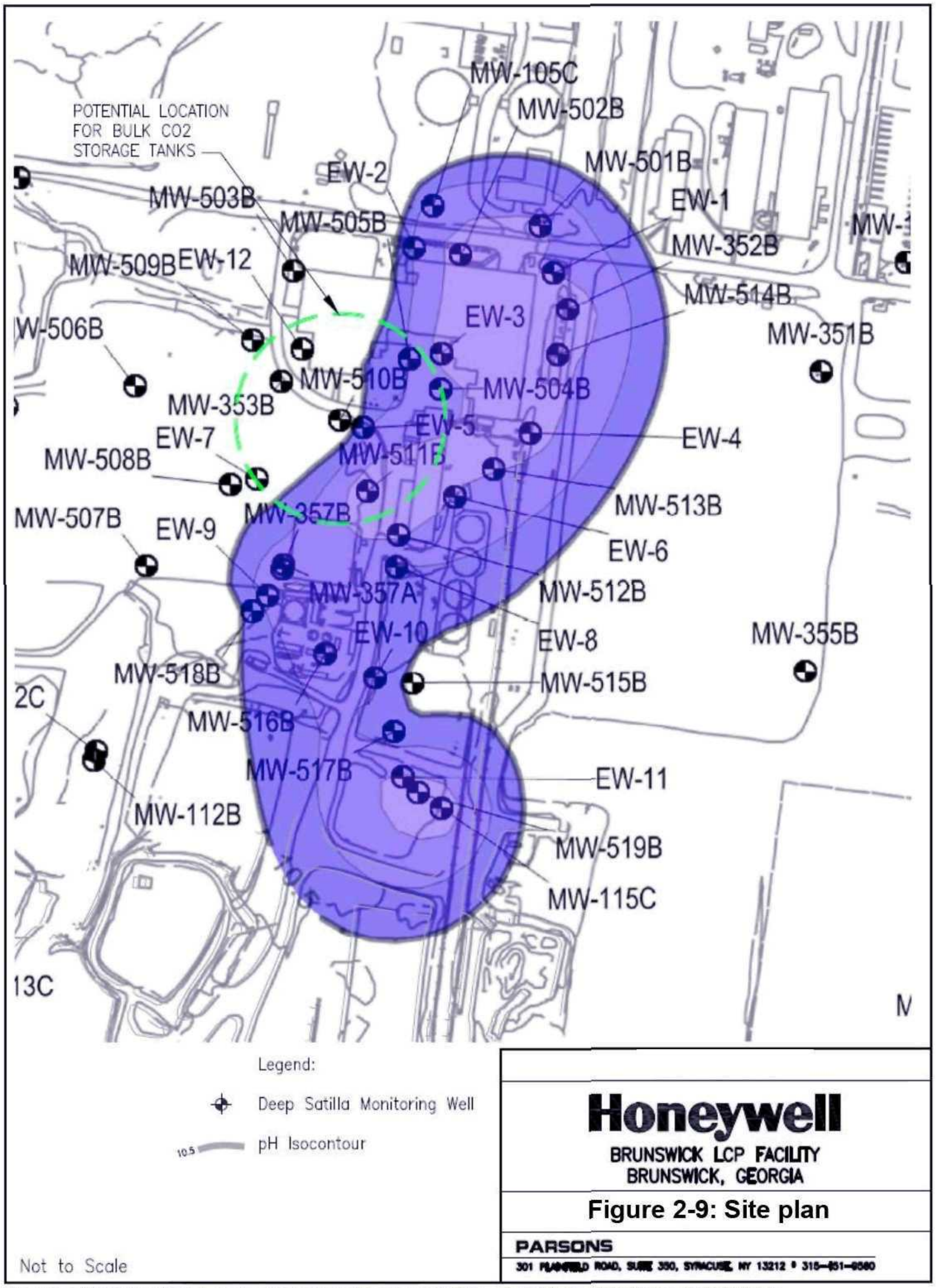


Figure 2-9: Site plan

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2.3.5. Sequence of Operation

As described in the Proof of Concept Test Report (Mutch Associates & Parsons, 2013), within individual wells, relatively short bursts of CO_2 (e.g., ½ hour to 4 hours) followed by rest periods will optimize CO_2 use and manage groundwater mounding. To illustrate how this will be accomplished in Year 1, a preliminary sparging plan is provided on Table 2-2. For purposes of evaluating an optimum injection sequence, the preliminary sparging plan lays out three different sparging regimens:

> Regimen A: Forty wells in five of the eight well groups will be sparged for 4 hrs followed by a 1-week rest.
> Regimen B: Sixteen wells in two of the eight well groups will be sparged for 4 hrs followed by a 2-week rest.
> Regimen C: Eight wells in one of the eight well groups will be sparged at 1-hr bursts every day for 4 days, followed by a 3-day rest.

