

EVO Carbon Footprint, Distribution, and Longevity: Summary of SRS[®] Case Histories

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ABSTRACT. Emulsified vegetable oil (EVO) is widely used electron donor to promote the anaerobic biodegradation of chlorinated solvents and metals like hexavalent chromium. Terra Systems, Inc.'s Slow Release Substrate or SRS[®] has been used at more than 200 sites. It contains soybean oil, food grade surfactants, sodium lactate, nutrient package, and water. Using the CCaLC Carbon Footprinting Tool, carbon calculations over the lifecycle of industrial activities (University of Manchester) with estimates for the transportation of the SRS[®] components and energy consumption for production, the carbon footprint of SRS[®] was estimated to be 0.73 pound CO₂e per pound of SRS[®]. Transportation to the site for injection will add approximately 0.000022 pound CO₂e per mile (0.000062 kg/km) assuming transportation by diesel truck carrying 46,000 pounds (20,866 kg) of SRS[®]. EVO can be injected by direct-push equipment, such as Geoprobe[®], or into wells previously installed by direct-push or auger-drilling rigs. Direct-push injections can be used when repeat application is not anticipated, for shallow sites, or at sites where installation of a large number of injection wells is not feasible. EVO can be injected into biobarriers to intercept the groundwater plume or into grids for source area treatment. EVO distribution and persistence is affected by site characteristics and the injection methodology with TOC distribution generally limited to about 20 feet (6.1) from the injection points and lasting from 162 to 2,529 days.

Background. Emulsified vegetable oil (EVO) is widely used electron donor to promote the anaerobic biodegradation of chlorinated solvents and metals like hexavalent chromium. Terra Systems, Inc.'s Slow Release Substrate or SRS[®] has been used at more than 200 sites. It contains soybean oil, food grade surfactants, sodium lactate, nutrient package, and water.

Using the CCaLC Carbon Footprinting Tool, carbon calculations over the lifecycle of industrial activities (University of Manchester) with estimates for the transportation of the SRS[®] components and energy consumption for production, the carbon footprint of SRS[®] was estimated to be 0.73 pound CO₂e per pound of SRS[®] (Table 1). Transportation to the site for injection will add approximately 0.000022 pound CO₂e per mile (0.000062 kg/km) assuming transportation by diesel truck carrying 46,000 pounds (20,866 kg) of SRS[®].

Activities and Lessons Learned. EVO can be injected by direct-push equipment, such as Geoprobe[®], or into wells previously installed by direct push or auger drilling rigs. Direct-push injections can be used when repeat application is not anticipated, for shallow sites, or at sites where installation of a large number of injection wells is not feasible. EVO can be injected into biobarriers to intercept the groundwater plume or into grids for source area treatment.

TABLE 1. Total CO₂e for SRS production and transportation to manufacturer.

Component	Actual CO ₂ e from Production	Actual CO ₂ e from Transportation	Total CO ₂ e
Soybean Oil	0.523	0.00858	0.532
Emulsifiers	0.162	0.000553	0.163
Nutrients	0.00291	0.000215	0.00313
Sodium Lactate	0.0192	0.00103	0.0202
Water	0.000189	N/A	0.000189
Electricity for Production			0.00912
Total	0.707	0.0104	0.728

Site 1. Two injection events were conducted over a 19 month period with a total of 13,858 pounds (6,286 kg) of soybean oil and lecithin with 8,789 gallons (33,266 L) of chase water by direct push and direct push installed wells for source area treatment in an area of 92 feet (28.0 m) long by 157 feet (47.9 m) wide by 50 feet (15.2 m) thick (Lee et al 2004). The EVO loading rate was equivalent to 0.029 pounds per cubic foot (0.46 kg/m³). The injections achieved a radius of influence of at least 20 feet (6.1 m) in a sandy aquifer on Long Island (Figure 1) with an estimated groundwater flow rate of 44 ft/year (13.4 m/yr.). Figure 2 shows the total organic carbon (TOC) persistence after the second injection for Site 1. The TOC persisted for more than 2,529 days at concentrations greater than 10 mg/L in wells 3 ft (0.9 m), 4 ft (1.2 m), 9 ft (2.7 m), and 17 ft (5.2 m) from the injection wells and for more than 2,360 days in wells 3 ft (0.9 m) and 9 ft (2.7 m) from the injection wells.

Site 2. Injection of 7,488 pounds (3,397 kg) of soybean oil and emulsifiers with 3,432 gallons (12,990 L) at a 100 foot (30.5 m) wide by 20 foot (6.1 m) x 30 foot thick (9.1 m) long biobarrier in Dover AFB, DE into direct push installed wells (Lee et al 2004). An EVO loading rate of approximately 0.19 pounds/ft³ (3.0 kg/m³) was achieved. The groundwater flow rate was estimated to be 128 ft/year (39 m/year). The maximum TOC level of 5,300 mg/L was found in one of the injection wells with TOC levels as high as 210 mg/L found as far as 15 feet (4.6 m) downgradient (Figure 3). Elevated TOC levels of greater than 10 mg/L at distances of 7.5 feet (2.3 m) to more than 20 feet (6.1 m) from the injection points were sustained for over 1,142 days (Figure 4) for many of the monitoring wells. However, the TOC distribution was not uniform with well AA-107 7.5 feet (2.3 m) downgradient of the nearest injection point not impacted by the substrate injections.

Site 3. About 3,236 pounds of SRS[®] and 990 gallons of chase water was injected at a 120 foot long x 40 foot wide by 25 foot thick bedrock site in New Jersey resulted in a loading rate of 0.027 pounds per cubic foot (0.43 kg/m³). The groundwater flow rate was estimated to be 394 ft/year (120 m/year). The SRS[®] and chase water was injected using the liquid atomized injection technique with high pressure nitrogen (Kirschner et al 2009). TOC distribution up to 32 feet (9.8 m) from the injection point with TOC persistence for

between 301 to greater than 405 days. TOC distribution was greater in the deeper wells with little impact in a shallow well 42 feet (12.8 m) from the injection point.

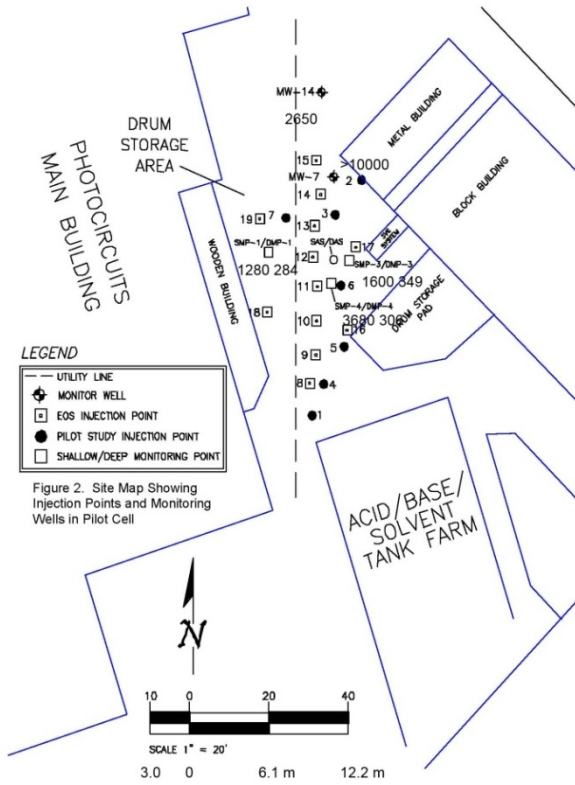


FIGURE 1. Maximum TOC distribution after second EVO injection for Site 1.

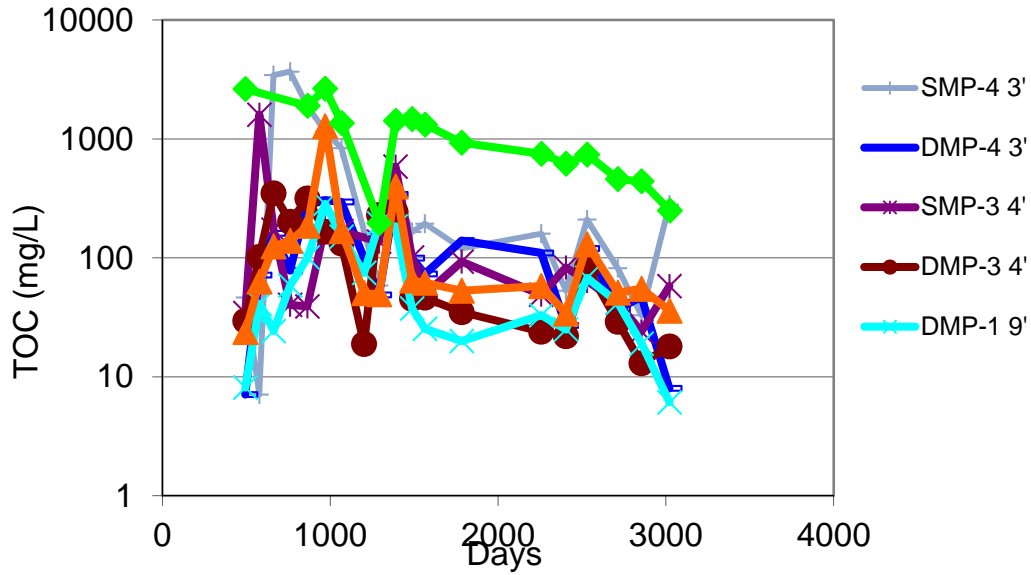


FIGURE 2. TOC persistence after second EVO injection for Site 1.

