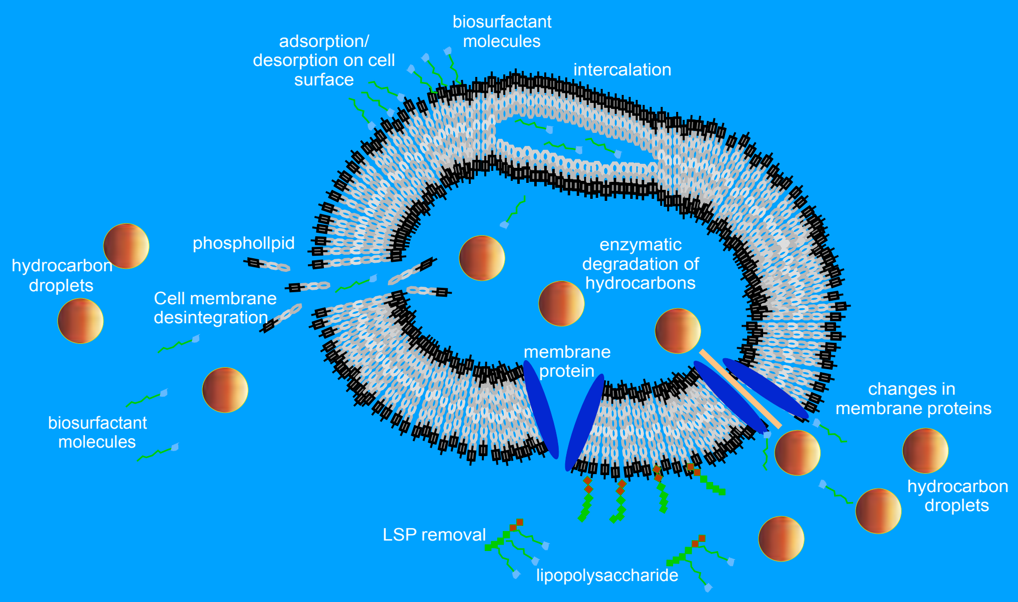
BIOPILE DESIGN OPTIMIZATION PRIMER WITH HC-2000



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1. BACKGROUND

Biopiles are especially effective for degrading petroleum-contaminated soils in an aerobic environment. Biopiles relieves the burden on landfills that are already overloaded with leachate and vapor intrusion. The primary mechanisms of petroleum hydrocarbons concentration reduction in biopiles are by native aerobic degradation and evaporation. Bioremediation is conducted by employing biostimulation (like bioventing and composting, except exsitu rather than insitu), supplying electron acceptors, water, catalysts (nutrients, in the form of organic nitrogen, phosphorus, trace elements, vitamins, excess carbon when needed) and surfactants. Surfactants have been demonstrated to be a significant factor in desorbing bound contaminates and may increase degradation rates by up to 20%.

Remtech has developed a bioremediation catalyst with biosurfactants that optimizes biodegradation in aerobic, methogenic, and anerobic environments for petroleum and chlorinated compounds in soil and groundwater. This treatise is focused on aerobic environments that are preferred in biopile applications.

Soil normally contains large population of diverse native microorganisms, bacteria, algae, fungi, protozoa, and actinomycetes that rapidly acclimate and degrade petroleum hydrocarbons. Less than 1% to 10% of petroleum degraders have been Identified by typical laboratory culture techniques, therefore it is recommended that total heterotrophic microbial plate counts (10^4 to 10^7 CFU/gm) be used to measure potential degrader populations. A minimum of 1,000 CFM/gm is generally required to identify contaminated soils that are capable of degrading petroleum contaminated soils in non-toxic environments.

Bacteria require carbon, nitrogen, and phosphorus for cell growth and an energy source to sustain metabolic functions required for growth. Petroleum hydrocarbons become the desired target carbon source for degradation but frequently require additional carbon supplements. Note that native heterotrophic bacterial degrader populations may frequently dominate over fungi.

Biopiles may be placed on an impermeable base to collect leachates and prevent migration into soil and groundwater. Leachate collection systems collect excess moisture and liquid biochemical catalysts for recirculation and/or treatment.

