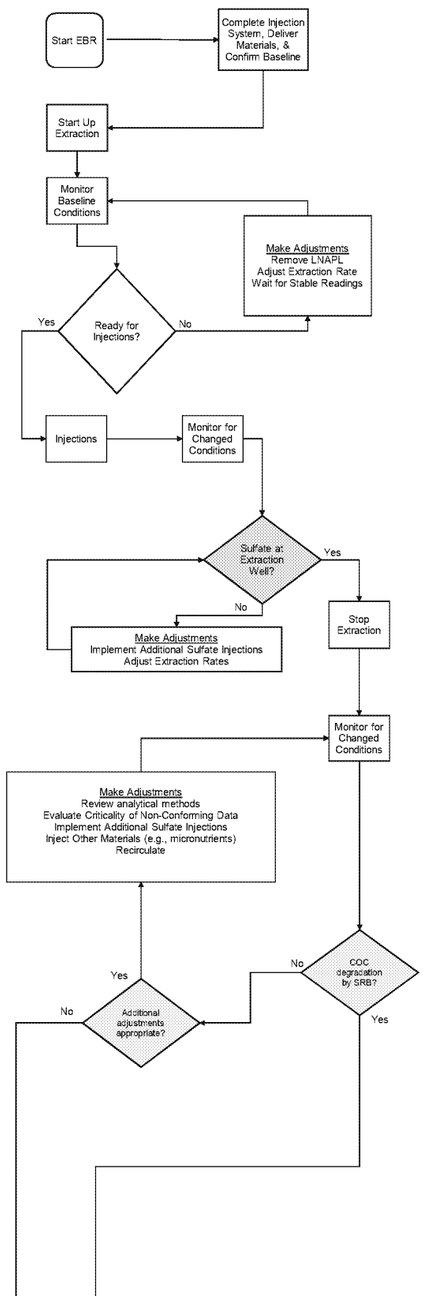
ST012 Decision Tree and Criteria for Enhanced Bioremediation
Former Williams Air Force Base
Mesa, Arizona



Decision Objective: To establish location is ready for EBR injections
Time Frame: 1 week-2 months

Criteria: Target Numerical Conditions

Parameter	Desired Trend	Method	Ideal	Non-Inhibiting	Units	Discussion
LNAPL	LNAPL recovery not sustained under pumping	field instrument	<1	<5	ft/week	LNAPL removal to be emphasized over EBR where significant migration to extraction wells occurs.
Water Levels	Hydraulic response consistent with expectation	field instrument				Differences may affect expected distribution
Extraction	Extraction rate and drawdown consistent with expectation	field instrument				Differences may affect travel times
Temperature	Stable or slowly changing	field instrument	<1		°F/day	Rapid temperature changes may lead to instability and population changes

Notes:
Parameters wil be evaluated in different areas of the site and may not be demonstrated everywhere simultaneously. Expansion of ideal conditions to all desired treatment areas will be part of the optimizaton step

Potential Adjustments

Condition	Potential Adjustments
1. LNAPL recovery does not meet criteria	a. Continue LNAPL removals, consider increased removal frequency b. Increase extaction drawdown to increase recovery rate. Once recovery diminishes return to design drawdown and retest recovery rate.
2. Water levels, extraction flow rate, or drawdown inconsistent with expecation	a. Evaluate data. Adjust extraction set points and remeasure or adjust expected sulfate travel times b. Evaluate data. Consider injection adjustments if flow directions are different than expected
3. Temperatures are changing rapidly at extraction or injection location	a. Continue to monitor and wait for stabilization

Decision Objective: To establish when pumping at individual extraction locations should be terminated
Time Frame: 10 weeks-1 year after injections start

Criteria: Target Numerical Conditions

Parameter	Desired Trend	Method	Target	Units	Discussion
Sulfate	Sulfate from injections arrives at extraction well	field kit	>50 above pre-injection	mg/L	Indicates arrival of injected sulfate

Notes:
Parameters will be evaluated in different areas of the site and decisions made for individual extraction wells.