Additional sparge regimens may be tested if there is evidence that they will improve efficiency.

Table 2-2: Preliminary Sequence of Operation

	Week 1					**Week 2**				
	M	**T**	**W**	**R**	**F**	**M**	**T**	**W**	**R**	**F**
Morning	1-1	1-3	1-5	1-7	Maintenance / Catch Up	1-1	1-3	1-5	1-7	Maintenance / Catch Up
	2-1	2-3	2-5	2-7		2-1	2-3	2-5	2-7	
	3-1	3-3	3-5	3-7		3-1	3-3	3-5	3-7	
	4-1	4-3	4-5	4-7		4-1	4-3	4-5	4-7	
	5-1	5-3	5-5	5-7		5-1	5-3	5-5	5-7	
	6-1		6-3				6-5		6-7	
		7-1		7-3		7-5		7-7		
	8-X	8-X	8-X	8-X		8-X	8-X	8-X	8-X	
Afternoon	1-2	1-4	1-6	1-8	Maintenance / Catch Up	1-2	1-4	1-6	1-8	Maintenance / Catch Up
	2-2	2-4	2-6	2-8		2-2	2-4	2-6	2-8	
	3-2	3-4	3-6	3-8		3-2	3-4	3-6	3-8	
	4-2	4-4	4-6	4-8		4-2	4-4	4-6	4-8	
	5-2	5-4	5-6	5-8		5-2	5-4	5-6	5-8	
		6-2		6-4		6-6		6-8		
	7-2		7-4				7-6		7-8	
	8-Y	8-Y	8-Y	8-Y		8-Y	8-Y	8-Y	8-Y	

Notes:
1. Well nomenclature:
   - General: 1-1 = Area 1, well 1
   - 8-X = Area 8, wells 1, 3, 5, 7
   - 8-Y = Area 8, wells 2, 4, 6, 8
2. Regimen A (light grey): Wells in Areas 1 through 5 (4-hr treatment followed by 1-week rest)
3. Regimen B (dark grey): Wells in Areas 6 and 7 (4-hr treatment followed by 2-week rest)
4. Regimen C (black): Wells in Area 8 (Daily cycle of 1-hr bursts per well for four days, followed by 3-day rest)

The preliminary sparging plan for Year 1 results in a repeatable 2-week cycle with seven wells being sparged at a time. This provides flexibility to increase to 70 scfm per well if required, to add additional wells, or increase treatment in certain areas if required. As described in Section 2.3.3, at a 10% CO_2 utilization efficiency, it is estimated that each well will require 56 hours of sparging.

It is anticipated that Year 1 sparging will require 2 to 4 months of operation under three different sparging regimens:

- Sparge wells on Regimen A will receive fourteen 4-hr sparge pulses to achieve 56 hours of sparging. Since these wells will be sparged weekly, 14 weeks will be required to complete Regimen A. The total time of sparging may be shortened if monitoring wells indicate better CO_2 utilization is achieved (i.e., target pH values are reached prior to 56 hours of sparging).
- Sparge wells on Regimen B will also be sparged using 4-hour pulses, except they will be sparged bi-weekly. As discussed earlier, the purpose of the longer relaxation period between pulses is to increase efficiency. Assuming that utilization efficiency can be increased from 10% to 20%, these wells will require seven 4-hour sparge pulses and 14 weeks to complete Regimen B. If Regimen B does not appear to be providing increased efficiency, these wells may be converted over to Regimen A.
- Sparge wells on Regimen C will receive four 1-hour pulses each week for a total of 4 hours of sparging per week. Thus, 14 weeks will be required to achieve 56 hours of sparging.