Refined petroleum products are generally more easily degraded than crude oil. Diesel contaminated soils generally do not require vapor emission treatment for volatile organic compound (VOC) reduction while gasoline contaminated soils may require activated carbon filtration or reinjection into the biopile for further degradation.

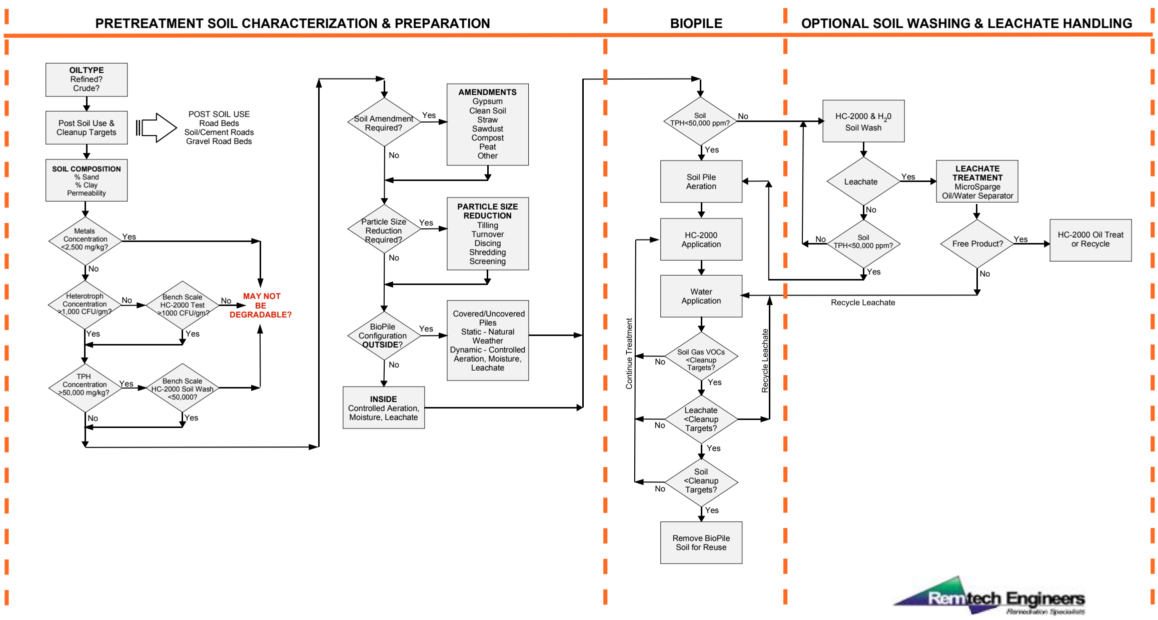
Piles may be covered with membranes, seeded with vegetation, or placed in a pole barn to protect from wind and rain. Total petroleum hydrocarbon concentrations may be limited to <50,000 ppm (ideal concentration <10,000 ppm), heavy metals concentrations <2,500 ppm, and trace concentrations of chlorinated compounds. Biopiles typically reduce petroleum hydrocarbon contaminated soils to 250 to 1,000 ppm with treatment times ranging from 3 to 6 months. Concentrations can be further reduced during shorter periods using more aggressive mass transfer mechanisms for mixing, aeration, and biochemical catalyst delivery.

2. SOIL BIOPILE APPLICABILITY

Figure 1 depicts an algorithm to determine the viability and decision tree to optimize the selection and implementation of biopile technology. To determine the suitability for biopile degradation, representative samples of contaminated soil are collected and tested for total petroleum hydrocarbons, PAHs, heavy metals, priority pollutants, PCBs, and other potentially toxic materials. Total heterotrophic plate counts in soil should exceed 1,000 CFU/gm indicating that bacterial activity is present.

The suitability of soil biodegradation is a function of particle size, organic sorption, and permeability. As soil particle size is reduced from small gravel, sand, silt, and clay, biodegradation can become more difficult. Soil screening and shredding can reduce particle size. Soil with clay or high-molecular-weight humic materials reduces permeability and reduces mass transport of air and additives. Clay and humic materials can absorb up to 60% of petroleum hydrocarbons restricting bioavailability to degraders. Bulking agents may be required to increase airflow, retain water, and overcome mass transfer limitations. Surfactants can be utilized to desorb contaminates to degraders.