Potential Adjustments:

Condition	Potential Adjustments
1. Sulfate shows up earlier or later than expected	a. Consider in designing future injections. b. Adjust extraction/injection rates or future injection concentration.

Decision Objective: To Establish Biological Degradation by Sulfate Reducing Bacteria (SRB) at ST012 and has been Enhanced
Time Frame: 3-9 months post injection

Criteria: Target Numerical Conditions

Parameter	Desired Trend	Method	Ideal	Non-Inhibiting	Units	Discussion
VOCs	Decreasing	8260B				Decreasing VOCS in the presence of sulfate may indicate degradation
TPH (DRO/GRO)	Decreasing	8015B				Decreasing TPH in the presence of sulfate may indicate degradation
Iron	Increased in contaminated area relative to upgradient	6010C				If most of total iron is assumed to be Fe(II) in the subsurface (because of higher solubility), increasing iron indicates reduction of Fe(III) to Fe(II)
Manganese	Increased in contaminated area relative to upgradient	6010C				If most of total manganese is assumed to be Mn(II) in the subsurface (because of higher solubility), increasing Mn indicates reduction of Mn(IV) to Mn(II)
Nitrate	Depleted	9056A	<0.5	<1	mg/L	Depleted nitrate indicates degradation by nitrate reducing bacteria is active on site but likely not active at the monitored location
Sulfate	Increased	9056A	2,000-10,000*	30000*	mg/L	Sulfate concentrations in targeted range
PLFA (SIP)	^{13}C-enriched content in PLFA	Microbial Insights				Incorporation of ^{13}C in PLFA demonstrates bacteria have degraded ^{13}C-enriched seed contaminant into bacteria cells
DIC (SIP)	^{13}C-enriched content in DIC	Microbial Insights				Incorporation of ^{13}C in DIC demonstrates bacteria have degraded ^{13}C-enriched seed contaminant into dissolved inorganic carbon
SRB (qPCR)	Increased relative to baseline	Microbial Insights				Increased population indicates SRB response to sulfate amendment
EBAC (qPCR)	Increased relative to baseline	Microbial Insights				Increased population indicates total bacteria response to sulfate amendment
Temperature	Stable or slowly changing	field instrument				Rapid temperature changes may lead to instability and population changes
pH	In Range	field instrument	7.5-8	5.5-9		Avoid pH range that would inhibit EBR
Eh	Reduced	field instrument	-220	<0	millivolts	(Correct to hydrogen electrode)Eh should be in expected range for anaerobic SRBs
DO	Depleted	field instrument	<0.5	<1.0	mg/L	Anaerobic activity will be inhibited if significant DO is present

Notes:
Parameters wil be evaluated in different areas of the site and different zones (CZ, UWBZ, LSZ) and may not be demonstrated everywhere. Expansion of conditions to all desired treatment areas will be part of the optimization step
*Preliminary ranges for target sulfate concentrations in the formation. Values are subject to modification based on observation of SRB responses in the field to sulfate. Higher concentration may be present in the immdiate vicinity of injection wells.

Potential Adjustments:

Condition	Action
1. Most desired trends are met, but a few are not	a. Verify data quality, potentially test by alternate analytical methods b. Evaluate if non-conforming data represents a critical uncertainty for SRB enhancement or other data supercedes
2. If several parameters are not met in all areas of the site	a. Implment additional injections to bring parameters into range and retest. b. Inject in different locations or recirculate to redistributed sulfate
3. If geochemical parameters are in desired range but there is no sign of VOC/TPH degradation and no enrichment of ^{13}C in the PLFA or DIC	a. Evaluate other factors that could be limited EBR (e.g., lack of micronutrients) and implement additional extraction/injections if necessary b. Implement additional injections if necessary (e.g., to address micronutrients)
4. If degradation by SRB can not be demonstrated after other measures, consider alternate technologies	a. Evaluate other technologies (e.g., pump and treat, chemical oxidation)