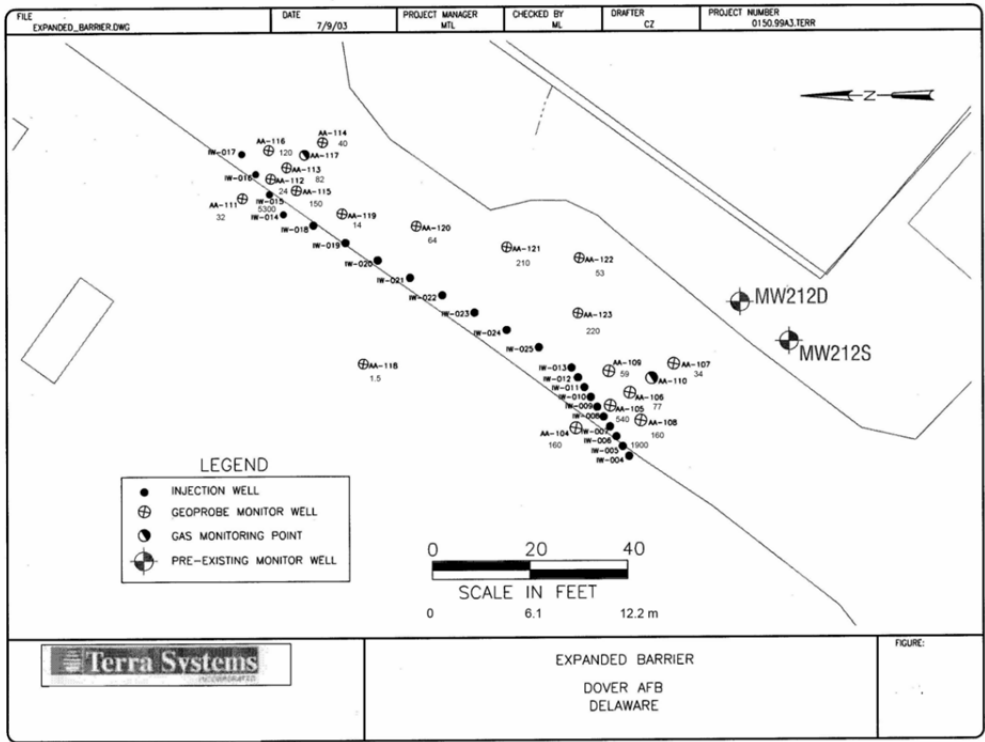


FIGURE 3. Maximum TOC distribution at Site 2.

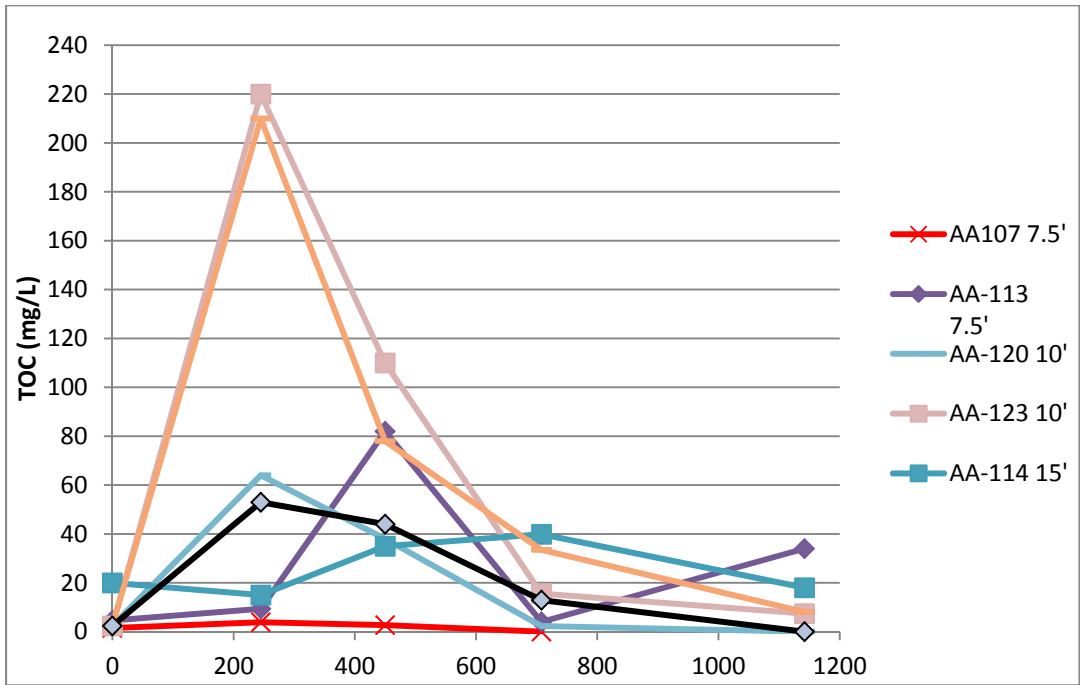


FIGURE 4. TOC concentrations in wells between 7.5 ft and 20 ft from injection wells Site 2.

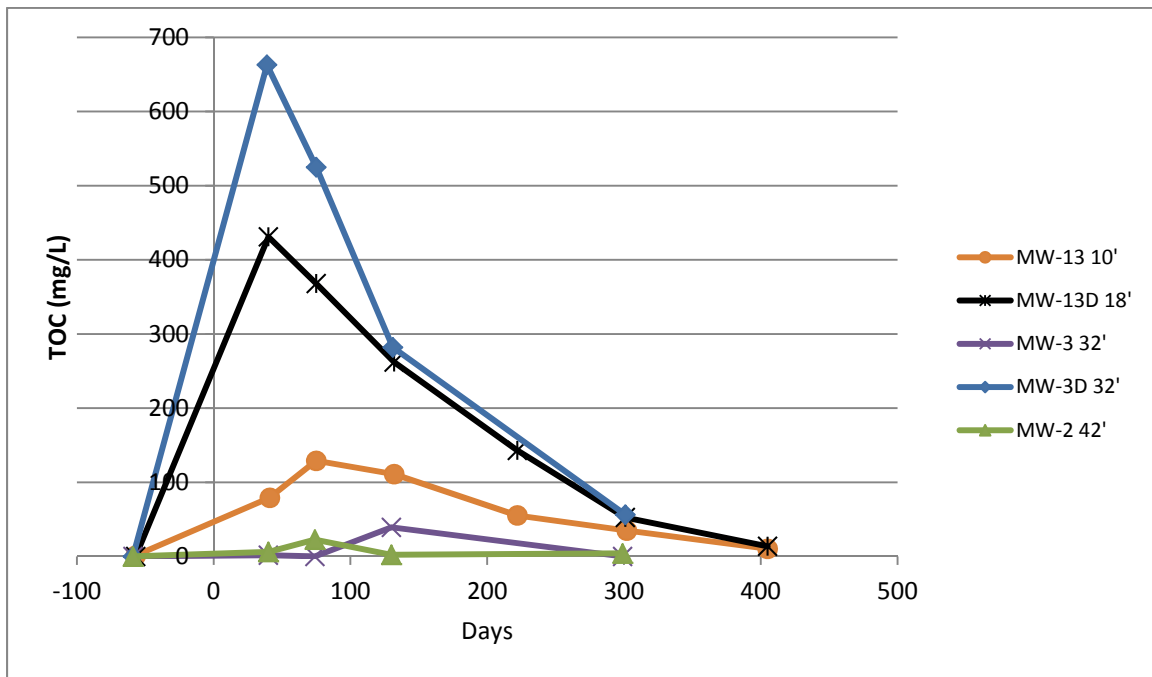


FIGURE 5. TOC longevity Site 3.

Site 4. At a New Jersey site where with the treatment volume was approximately 1,728,000 cubic feet (48,932 m³), a total of 52,500 pounds (23,814 kg) SRS[®] was injected into 44 drilled wells with 323,000 gallons of groundwater recirculation (Lee et al 2010). The groundwater flow rate was estimated to be 51 ft/year (15.5 m/yr). The SRS[®] loading was equivalent to 0.030 pounds/ft³ (0.000385 kg/m³). TOC levels as high as 99 mg/L were seen up to 14 feet (4.3 m) from the injection wells and persisted for 162 days (Figure 6). In another well 11 feet (3.4 m) from the nearest injection well, TOC levels were increasing after 817 days, but had fallen below 10 mg/L after 1,090 days. TOC levels in the injection wells persisted above 10 mg/L for over 1,000 days (Figure 7).

Site 5. The treatment volume at a site in Indiana was estimated to be 240,000 cubic feet (Gray et al., 2006) with a seepage velocity of 5 to 10 feet per year (1.5 to 3.0 m/yr). The source area of approximately 960,000 cubic feet (27,184 m³) was treated by injection of 26,500 pounds of SRS[®] via 180 direct push injection on approximately 30 foot centers and injection into two temporary wells; the source area loading was approximately 0.028 pounds/ft³ or 0.45 kg/m³. The centerline of the dissolved TCE plume covering approximately 288,000 ft³ was injected with 20,500 pounds of SRS[®] through six temporary wells and 40 additional direct push injections with an estimated loading of 0.071 pounds/ft³ or 1.14 kg/m³. Greater TOC distribution and longevity by the direct push injection technique with a maximum of 1,510 mg/L in well MW-700 and longevity for more than 1,371 days (Figure 8). The permanent wells showed a maximum TOC of 271

mg/L at a distance of 18 feet from the injection point and longevity of 1,133 days. Well PT-8 which was 8 feet from the nearest injection showed increased TOC loadings of up to 98 mg/L, but only for about 100 days. None of the wells further from the injection wells showed appreciable TOC levels.