FIGURE 1: REMTECH HC-2000 BIOPILE DESIGN AND OPERATION ALGORITHM ©



3. Site Selection

Biopiles require adequate space for equipment access, soil hauling, soil storage, and availablility of utilities such as water and power. Local, remote, and temporary or permanent treatment sites are frequently dictated by the amount of soil to be treated (>250 cy).

4. Soil Preparation

Tilling, discing, shredding, and/or screening may be necessary to reduce particle size and provide a more homogeneous matrix. Blending or mixing agents such as sand, wood chips, straw, mulch, grass clippings, compost, gypsum, waste from grape producers (shredded stems, pumice, etc.) may be added to increase soil porosity, homogeneity, and/or retain moisture. Reducing particle size prior to excavation by plowing, cultivating, or discing may be all that is required for select soils. Typical biopile blending agent additions range from 10 to 20% combined with 80 to 90% contaminated soil.

5. BioPile Control Parameters

- *Moisture* – 75% field holding capacity (12 to 30% water by weight)
- *Biochemical Catalysts* –Typical carbon: nitrogen: phosphorus ratios necessary for biodegradation fall in the range of 100:10:1 to 100:1:0.5 depending on specific contaminants and degraders present in the soil. Excessive concentrations of phosphate and sulfate can retard microbial metabolism
- *Oxygen Concentration* – mechanical aeration is superior to chemical oxidants that can be wasted oxidizing natural organics in soil that are not target contaminants
- *pH* – 5 to 9, adjust with soda ash, NaOH, citric acid
- *Mass Transfer Confirmation* – radius of influence testing by air injection measured by magnehillic gages
- *Soil Temperature* – 10ºC to 45ºC (50 to 113ºF). For every 10ºF rise in temperature, degradation rates may double. Note that heat of compression from regenerative blowers produce heat in the

range of 140ºF which is ideal for pressurized aeration of biopiles. Heat dissipation hose a certain distance from the blower is required to drop temperature below the softening temperature of PVC aeration piping and screens.

6. Bench-Scale Tests

A standard method for biopile treatability studies does not exist. Bench-scale treatability tests do not provide reliable scale up information for full-scale design. Catalyst and carbon requirements are dynamic and are different for each soil and contaminant. Maintaining elevated heterotrophic plate counts after amendment addition is a good indicator that degradation is proceeding, and adequate moisture levels are being maintained.

Amendment frequencies and dosages may need to be adjusted to achieve optimal degradation rates. Note that as petroleum hydrocarbon chains are degraded or broken down into smaller more numerous chains, a "bouncing ball" degradation curve may be observed, with concentrations dropping and rebounding until asymptotic concentrations are reached. Applying too much organic catalysts can be detrimental as microbes may prefer to degrade additives rather than target contaminants.

Remtech has performed soil bench-scale tests using metal (minimal contaminant adsorption) pans or pails. Prior to splitting soil between different bioreactors, rocks and roots are removed, clumps broken down with nitrile gloves, then screened. Catalysts are added with spray bottles that deliver a known amount per pump, mixing with a stainless-steel paddle or spoon, and adding distilled water to maintain adequate moisture without producing a *pasty soil* with no free liquids in the bottom of the container. Additional water may be required to ensure that catalysts are distributed throughout the entire matrix. Samples can be removed from the same test vessel providing mixing is maintained during the test period to determine degradation rates and plate counts. A contaminated sample blank should be run without catalyst addition for natural attenuation comparison.

Continuously Stirred Slurry Reactors (CSTRs) with shakers or magnetic stirrers have also been used by Remtech to determine relative biodegradation rates using erlenmeyer flasks covered with tin foil. Flask studies are primarily used for water-phased bioremediation studies, not biopile studies.