2.4. Monitoring

2.4.1. Pre-Sparge Monitoring

All deep, mid, and shallow Satilla wells within the treatment area and seven deep Satilla wells outside of the treatment area will be sampled to provide a pre-sparge groundwater quality baseline (Table 2-3). The 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) – October 2011. 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 twelve of the deep Satilla wells (see Table 2-3). Samples will also be sent to TestAmerica (Savannah, GA) or similar certified laboratory for chemical analysis. A summary of the analytical parameters and associated methods is provided in Table 2-4.

After sparge well development, groundwater from all sparge wells will be analyzed for pH, SC, DO, temperature, and ORP in the field.

2.4.2. Monitoring During CO_2 Sparging

Groundwater pH and conductivity from deep Satilla wells will be monitored weekly. A portable peristaltic pump will be used to pump water to the surface where it will be collected in polyethylene bottles. A Hach model PHC101 Rugged electrode will be used to record pH. A Hach IntelliCAL CDC401 Rugged probe will be used to measure conductivity. The electrodes will be connected to portable field pH meters (Hach Model HQ40d) for data acquisition. The data will be recorded and stored within the internal memory of the meters and downloaded daily.

All pH electrodes will be calibrated daily to ensure accuracy of results. A four point standard curve using pH 4.01, 7.00, 10.01 and 12.45 standards will be used. A valid pH calibration curve will be obtained only when the slope is within 5% of the theoretical value of −59 mV/pH. A calibration check will be performed 4 times per day to ensure electrode stability. All pH electrodes will be reconditioned once per week.

Groundwater levels within the shallow 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 and securely affixed to prevent any movement. The automatic data loggers will be synchronized for time and will be programmed to record water levels at five 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.

Table 2-3: Monitoring Wells for Full Scale CO_2 Sparging

	Monitoring or Extraction Well		Monitoring or Extraction Well
Deep Satilla	MW-105C[b]		MW-514B[b]
	MW-112C[a]		MW-515B
	MW-113C[a]		MW-516B[b]
	MW-115C[b]		MW-517B
	MW-352B		MW-518B[b]
	MW-353B[a]		MW-519B
	MW-357A		MW-1C
	MW-357B		MW-2C
	MW-358B[a]		EW-1
	MW-501B[b]		EW-2
	MW-502B[b]		EW-3
	MW-503B[b]		EW-4
	MW-504B[b]		EW-5
	MW-505B		EW-6
	MW-507B[a]		EW-8
	MW-508B[a]		EW-9
	MW-510B[a]		EW-10
	MW-511B[b]		EW-11
	MW-512B[b]		EW-12
	MW-513B[b]		
Mid Satilla	MW-105B		MW-513A
	MW-115B		MW-514A
	MW-352A		MW-516A
	MW-501A		MW-517A
	MW-502A		MW-518A
	MW-504A		MW-519A
	MW-505A		MW-1B
	MW-511A		MW-2B
	MW-512A		
Shallow Satilla	MW-105A		
	MW-115A		
	MW-1A		
	MW-2A		
	MW-3A		
Coosa-whatchie A/B	HWEast2		MW-115D
	HWEast3		MW-352D
	HWEast5		MW-360D

(a) indicates a well outside of the sparging area which will serve as a background monitoring well
(b) indicates well will be measured for specific gravity in the field pre and post sparging

Table 2-4: 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
Chloride and sulfate	EPA SW-846 9056	Ion chromatography
Sulfide	SM 4500 S2 F	Iodometric titration
Total metals & silica[a]	EPA SW-846 6010B	Inductively Coupled Plasma – Atomic Emission Spectroscopy
Dissolved and total organic carbon	SM 5310B	Combustion / Infrared Spectrophotometry
Ferrous iron	SM 3500-Fe-D	Spectrophotometry
[a] Total metals included aluminum, barium, beryllium, calcium, cobalt, chromium, iron, potassium, magnesium, manganese, sodium, nickel, selenium, vanadium, zinc.		

2.4.3. Post-Sparge Monitoring

One week after the conclusion of the full scale sparging program at the end of Year 1, the monitoring wells selected for pre-sparge monitoring will be resampled and analyzed for the same parameters as before as described in Section 2.4.1 and Table 2-4. Six months after the Year 1 sparging ends, these same monitoring wells will be resampled and analyzed for the parameters shown in Table 2-4. Specific gravity will be measured in the same twelve deep Satilla wells sampled as part of the pre-sparge monitoring (see Table 2-3). In addition, pH and conductivity from all sparge wells will be analyzed as described in Section 2.4.2.

