Surfactant Enhanced PFAS Mass Removal From Soil Groundwater and AFFF Fire Suppression Systems

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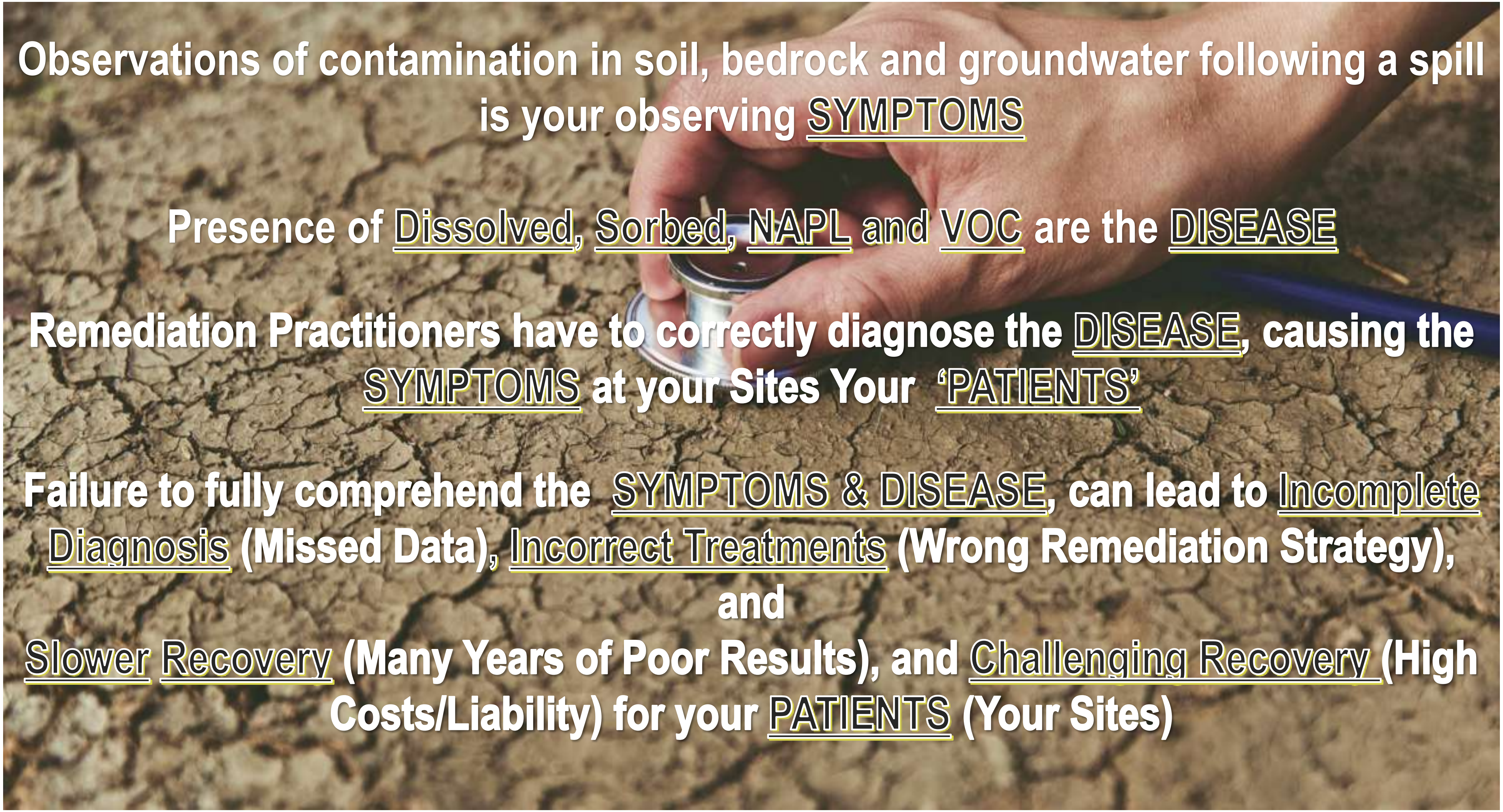
Session 13 PFAS
Remediation/Destruction/Risk Reduction
March 19, 2025 [14:00 to 14:30]



Observations of contamination in soil, bedrock and groundwater following a spill is your observing SYMPTOMS

Presence of Dissolved, Sorbed, NAPL and VOC are the DISEASE

Remediation Practitioners have to correctly diagnose the DISEASE, causing the SYMPTOMS at your Sites Your 'PATIENTS'

Failure to fully comprehend the SYMPTOMS & DISEASE, can lead to Incomplete Diagnosis (Missed Data), Incorrect Treatments (Wrong Remediation Strategy),
and
Slower Recovery (Many Years of Poor Results), and Challenging Recovery (High Costs/Liability) for your PATIENTS (Your Sites)

USEPA 542-R-18-002, May 2018

- This USEPA publication evaluated 30 in-situ remediation projects involving NAPL;
- With n=30 (number of observation), this is of statistical importance to draw conclusions with a 95% Confidence Level;
- The 30 sites used a variety of physical, biological and chemical remediation methods;
- The in-situ soil and groundwater remediation took between 3 and 27 years, with a median of 8 years; and
- Site remediation was generally shorter for sites with less complex hydrogeological settings, with the exception of 3 sites with mild heterogeneity that were >15 years for remediation.

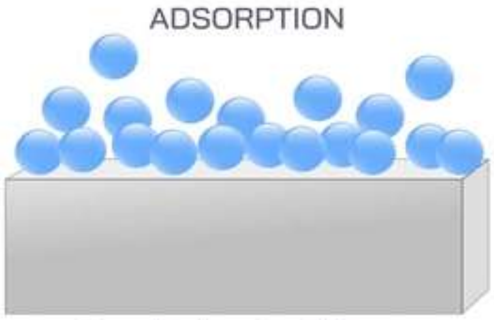
≥ 8 Years For Site Remediation…Why?....Let Me Share Some Insights As To Why.

Sorption Literature Reference

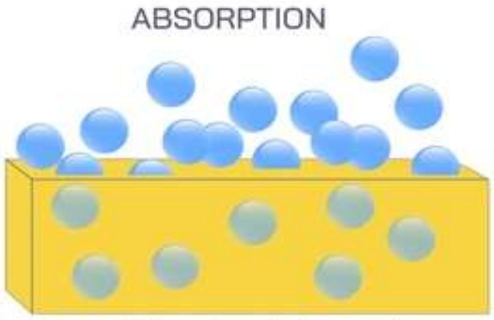
The growing concern regarding contaminant sorption, and its reduced availability for remediation, has been well cited in literature as demonstrated by the following quotation:

> ***"During the past decade, much discussion has centered on the unavailability of absorbed compounds to soil microorganisms; it is generally now assumed that desorption and diffusion of bound contaminants to the aqueous phase is required for microbial degradation."***

(W.P. Inskeep, J.M. Wraith, C.G. Johnston, Hazardous Substance Research Center, 2005).



The adhesion of particles onto a surface of a substance.



The particles of a substance enter into the volume/bulk of another.

Both sportive mechanisms decrease the 'Availability' of the sorbed contamination for Remediation.

Phase Partitioning Hinders Remediation

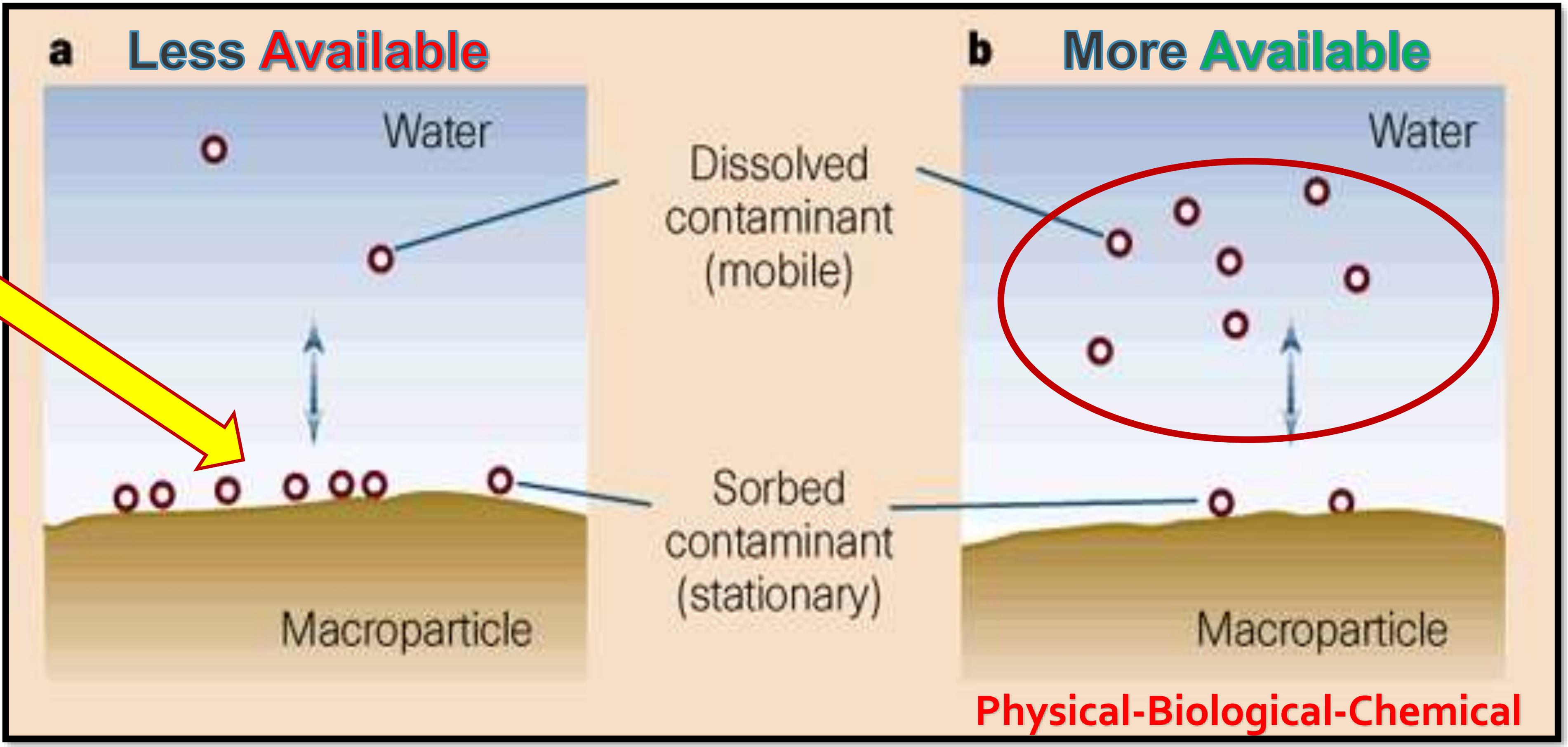
Petroleum & Halogenated Organics (Including PFAS) have limited water solubility. Hence they will Phase Partition and Sorb onto Surfaces, Agglomerate to to thicker Layers, Globules, or NAPL

Phase Partitioning = Reducing their '*Availability*' for Remediation.

Sorbed Contamination Expressing Limited 'Availability' For Remediation

Solubility:
PFOS = 680 mg/L*
PFOA = 9600 mg/L*
MTBE=50,000 mg/L
NaCl = 357,000g/L
Sugar = 909,000 g/L

* Both Sorb to Surfaces
PFOS > PFOA



Physical-Biological-Chemical

Agglomeration

Contaminant **agglomeration** is the ‘sticking’ (cohesive or adhesive forces) of organic molecules to one another, onto surfaces (Sorption), can increase in thickness….its a very a natural phenomenon.