7. BioPile Construction

Select biopile configurations are presented in Figures 2 and 3. Adding or eliminating system options may be appropriate for specific contaminates and soils. General construction rules thumb are summarized below:

- Pile height - 4 to 10 ft
- 10 ft space between piles if equipment access is required, no equipment movement on piles
- 1% slope of pile base for leachate drainage
- Less than 45% slope of pile sides
- Membrane under and/or over pile
- Aeration – mechanical mixing or pressurized or vacuum aeration
- Catalyst and water addition – soaker hoses, surface spray or vacuum communication through piles. Add catalyst during initial mixing operation
- Leachate Collection – gravity or vacuum extraction
- Leachate Treatment – recirculation or treatment
- Off gas treatment required for volatile petroleum compounds like gasoline, generally not required for diesel

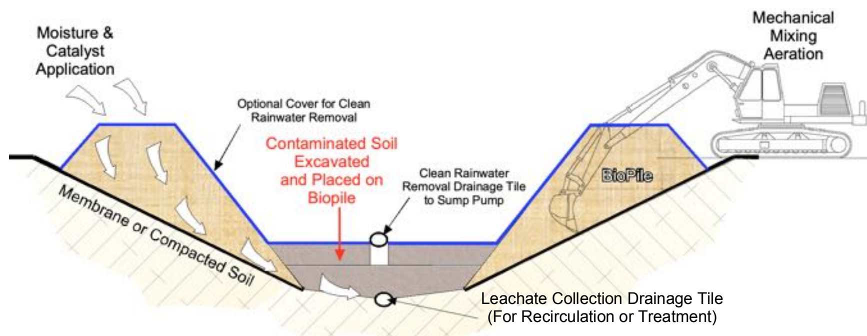


Figure 2: Inclined Biopile - Excavated Contaminated Soil Placed on Inclined Slope

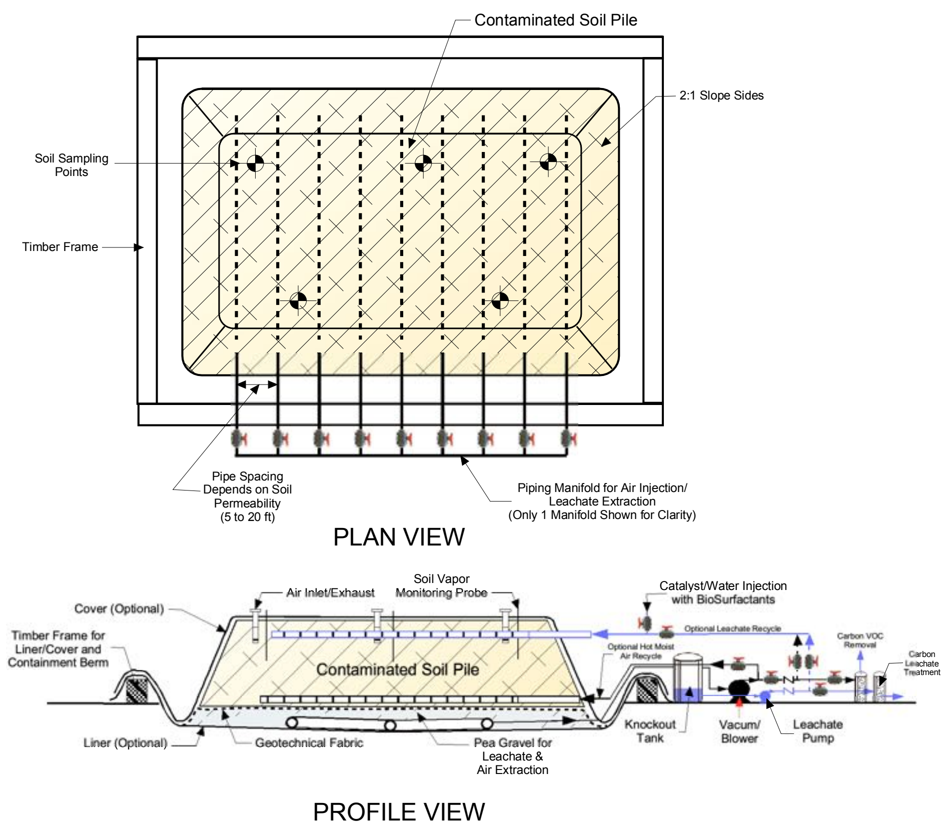


Figure 3: Remtech Aggressive Heated Biopile

8. HC-2000 BIOCHEMICAL CATALYST

HC-2000 was formulated by Remtech Engineers with known natural biochemical catalysts that have been historically field demonstrated by others in successful full-scale bioremediation projects. HC-2000 has been used successfully by Remtech on over 400 full-scale bioremediation projects over the past 23 years (1998 to 2021).

