CHANGE REQUEST FORM

Contract/Project: Seattle District of the Army Corps of Engineers (USACE)
W912DQ-08-D-0018, Task Order (TO) EC05/Well12A Technical & Design Support

Date: 03/15/2013

Requested by: CDM Smith

Description of requested change(s):

1. Modify the amendment mixing process used for the Enhanced Anaerobic Bioremediation (EAB) pilot study as shown in **Figure 1**.
2. Modify the injection strategy and pilot study well layout to incorporate:
    a. Newly installed shallow injection well INJ-3 screened between 45-52.5 feet (ft) below ground surface (bgs) (to target injection above the Qpf unit);
    b. Injection well INJ-1 with modified screened interval to 48-55 ft bgs (modified by grouting up the bottom 8 feet of the well to target injection just below the Qpf unit);
    c. New Electrical Resistivity Tomography (ERT) electrode borehole installed in the vicinity of INJ-1 and INJ-3 (as shown in **Figure 2**); and
    d. Modified target radii of influence (ROI) and amendment composition for the shallow and the deep injection (modified as shown in **Table 1**).
3. Modify the sampling and analysis plan (SAP) to reflect the aforementioned changes as shown in **Table 2**. Additional sampling will be conducted to evaluate injection performance at INJ-3. Total organic carbon (TOC) and tracer samples will be collected at the end of each injection event and at select monitoring wells to monitor injection performance using low-flow groundwater sampling procedures with bladder pumps. Hydrasleeves® instead of bladder pumps will be used in all other EAB performance evaluation sampling events.

Reason for change:

1. Mixing process modification: results from the bench-scale mixing tests indicate that a small oil droplet size conducive to bioremediation (approximately 2 to 4 microns) can be achieved with a mixing configuration that is slightly different from specified in the original work plan. Specifically, it was determined that overnight hydration of the Xanthan gum followed by introduction of the oil is necessary to achieve the target oil droplet size of 2 to 4 microns. The pilot mixing and injection configuration, therefore, were modified accordingly as shown in **Figure 1.**
2. Injection strategy and layout modification: Installation of INJ-3 and modification to the existing INJ-1 are designed to limit amendment delivery to the non-target, highly permeable zones within the lower Qpfc of the aquifer. During the initial tracer study, the majority of injected volume went out of the bottom of the injection well and was delivered below 58 feet bgs as indicated by the lack of tracer detection in EAB-1 and EAB-2. The intent of the revised injection design is to more effectively deliver amendments in and around the low-permeability Qpf unit where contaminant mass is greatest. Target injection ROI are modified to reduce the volume of amendment injected to more precisely track distribution characteristics and minimize potential for transport

of carbon near the GETS extraction well EW-3. Tracer concentrations are reduced to optimize oil droplet size based on the results of the bench-scale mixing tests which showed that higher concentrations of bromide (500 mg/L) resulted in a population of larger-sized oil droplets compared to lower bromide concentrations (250 mg/L). Not only was the average oil droplet size associated with the higher tracer concentration slightly larger (3 microns versus 2.8 microns), the maximum droplet size, standard deviation, and skew using the higher tracer concentration were all larger. Collectively, such observation indicated a larger population of bigger oil droplets in the presence of higher tracer concentrations. Therefore, the bromide tracer concentration will be reduced from 500 mg/L to 250 mg/L in the EAB pilot study.

3. SAP modification: collection of additional samples and analytes will facilitate better understanding of the injection processes and amendment delivery in the subsurface.

Expected results or impact:

1. Mixing process modification: a target oil droplet size conducive to EAB of approximately 2 to 4 microns will be achieved. This will result in improved amendment delivery, achieved target ROIs, and enhanced remediation performance.
2. Injection strategy and layout modification: more effective delivery of amendment into the target zones of the aquifer.
3. SAP modification: changes to the SAP are expected to result in better understanding of amendment delivery and EAB performance. This information will be used for optimizing injection strategy for the full-scale EAB implementation.

Submit this form to the project manager immediately.