(like dissolves like & like attracts like)

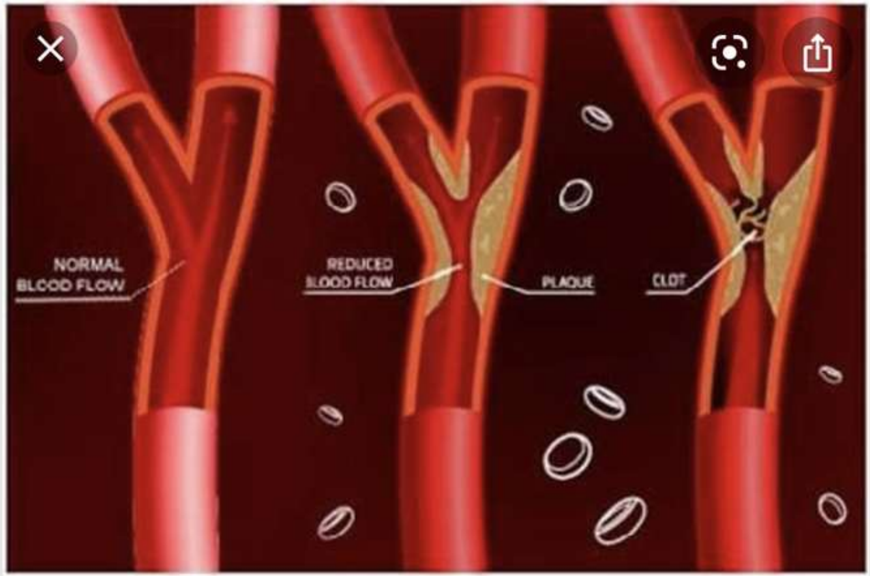
Agglomeration may be viewed as unwanted surface Sorption, that amasses to Globules or Ganglia, to NAPL and/or **VOC** layers in formations.

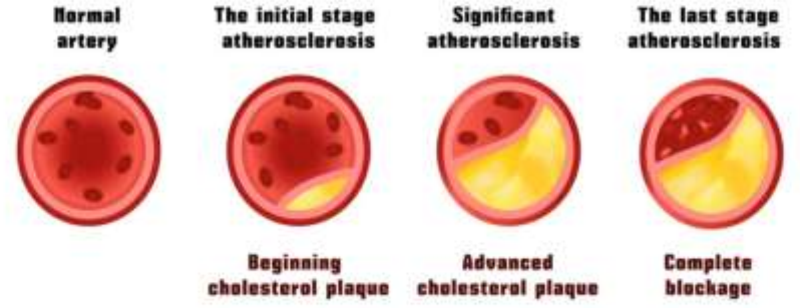
(medical analogy - clogging of arteries)

Within geology, this causes caking, bridging, and/or blockage of effective pathways = ‘***Pathway Interference***’

*(hence **delivery** or **extraction** issues!)*

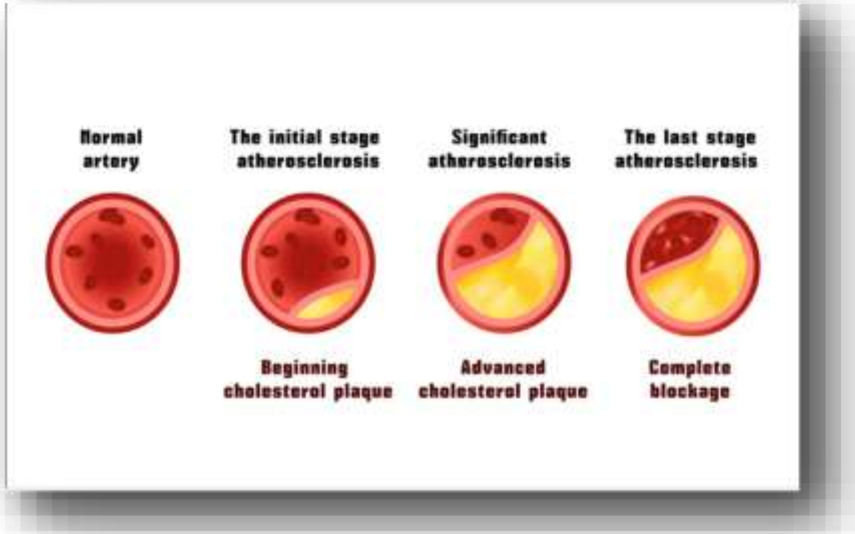
Diameter of Soil Pore Openings « Diameter of Hair « Veins « Arteries

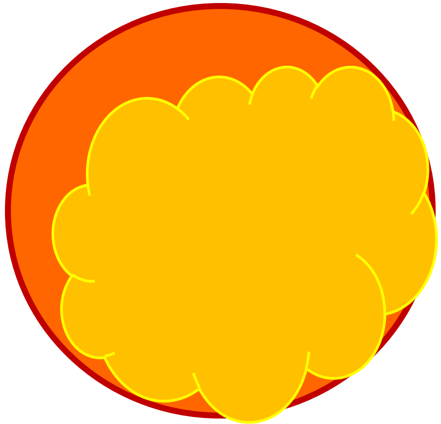


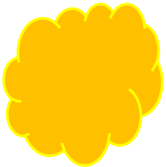


Atherosclerosis

Relative Diameters of Soil Pore Opening to Average Hair, Vein and Artery Diameters





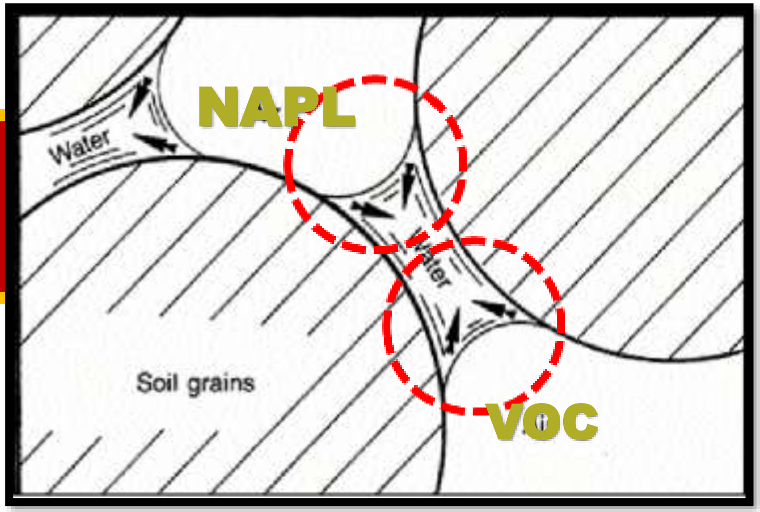


Artery (3.5 mm)	Vein (0.95 mm)	Hair (0.125 mm)	Soil Pore (0.052 mm)
			1/20th of a mm
67.3 X	18.3 X	2.4 X	1

Interfacial Tension Between Phases
Oil and Water

Water *Clusters* Have Interfacial Tension of ~73 Dynes

LNAPL - DNAPL – VOC Interfacial Tension ~21 to 23 Dynes

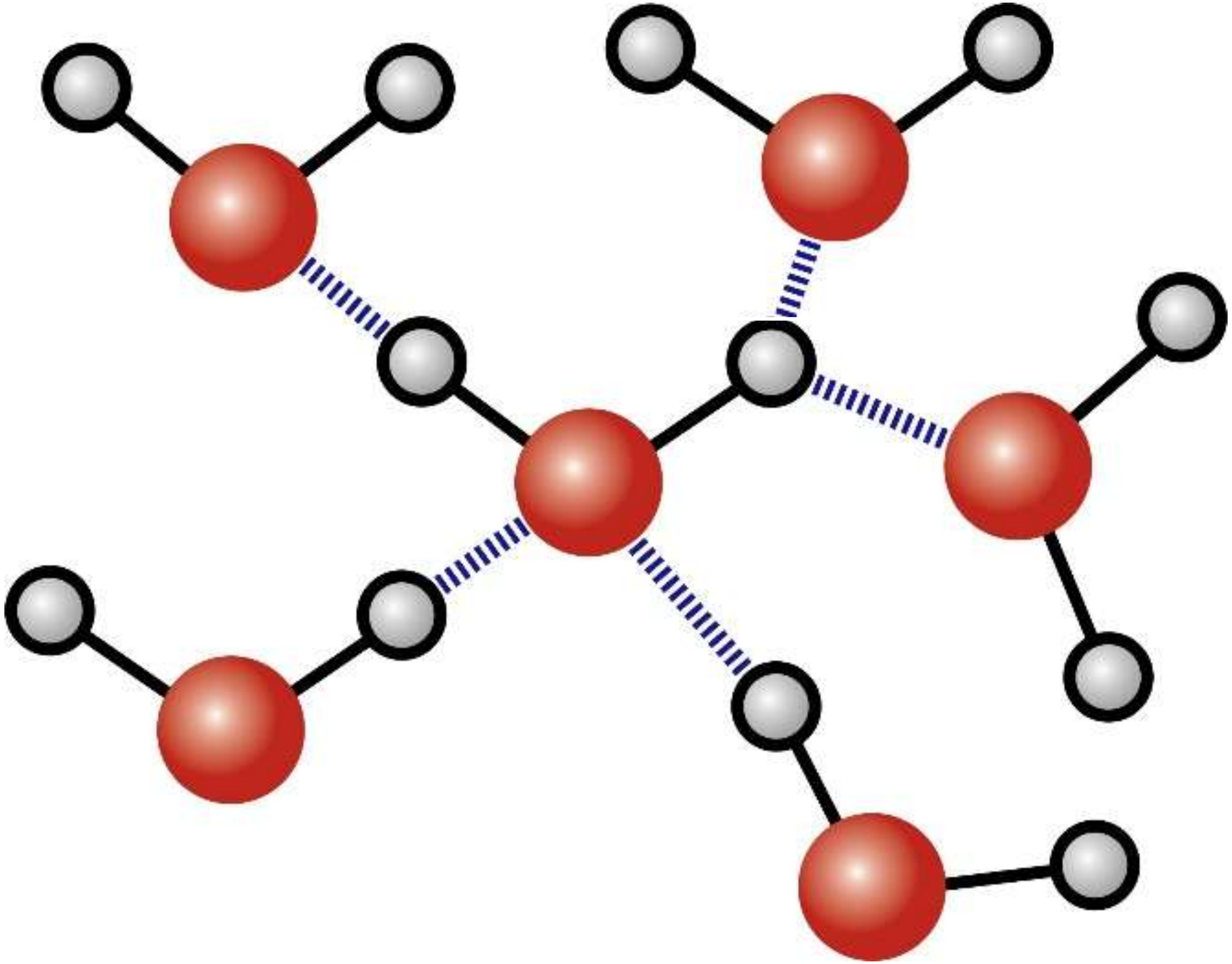


The interfacial pressure characterizes the package density of the molecules in the interfacial layer between the aqueous and the organic phase..

NAPL molecules at molecular interface between the 2 phases actually <u>reorganize</u> to cause a net increase in NAPL Interfacial Tension to >>30 Dynes!!

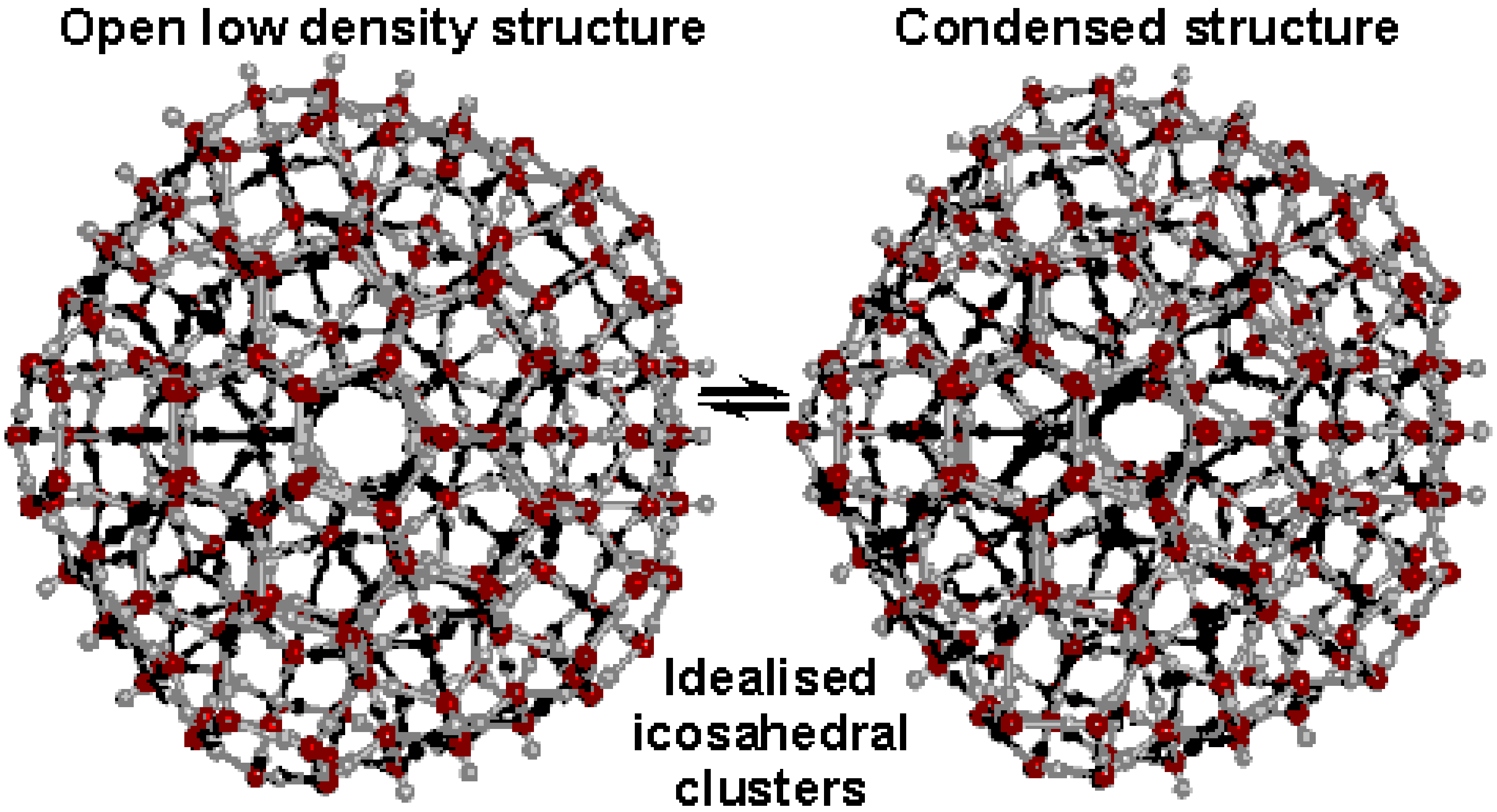
Hydrogen Bonding Between H_2O Molecules

Hydrogen Bonding - Expanded



Water Is A 3-Dimensional ‘*Cluster’* - With Surface Tension of 73 Dynes
Water Cluster Size Limits (K) It’s Ability To Move In Finer Texture Geology