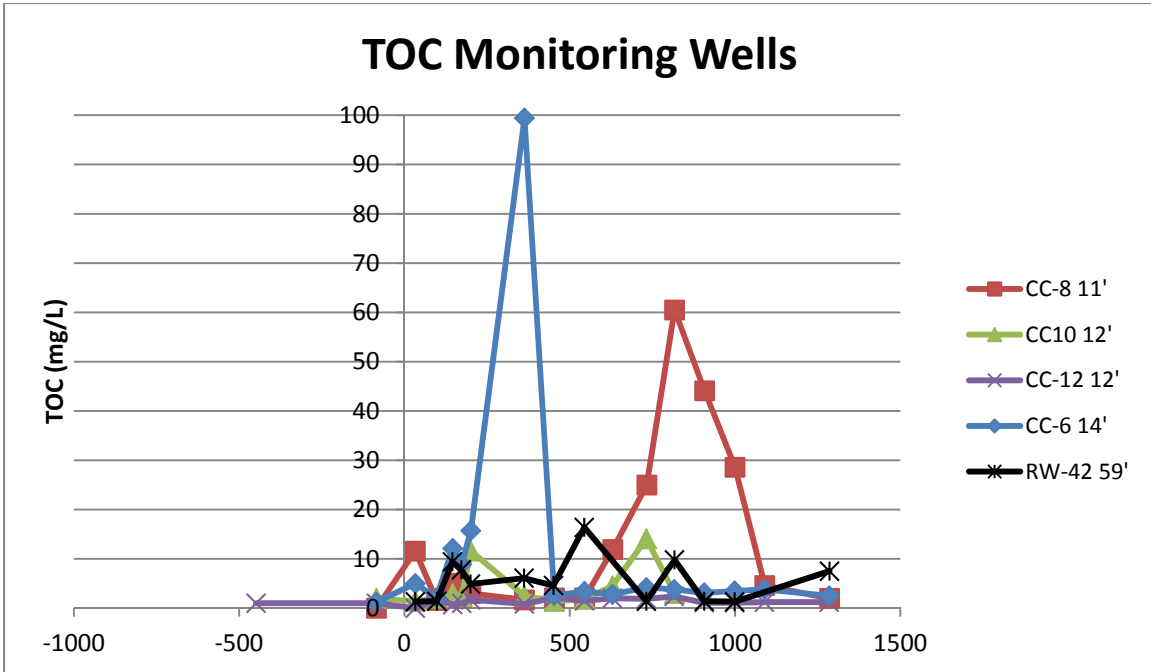


FIGURE 6. TOC concentrations in monitoring wells for Site 4.

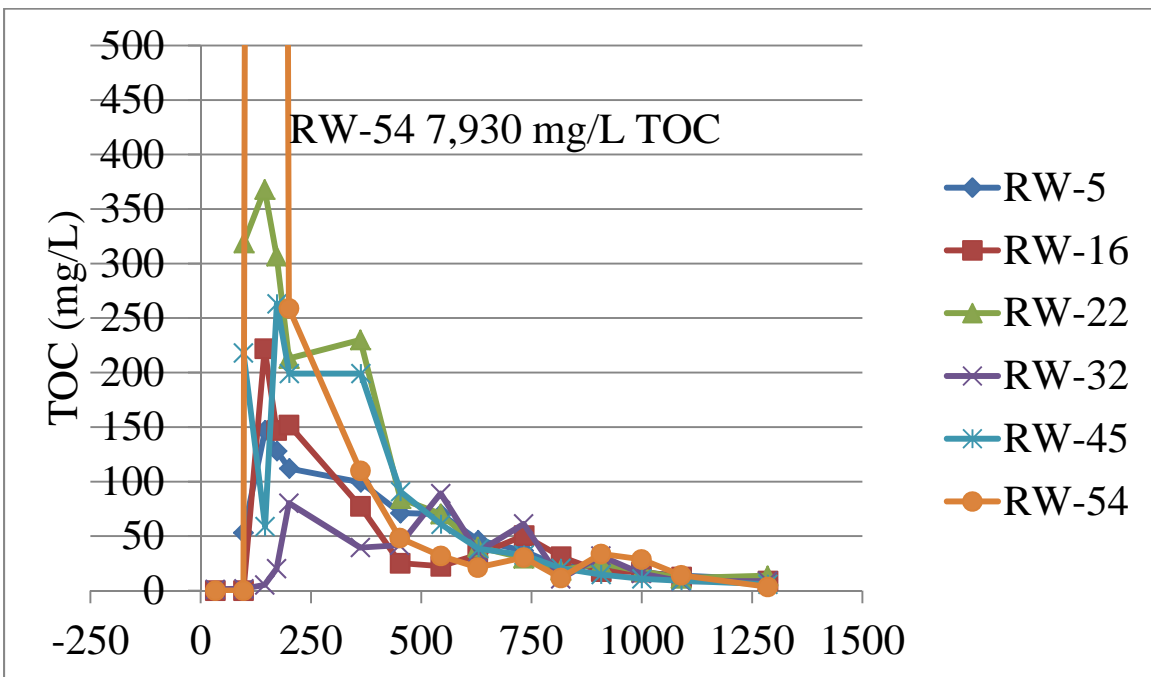


FIGURE 7. TOC concentrations in remediation wells for Site 4.

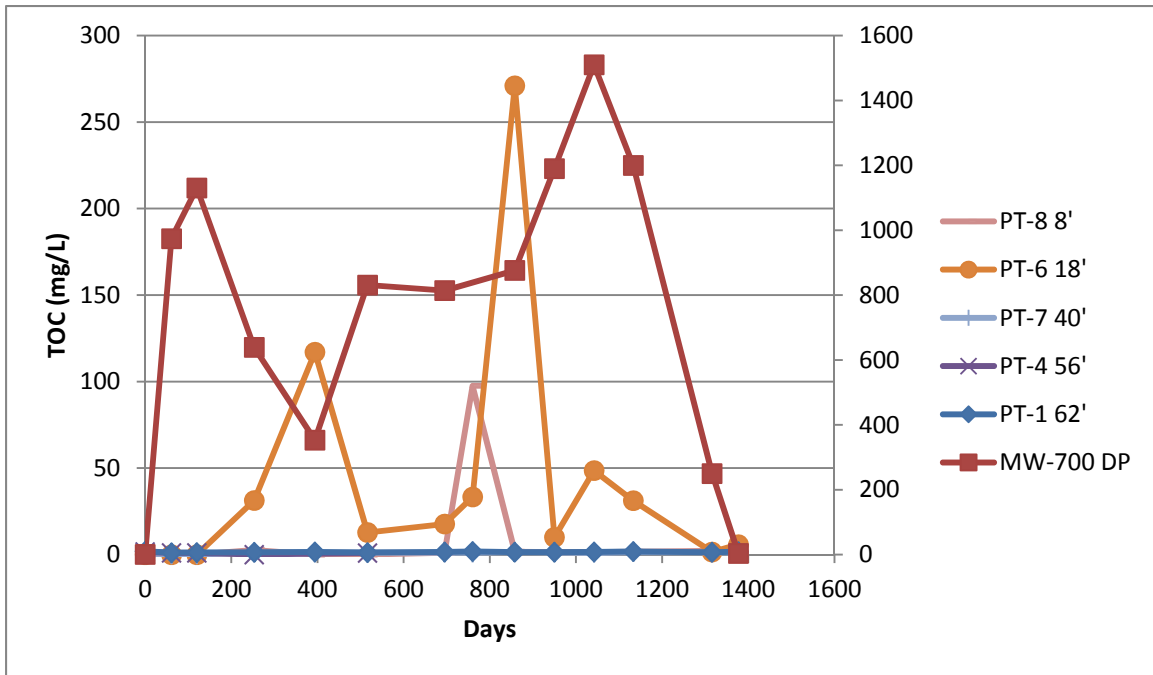


FIGURE 8. TOC by distance from injection wells and direct-push points for Site 5

Table 1 summarizes the five sites. EVO distribution and persistence is affected by site characteristics, substrate loadings, and the injection methodology with TOC distribution generally limited to about 20 feet from the injection points and lasting from 80 to 2,529 days.

TABLE 1. Groundwater flow rates, EVO loading, and TOC persistence >10 mg/L with distance.

Site	GWFR ft/yr	Injection Method	Loading Lbs/ft ³	No Wells out of Total Wells With Median TOC Persistence in Days			
				Wells 0-5 ft	5-10 ft	10-15 ft	>15 ft
1	44	Direct Push and Wells	0.029	4/5 >2529 1/5 2360	1/2 >2529 1/2 2360		1/1 >2529
2	128	Wells	0.29	4/10 >1,142 3/10 500-1000 2/10 100-500 1/10 <100	1/4 >1142 2/4 500-1000 1/4 <100	1/2 >1142 1/2 1120	1/1 800
3	394	LAI wells	0.027			1/1 >405	3/4 >300 1/4 130
4	51	Wells	0.030	6/6 1040 >1285		2/4 294-450	1/1 96
5	5-10	Direct Push Wells	Source 0.028 Plume 0.071	1360	1/1 80		1/4 1022 3/4 0

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- Gray, D., F. Coll, J. Powers, K. Gaskill, D. Raymond, and T.A. King. 2006. "Enhanced in-situ bioremediation of chlorinated VOCs as a cost effective remedial alternative." Paper M-08. In: B.M. Sass (Conference Chair), *Remediation of Chlorinated and Recalcitrant Compounds—2006*. Battelle Press, Columbus, OH (CD format).
- Kirschner, S.W., M. Lee, and M. Liskowitz. 2009. "Fracturing emplaced vegetable oil emulsion and bioaugmentation in a bedrock aquifer." Paper L-19. In G.B. Wickramanayake and H.V. Rectanus (Symposium Chairs), *In Situ and On-Site Bioremediation—2009*. Battelle Press, Columbus, OH (CD format).
- Lee, M.D., R.C. Borden, M.T. Lieberman, E.K. Becvar, and P.E. Haas. 2004. "TCE plume management through edible oil Injection and natural attenuation." Paper 3D-09. In A.R. Gavaskar and A.S.C. Chen (Eds.), *Remediation of Chlorinated and Recalcitrant Compounds -2004*. Battelle Press, Columbus, OH (CD format).
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EVO Carbon Footprint, Distribution, and Longevity – Summary of SRS[®] Case Histories

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TERRA SYSTEMS, INC.

