Activated Carbon-Amended Enhanced Natural Recovery (ENR): Results from the Lower Duwamish Waterway Pilot Study – Year 1

AUTHORS

Victor S. Magar, Lis Castillo Nelis, Ramboll; Jason Conder, Geosyntec; Gretchen Heavner, Floyd Snyder; Cliff Whitmus, Wood; Rob Webb, Dalton, Olmsted & Fuglevand; Debra Williston, Jeff Stern, King County; Brian Anderson, Joe Flaherty, The Boeing Company; David Schuchardt, Peter D. Rude, Allison Crowley, City of Seattle; Joanna Florer, Port of Seattle

BACKGROUND

The use of activated carbon (AC) as a standalone *in situ* treatment, or to augment enhanced natural recovery (ENR), is an increasingly recognized remedy alternative to reduce the bioavailability of hydrophobic, bioaccumulative compounds. Studies have shown that the application of AC in contaminated sediment can reduce the bioavailability of organic chemicals to benthic organisms and higher trophic receptors by an order of magnitude or more. A pilot program is underway on the Lower Duwamish Waterway (LDW) (Seattle, Washington, USA) to test the use of AC to augment an ENR layer of sand or gravelly sand materials.

GOALS

- Verify that ENR amended with AC (ENR+AC) can be successfully applied in the LDW by monitoring physical placement success (uniformity of coverage and percent of carbon in a placed layer)
- Evaluate performance of ENR+AC compared to ENR alone in locations with a range of PCB concentrations
- Assess potential impacts to the benthic community in ENR+AC compared to ENR alone
- Assess changes in bioavailability in ENR+AC compared to ENR alone
- Assess the stability of ENR and ENR+AC in scour areas (such as berthing areas)

METHODS

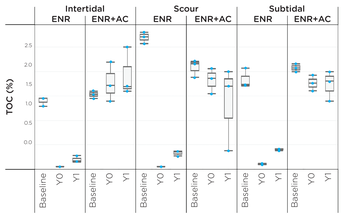
This pilot project compares the effectiveness of ENR with ENR+AC in the Lower Duwamish Superfund Site, an active, urban, deep draft waterway subject to a range of flow conditions and sediment characteristics. Paired ENR and ENR+AC plots were placed in 3 separate 1-acre plots: one in the deeper navigation channel (subtidal plot), one in a berthing area subject to scour (scour plot) and one in an intertidal location subject to waves and wakes (intertidal plot). Construction took place November 2016 to February 2017, with oversight by USEPA Region 10 and USACE Seattle district.

Monitoring is scheduled for 3 years to evaluate and compare ENR and ENR+AC performance in reducing the bioavailability of PCBs in the uppermost 10-cm surface layer. Monitoring events already completed include baseline sampling before construction, post-construction monitoring in January–February 2017, and the Year 1 monitoring event completed March–June 2018. Monitoring metrics include evaluation of ENR and ENR+AC stability, including the stability of AC in the ENR+AC layers, and PCB bioavailability using whole sediment and porewater (freely-dissolved) analyses, as well as biological conditions using sediment profile imaging (SPI).

RESULTS

Results presented here are the first annual results in a 3-year study.

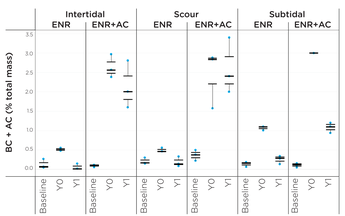
Figure 1. Total organic carbon results



Boxes show first quartile, median and third quartile. Dots show data points.

Carbon remains at levels of 1–3% in ENR+AC subplots in Year 0 (Y0) and Year 1 (Y1). Baseline was 2016, Year 0 was 2017, and Year 1 was 2018.

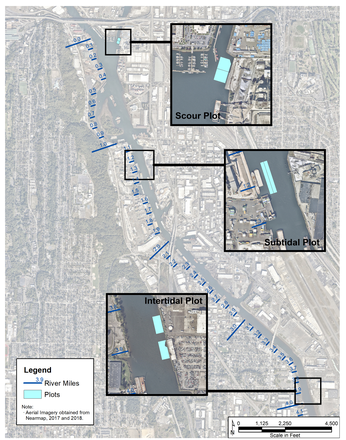
Figure 2. Black carbon plus activated carbon results



Boxes show first quartile, median and third quartile. Dots show data points.