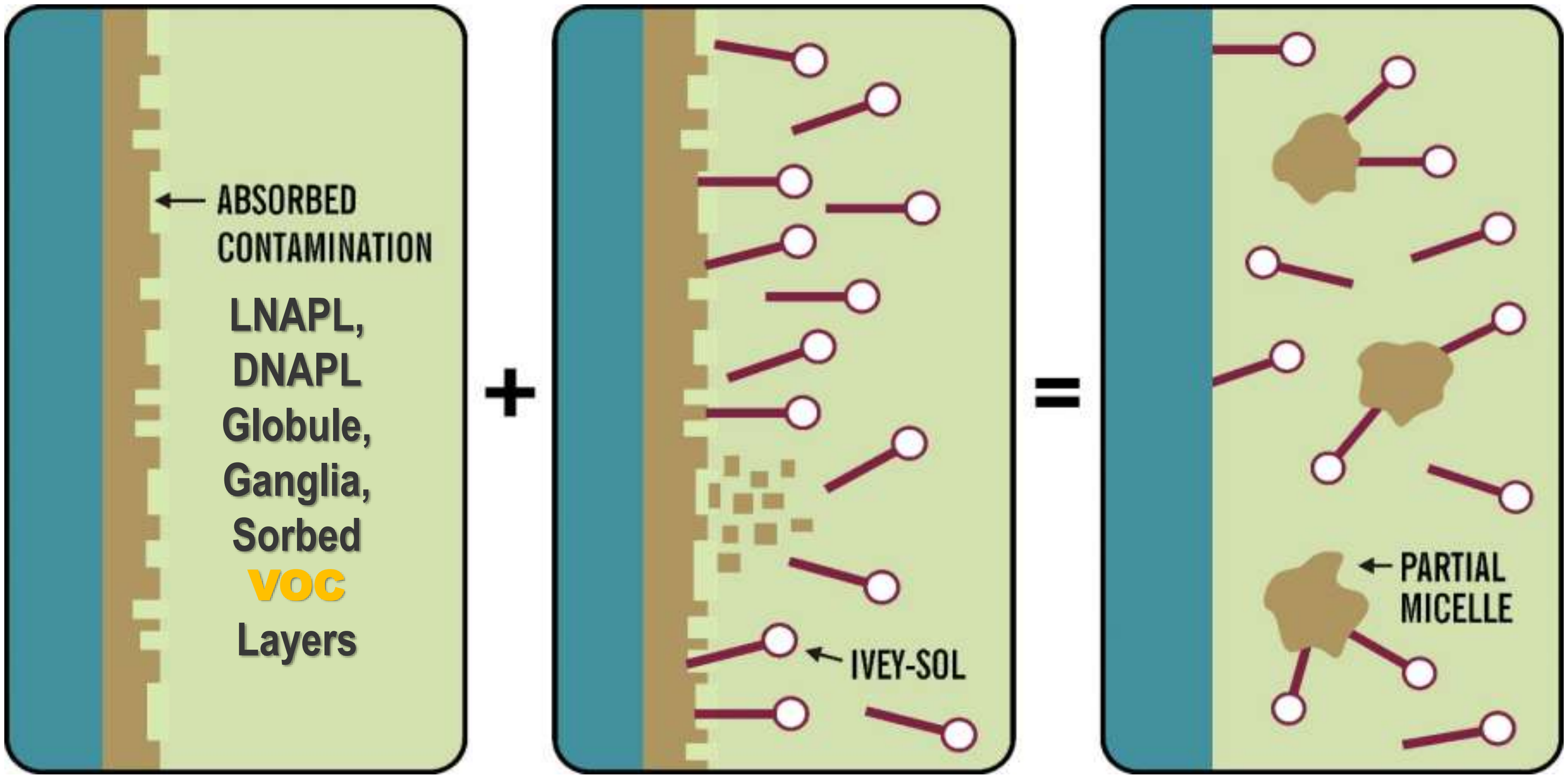
Ivey-sol® Makes Water Clusters Smaller So Enter & Transport More Easily Through Finer Grain Soil ***[Lower Surface Tension <30 Dynes + Overcome IFT]***

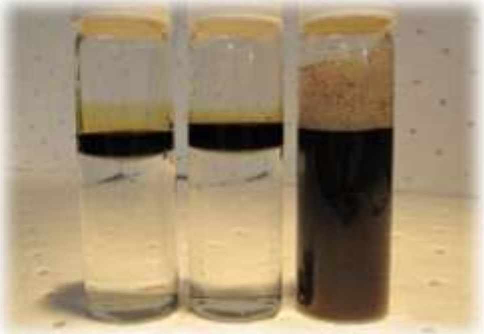


IVEY-SOL
Surfactant Technology

PFAS SOL

DECON-IT®
Omni Surface Decontaminator

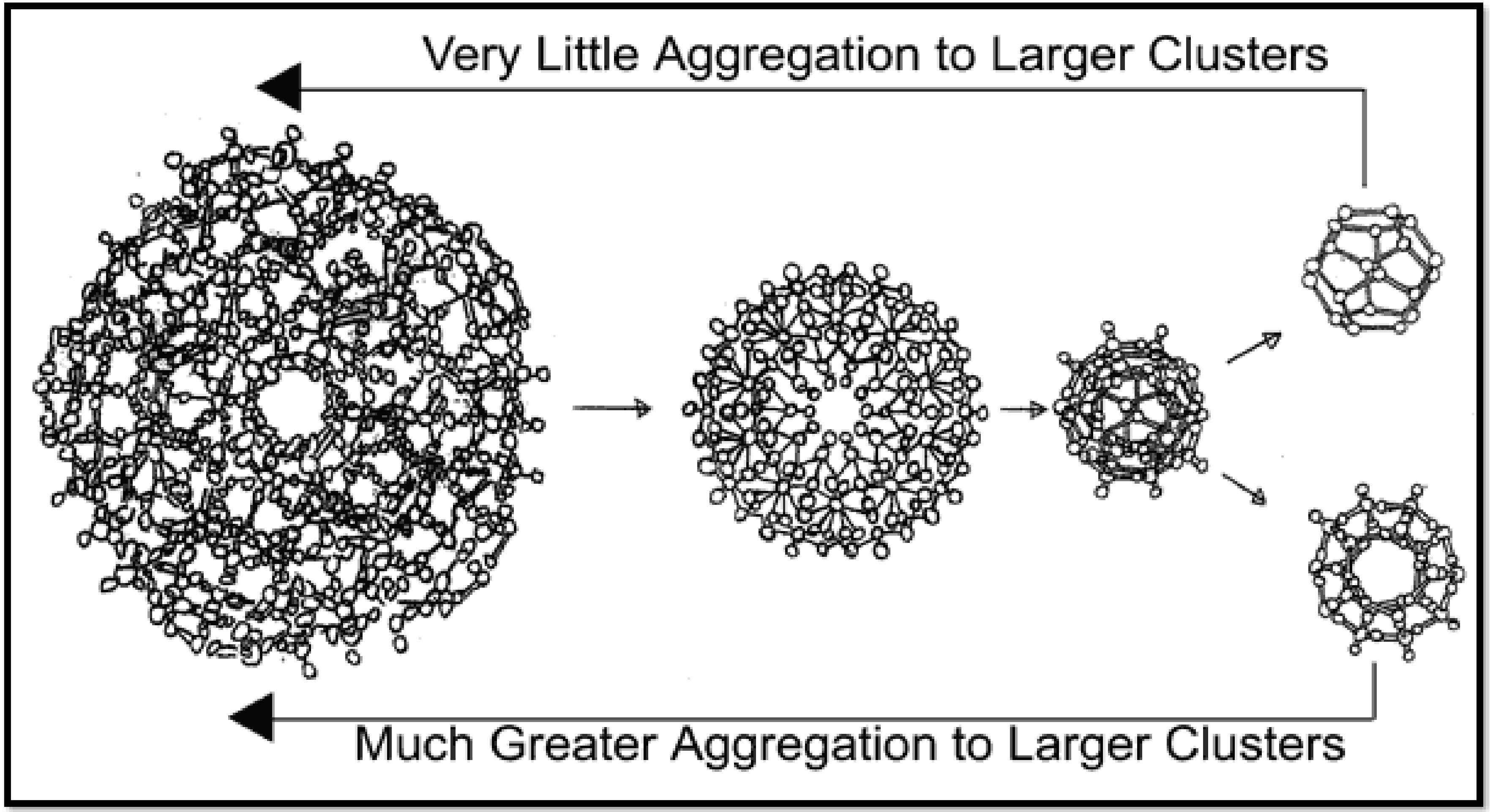


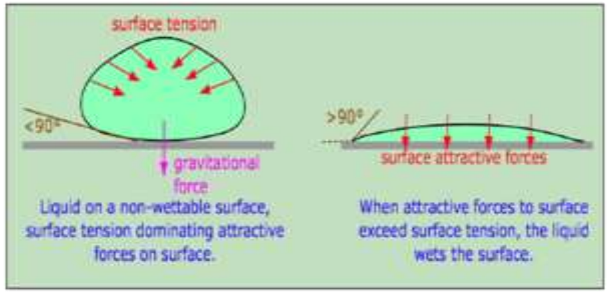


Ivey-sol® selectively desorbs, Sorbed, NAPL, VOC below the CMC

Increasing Physical, Biological and/or Chemical Availability For Enhanced Remediation

Ivey-sol Reduces The Size of Water Clusters Improving
(Lower Surface Tension from 73 Dynes to < 30 dynes)
Access & Regress within Fine Grain Soil Textures ~ Improving K