Required before implementation of major changes:

Approved by: CDM Smith PM Date: 3/15/13

Acknowledged by: USACE Project Rep. Date:

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cc: Contract QA Coordinator

CDM Smith

Table 1. Modified injection strategy

	Parameters	Injection Well ID			Unit	Comment
		INJ-3 (shallow)	INJ-1 (shallow)	INJ-2 (deep)		
Site-specific info	Assumed effective porosity	15%	15%	15%	-	Assumed
	Assumed pilot study ROI	7.5	7.5	10	ft	Actual ROI may vary depending on actual Site characteristics (actual effective porosity, presence of preferential flow paths).
	Approximate pilot study area	177	177	314	ft^2	-
	Screen interval for injection	45-52.5	48-55	92-102	ft bgs	-
	Target pilot study treatment depth	7.5	7	10	ft	-
	Volume groundwater to be treated	199	186	471	ft^3	-
	Volume groundwater to be treated	5629	5254	13344	L	Conversion: 1 ft^3 = 28.3168 L
	Volume groundwater to be treated	1487	1388	3525	gal	Conversion: 1 ft^3 = 7.48052 gallon
XG injection requirements	Target XG concentration	2500	2500	2500	mg/L	0.25% (wt/wt)
	Amount of XG needed for injection	14	13	33	kg	-
	Pricing	$ 877.16	$ 877.16	$ 877.16	/25 kg bag	Integra part # X201.30.65
	Number of bags to order (roundup)	1	1	2	bags	-
Tracer requirements	Target Br concentration	250	250	0	mg/L	Bromide is used as a conservative tracer for the shallow injection; concentration was reduced based on results of lab mixing tests to optimize oil droplet size
	Amount of Br needed	1	1	0	kg	
	% Br in NaBr	78%	78%	-	-	
	Amount of NaBr needed	2	2	0	kg	
	Pricing	$ 128.29	$ 128.29	$ 128.29	/2.5 kg	Integra part # S296.50.40
	Number of bags to order (roundup)	1	1	0	bags	-
	Target Cl concentration	0	0	100	mg/L	Chloride is used as a conservative tracer for the deep injection; concentration was reduced based on results of lab mixing tests to optimize oil droplet size
	Amount of Cl needed	0	0	1	kg	
	% Cl in NaCl	-	-	61%	-	
	Amount of NaCl needed	0	0	2	kg	
	Pricing	$ 26.25	$ 26.25	$ 26.25	/2.5 kg	Integra part # S312.50.40
	Number of bags to order (roundup)	0	0	1	bag	-
WO requirements	Target WO injection concentration	30,000	30,000	30,000	mg/L	2.3% w/w as carbon determined from EAB bench study which equates to approximately 3% w/w as waste oil
	WO injection mass	168,885	157,626	400,319	g	-
	WO density	0.9	0.9	0.9	g/mL	-
	WO injection volume	188	175	445	L	-
	WO injection volume	50	46	118	gal	Conversion: 3.78541 L = 1 gallon

*__Notes__:
- bgs: below ground surface

- ft: feet
- ft^2: feet squared
- ft^3: cubic feet
- g/mL: gram per milliliter
- gal: gallon
- ID: identification
- INJ: injection well
- kg: kilogram
- L: liter
- mg/L: milligram per liter
- NaBr: sodium bromide
- NaCl: sodium chloride
- ROI: radius of influence
- wt/wt: weight by weight
- XG: Xanthan gum