OUTLINE

- SRS DESCRIPTION
- SRS CARBON FOOTPRINT
- SRS CASE HISTORIES
- CONCLUSIONS

SRS®

- **STANDARD EVO WITH 60% SOYBEAN OIL, 4% SODIUM LACTATE, FOOD GRADE EMULSIFIERS, NUTRIENTS, AND VITAMIN B₁₂ PROMOTES REDUCTIVE DECHLORINATION**
- **AVAILABLE IN SMALL DROPLET (SD), LARGE DROPLET (FR), WITH POTASSIUM LACTATE (PL), HEAVY METAL TREATMENT (M), AND IN COMBINATION WITH ZERO VALENT IRON (Z) FORMS**

SRS[®] CARBON FOOTPRINT

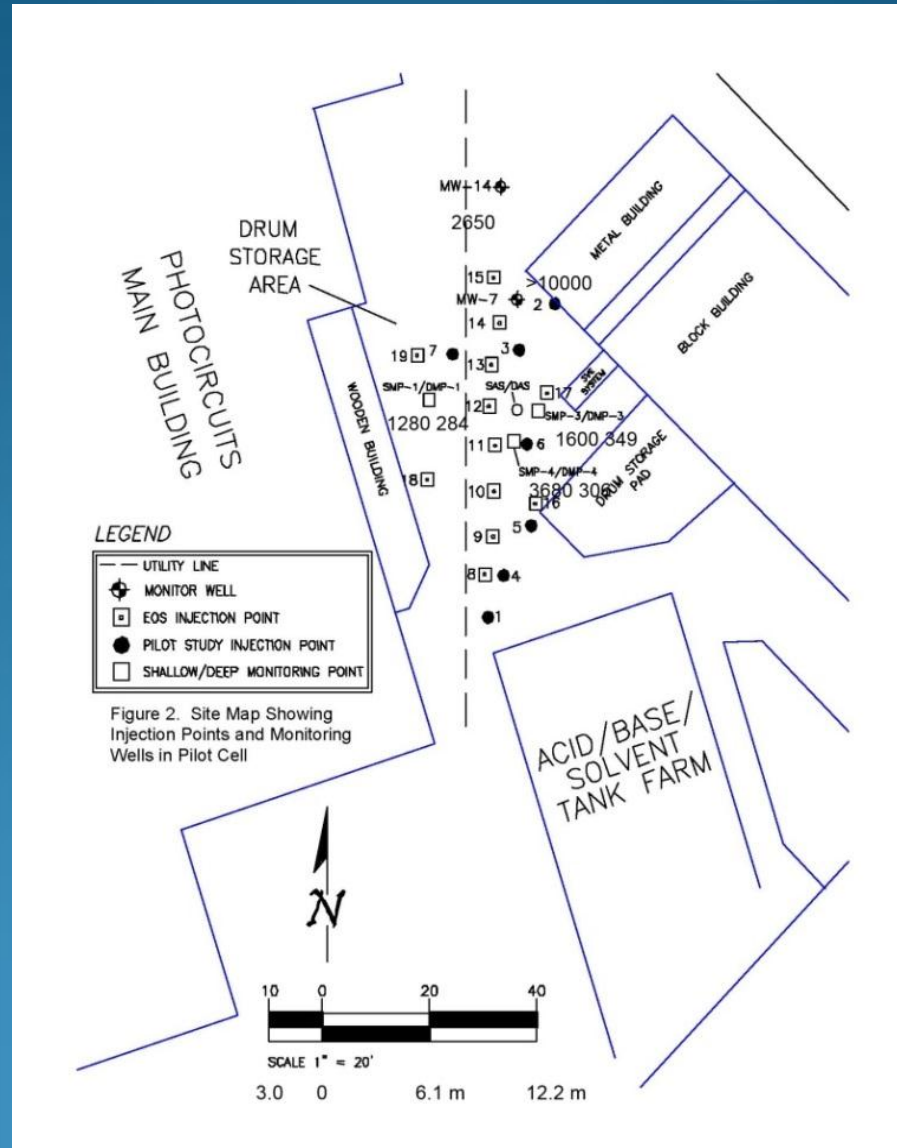
COMPONENT	ACTUAL CO ₂ E POUNDS FROM PRODUCTION/ POUND PRODUCT	ACTUAL CO ₂ E FROM TRANSPORTA TION/ POUND PRODUCT	TOTAL CO ₂ E/ POUND PRODUCT
SOYBEAN OIL	0.523	0.00858	0.532
EMULSIFIERS	0.162	0.000553	0.163
NUTRIENTS	0.00291	0.000215	0.00313
SODIUM LACTATE	0.0192	0.00103	0.0202
WATER	0.000189	N/A	0.000189
ELECTRICITY FOR PRODUCTION			0.00912
TOTAL	0.707	0.0104	0.728
TRANSPORTATION	0.000022/MILE		

CCaLC Carbon Footprinting Tool, Carbon Calculations over the Lifecycle of Industrial Activities (*University of Manchester*)

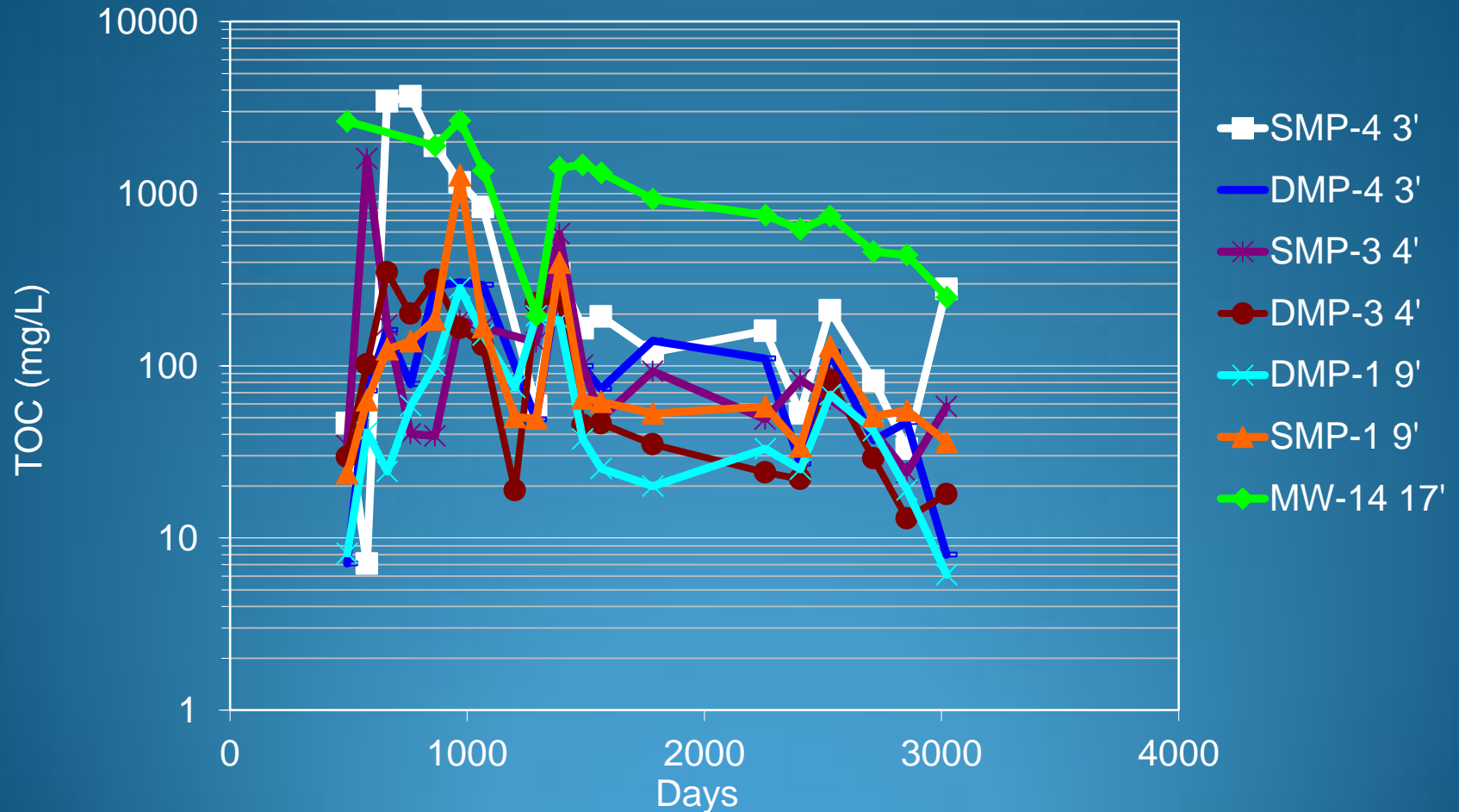
SITE 1 LONG ISLAND NY

- TWO INJECTION EVENTS OVER 19 MONTHS
- TOTAL OF 13,385 POUNDS SOYBEAN OIL AND LECITHIN WITH 8,789 GALLONS OF CHASE WATER
- INJECTED WITH DIRECT PUSH AND THROUGH DIRECT PUSH INSTALLED WELLS
- TREATMENT AREA 92 X 157 X 50 FEET
- LOADING 0.029 POUNDS/FT³
- GROUNDWATER FLOW RATE 44 FT/YR