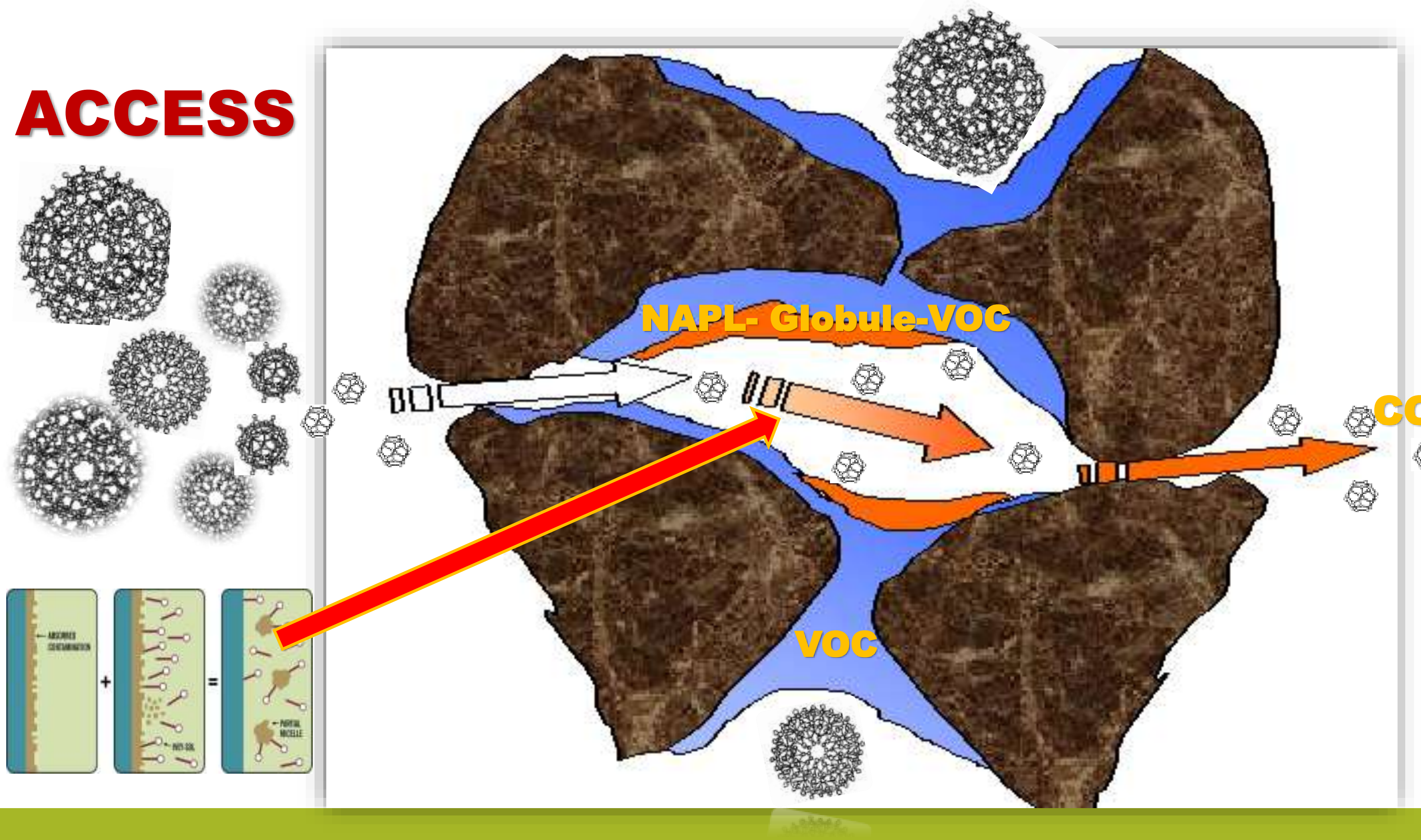
Liquid on a non-wettable surface, surface tension dominating attractive forces on surface.

When attractive forces to surface exceed surface tension, the liquid wets the surface.

IVEY-SOL®
Surfactant Technology
"TODAY'S ENVIRONMENTAL SOLUTIONS FOR A BETTER TOMORROW"

Ivey-sol® Overcomes Low K and Retardation In Finer Grain Soil Improving Access, Egress, and Remediation

ACCESS



Interfacial Tension Will Effect NAPL Behaviors

More Available
(Physio-Bio-Chem)

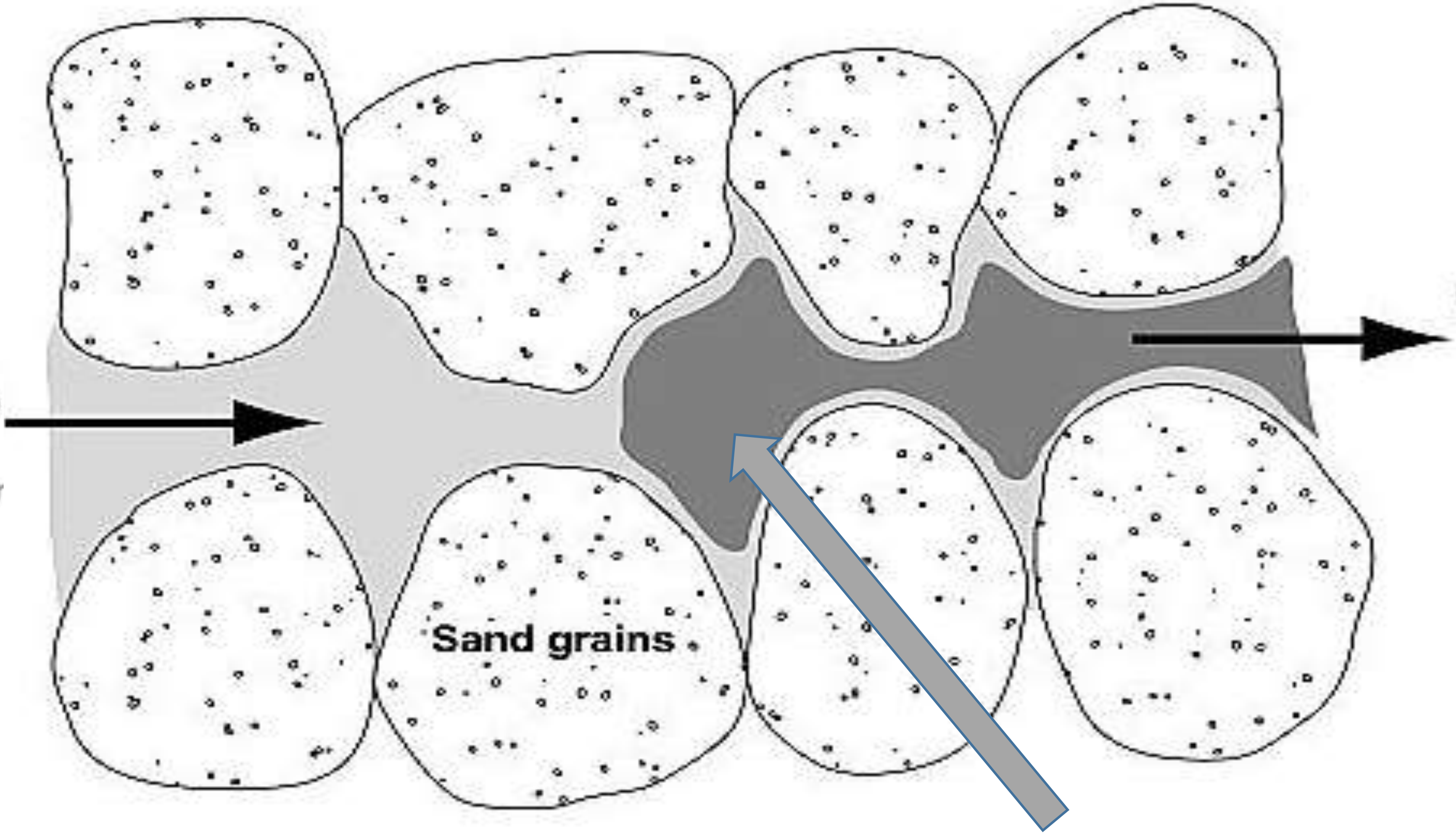
EGRESS

SER® Aiding Contaminant (PFAS) ‘*Availability*’ Within Pore Spaces

IVEY-SOL
Surfactant Technology

DECON-IT®
Omni Surface Decontaminator

PFAS SOL



Liberated PFAS
Contamination With
Increased **P**hysical,
Biological, and
Chemical Availability
For Remediation

PFAS, TPH, PCB, TCE, LNAPL, DNAPL, Etc.

Factors That Can Negatively Effect

Vapor Soil, Bedrock and Groundwater Contaminant Physical, Biological, and Chemical *Availability* for Remediation

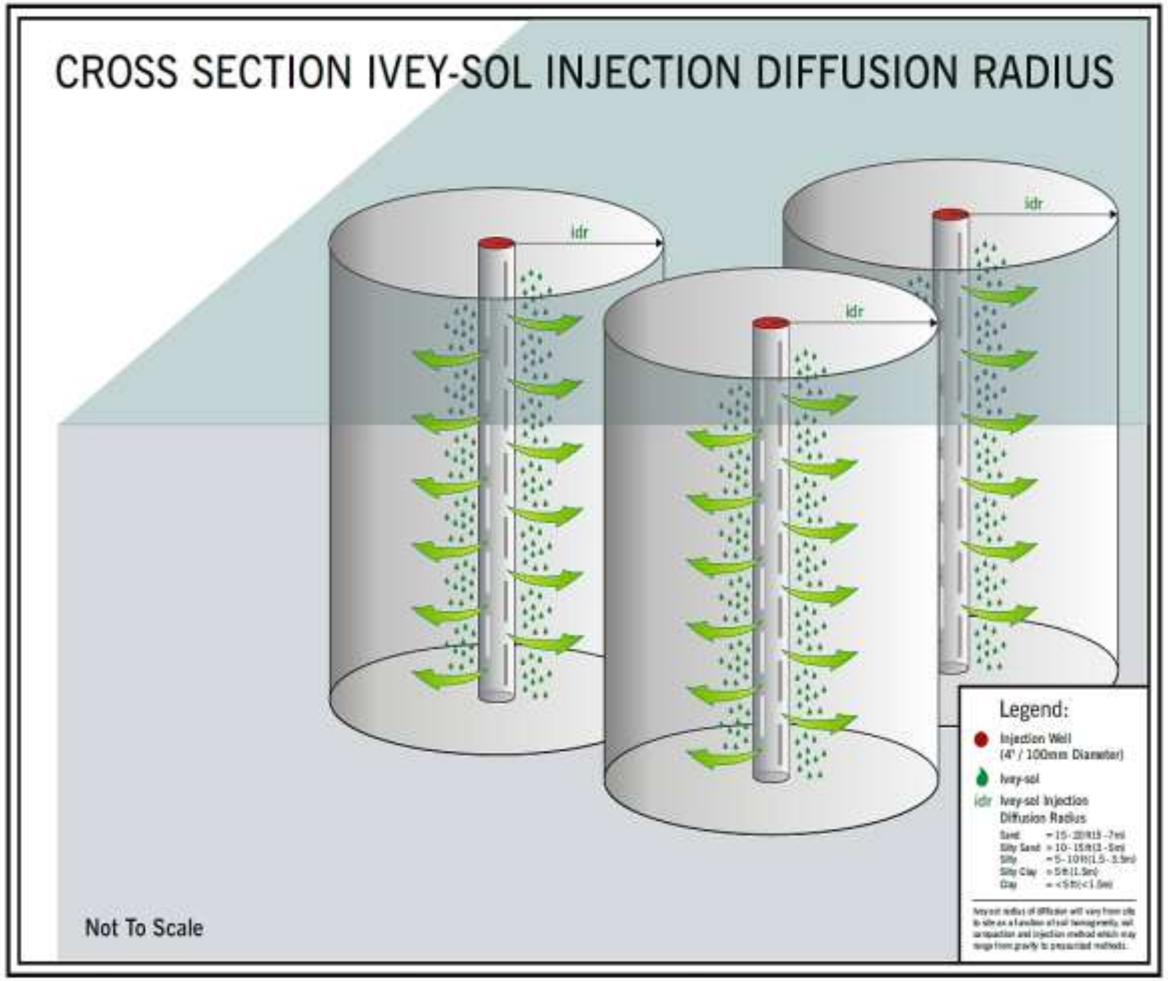
FACTORS THAT REDUCE CONTAMINANT AVAILABILITY

- **Limited Solubility of Contaminants**
- **Sorption (adsorption + absorption) To Surfaces - *Reduced Availability***
- **Aggregation → Globules, Ganglia to LNAPL and DNAPL - *Phase Separation***
- **Restricted Pore Space Opens - *Blockage, Lower K & Transmissivity***
- **Interfacial Tension Water Vs. Contamination *(73 vs. ~23 Dynes)***
- **Water Cluster Size (need much smaller) - *Lower Contact, K & Transmissivity***
- **Soil Texture Limitations (coarse to fine) - *Lower Contact, K & Transmissivity***
- **Contaminant Molecule Size (Large - Medium - Small) - *Steric Hinderance***