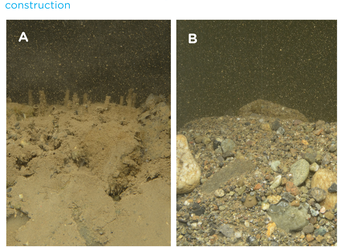
Black carbon (Baseline), total volatile solids (TVS) (Year 0) and AC/BC (Year 1) results. Carbon remains at levels of 1–3% in ENR+AC subplots in Year 0 and Year 1. Baseline was 2016, Year 0 was 2017 and Year 1 was 2018.

Figure 3. Study plots along the Lower Duwamish Waterway



Each plot is composed of one ENR and one ENR+AC subplot.

Figure 4. Sediment profile images before (A) and after (B) construction

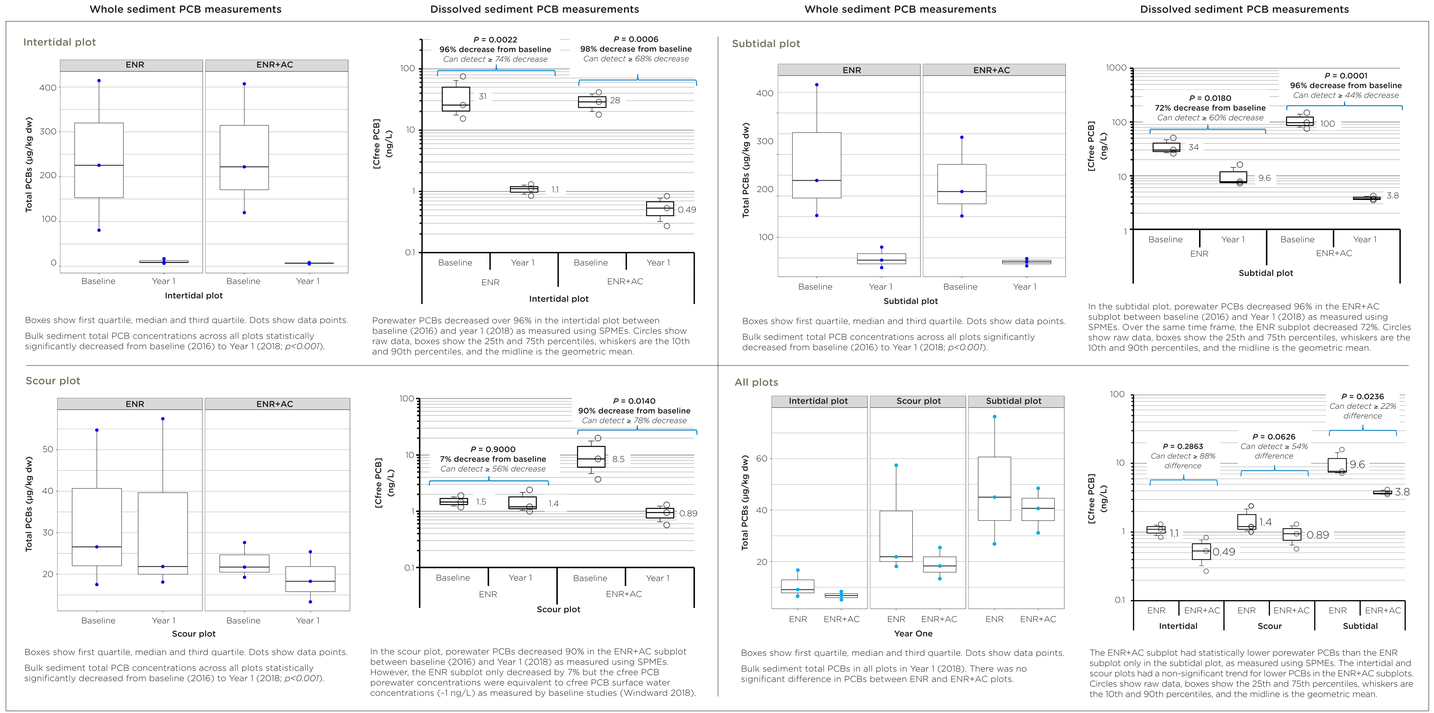


Representative SPI indicated stability of ENR and ENR+AC materials, with recolonization of benthic organisms and minor (0.6–2.5 cm on average) silt deposition

CONCLUSIONS

- ENR and ENR+AC materials remain stable in 3 study plots 1 year after placement
- PCB availability has decreased significantly
- Monitoring will continue in Year 2 (2019) and Year 3 (2020)

Figure 5. Whole sediment and dissolved (Cfree) porewater PCB concentrations



Boxes show first quartile, median and third quartile. Dots show data points.