This formulation information is proprietary and not to be used, duplicated, copied, stored in an electronic retrieval recording system or otherwise without the expressed written consent of Remtech Engineers

Table 1: HC-2000 Composition

Parameter	% **Composition**	**Parameter**	% **Composition**
Calcium	<0.1%	Fermented Grapes/Molasses	proprietary
Alcohols	proprietary	Other Vitamins	proprietary
Amino Acids	proprietary	pH	3.1 - 3.3
Biosurtactants	proprietary	Potassium	<1%
Biotin	proprietary	Protein	proprietary
Chloride	proprietary	Pyridoxine	proprietary
Choline	proprietary	Riboflavin	proprietary
Citric Acid	proprietary	Salmonella	none
Cofactors	proprietary	Sodium	<1%
Enzymes	proprietary	Sugars	proprietary
Fecal Coliform	BDL*	Sulfate	<1%
Folic Acid	proprietary	Sulfite	BDL*
Inositol	proprietary	Thiamine	proprietary
Iron	<0.1%	TKN	<1%
Magnesium	<0.1%	Total Phosphorus	<0.1%
Mold	proprietary	Vitamin A	proprietary
Nicotinic Acid	proprietary	Yeast	proprietary
Nitrate Nitrogen	BDL*	Zn, Fe	proprietary

BDL - Below Laboratory Detection Limits

9. BIOPILE MONITORING PARAMETERS & INSTRUMENTATION

- Total heterotrophic plate counts (HPC) - Standard Methods 9215
- Gasoline Recoverable Organics - EPA Modified Method 8015D
- Diesel Recoverable Organics - EPA Modified Method 8015D
- Oil and Grease - Method 1664B
- Hydrocarbons - EPA method 8010, EPA Method 5030, EPA Method 9071
- EPA TCLP Metals - Method 1311
- PAHs - SW 846 Test Method 8100, 8270D
- Water quality of leachates - pH, DO, specific conductance, temp, BOD, COD, total petroleum hydrocarbons, BOD - SM 5210 B, COD - Hach Method 8000
- Soil gas piezometers - CO_2, O_2, CH_4, VOCs and sVOCs
- Dynamax PR2 Multi Depth Soil Moisture Probe
- Lantec GA5000 Gas Extraction Monitor - CH_4, CO_2, O2, H_2S
- QRAE 3, RAE Systems (Honeywell), 4 gas pump monitor - LEL, CH_4, CO, H_2S
- MultiRAE, RAE Systems (Honeywell), Model PGM6228 pump monitor - NH_3, O_2, CH_4, VOC
- Hand auger
- Whirl-Pak sampling bag
- Sampling port, pump or bailer to collect leachate samples
- Fluke Model 52 K/J Thermometer, John Fluke Manufacturing Co., Inc. Everett, WA
- Soil temperature J Type or K Type thermocouples placed within the biopile
- Radius of influence testing of air injection or extraction - magnehelic gages

10. HC-2000 DOSAGE RATES

Optimal degradation conditions are present when total heterotrophic plate counts, or specific degrader counts are elevated and maintained during the treatment period. Elevated plate counts indicate that sufficient nutrients, moisture, and environmental conditions are present.

Secondary parameters that may be monitored include respiration by-products, moisture, dissolved oxygen, pH, total dissolved solids, Total Organic Carbon (TOC), and redox potential. Monitoring the reduction of the contaminant(s)-of-concern determines when treatment is complete and/or when natural attenuation can complete the degradation process.