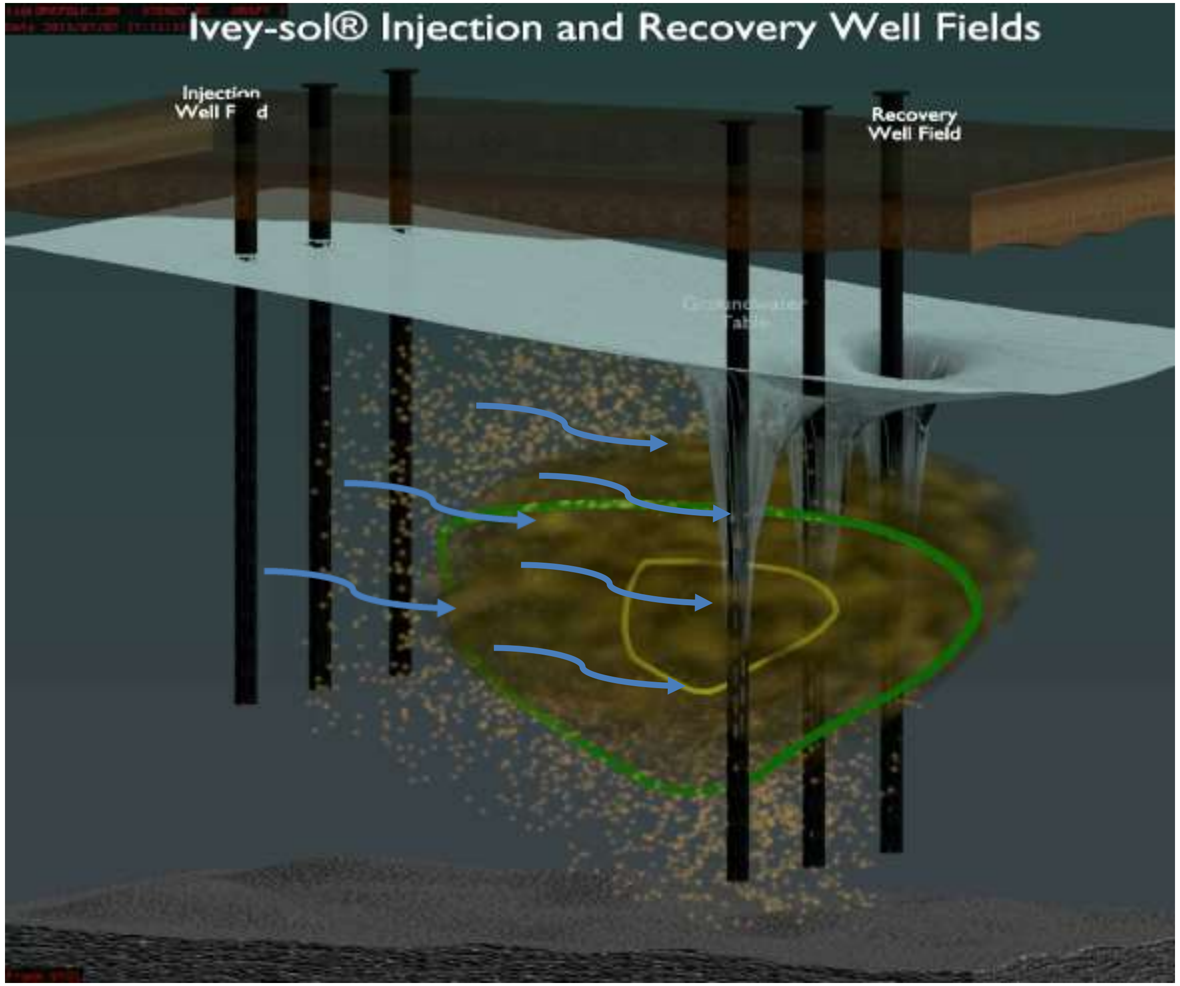
These Hydro-Geo-Chemical factors negatively impact Physical, Biological and Chemical Remediation

At All Sites!

In-situ Ivey-sol® ‘*Push-Pull*’ + ‘*Sweep*’ Applications

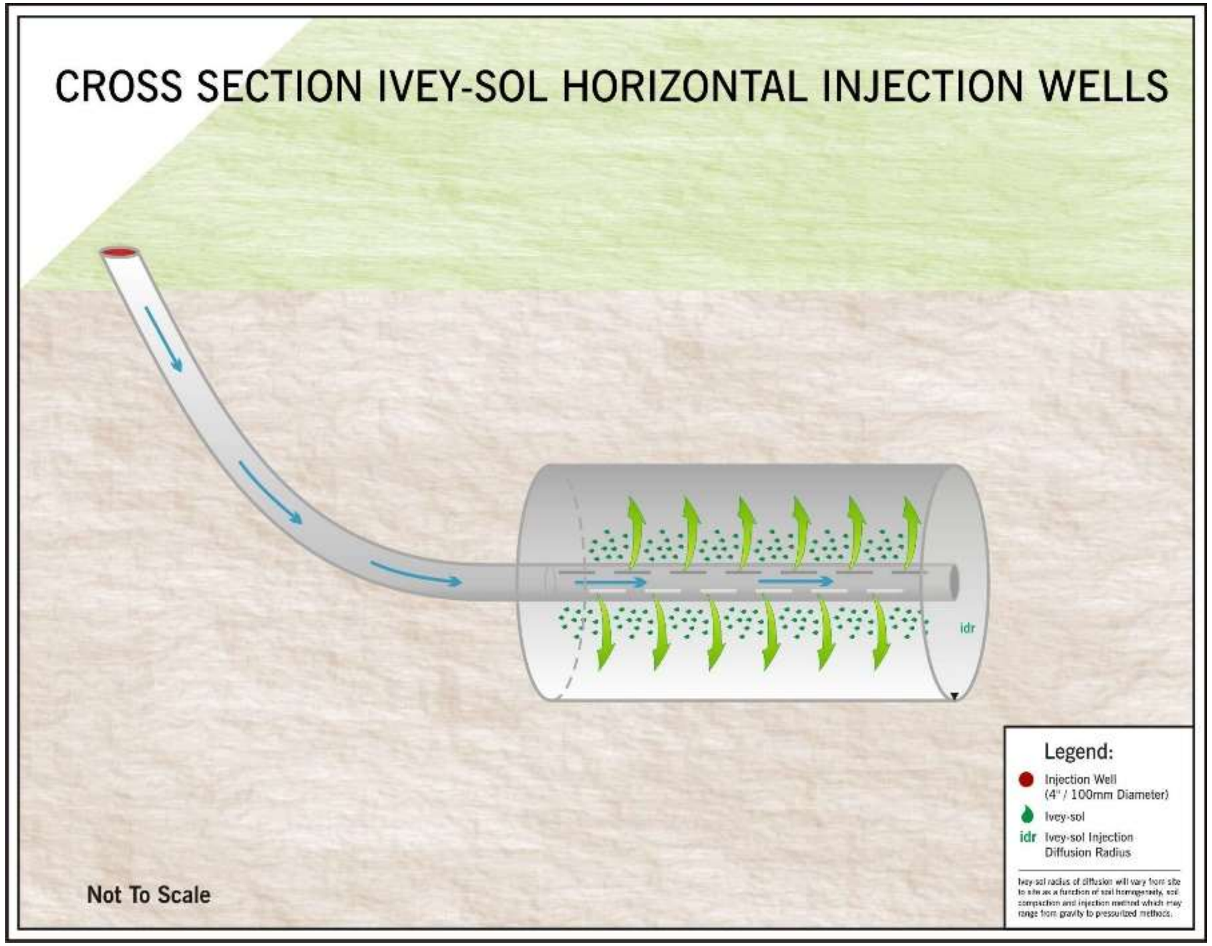


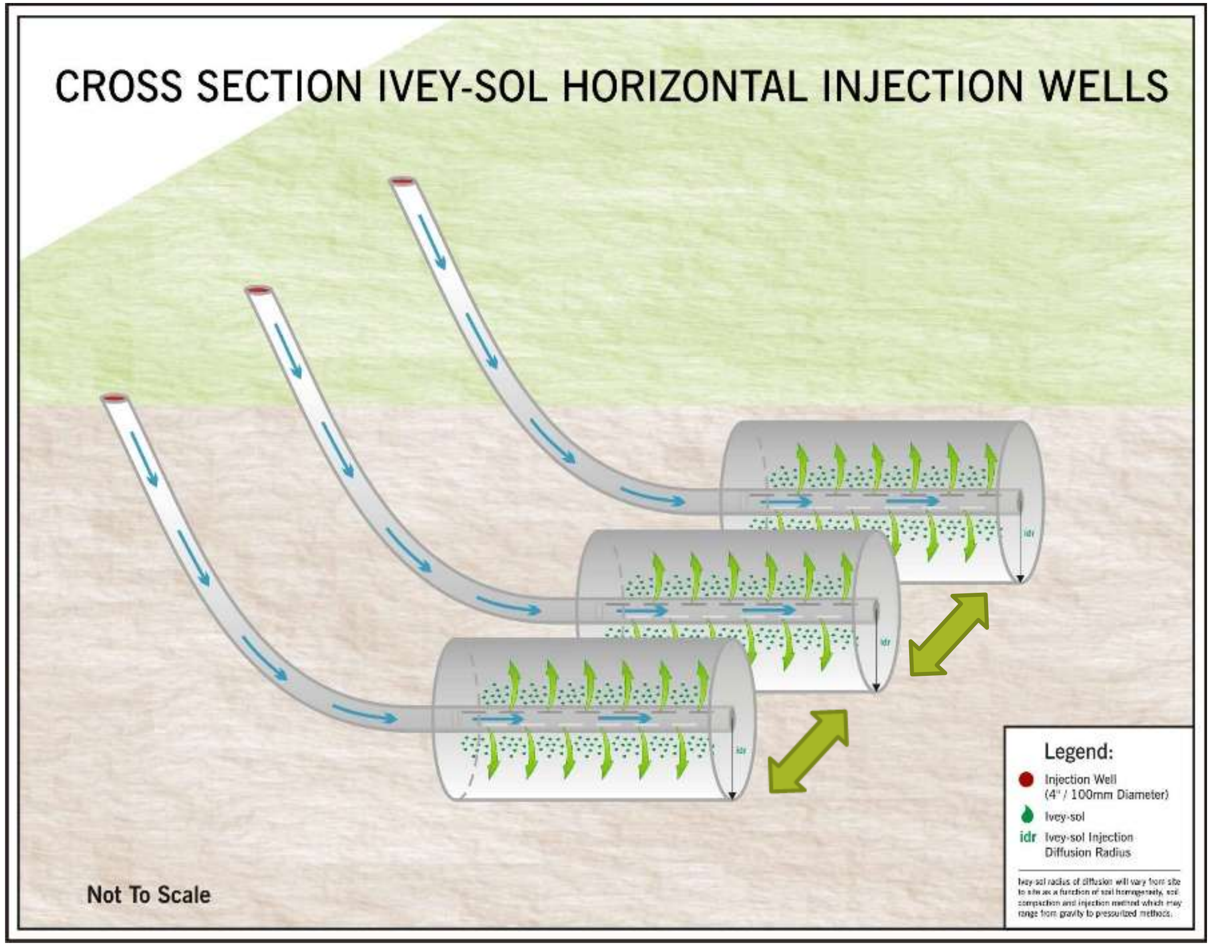
CROSS SECTION IVEY-SOL INJECTION DIFFUSION RADIUS



Ivey-sol® Injection and Recovery Well Fields

Horizontal Well ***Push-Pull*** **+** ***Sweep*** Applications





PER AND POLYFLUOROALKYL SUBSTANCES (PFAS) PFAS = PFOA + PFOS
A.K.A. C8 - FOREVER CHEMICALS

PRODUCTS THAT CONTAIN PFAS

- Pesticides
- Stain Resistant Products
- Firefighting Foams
- Microwave Popcorn Bags
- Eye Makeup
- Pizza Boxes
- Paints, Sealants and Varnishes
- Cleaning Products
- Nail Polish
- Dental Floss
- Non-stick Cookware
- Water Resistant Clothing
- Shampoo
- Candy Wrappers
- Fast Food Packaging/ Wrappers

- Per- and Polyfluoroalkyl Substances (PFAS) are a group of manufactured chemicals that have been used in industry and consumer products since the 1940s.

- Many organizations worldwide mandated the use of fire fighting foam that contains PFAS, known as Aqueous Film Forming Foam (AFFF). Plus, in many commercial products.

- However, per the Environmental Protection Agency (EPA), certain PFAS can cause serious health problems, including cancer, if people are exposed to them over a long period of time, and they can also be harmful to aquatic and terrestrial organisms.

- There are >15,000 PFAS chemicals (USEPA CompTox Database).

- **3M + DuPont** + Chemours + Corteva Sued **>100 Billion**

  For PFAS Groundwater & Health Impacts In USA alone.

PFAS IN USA CONTAMINATION FACTS

Approximately 71 to 95 million people in the Lower 48 states, more than 20% of the country's population may rely on groundwater that contains detectable concentrations of per- and polyfluoroalkyl substances, also known as PFAS, for their drinking water supplies.