SITE 1 MAXIMUM TOC AFTER 2ND INJECTION



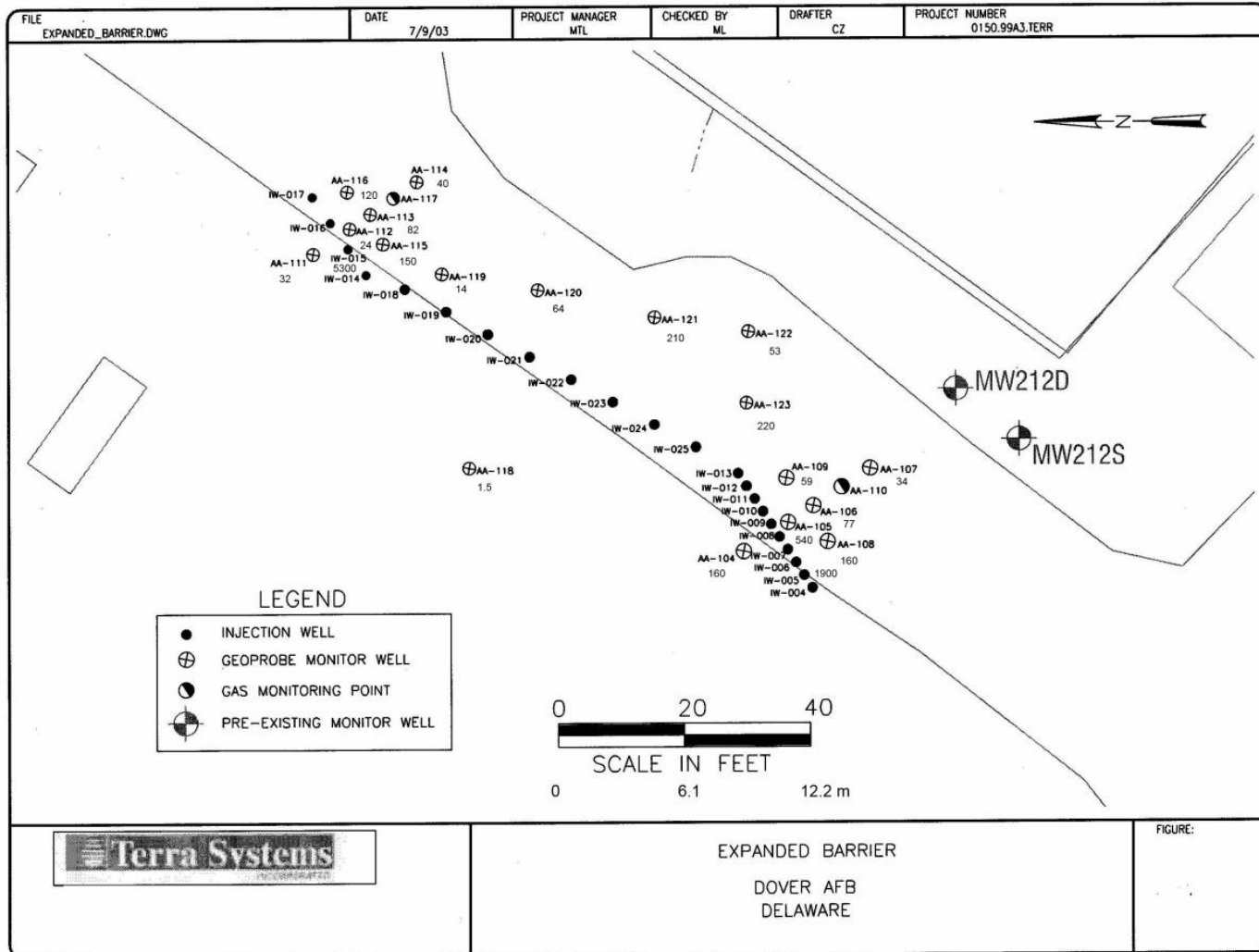
TOC PERSISTENCE AFTER SECOND EVO INJECTION FOR SITE 1



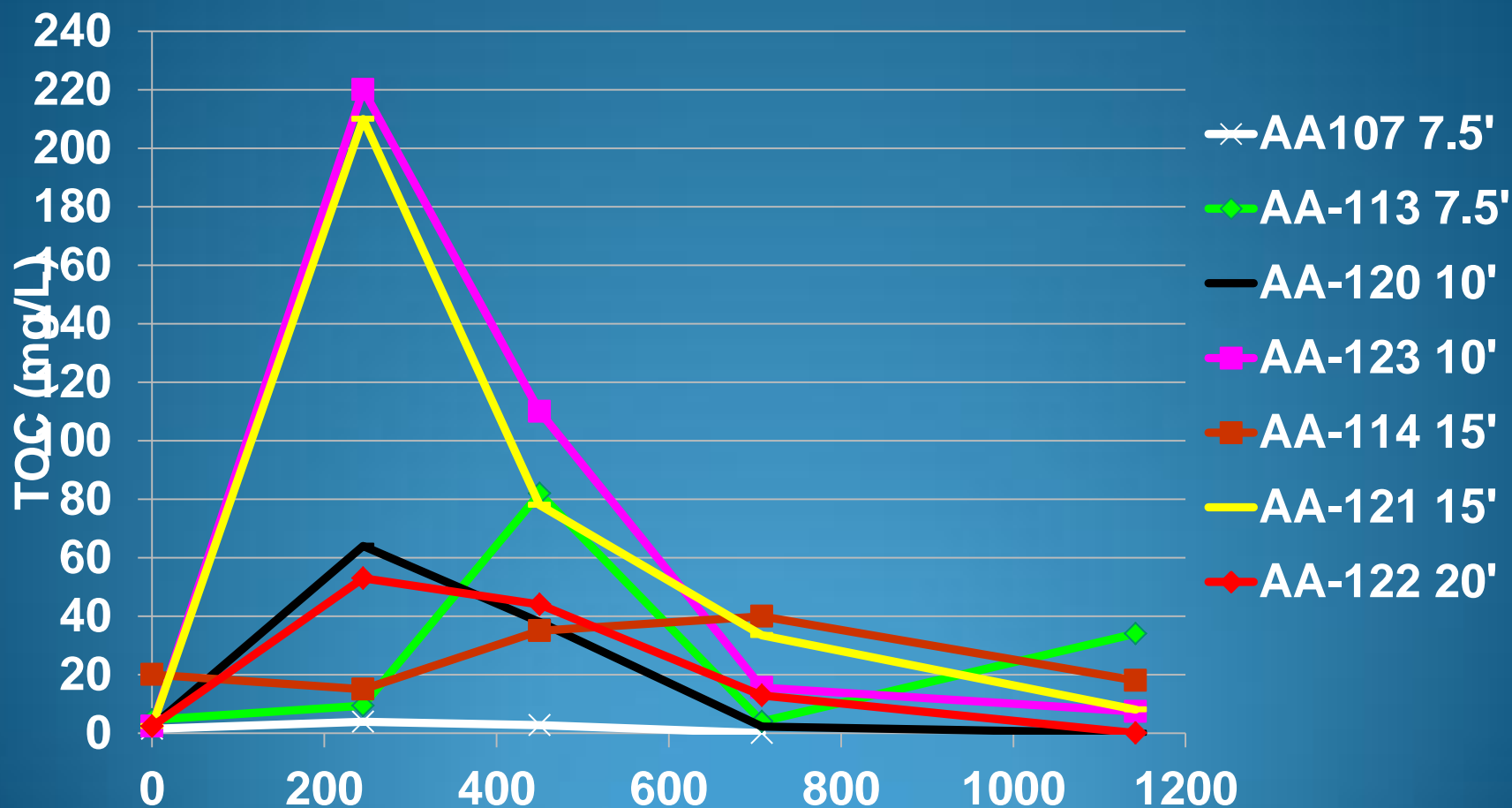
SITE 2 DOVER AFB DE

- INJECTION INTO 100 FT WIDE X 20 FT LONG X 30 FT THICK BIOBARRIER
- TOTAL OF 7,488 POUNDS SOYBEAN OIL AND EMULSIFIERS WITH 3,432 GALLONS OF CHASE WATER
- INJECTED DIRECT PUSH INSTALLED WELLS
- LOADING 0.29 POUNDS/FT³
- GROUNDWATER FLOW RATE 128 FT/YR