Solinst Level Loggers (or equivalent) will be employed for automatic data logging.in selected shallow and deep Satilla wells at the end of the Year 1 sparging effort. The loggers will remain in place until the following year. These loggers will provide data on seasonal trends in shallow Satilla groundwater during non-sparging conditions. This data will be used to better define the site locations and seasonal periods where there is the greatest potential for groundwater surfacing. The pre-sparge, sparge, and post-sparge monitoring cycle will continue for Years 2+. For example, prior to the start of Year 2 of sparging, the wells sampled prior to the start of sparging will be resampled and submitted for analysis for the analytical parameters in Table 2-4.

2.5. Potential Complications

The full scale CO_2 sparging effort described in this work plan has been designed to reduce the likelihood of complications such as groundwater surfacing, mobilization of the CBP, development of fractures in the geologic formation, break-through of the partially cemented sandstone, and reduction in transmissivity of the aquifer. Methods for observing these potential complications and steps taken to reduce the likelihood their occurrence are shown in Table 2-5. Lateral migration of the CBP in the deep Satilla during sparging is not expected to be excessive nor permanent.

Table 2-5: Potential Complications and Steps Taken to Minimize Occurrence

Potential Complication	**Observation Method**	**Likelihood of Occurrence**	**Steps Taken to Reduce Likelihood of Occurrence and/or Corrective Actions**
Surfacing of groundwater	Manual and electronic water level measurements will be taken from sixteen piezometers and five monitoring wells screened in the shallow Satilla prior to and during CO_2 sparging	Moderate to High	Wells are being placed on a coarse grid and adjacent wells will not be sparged simultaneously; extensions are being placed on all wells to prevent groundwater flow to the surface; flow rates can be decreased and/or sparge pulse durations can be shortened to prevent excessive groundwater rise in the shallow Satilla.
Reduction in transmissivity of the aquifer	Ten representative sparge wells that have nearby deep monitoring wells will be used to conduct very short-term (i.e. 10 minute) pre- and post sparging aquifer tests (Section 2.4.3)	Moderate	The Proof of Concept Test was designed to evaluate changes in transmissivity; SW-1 transmissivity was lowered by 66%. Once testing is complete at the end of Year 1, this data will be used to design Years 2+ sparging efforts.
Lateral migration of the CBP plume	Deep Satilla wells outside of the sparging area will be monitored routinely for pH and conductivity to check for CBP movement	Low (movement is expected to be minimal)	Full scale implementation will employ smaller sparging pulses than that employed in the Proof of Concept Test
Fracturing of the geologic formation	Decreased sparge pressures to achieve the same flow rate would provide evidence for fracturing of the formation	Low	Sparging pressures will be kept at values less than the fracture initiation pressure; if there is evidence of fracturing of the formation, lower sparge pressures will be employed for further sparging (Section 2.3.1).
Break-through of the partially cemented sandstone	Selected wells screened in the Coosawhatchie A/B aquifer will be monitored for pH and water levels	Low	Vertical placement of the sparge well screen will be performed with extreme care as to not compromise the variably cemented sandstone aquitard (Section 2.2.1).

3. PROJECT IMPLEMENTATION

3.1. Health and Safety

A Health and Safety Plan (HASP) will be developed for the project that will address project activities. The HASP will include a site monitoring plan, which will include monitoring of ambient oxygen, carbon dioxide, and hydrogen sulfide in the breathing zone in the immediate vicinity of injection wells to confirm safe working conditions. If levels exceed or drop below permissible levels, the injections will be stopped and the area will be evacuated until normal concentrations resume. In addition, it is anticipated that grab sample testing for mercury vapor will also be conducted at pre-approved intervals in the breathing zone. The HASP will dictate the response and protective equipment, as appropriate, in the event that mercury vapor is detected in the breathing zone. It is anticipated that ambient oxygen, carbon dioxide, and hydrogen sulfide level will be monitored with a standard multi-gas meter such as a Multi-Rae, or an equivalent. Mercury vapor in the breathing zone will be monitored by a Jerome 413X Mercury Vapor Analyzer, or equivalent.

3.2. Project Schedule

A preliminary schedule for the project is attached as Figure 3-1. When allowances are made for preparation of procurement packages, procurement, and construction, it is assumed that system start-up would commence in approximately September 2013.