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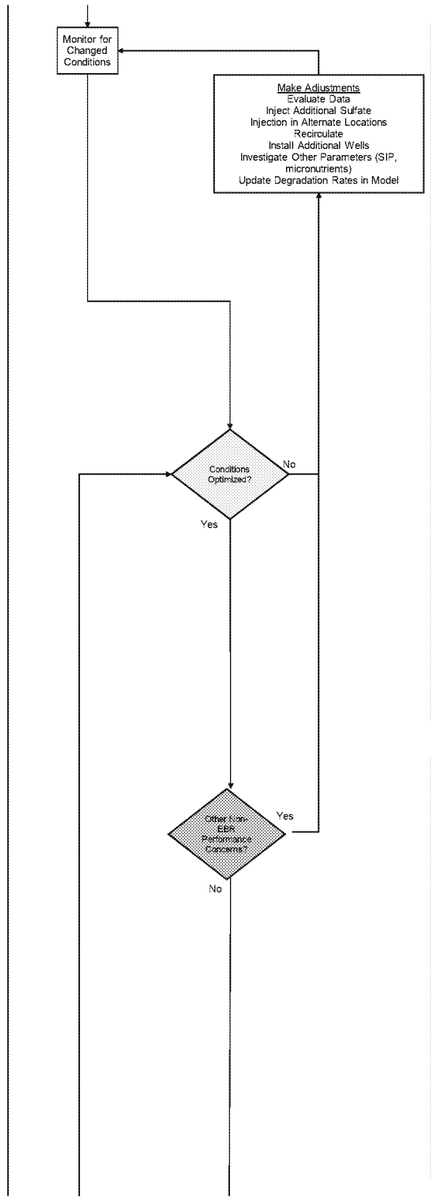

Decision Objective: Target Criteria to Optimize Biological Degradation by SRB at ST012
Time Frame: 6-36 months post initial injection

Criteria:

Parameter	Desired Trend	Method	Target Numerical Conditions: Average	Maximum	Units	Discussion
Benzene in CZ	Decreasing toward post EBR model targets	8260B	21*	27*	µg/L	Plot benzene trends by well and average for the zone over time and project timeframe to reach goal
Benzene in UWBZ	Decreasing toward post EBR model targets	8260B	210*	1400*	µg/L	Plot benzene trends by well and average for the zone over time and project timeframe to reach goal
Benzene in LSZ	Decreasing toward post EBR model targets	8260B	31*	270*	µg/L	Plot benzene trends by well and average for the zone over time and project timeframe to reach goal
TPH (DRO/GRO)	Decreasing	8015B				Decreasing TPH is an indicator of decreasing TPH flux from NAPL
Iron	Increased in contaminated area relative to upgradient	6010C				If most of total iron is assumed to be Fe(II) in the subsurface (because of higher solubility), increasing iron indicates reduction of Fe(III) to Fe(II)
Manganese	Increased in contaminated area relative to upgradient	6010C				If most of total manganese is assumed to be Mn(II) in the subsurface (because of higher solubility), increasing Mn indicates reduction of Mn(IV) to Mn(II)
Nitrate	Depleted	9056A	<0.5		mg/L	Depleted nitrate indicates degradation by nitrate reducing bacteria is active on site but likely not active at the monitored location
Sulfate	Sustained in target range	9056A	2,000-10,000**	30000**	mg/L	Sulfate concentrations in targeted range
PLFA (SIP)	^{13}C-enriched content in PLFA	Microbial Insights				Incorporation of ^{13}C in PLFA demonstrates bacteria have degraded ^{13}C-enriched seed contaminant into bacteria cells
DIC (SIP)	^{13}C-enriched content in DIC	Microbial Insights				Incorporation of ^{13}C in DIC demonstrates bacteria have degraded ^{13}C-enriched seed contaminant into dissolved inorganic carbon
SRB (qPCR)	Increased	Microbial Insights				Increased population indicates SRB response to sulfate amendment
EBAC (qPCR)	Increased	Microbial Insights				Increased population indicates total bacteria response to sulfate amendment
LNAPL	LNAPL measurements decreasing or consistently low (<1 ft)	field instrument				LNAPL removal to be emphasized over EBR where significant migration to extraction wells occurs.
Temperature	Stable or slowly changing	field instrument				Rapid temperature changes may lead to instability and population changes
pH	In Range	field instrument	6.5-8	5.5-9		Avoid pH range that would inhibit EBR
Eh	Reduced	field instrument	-220	<0	millivolts	(Correct to hydrogen electrode)Eh should be in expected range for anaerobic SRBs
DO	Depleted	field instrument	<0.5	<1.0	mg/L	Anaerobic activity will be inhibited if significant DO is present