Table 2. Modified sampling and analysis plan

Sampling Location	Laboratory Analyses						Bromide		Chloride		Groundwater Levels	Field Parameters[2]
	VOCs	Bioremediation Parameters [1]	TOC	Alkalinity	DHC	TAL Metals	Down-hole Probe	Analytical Laboratory	Down-hole Probe	Analytical Laboratory	Manual Water Level	
Shallow Injection												
Amendment Mixing Tank Sampling Ports	-	-	-	-	-	-	Start, midpoint, and end of the injection	-	-	-	-	-
Injection Well INJ-3	Baseline, 1-month and 3-month	Baseline, 1-month and 3-month	Baseline, 1-month, 3-month	Baseline and 3-month	3-month	Baseline and 3-month[3]	-	Baseline, 1-month and 3-month	-	-	Baseline, 1-month and 3-month, every 4 hours during injection	Baseline, 1-month and 3-month
Injection Well INJ-1	1-month and 3-month	1-month and 3-month	1-month, 3-month, and at the end of injection at INJ-3	3-month	3-month	3-month[3]	-	1-month, 3-month, and at the end of injection at INJ-3	-	-	1-month and 3-month, every 4 hours during injection	1-month and 3-month
Monitoring Wells EAB-1 and EAB-2	1-month and 3-month	1-month and 3-month	1-month, 3-month, at end of injection at INJ-3, and at end of injection at INJ-1	3-month	3-month	3-month[3]	Continuous	1-month, 3-month, at end of injection at INJ-3, and at end of injection at INJ-1	-	-	1-month and 3-month, every 4 hours during injection	1-month and 3-month
Monitoring Wells EAB-5	Baseline, 1-month and 3-month	Baseline, 1-month and 3-month	Baseline, 1-month, 3-month, at end of injection at INJ-3, and at end of injection at INJ-1	Baseline and 3-month	3-month	Baseline and 3-month[3]	Continuous	Baseline, 1-month, 3-month, at end of injection at INJ-3, and at end of injection at INJ-1	-	-	Baseline, 1-month and 3-month, every 4 hours during injection	Baseline, 1-month and 3-month
Existing Monitoring Wells TOW-5 and TOW-6	-	-	-	-	-	-	Continuous	-	-	-	Every 4 hours during injection	-
GETS Extraction Well EW-3	-	-	1-month and 3-month	-	-	-	Continuous	-	-	-	-	-
Deep Injection												
Amendment Mixing Tank Sampling Ports	-	-	-	-	-	-	-	-	Start, midpoint, and end of the injection	-	-	-
Injection Well INJ-2	1-month and 3-month	1-month and 3-month	1-month and 3-month	3-month	3-month	3-month[3]	-	-	-	1-month and 3-month	1-month and 3-month, every 4 hours during injection	1-month and 3-month
Monitoring Wells EAB-3 and EAB-4	1-month and 3-month	1-month and 3-month	1-month and at end of injection at INJ-2	3-month	3-month	3-month[3]	-	-	Continuous	1-month and 3-month and at end of injection at INJ-2	1-month and 3-month, every 4 hours during injection	1-month and 3-month
Existing Monitoring Well MW-302	1-month and 3-month	1-month and 3-month	1-month and 3-month	3-month	3-month	3-month[3]	-	-	Continuous	1-month and 3-month	1-month and 3-month, every 4 hours during injection	1-month and 3-month
Existing Monitoring Well TOW-4	-	-	-	-	-	-	-	-	Continuous	-	Every 4 hours during injection	-

Notes:

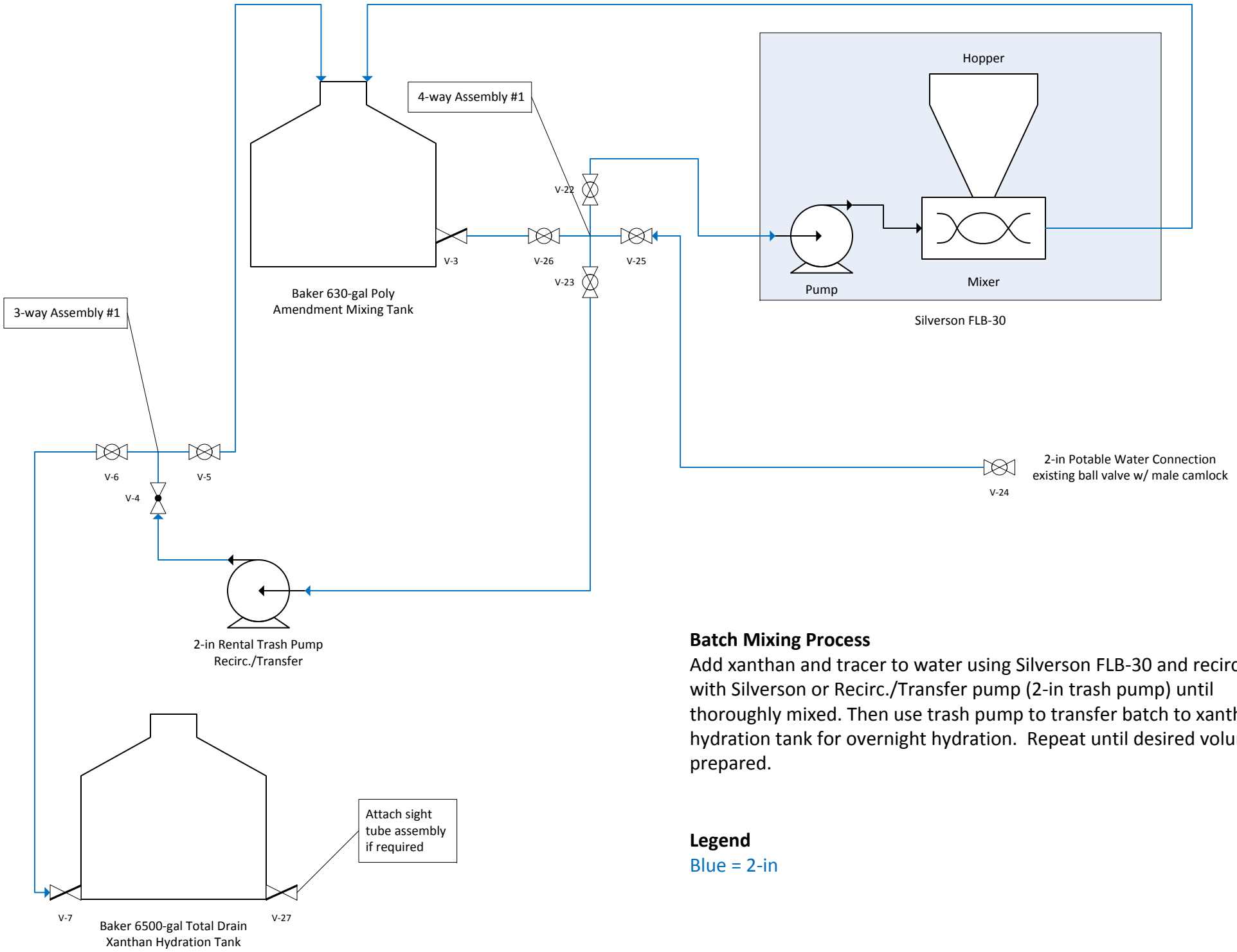
[1] Bioremediation parameters include anions (sulfate, chloride), dissolved gases (methane, ethene, ethane), and ferrous iron and volatile fatty acids. All of these parameters will be analyzed by an analytical laboratory except for ferrous iron, which will be analyzed in the field.

[2] Field parameters include: temperature, conductivity, dissolved oxygen (DO), oxidation-reduction potential (ORP), and pH.

[3] TAL metals will only be sampled for if the ferrous iron concentration is greater than 1 mg/L.

DHC - *Dehalococcoides spp* by qPCR.