PFAS

PER- AND POLY-FLUOROALKYL SUBSTANCES

DUPONT

3M

MOVIE DARK WATERS (2019)

Dark Waters is a 2019 American legal thriller film directed by Todd Haynes and written by Mario Correa and Matthew Michael Matthew.

The story dramatizes Robert Bilott's case against the chemical manufacturing corporation DuPont after they contaminated a town with unregulated PFAS chemicals.

It starred Mark Ruffalo as Bilott, along with Anne Hathaway, Tim Robbins, Bill Camp, Victor Garber, Mare Winningham, William Jackson, and Bill Pullman.

PFAS

PER- AND POLY-FLUOROALKYL SUBSTANCES

PFAS Filtration (Water Treatment) Market Size Forecasts to Reach USD 3.7 Billion by 2034 AGR of 6.9%: *Prophecy Market Insights*

GLOBAL MARKET PFAS OPPORTUNITY

The global PFAS filtration market is valued at USD 2.0 billion in 2024 and is projected to reach 2.8 billion by 2029, growing at 7.1% compound aggregated growth rate (cagr) from 2024 to 2029.

ENVIRONMENTAL BUSINESS JOURNAL, VOLUME 37 NUMBERS 5/6: Q3 2024 REMEDIATION & PFAS MARKET REPORT

- **Environmental Business Journal's comprehensive analysis on PFAS and Remediation markets featuring the 2024 update of the EBJ PFAS Market Model and detailed quantitative analysis of the *$15 billion US site remediation market* as part of the broader environmental contracting segments of the environmental industry.**
- **The site count and estimated remediation costs for PFAS exceed 44,000 sites and $138 billion, and new scenario analysis looks at a 40-year horizon, and accelerated 20-year scenario as well as a limited cost scenario. Similar perspective is also provided for wastewater treatment and drinking water facilities that also exceed $100 billion in costs to meet standards expected to be enforced in the next two decades.**
- **This focused report also presents summarized results from EBJ's 2024 survey of remediation markets and technology, with technology trends summarized for soil and groundwater remediation over the recent history and dating back to EBJ's first remediation survey in the early 90s, as well as comments by scores of respondents to open-ended prompts on remediation market drivers and technology applications. This review also includes executive Q&A with 15 leading practitioners across the industry.**

- ☐ **Regulations**
- ☐ **Enforcement**
- ☐ **Compliance**
- ☐ **Liability Management**

4-Year Research Project With Greenwich University (2019-2023)
Provisional Patent USPTO Filed (August 28, 2023)
Expanded Research Scope of PFAS Applications (Aug. 2023-July 2024)
PCT (Patent Agreement Treaty) Filed (August 2024)
PCT Approval Yields 157 Countries For Globally Patenting
Trademarks for PFAS-SOL® Approved In Over 30 Countries
Multiple Publications and Awards In 2024
PFAS-SOL® Treats Broad Range of PFAS (C4 to C12)

EVOLUTION OF PFAS-SOL® (CA. 2019-2023)

Research Collaborators:

- Dr. Cecilia MacLeod (University of Greenwich)
- David Holmes, Ph.D. (UK Environmental Consultant)
- George Ivey, B.Sc, CES, CESA, P.Chem, EP (Ivey International Inc.)
- ALS Laboratory (UK) (PFAS Soil and Water Testing Services)

- Research question: ‘can the recovery rate of PFAS from soil/groundwater be improved?’

- We started discussions regarding R&D column testing, to treat PFAS in 2019, which eventually lead to graduate student testing, which was challenged by COVID. I am here to share some of the interim results within this 2023 presentation, with more data to become ‘*public domain*’ following further work.

- IVEY is working with collaborators to generate addition results, with plans to secure sites for pilot to full scale applications, to evaluate field-scale testing, taking a step-by-step approach to product/technology development.

COLUMN TESTING PROCESS

- Mineral soil (a building sand)
- Mineral soil with 10% by mass powdered activated carbon (left) to provide *organic sportive* content.
- The column was filled with dry media, slowly saturated from the base and then drained to a set volume. It was then re-filled and spiked with 250 mg of PFOA and 250 mg of PFOS (250 mg/kg = 250,000,000 ppt)
- The column was then drained and filled twice to show PFAS recovery in water
- The column was re-filled with PFAS-SOL® sol at 4% and drained to show the PFAS recovery with novel surfactant formulation
- Results are presented for the activated carbon tests

PRELIMINARY INTERPRETATION OF COLUMN TEST RESULTS:

Ivey International Inc. (IVEY) interim interpretation, in order of data in table below:

Column flushing tests using 4% PFAS-SOL® in a soil with <u>10% activated carbon</u>:

- **PFOA Improvement in recovery average of 160%, with best results of 185%**
- **PFOS Improvement in recovery average of 297%, with best results of 732%**
- **PFAS Improvement in recovery average of 242%, with best results of 622%**

****** Moderate mixing of sub-sample for less than 1 minute:**

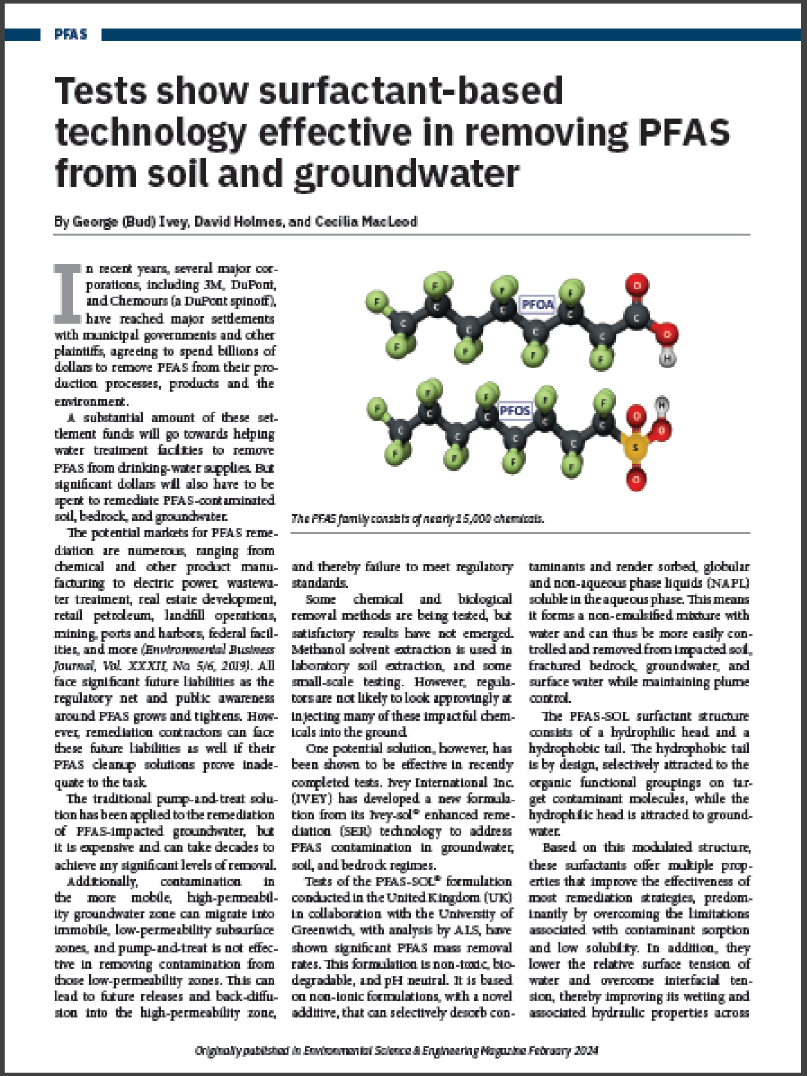
- **TOTAL PFAS Effluent had 5.85 mg/L PFAS (3.29 mg/L PFOA and 2.56 mg/L PFOS)**

These data show that PFAS-SOL® can significantly increase PFAS mass recovery in soil, bedrock, and groundwater, several fold, and when combined with in-situ PFAS-SOL flushing (Push-Pull, Sweep, DP, Wand-Injection, and HW Type Strategies).

This can result in significantly improved PFAS desorption when applied in soil, bedrock, and groundwater regimes.

<u>A Unique Flexible Solution</u> – May improve in-situ stabilization, which is limited by substrate mass it can inject, and associated risk of PFAS back diffusion. By lowering PFAS mass, the substrate can better tie-up residual mass! Lower Risk!

Total PFAS Mass Recovery 242% to 622%



PFAS

Tests show surfactant-based technology effective in removing PFAS from soil and groundwater

By George (Bud) Ivey, David Holmes, and Cecilia MacLeod

In recent years, several major corporations, including 3M, DuPont, and Chemours (a DuPont spinoff), have reached major settlements with municipal governments and other plaintiffs, agreeing to spend billions of dollars to remove PFAS from their production processes, products and the environment.

A substantial amount of these settlement funds will go towards helping water treatment facilities to remove PFAS from drinking-water supplies. But significant dollars will also have to be spent to remediate PFAS-contaminated soil, bedrock, and groundwater.

The potential markets for PFAS remediation are numerous, ranging from chemical and other product manufacturing to electric power, wastewater treatment, real estate development, retail petroleum, landfill operations, mining, ports and harbors, federal facilities, and more (*Environmental Business Journal, Vol. XXXII, No. 5/6, 2019*). All face significant future liabilities as the regulatory net and public awareness around PFAS grows and tightens. However, remediation contractors can face these future liabilities as well if their PFAS cleanup solutions prove inadequate to the task.

The traditional pump-and-treat solution has been applied to the remediation of PFAS-impacted groundwater, but it is expensive and can take decades to achieve any significant levels of removal.

Additionally, contamination in the more mobile, high-permeability groundwater zone can migrate into immobile, low-permeability subsurface zones, and pump-and-treat is not effective in removing contamination from those low-permeability zones. This can lead to future releases and back-diffusion into the high-permeability zone, and thereby failure to meet regulatory standards.

The PFAS family consists of nearly 15,000 chemicals.

Some chemical and biological removal methods are being tested, but satisfactory results have not emerged. Methanol solvent extraction is used in laboratory soil extraction, and some small-scale testing. However, regulators are not likely to look approvingly at injecting many of these impactful chemicals into the ground.

One potential solution, however, has been shown to be effective in recently completed tests. Ivey International Inc. (IVEY) has developed a new formulation from its Ivey-sol® enhanced remediation (SER) technology to address PFAS contamination in groundwater, soil, and bedrock regimes.

Tests of the PFAS-SOL® formulation conducted in the United Kingdom (UK) in collaboration with the University of Greenwich, with analysis by ALS, have shown significant PFAS mass removal rates. This formulation is non-toxic, biodegradable, and pH neutral. It is based on non-ionic formulations, with a novel additive, that can selectively desorb contaminants and render sorbed, globular and non-aqueous phase liquids (NAPL) soluble in the aqueous phase. This means it forms a non-emulsified mixture with water and can thus be more easily controlled and removed from impacted soil, fractured bedrock, groundwater, and surface water while maintaining plume control.

The PFAS-SOL surfactant structure consists of a hydrophilic head and a hydrophobic tail. The hydrophobic tail is by design, selectively attracted to the organic functional groupings on target contaminant molecules, while the hydrophilic head is attracted to groundwater.

Based on this modulated structure, these surfactants offer multiple properties that improve the effectiveness of most remediation strategies, predominantly by overcoming the limitations associated with contaminant sorption and low solubility. In addition, they lower the relative surface tension of water and overcome interfacial tension, thereby improving its wetting and associated hydraulic properties across broader soil textures.

Originally published in Environmental Science & Engineering Magazine February 2024

PFAS-SOL can selectively remove PFAS from sorbed soil and bedrock surfaces.

PFAS-SOL can selectively remove PFAS from sorbed soil and bedrock surfaces, from globule and/or NAPL phase-partitioned layers, to make them more available for enhance physical, biological, and/or chemical remediation.

For the column tests, one metre by 14 centimetre diameter columns were filled with a mineral sand (a building sand), with 10% activated carbon to act like natural organic carbon absorptive content within the soil. The columns were then slowly saturated with water from the base and drained to a set the volume. They were next spiked with 250 mg each of PFOA and PFOS to mimic a PFAS source zone and then drained and filled, with the effluent sampled to show contaminant recovery in water.

The columns were filled again, one with methanol at a 50% concentration in water, the other with the PFAS-SOL surfactant formation at a 4% concentration. They were then drained, with the increased concentration in the effluent in the PFAS-SOL column showing a large increase in PFAS concentration. The columns were then slowly taken apart to deliver a moisture profile and obtain soil samples to measure retained PFAS.