Notes:
Parameters to be evaluated in different areas of the site with objective to establish desired trends in all monitored areas of known contamination
*Values as presented in the modeling in RDRAWP, Appendix E. Update of the groundwater model using data from the full-scale EBR may result in updated values.
**Preliminary ranges for target sulfate concentrations in the formation. Values are subject to modification based on observation of SRB responses in the field to sulfate. Higher concentration may be present in the immdiate vicinity of injection wells.

Potential Adjustments:

Condition	Action
1. Limited sulfate distribution	a. Evaluate hydraulic data compared to model predictions.
	b. Inject additional sulfate
	c. Inject sulfate in alternate wells
	d. Extract and recirculate to improve sulfate distribution
	e. Install additional wells for injection/extraction
2. Slow sulfate depletion	a. Evaluate data for possible causes
	b. Investigate with SIP and other supplemental analysis (e.g., for micronutrients)
	c. Estimate revised degradation rates in the model and evaluate redistribution options
3. Limited VOC reduction	a. Review microbial data, perform additonal tests if necessary
	b. Additional sulfate injections (if SRB populations confirmed)
	c. Assess back diffusion and LNAPL dissolution as potential causes

Decision Objective: Other non-EBR performance criteria that may require action during active EBR
Time Frame: Any time during active EBR

Criteria:

Parameter	Desired Trend	Method	Discussion
LNAPL Accumulation	LNAPL accumulation remains low	field instrument	LNAPL removal is generally more efficient than EBR. LNAPL not removed can increase EBR timeframe.
VOC migration	VOCs don't migrate to perimeter wells	8260B	VOC migration would expand area requiring treatment
Sulfate migration	Sulfate doesn't significantly migrate outside of COC-areas	field kit/9056A	Sulfate moving outside of COC-impacted areas will not benefit EBR and can cause exceedance of the secondary MCL
Arsenic Concentrations	Arsenic concentrations exceed MCL	6010C	Arsenic in injection solution or naturally occuring arsenic liberated by reduced conditions might exceed MCLs
Biofouling	Biofouling does not hinder injections or sulfate distribution	field instrument	Significant changes in water levels or sustainable flow rates in the monitoring/injection/extraction wells with time may indicate biofouling (except what is attributable to the regional rise)

Notes:
Parameters to be evaluated on an individual monitoring well basis for achievement of maximum transition criteria concentrations and on an overall avergage for average transition criteria.