MAXIMUM TOC DISTRIBUTION AT SITE 2



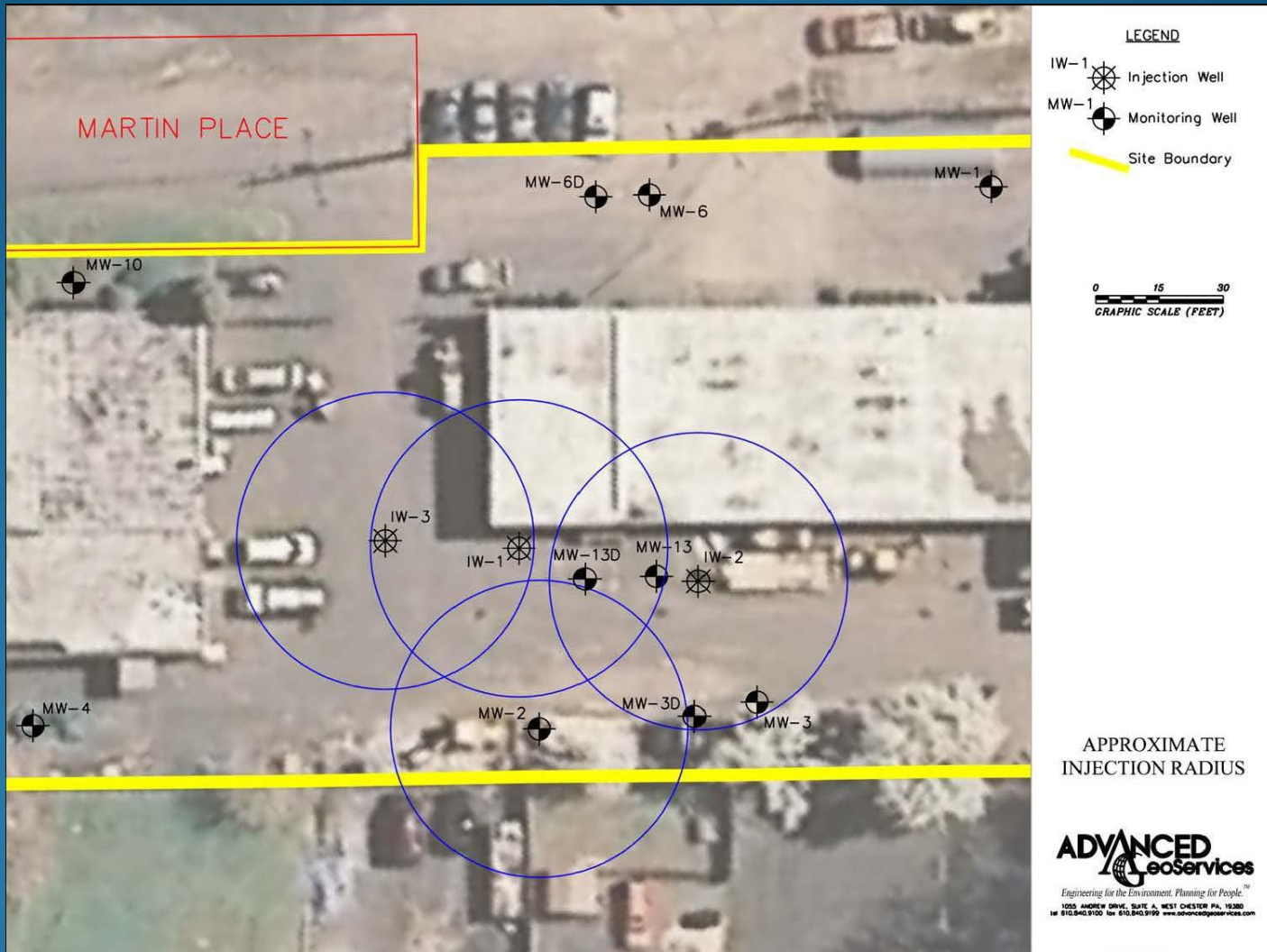
TOC CONCENTRATIONS IN WELLS BETWEEN 7.5 AND 20' FROM INJECTION WELLS SITE 2



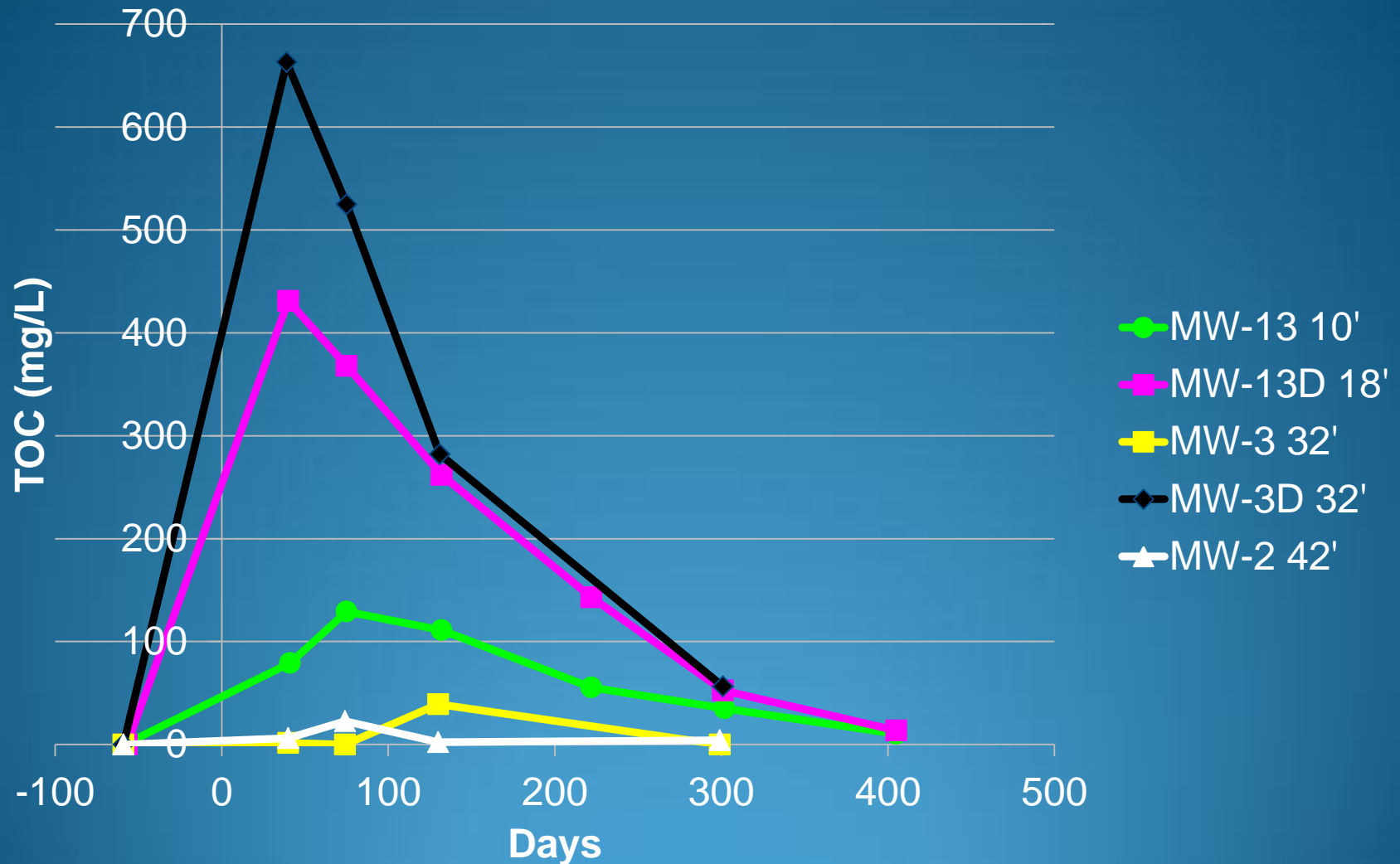
SITE 3 NEW JERSEY BEDROCK

- **INJECTION INTO 40 FT WIDE X 120 FT LONG X 25 FT THICK BEDROCK**
- **TOTAL OF 3,236 POUNDS SRS WITH 990 GALLONS OF CHASE WATER**
- **LIQUID ATOMIZED INJECTION (LAI) PROCESS**
- **LOADING 0.027 POUNDS/FT³**
- **GROUNDWATER FLOW RATE 394 FT/YR**