Figure 1. Modified injection configuration

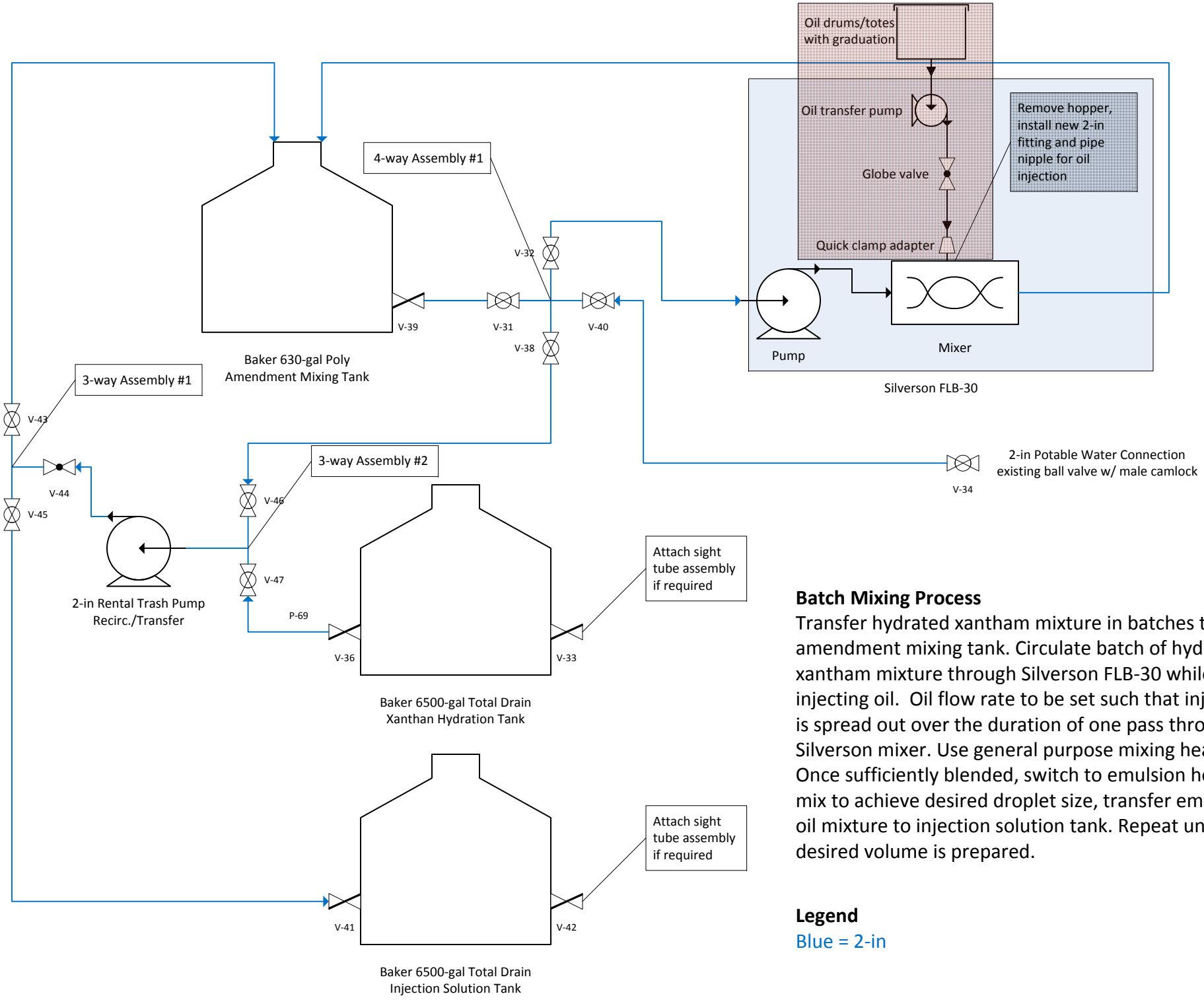


Batch Mixing Process

Add xanthan and tracer to water using Silverson FLB-30 and recirculate with Silverson or Recirc./Transfer pump (2-in trash pump) until thoroughly mixed. Then use trash pump to transfer batch to xanthan hydration tank for overnight hydration. Repeat until desired volume is prepared.