Potential Contigencies:

Condition	Action
1. LNAPL accumulates >5' in a site well	a. Remove LNAPL from well
2. VOCs migrate to perimeter wells	a. Evaluate if sulfate migration with EBR may eventually address location. If yes, monitor
	b. Evaluate and implement extraction to prevent further migration
3. Sulfate migrates outside COC-areas	a. Depending on location and sulfate concentration, extract and reinject upgradient
4. Arsenic exceeds MCL	a. Adjust injections (if arsenic measured in injection solution)
	b. Evaluate and implement extraction to prevent migration outside the active EBR area
5. Biofouling in injection well	a. Pressurized injections
	b. Well redevelopment
6. Biofouling in formation	a. Develop alternate sulfate injection/delivery for area of fouling

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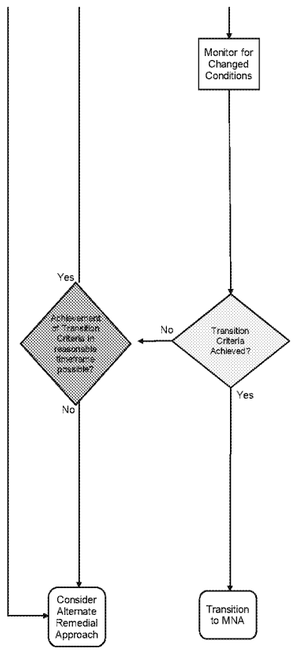

Decision Objective: Transition Criteria Achieved?
Time Frame: 18-36 months post initial injection

Criteria: Target Numerical Conditions

Parameter	Desired Trend	Method	Average	Maximum	Units	Discussion
Benzene in CZ	Post EBR model targets met	8260B	21*	27*	µg/L	Average and maximum concentrations consistent with these model values would indicate that MNA could complete remediation in about 13 years.
Benzene in UWBZ	Post EBR model targets met	8260B	210*	1400*	µg/L	Average and maximum concentrations consistent with these model values would indicate that MNA could complete remediation in about 13 years.
Benzene in LSZ	Post EBR model targets met	8260B	31*	270*	µg/L	Average and maximum concentrations consistent with these model values would indicate that MNA could complete remediation in about 13 years.
Sulfate	Sulfate distributed to support ongoing MNA	9056A	2,000-10,000**	30000**	mg/L	Sulfate concentrations in targeted range
LNAPL	No measureable LNAPL in wells	field instrument				LNAPL removal to be emphasized over EBR where significant migration to extraction wells occurs.

Notes:
Parameters to be evaluated for each zone (CZ, UWBZ, and LSZ).
*Values as presented in the modeling in RDRAWP, Appendix E. Update of the groundwater model using data from the full-scale EBR may result in updated values.
**Preliminary ranges for target sulfate concentrations in the formation. Values are subject to modification based on observation of SRB responses in the field to sulfate. Higher concentration may be present in the immdiate vicinity of injection wells.

Potential Adjustments:

Condition	Action
None - Move to next decision step	Not applicable

Decision Objective: Degradation Trends Support Transition Criteria Can be Achieved in a Reasonable Timeframe or Can be further Optimized
Time Frame: 18-36 months post initial injection

Criteria:

Parameter	Desired Trend	Method	Discussion
CZ Benzene Rate of Change	Benzene half-life supports transition criteria achievement	8260B	Half-life calculations using EBR data support achievment of transition criteria within a ~36 month timeframe.
UWBZ Benzene Rate of Change	Benzene half-life supports transition criteria achievement	8260B	Half-life calculations using EBR data support achievment of transition criteria within a ~36 month timeframe.
LSZ Benzene Rate of Change	Benzene half-life supports transition criteria achievement	8260B	Half-life calculations using EBR data support achievment of transition criteria within a ~36 month timeframe.

Notes:
Parameters to be evaluated on an individual monitoring well basis for achievement of maximum transition criteria concentrations and on an overall avergage for average transition criteria.

Potential Contingencies:

Condition	Action
1. Transition criteria achievement not predicted within 36 months post initial injection	a. Implement further optimizations if possible. b. Evaluate among BCT if predicted timeframe is sufficiently close to 36 months to continue with current remedy. If yes, continue active EBR. c. Evaluate alternative approaches (e.g. pump and treat, chemical oxidation, continued active EBR with longer timeframe).