SITE 3 NEW JERSEY BEDROCK

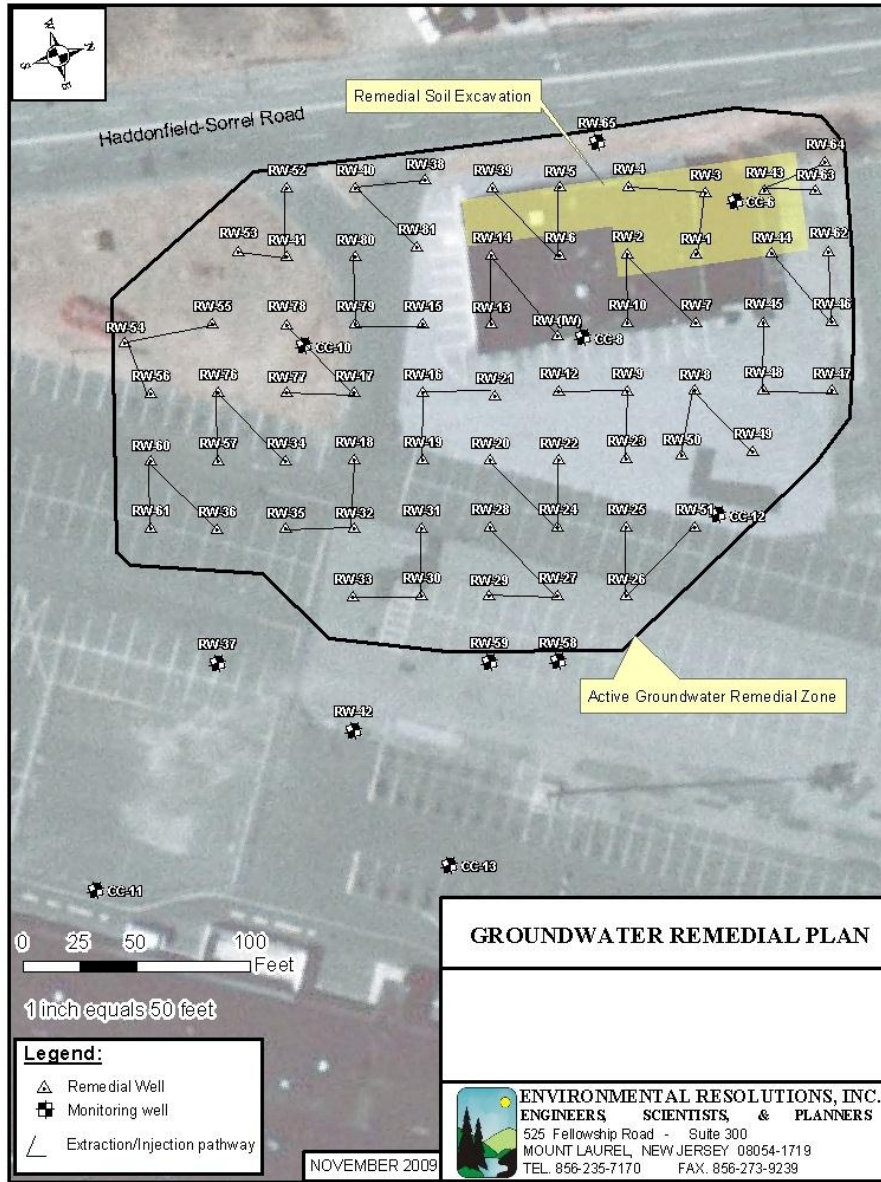


SITE 3 NEW JERSEY BEDROCK



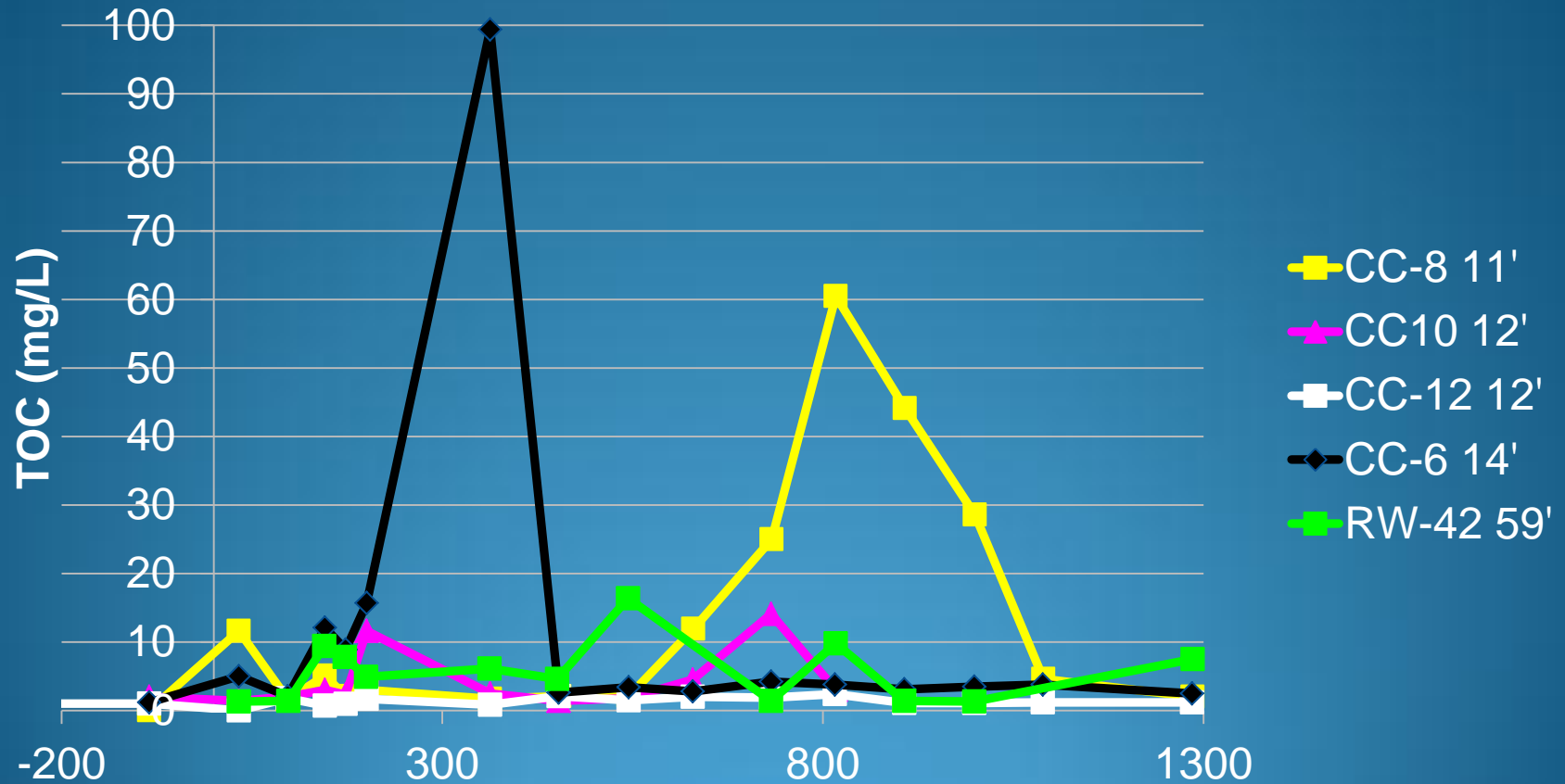
SITE 4 NEW JERSEY ACIDIC SITE

- **INJECTION INTO 183 FT WIDE BY 383 FT LONG X 25 THICK ABOUT 60 FT BELOW GROUND SURFACE**
- **TOTAL OF 52,500 POUNDS SRS AND 9,900 POUNDS SODIUM CARBONATE BUFFER WITH 323,000 GALLONS OF CHASE GROUNDWATER**
- **TWO INJECTION EVENTS SEPARATED BY 3 MONTHS**
- **LOADING 0.030 POUNDS/FT³**
- **INJECTION INTO 66 DRILLED WELLS WITH RECIRCULATION**
- **GROUNDWATER FLOW RATE 51 FT/YR**