Legend

Blue = 2-in

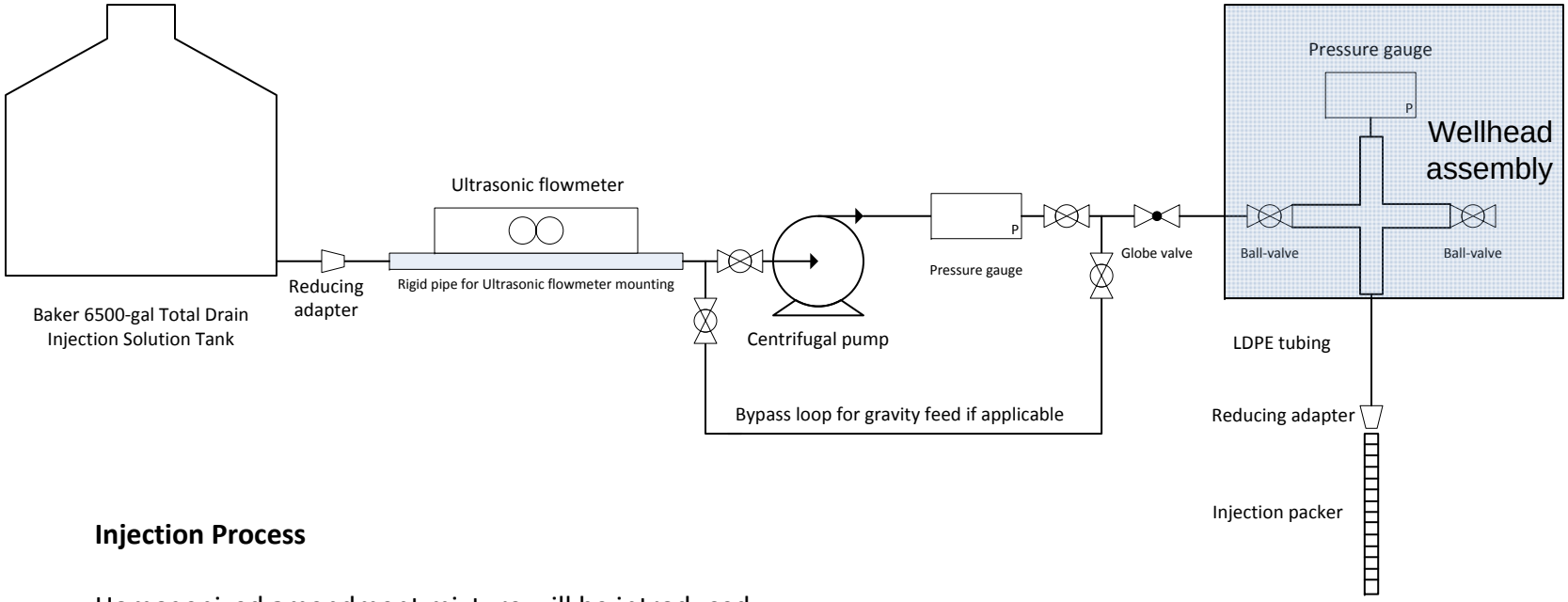


Batch Mixing Process

Transfer hydrated xantham mixture in batches to the amendment mixing tank. Circulate batch of hydrated xantham mixture through Silverson FLB-30 while injecting oil. Oil flow rate to be set such that injection is spread out over the duration of one pass through the Silverson mixer. Use general purpose mixing head. Once sufficiently blended, switch to emulsion head and mix to achieve desired droplet size, transfer emulsified oil mixture to injection solution tank. Repeat until the desired volume is prepared.