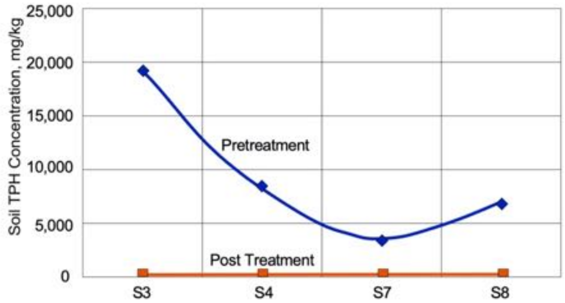
The rules of thumb dosage for HC-2000 (HC2) range from one gallon of HC2 concentrate to three (3) to ten (10) cubic yards of contaminated media over the treatment period. HC-2000 may be applied topically by spray, soaker hoses or injected via infiltration galleries. Treatment periods range from five weeks to several months. Concentrate dilution ratios of one part of HC-2000 to sixteen parts of water (6% solution) is recommended for soil. The number of applications and concentrations may vary according to site specific requirements. Care should be exercised to prevent overdosing with HC2 to prevent native microbes from utilizing HC2 rather than targeted contaminants.

11. CASE HISTORIES

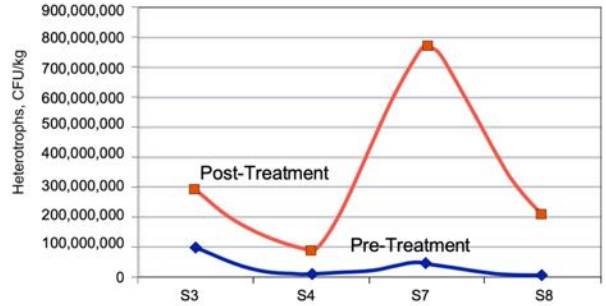
Jet A Airport Biopile Bioremediation with HC-2000
Location: Atlanta, GA
Client: International Airport
Contract Amount: Confidential

PROBLEM
The drive train on a tanker carrying 10,000 gallons of Jet A exploded and punctured the shell releasing 8,000 gallons of fuel on a perimeter road at an International Airport. The site was in a restricted area in direct line with aircraft approach runways. Fuel was released on asphalt pavement and migrated overland and 1-mile downstream into airport drainage ditches, tunnels, and a creek. The airport authority required that a remedial approach with minimal access and visual disturbances to approaching aircraft be implemented.

SOLUTION
Approximately 6,500 gallons of fuel were recovered from a one-mile section of stream utilizing skimmers, vacuum trucks, wash down pumps, and a polypropylene rope mop. An estimated 1,500 gallons of fuel were spilled on 850 cubic yards of soils at the release point. Contaminated soils were also excavated from the drainage ditch and the Sandy CLAY soils were cultivated and disc/harrowed to reduce particle size prior to placing on the biopile.
Three (3) horizontal aeration manifolds were placed under the pile and aerated with a regenerative blower. Ten (10) gallons of HC-2000 (diluted with 16 volumes of water) were applied topically on a weekly basis. A surface sprinkler system-maintained soil moisture levels. Total petroleum hydrocarbon (TPH) concentrations were reduced from concentrations as high as 19,000 ppm to below 200 ppm in 16 weeks (99% reduction). Total heterotrophic plate counts were elevated from 6,000,000 to over 100,000,000 CFU/gm.



TPH Concentrations Reduced by Over 95% after 4 Months



Total Heterotrophs Increase with HC-2000 Applications

COST/BENEFITS
Remtech trained airport personal to maintain the bioremediation systems and reduce project costs. Remediating soils onsite with HC-2000 minimized site access and resident time that met airport authority security and aircraft safety requirements.

Enhanced Bioremediation of JP-4 in Soils and Groundwater with HC-2000
Location: Atlanta, Georgia
Client: Major Tank Line/Insurance Company
Contract Amount: $430,000

PROBLEM
A tanker carrying 8,000 gallons of JP-4 on a major interstate highway rolled down a steep embankment releasing 2,600 gallons of jet fuel into a forested sandy soil adjacent to a stream feeding a major recreational lake in North Atlanta. The spill site was immediately adjacent to a golf course. Remtech was engaged by the insurance company to remediate the site.