3.3. Data Evaluation and Reporting

Data collected during Year 1 sparging will be compiled and evaluated in a report, which will include the following:

- A description of the installed CO_2 injection and distribution system, including boring / well construction logs.
- A tabular summary of injection activities at each well, including mass of CO_2 injected per event and in total.
- Changes in pH observed in the monitoring well network, based on pre-sparge, during-sparge, and post-sparge monitoring data.
- Pre- and post-sparge groundwater monitoring results of other constituents.
- An assessment of the overall effectiveness of the Year 1 sparging effort, including evaluation of ROI and CO_2 efficiency of use.
- An assessment of the relative effectiveness of the three injection regimens.
- Recommendations regarding Years 2+ activities, including Years 2+ well installation pattern and sequence of operation.

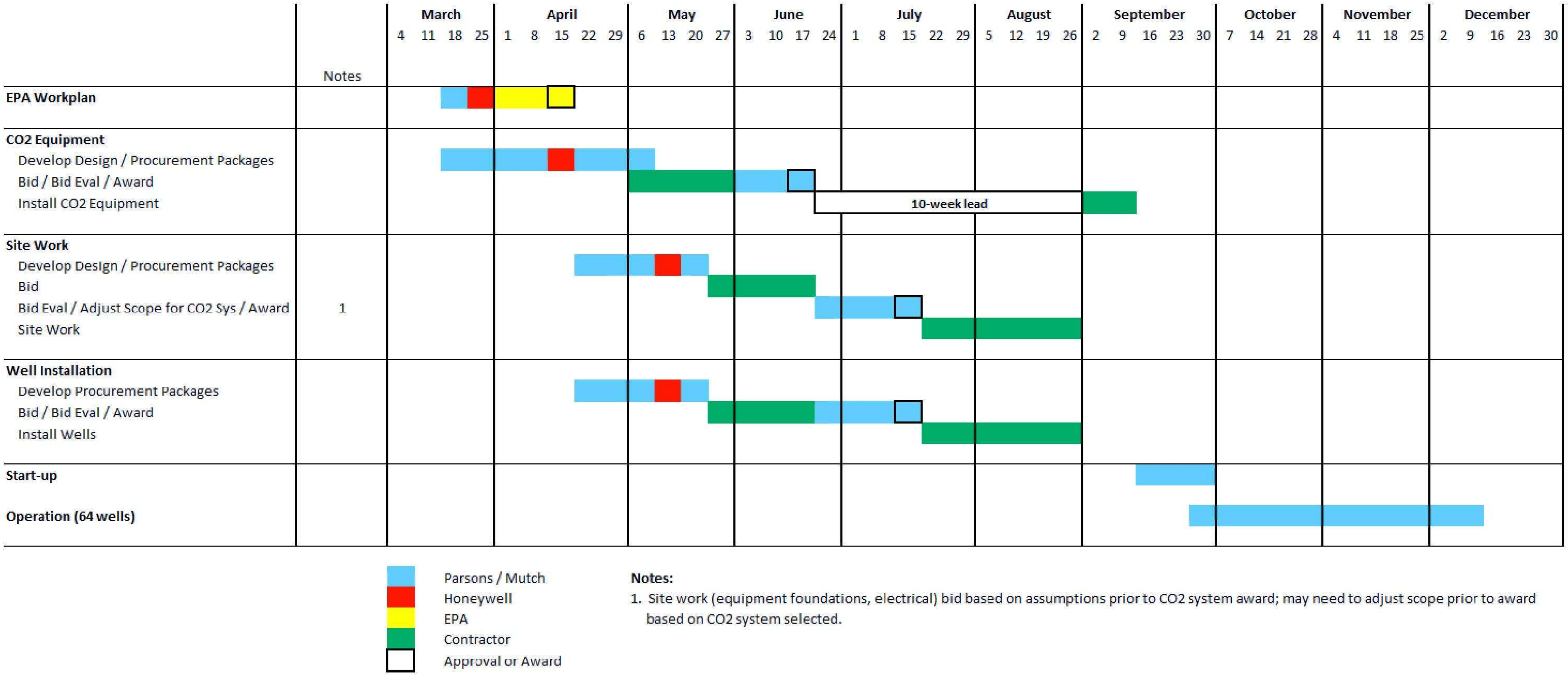

Figure 3-1: Preliminary Schedule for Year 1 of Full Scale Sparging

4. REFERENCES

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