The results showed significant mass PFAS removal from the PFAS-SOL flushes. Flushes with water alone yielded PFAS recovery of approximately 5 micrograms per liter (µg/L), whereas surfactant flushes exhibited improved recovery of up to 30.45 micrograms per liter (µg/L). This meant an average improvement in PFAS removal of 240%, with concentration spikes of up to 622%. PFOA recovery averaged 160%, with best results of 185%. PFOS recovery averaged 297%, with best results of 732%. Total PFAS recovery averaged of 242%, with best results of 622%.

The two test column tubes were spiked with 250 mg each of PFOA and PFOS to mimic a PFAS source zone.

Subsequent tests have shown similarly impressive results, suggesting a bright future for this surfactant-based PFAS remediation compared with other methods that are time-consuming and costly, and don't provide assurances against future back-diffusion risks liability associated with new sportive technologies.

Ivey International Inc. won the 2023 M&A Today Global Awards 'Best Environmental Technology Company' in recognition for their innovative technology developments.

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Dr. Cecilia MacLeod is with the University of Greenwich (UK). Email: c.macleod@greenwich.ac.uk

Originally published in Environmental Science & Engineering Magazine February 2024

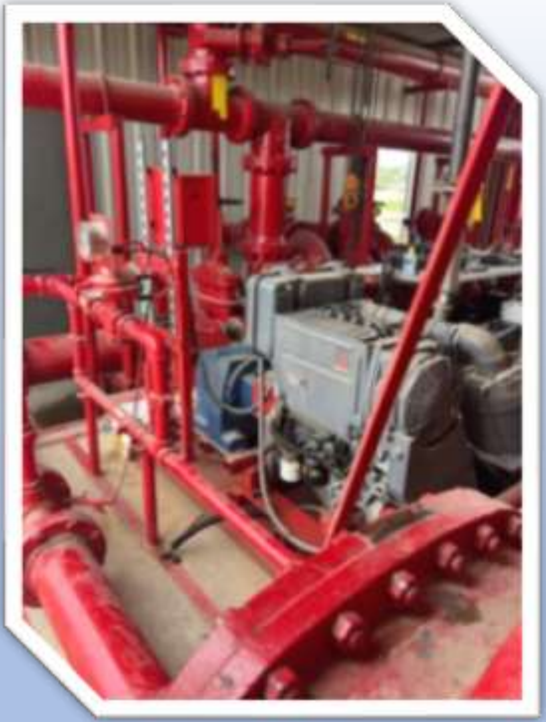
Environmental Science & Engineering February 2024

AFFF Fire Suppression System Equipment PFAS Decontamination Case Study

Background Objective:

- Aqueous Film Forming Foam (AFFF) containing PFAS was stored in a petroleum facility's firefighting equipment, which was removed for non-fluorinated replacement.
- Draining AFFF flowed by a potable water flush left substantial PFAS residual concentrations on equipment surface (372,643 ng/100 cm^2) – FAA Approach ☹
- A proprietary decontamination process using a heated pressured application of **PFAS-SOL®** solution (Patent Pending) was used to scrub the equipment interior of residual PFAS.
- Geologic Science and Technology Group, Inc. (GST) was contracted to provide decontamination of specified firefighting equipment.

GST
GEOLOGIC SCIENCE & TECHNOLOGY



APPROACH

- GST selected a specialty surfactant uniquely formulated for PFAS liberation from impermeable solid surfaces know by the trade mark name: PFAS-SOL®

- PFAS-SOL® is a patent pending non-ionic surfactant formulation that is pH neutral, non-caustic, non-corrosive, and biodegrade. PFAS-SOL® has the unique capacity for desorbing PFAS compounds, associated with AFFF, from a broad range of impacted surfaces.

- Blending tanks were staged next to pipe fittings on the portion of the fire-fighting system to be decontaminated. The blending tanks were connected to the upstream and downstream piping connections to establish a closed-loop re-circulation system.

- The decontamination was staged in sequential phases. Decontamination fluids were heated to 40^{0}C, recirculated by redundant pumps at high velocity under increased pressure. Heat and pressure were carefully monitored to ensure gasket and fitting tolerances were not exceeded. Each decontamination phase included 1 to 1.5 hours of heated high pressure, high velocity recirculation.

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APPROACH Continued:

- Tanks for blending the surfactant with municipal potable water were staged by the pipe fittings on the portion of the fire-fighting system to be decontaminated, both upstream and downstream to create a closed-loop system.

- The emptied piping system was initially flushed with filtered potable water at an ambient temperature (approximately 19ºC) and then flushed three times with filtered potable water heated to 40ºC. Following this flushing and wipe sampling at the discharge point, laboratory analysis detected a total of 12 PFAS analytes (PFAS C_4 to C_{12}) on the piping interior surface. These analytes consisted of nine acid compounds and three sulfonate compounds.

- The remediation project then proceeded with a series of five (5) flush cycles using combinations of PFAS-SOL® and filtered municipal potable water.

- The cycles used varying balances of the surfactant and water (by volume) in the following sequence:
  - ☐ Cycle 1: **5%** PFAS-SOL®, 95% filtered potable water.
  - ☐ Cycle 2: **4%** PFAS-SOL®, 96% filtered potable water.
  - ☐ Cycle 3: **3%** PFAS-SOL®, 97% filtered potable water.
  - ☐ Cycle 4: **2%** PFAS-SOL®, 98% filtered potable water.
  - ☐ Cycle 5: **1%** PFAS-SOL®, 99% filtered potable water.

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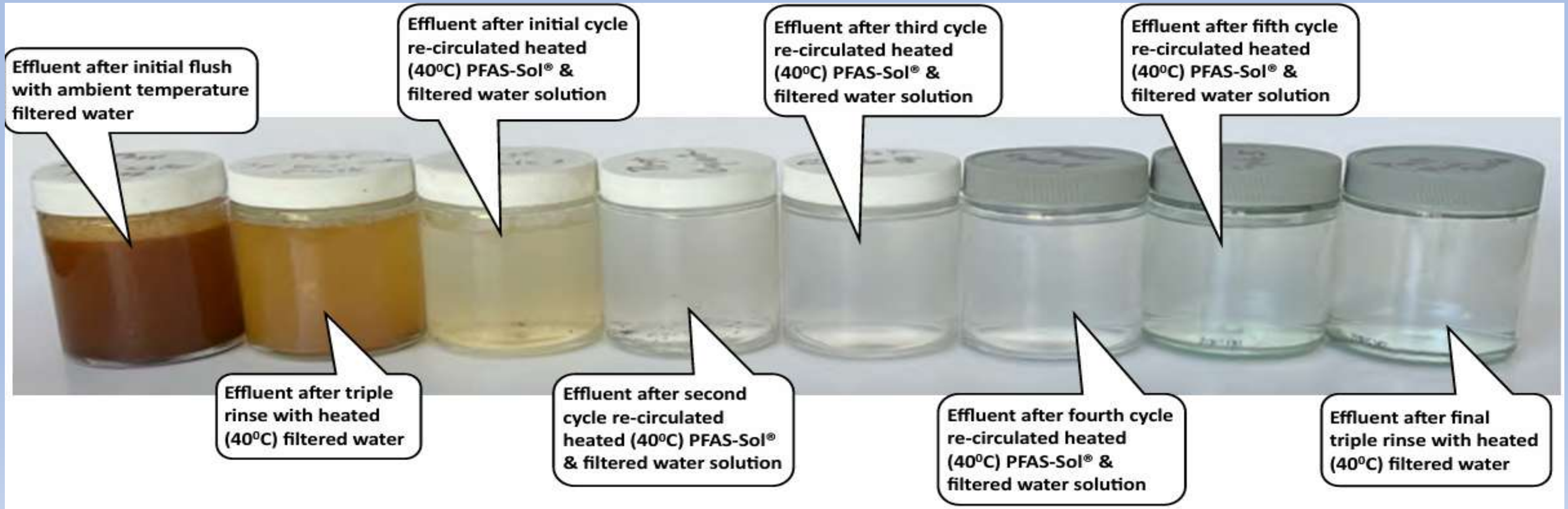
AFFF Equipment PFAS Decontamination

- The decontamination process reduced equipment surface residual PFAS contamination an additional 99.99998% beyond AFFF removal with the potable water flush (*FAA Approach*).
- The PFAS-SOL® solution has the ability to penetrate into much smaller pore spaces than water alone. Accessing smaller pore spaces results in higher surface removal efficiency and minimizes rebound potential.
- The samples collected over the course of the five (5) PFOS-SOL® decontamination flushes, as shown below, becoming successively clearer and clearer



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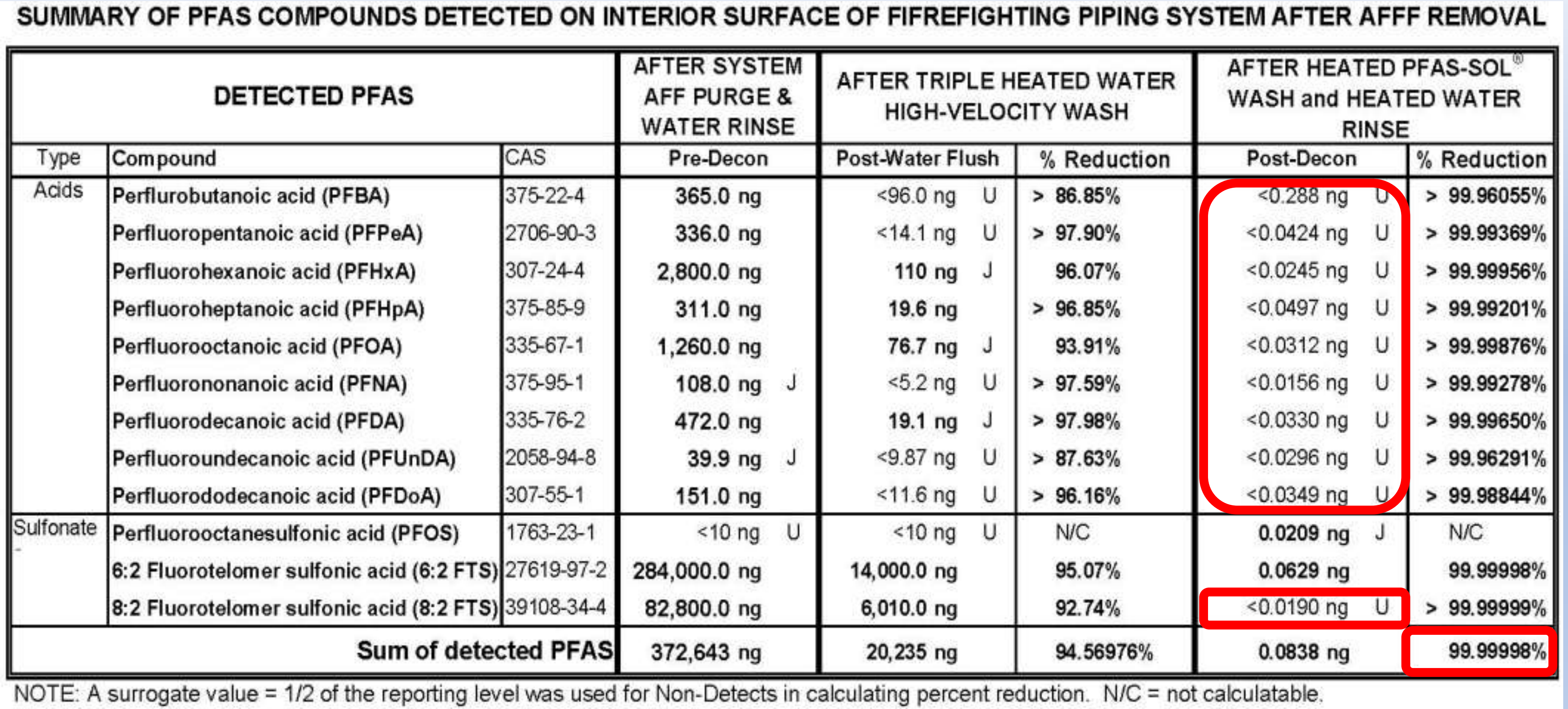
Results AFFF Equipment Decontamination