SOLUTION
Remtech installed a series of interceptor trenches to collect free product. The interceptor trenches were also designed to serve as insitu biosparge reactors to collect soil leachates and treat groundwater. HC-2000 was applied to enhance the biodegradation of jet fuel in the vadose (soil) and saturated (groundwater) zones.

During the first month of operation, 700 gallons of free product were recovered from the interceptor trenches (using recovery well pumps) and from an oxbow using a polypropylene rope mop. Leachates were pumped to Remtech's treatment system consisting of an oil/water separator, twin LPAS (Low-Profile Air Strippers), and aqueous phase activated carbon filter discharged to the stream.

HC-2000 was applied to surface soils and injected into interceptor trenches. Interceptor trenches were utilized to sparge groundwater and generate bio-foam and to elevate groundwater dissolved oxygen levels from 0.5 mg/l to over 3.5 mg/l. Total groundwater heterotrophic plate counts increased from 10,000 CFUs/ml to over 1,000,000 CFUs/ml during the first month of biosparging. During the first 30 days of treatment solution phase total petroleum hydrocarbons (TPH via EPA method 418.1) were reduced by over 83% and soil TPH concentrations were reduced by over 70%.

Over a four-month period, soil TPH concentrations were reduced over 91% and groundwater TPH concentrations by over 94%. Benzene groundwater concentrations were reduced from 125 ppb to below detection limits. No benzene groundwater rebound concentrations were recorded six (6) years later.