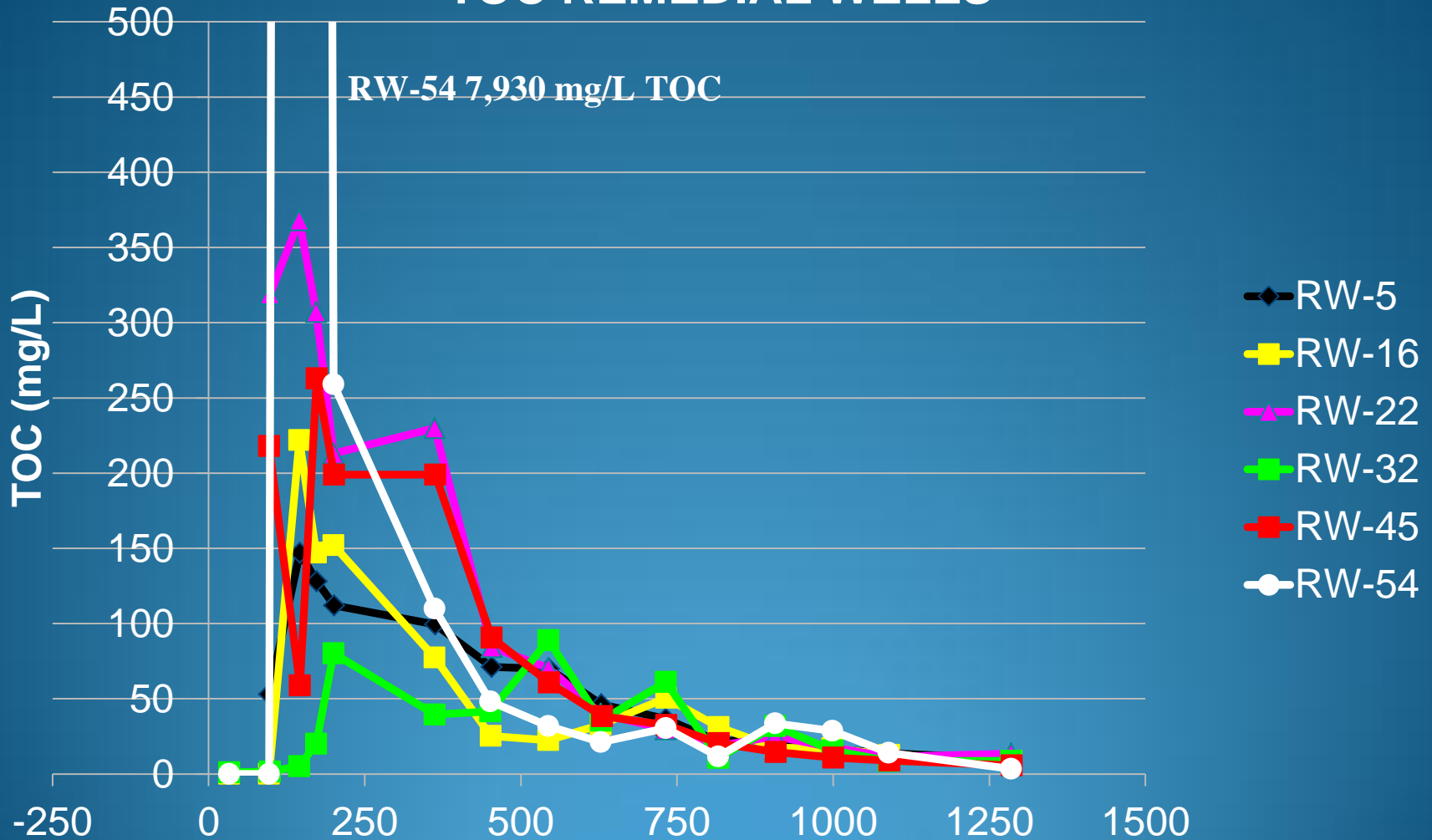
SITE 4 NEW JERSEY ACIDIC SITE

TOC Monitoring Wells



SITE 4 NEW JERSEY ACIDIC SITE

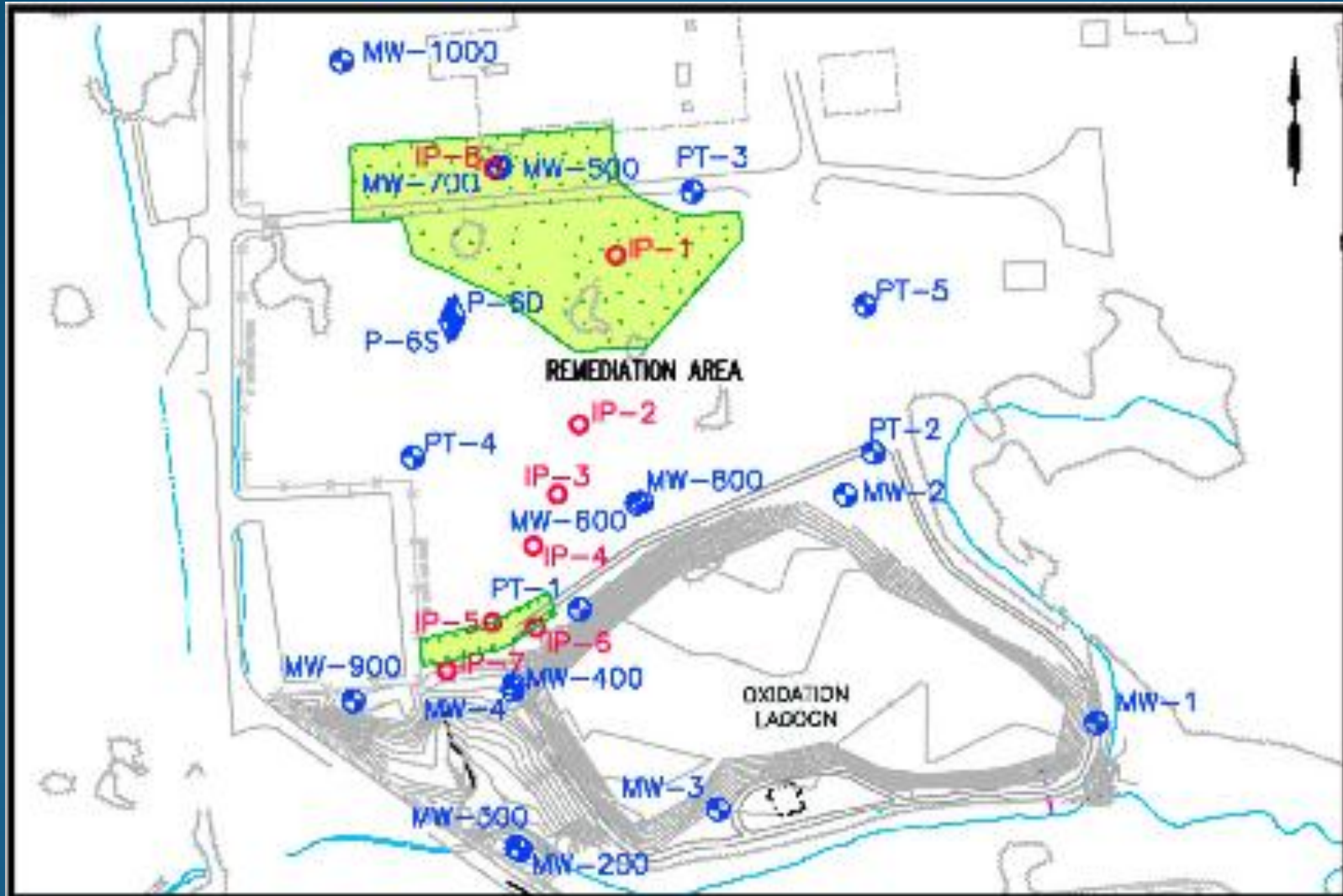
TOC REMEDIAL WELLS



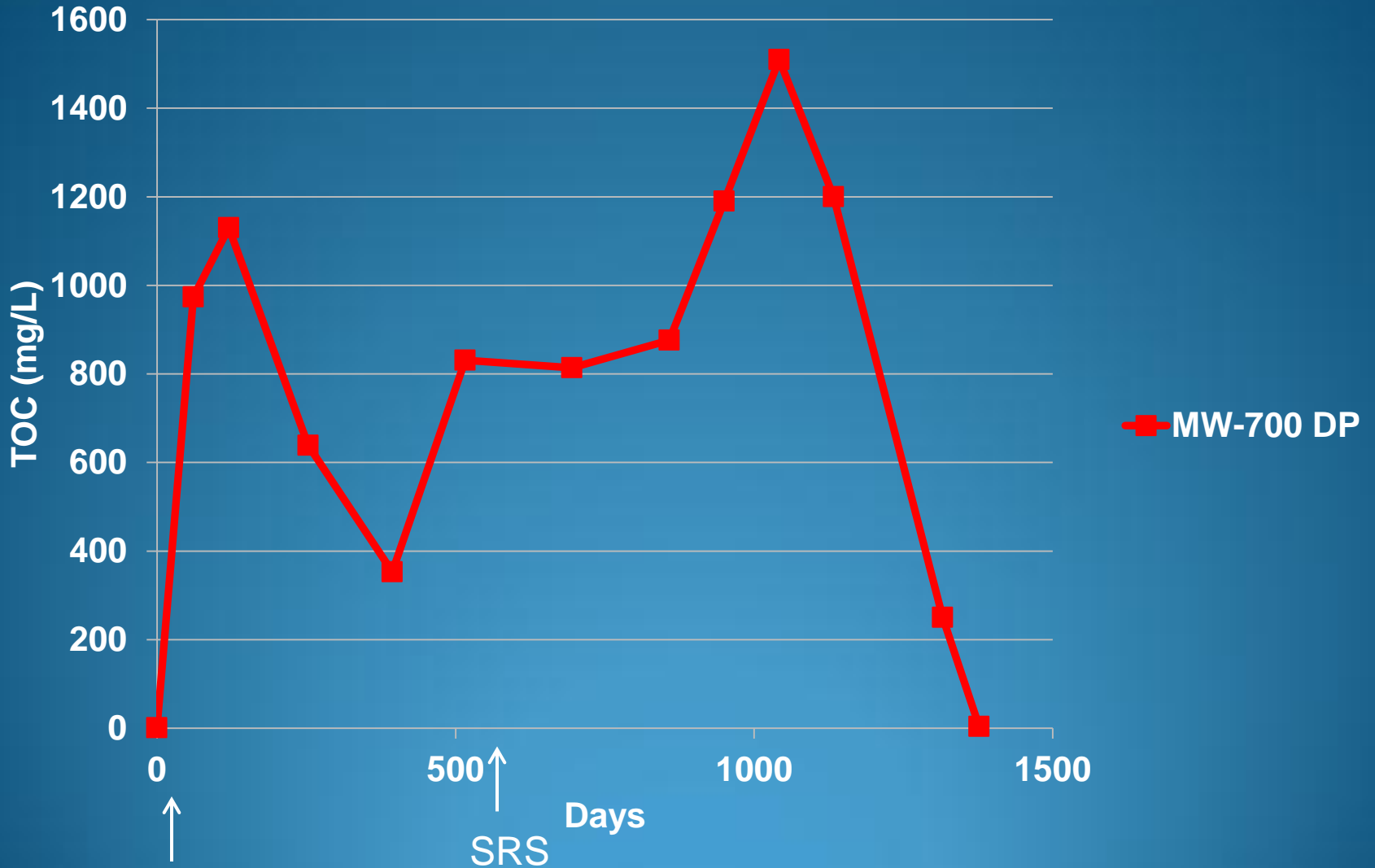
SITE 5 INDIANA SITE

- INJECTION BY DIRECT PUSH OF 26,500 POUNDS SRS INTO 180 POINTS AND TWO TEMPORARY WELLS IN SOURCE ZONE NEAR MW-700 LOADING 0.028 POUNDS/FT³
- INJECTION OF 20,500 POUNDS SRS INTO CENTERLINE OF PLUME WITH 6 INJECTION WELLS AND 40 DIRECT PUSH POINTS 0.071 POUNDS/FT³
- GROUNDWATER FLOW RATE 5-10 FT/YR

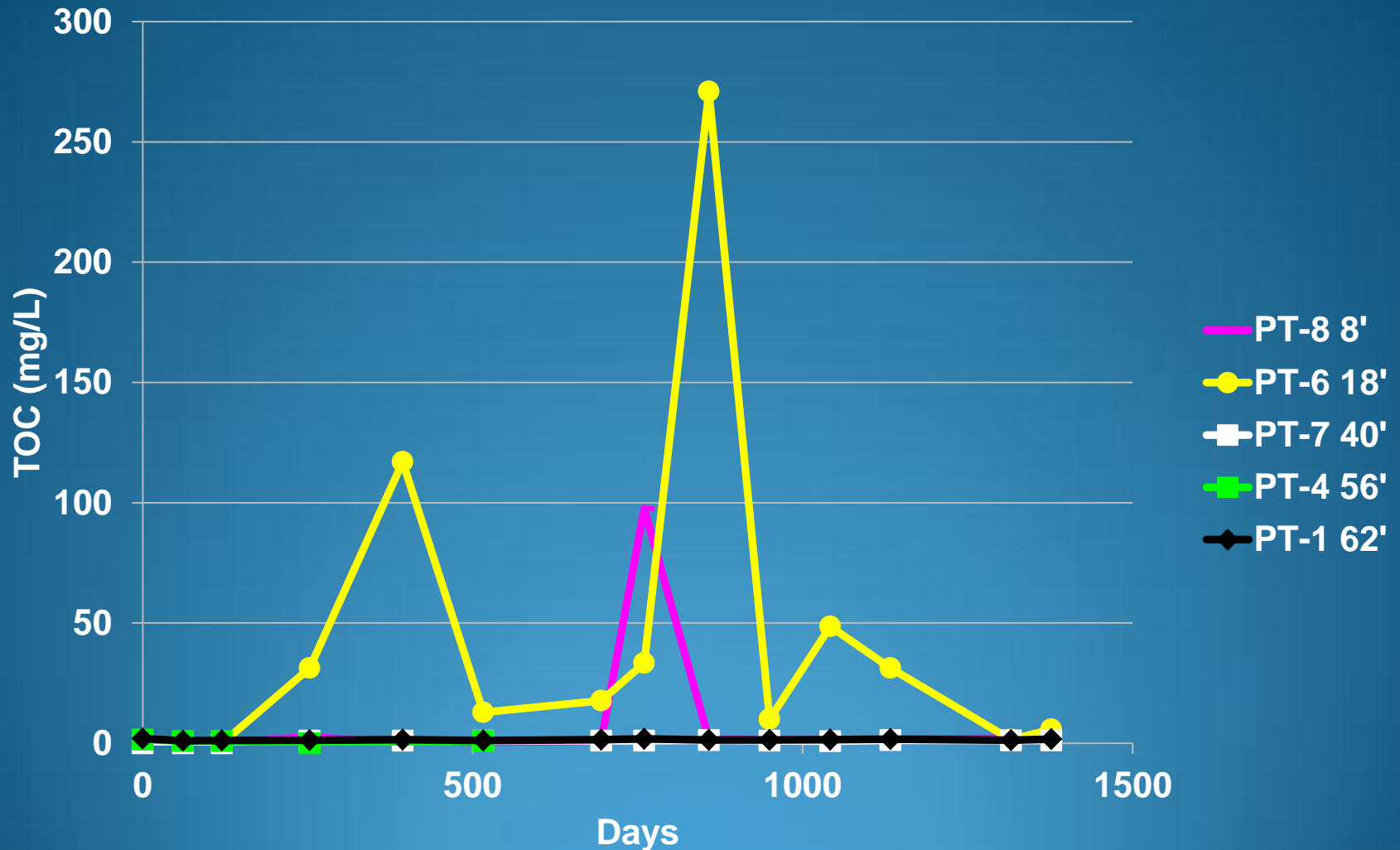
SITE 5 INDIANA SITE



SITE 5 INDIANA SITE DP MW-700



SITE 5 INDIANA SITE INJECTION POINTS



SUMMARY

Site	GWFR	Injection Method	Loading	# Wells out of Total Wells With TOC Persistence >10mg/L in Days			
				ft/yr	Lbs/ft ³	Wells 0-5'	5-10'
1	44	Direct Push and Wells	0.029	4/5 >2529 1/5 2360	1/2 >2529 1/2 2360		1/1 >2529
2	128	Wells	0.29	4/10 >1,142 3/10 500-1000 2/10 100-500 1/10 <100	1/4 >1142 2/4 500-1000 1/4 <100	1/2 >1142 1/2 1120	1/1 800

SUMMARY

Site	GWFR	Injection Method	Loading	# Wells out of Total Wells With Median TOC Persistence in Days			
				ft/yr	Lbs/ft ³	Wells 0-5'	5-10'
3	394	LAI wells	0.027			1/1 >405	3/4 >300 1/4 130
4	51	Wells	0.030	6/6 1040 to >1285		2/4 294-450	1/1 96
5	5-10	Direct Push Wells	Source 0.028 Plume 0.071	1/1 800	1/1 80		1/4 1022 3/4 0
Range	5-394		0.027-0.29 (0.87 to 9.3 g C/L)	73% >500	71% >500	29% >500	30% >500

CONCLUSIONS

**SRS CARBON FOOTPRINT ABOUT 0.73 POUNDS
CO₂E POUND PRODUCT PLUS TRANSPORTATION
TO SITE**

EVO DISTRIBUTION IS AFFECTED BY:

- **SITE CHARACTERISTICS SUCH AS GWFR**
- **SUBSTRATE LOADINGS**
- **INJECTION METHODOLOGY**

**TOC DISTRIBUTION IS GENERALLY LIMITED TO
ABOUT 20 FEET FROM THE INJECTION POINTS**

TOC LASTS FOR 80 TO 2,529 DAYS