Legend

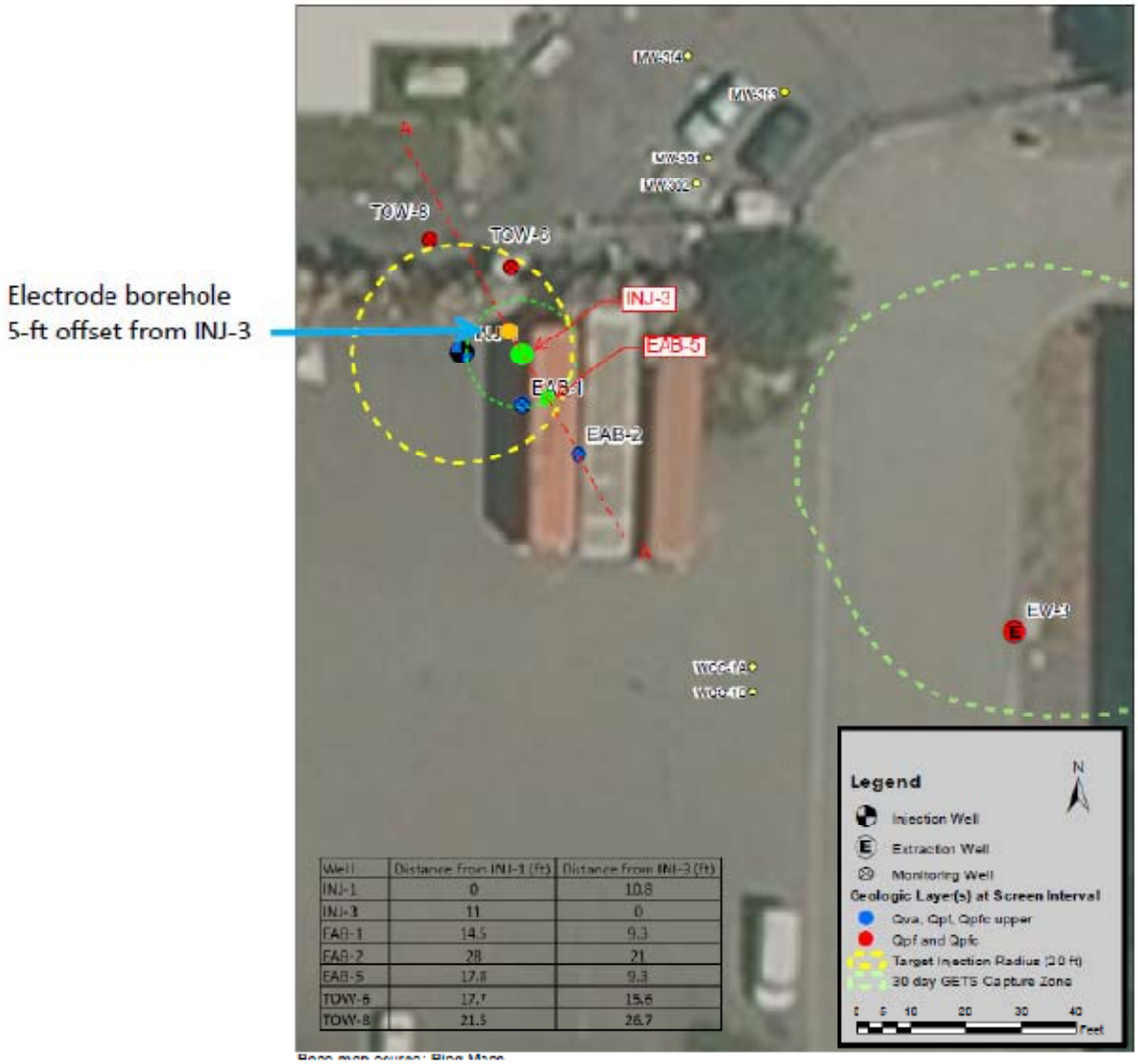
Blue = 2-in



Injection Process

Homogenized amendment mixture will be introduced into the well from the amendment mixing tank. An ultrasonic flowmeter mounted on a piece of rigid pipe will be used to assess flow rate. Pressurized injection may not be necessary for the shallow injection. In such case, the amendment will be introduced via gravity feed thru the bypass loop. The well head assembly will be used to purge the well and to monitor & maintain an injection pressure of less than 30 psi. Flow rate will be controlled at the globe valve. LDPE tubing will be used to connect the wellhead assembly to the injection packer.

Figure 2. Modified injection layout



Well	Distance from INJ-1 (ft)	Distance from INJ-3 (ft)
INJ-1	0	10.8
INJ-3	11	0
EAB-1	14.5	9.3
EAB-2	28	21
EAB-5	17.8	9.3
TOW-6	17.7	15.6
TOW-8	21.5	26.7

Base map source: Bing Maps