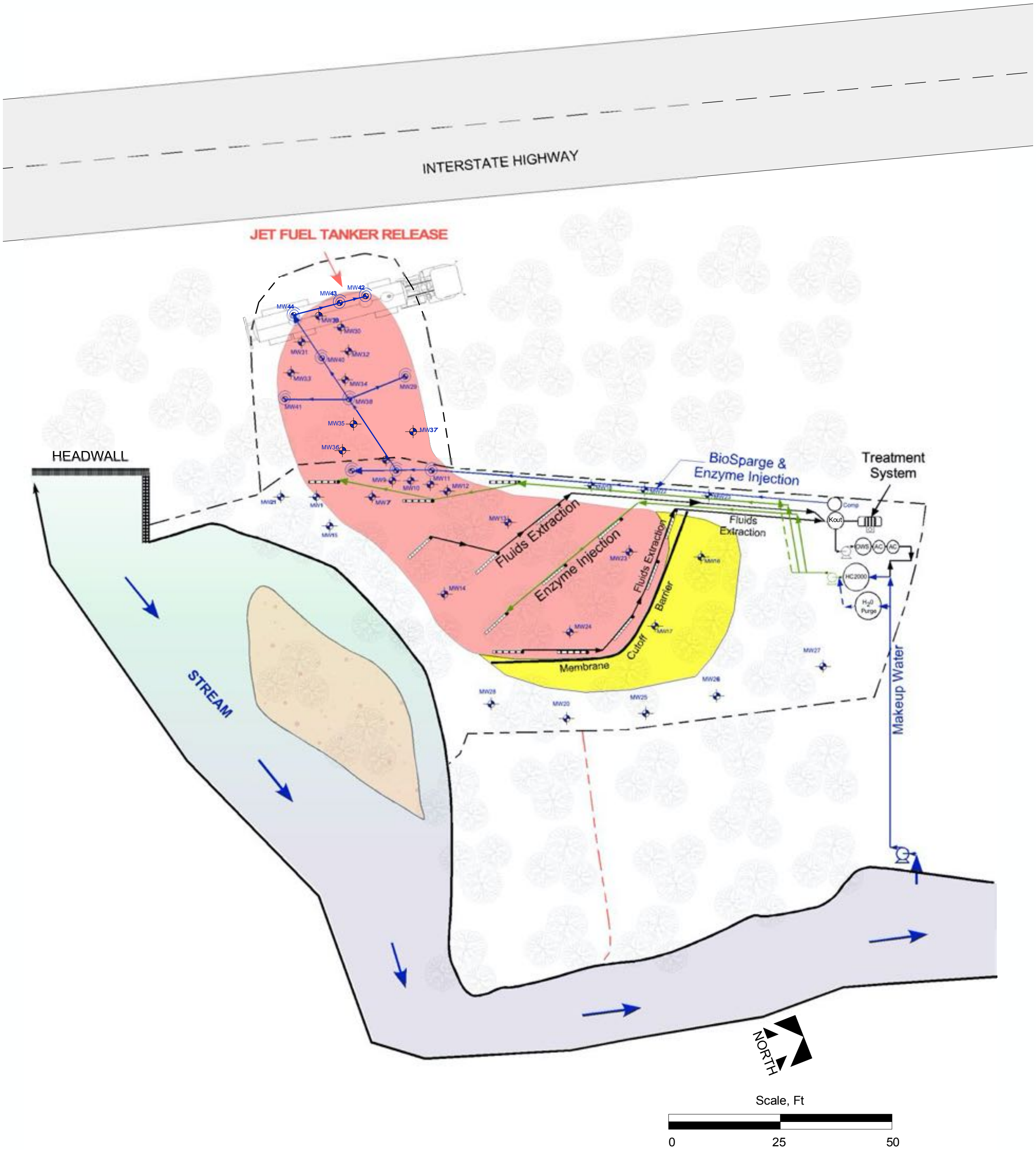


Figure 4: HC-2000 Treatment of 5,000 cy of Jet Fuel Contaminated Soil and Groundwater

COST/BENEFITS

HC-2000 biostimulation was selected over other remedial strategies due to limited site access and significant cost savings over other methods, i.e., less than 50% of site excavation and restoration costs.

Approximately 5,000 cy of contaminated media (soil and groundwater) were treated for $86/cy. Insitu treatment prevented traffic interruptions from hauling hundreds of loads onto the interstate and site erosion was avoided.

12. REFERENCES

1. Ryckman, M.D, P.E., DEE, et.al, *Bioremediation Optimization Primer* with HC-2000, Remtech Engineers, 2019.
2. Ryckman, M. D., *HC-2000 Biodegradation & Cleaning Application on Petroleum Hydrocarbon & Solvent Cleanups* (A Green Sustainable Technology), Remtech Engineers website, www.remtech-eng.com, 2016.
3. Cookson, John T, *Bioremediation Engineering-Design and Application*, McGraw-Hill, Inc., 1995.
4. Battelle Memorial Institute, *Biopile Design and Construction Manual*, Technical Memorandum TM-2189-ENV, Battelle, Columbus, Ohio, June 1996
5. Westinghouse Savannah River Company, *Biopiles for Remediation of Petroleum Contaminated Soils: A Polish Case Study*, January 2003
6. EPA, *How to Evaluate Biopile Cleanup Technologies for Underground Storage Tank Sites, A Guide for Corrective Action Plan Reviewers*, EPA 510-B-17-003, October 2017.
7. Ryckman, M.D.P.E., DEE, *Petroleum Hydrocarbon Degradation Efficacy & Aquatic Toxicity Testing of HC-2000 Enhanced Bioremediation Product in Freshwater and Soil Environments*, Remtech 2016
8. Ryckman, M.D., P.E., DEE, *Range Finding Aquatic Toxicities of Enhanced Bioremediation Degrader Product (HC-2000),* Remtech 2016
9. Ryckman, Mark D., et. al., *Enzyme helps Remediate at Lightning Speed*, Soil and Groundwater Cleanup Magazine, February - March 1997
10. Ryckman, Mark D., et.al., *Cut Project Life Cycle Costs*, Soil and Groundwater Cleanup Magazine, January - February 1996.
11. Ryckman, M.D., P.E., DEE, *Enhanced Bioremediation with HC-2000*, Remtech Engineers Newsletter, Vol. 6, December 2002.
12. Ryckman, M.D., P.E., DEE, *HC-2000 Multi-Media Applications*, Remtech Engineers Newsletter, Vol. 9., November 2004
13. Ryckman, M.D., P.E., DEE, Remtech Engineers, *Confidential Client Project Report Files*,1997-2021.

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