SUMMARY OF PFAS COMPOUNDS DETECTED ON INTERIOR SURFACE OF FIREFIGHTING PIPING SYSTEM AFTER AFFF REMOVAL

DETECTED PFAS			AFTER SYSTEM AFF PURGE & WATER RINSE	AFTER TRIPLE HEATED WATER HIGH-VELOCITY WASH		AFTER HEATED PFAS-SOL® WASH and HEATED WATER RINSE	
Type	Compound	CAS	Pre-Decon	Post-Water Flush	% Reduction	Post-Decon	% Reduction
Acids	Perflurobutanoic acid (PFBA)	375-22-4	365.0 ng	<96.0 ng U	> 86.85%	<0.288 ng U	> 99.96055%
	Perfluoropentanoic acid (PFPeA)	2706-90-3	336.0 ng	<14.1 ng U	> 97.90%	<0.0424 ng U	> 99.99369%
	Perfluorohexanoic acid (PFHxA)	307-24-4	2,800.0 ng	110 ng J	96.07%	<0.0245 ng U	> 99.99956%
	Perfluoroheptanoic acid (PFHpA)	375-85-9	311.0 ng	19.6 ng	> 96.85%	<0.0497 ng U	> 99.99201%
	Perfluorooctanoic acid (PFOA)	335-67-1	1,260.0 ng	76.7 ng J	93.91%	<0.0312 ng U	> 99.99876%
	Perfluorononanoic acid (PFNA)	375-95-1	108.0 ng J	<5.2 ng U	> 97.59%	<0.0156 ng U	> 99.99278%
	Perfluorodecanoic acid (PFDA)	335-76-2	472.0 ng	19.1 ng J	> 97.98%	<0.0330 ng U	> 99.99650%
	Perfluoroundecanoic acid (PFUnDA)	2058-94-8	39.9 ng J	<9.87 ng U	> 87.63%	<0.0296 ng U	> 99.96291%
	Perfluorododecanoic acid (PFDoA)	307-55-1	151.0 ng	<11.6 ng U	> 96.16%	<0.0349 ng U	> 99.98844%
Sulfonate-	Perfluorooctanesulfonic acid (PFOS)	1763-23-1	<10 ng U	<10 ng U	N/C	0.0209 ng J	N/C
	6:2 Fluorotelomer sulfonic acid (6:2 FTS)	27619-97-2	284,000.0 ng	14,000.0 ng	95.07%	0.0629 ng	99.99998%
	8:2 Fluorotelomer sulfonic acid (8:2 FTS)	39108-34-4	82,800.0 ng	6,010.0 ng	92.74%	<0.0190 ng U	> 99.99999%
		Sum of detected PFAS	372,643 ng	20,235 ng	94.56976%	0.0838 ng	99.99998%

NOTE: A surrogate value = 1/2 of the reporting level was used for Non-Detects in calculating percent reduction. N/C = not calculatable.

Non Detectable Post Five (5) PFAS-SOL® Application

The decontamination process reduced residual PFAS contamination on the equipment surfaces by an additional 99.99998% beyond what the AFFF removal and potable water flushing were able to achieve, down to 0.0838 ng/100 cm^2.

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99.99998% PFAS Mass Removal

Decontaminating fire-fighting equipment to prevent PFAS from entering water supplies

By J. Scott Poynor

Although there is still much to learn, we know that the class of chemicals known as per- and polyfluoroalkyl substances, referred to generally as PFAS, is ubiquitous in the environment and poses risks to human health and the environment. Of utmost concern lately, PFAS in water supplies has become recognized as a special risk, and municipal water systems, or government agencies acting on their behalf, have taken the lead in suing manufacturers to phase out PFAS production and provide the funds for remediation.

Meanwhile, the development of technologies for removing PFAS from the environment is playing catch-up. These environmental endpoints include not only water and soil but surfaces of all kinds of products and equipment that present human exposure risks. Although multiple technology development efforts are underway, there remains a lack of efficient, scalable, cost-effective, and environmentally benign technologies to deal with this broad range of contamination issues.

One promising technology was recently successfully deployed at a petroleum storage facility, which faced PFAS problems associated with its fire-suppression equipment. The facility operator, recognizing the rapidly advancing tide of PFAS-related action, sought to address contamination in certain equipment, in the interest of liability and risk management and out of concern for potential employee exposures.

The equipment in question consisted of a fire-fighting system, including piping that stored aqueous film-forming foam (AFFF), a fire-fighting liquid that contains PFAS compounds.

Replacing the PFAS-contaminated equipment was not viable, due to cost considerations and, even more, to the time required for procurement and installation of new equipment. Fire-fighting systems at petroleum storage facilities are required to be operational essentially full-time, so removing the residual PFAS from the existing equipment was deemed the preferred option.

Following removal of the AFFF from the system, residual concentrations of PFAS were detected on the equipment surfaces. The facility operator performed a thorough, high-pressure flushing of the system using filtered municipal potable water, but that action left a PFAS concentration of 342,643 ng/100 cm² on the equipment's interior surface, a level deemed significant and falling short of the facility operator's decontamination goals.

The facility operator then engaged Geologic Science and Technology Group (GST), an environmental consulting firm with which the operator had frequently worked in the past, to undertake the equipment decontamination project. The objective of the project was to reduce residual concentrations of detected PFAS constituents to the maximum extent possible using currently available technology.

In initial discussions with the facility operator, GST reviewed the known available options for removing PFAS from surfaces. Flushing with an alcohol-based solvent (ethanol or methanol) has historically worked better than flushing with water, but it is known to leave PFAS concentrations in residue of about 10%, which was substantial and considered to be too high.

GST then presented a surfactant-based solution that had shown the potential to achieve substantially improved removal rates compared with alcohol-based solvents. PFAS-SOL® is a patent-pending, non-ionic surfactant developed by British Columbia based Ivey International Inc. (IVEY) that is pH neutral, non-caustic, non-corrosive, non-toxic, and biodegradable.

The facility operator agreed to GST's recommendation that PFAS-SOL be deployed to reduce the concentrations of PFAS residues on the fire-fighting system piping and equipment surfaces.

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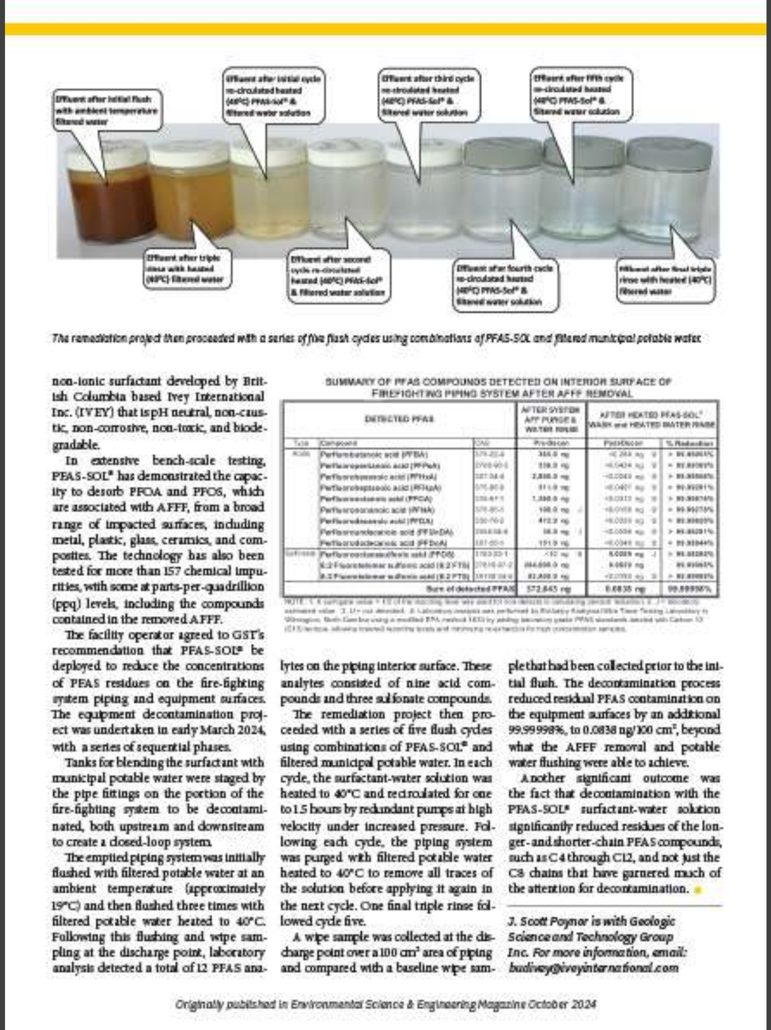

The remediation project then proceeded with a series of five flush cycles using combinations of PFAS-SOL and filtered municipal potable water.

In extensive bench-scale testing, PFAS-SOL® has demonstrated the capacity to desorb PFOA and PFOS, which are associated with AFFF, from a broad range of impacted surfaces, including metal, plastic, glass, ceramics, and composites. The technology has also been tested for more than 157 chemical impurities, with some at parts-per-quadrillion (ppq) levels, including the compounds contained in the removed AFFF.

The facility operator agreed to GST's recommendation that PFAS-SOL® be deployed to reduce the concentrations of PFAS residues on the fire-fighting system piping and equipment surfaces. The equipment decontamination project was undertaken in early March 2024, with a series of sequential phases.

Tanks for blending the surfactant with municipal potable water were staged by the pipe fittings on the portion of the fire-fighting system to be decontaminated, both upstream and downstream to create a closed-loop system.

The emptied piping system was initially flushed with filtered potable water at an ambient temperature (approximately 19°C) and then flushed three times with filtered potable water heated to 40°C. Following this flushing and wipe sampling at the discharge point, laboratory analysis detected a total of 12 PFAS analytes on the piping interior surface. These analytes consisted of nine acid compounds and three sulfonate compounds.

The remediation project then proceeded with a series of five flush cycles using combinations of PFAS-SOL® and filtered municipal potable water. In each cycle, the surfactant-water solution was heated to 40°C and recirculated for one to 1.5 hours by redundant pumps at high velocity under increased pressure. Following each cycle, the piping system was purged with filtered potable water heated to 40°C to remove all traces of the solution before applying it again in the next cycle. One final triple rinse followed cycle five.

A wipe sample was collected at the discharge point over a 100 cm² area of piping and compared with a baseline wipe sample that had been collected prior to the initial flush. The decontamination process reduced residual PFAS contamination on the equipment surfaces by an additional 99.99998%, to 0.0838 ng/100 cm², beyond what the AFFF removal and potable water flushing were able to achieve.

Another significant outcome was the fact that decontamination with the PFAS-SOL® surfactant-water solution significantly reduced residues of the longer- and shorter-chain PFAS compounds, such as C4 through C12, and not just the C8 chains that have garnered much of the attention for decontamination.

SUMMARY OF PFAS COMPOUNDS DETECTED ON INTERIOR SURFACE OF FIREFIGHTING PIPING SYSTEM AFTER AFFF REMOVAL

DETECTED PFAS			AFTER SYSTEM AFF PURGE & WATER RINSE	AFTER HEATED PFAS-SOL® WASH and HEATED WATER RINSE	
Type	Compound	CAS	Pre-Decon	Post-Decon	% Reduction
Acids	Perfluorobutanoic acid (PFBA)	[illegible]	[illegible]	[illegible]	[illegible]
	Perfluoropentanoic acid (PFPeA)	[illegible]	[illegible]	[illegible]	[illegible]
	Perfluorohexanoic acid (PFHxA)	[illegible]	[illegible]	[illegible]	[illegible]
	Perfluoroheptanoic acid (PFHpA)	[illegible]	[illegible]	[illegible]	[illegible]
	Perfluorooctanoic acid (PFOA)	[illegible]	[illegible]	[illegible]	[illegible]
	Perfluorononanoic acid (PFNA)	[illegible]	[illegible]	[illegible]	[illegible]
	Perfluorodecanoic acid (PFDA)	[illegible]	[illegible]	[illegible]	[illegible]
	Perfluoroundecanoic acid (PFUnDA)	[illegible]	[illegible]	[illegible]	[illegible]
	Perfluorododecanoic acid (PFDoA)	[illegible]	151.0 ng	[illegible]	[illegible]
Sulfonates	Perfluorooctanesulfonic acid (PFOS)	[illegible]	<10 ng	[illegible]	[illegible]
	6:2 Fluorotelomer sulfonic acid (6:2 FTS)	[illegible]	[illegible]	[illegible]	[illegible]
	8:2 Fluorotelomer sulfonic acid (8:2 FTS)	[illegible]	[illegible]	[illegible]	[illegible]
	Sum of detected PFAS		372,643 ng	0.0838 ng	99.99998%

NOTE: [illegible]

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ENVIRONMENTAL BUSINESS JOURNAL®

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