Bulk sediment total PCB concentrations across all plots statistically significantly decreased from baseline (2016) to Year 1 (2018; *p<0.001*).

Porewater PCBs decreased over 96% in the intertidal plot between baseline (2016) and year 1 (2018) as measured using SPMEs. Circles show raw data, boxes show the 25th and 75th percentiles, whiskers are the 10th and 90th percentiles, and the midline is the geometric mean.

Boxes show first quartile, median and third quartile. Dots show data points.

Bulk sediment total PCB concentrations across all plots significantly decreased from baseline (2016) to Year 1 (2018; *p<0.001*).

In the subtidal plot, porewater PCBs decreased 96% in the ENR+AC subplot between baseline (2016) and Year 1 (2018) as measured using SPMEs. Over the same time frame, the ENR subplot decreased 72%. Circles show raw data, boxes show the 25th and 75th percentiles, whiskers are the 10th and 90th percentiles, and the midline is the geometric mean.

Boxes show first quartile, median and third quartile. Dots show data points.

Bulk sediment total PCB concentrations across all plots statistically significantly decreased from baseline (2016) to Year 1 (2018; *p<0.001*).

In the scour plot, porewater PCBs decreased 90% in the ENR+AC subplot between baseline (2016) and Year 1 (2018) as measured using SPMEs. However, the ENR subplot only decreased by 7% but the cfree PCB porewater concentrations were equivalent to cfree PCB surface water concentrations (~1 ng/L) as measured by baseline studies (Windward 2018).

Boxes show first quartile, median and third quartile. Dots show data points.

Bulk sediment total PCBs in all plots in Year 1 (2018). There was no significant difference in PCBs between ENR and ENR+AC plots.

The ENR+AC subplot had statistically lower porewater PCBs than the ENR subplot only in the subtidal plot, as measured using SPMEs. The intertidal and scour plots had a non-significant trend for lower PCBs in the ENR+AC subplots. Circles show raw data, boxes show the 25th and 75th percentiles, whiskers are the 10th and 90th percentiles, and the midline is the geometric mean.

LIST OF ACRONYMS/ABBREVIATIONS

LDW = Lower Duwamish Waterway
AC = Activated carbon
BC = Thermal black carbon
NS = Native sediment
ENR = Enhanced natural recovery
TOC = Total organic carbon
TVS = Total volatile solids

REFERENCES

Amec Foster Wheeler Environment & Infrastructure, Inc.; Dalton, Olmsted & Fuglevand, Inc.; Ramboll, FloydSnider, and Geosyntec Consultants (Amec Foster Wheeler et al.). 2015a. Narrative Design Report, Enhanced Natural Recovery/Activated Carbon Pilot Study, Lower Duwamish Waterway. Prepared on behalf of Lower Duwamish Waterway Group, Seattle, Washington. December.

_____. 2015b. Construction Plans and Specification, Appendix D in Narrative Design Report, Enhanced Natural Recovery/Activated Carbon Pilot Study, Lower Duwamish Waterway. Prepared on behalf of Lower Duwamish Waterway Group, Seattle, Washington. December.

_____. 2016a. Quality Assurance Project Plan, Enhanced Natural Recovery/Activated Carbon Pilot Study Lower Duwamish Waterway. Prepared on behalf of Lower Duwamish Waterway Group, Seattle, Washington. February.

_____. 2016b. Quality Assurance Project Plan Addendum 1, Enhanced Natural Recovery/ Activated Carbon Pilot Study, Lower Duwamish Waterway, Baseline Ex-situ SPME Sampling at the Subtidal Plot. Prepared on behalf of Lower Duwamish Waterway Group, Seattle, Washington. November.

_____. 2016c. Construction Quality Assurance Project Plan (CQAPP) Addendum 1, Enhanced Natural Recovery/Activated Carbon Pilot Study, Lower Duwamish Waterway, ENR Layer Thickness Measurement during Construction at the Subtidal Plot and Grade Stakes at Test, Intertidal, and Scour Plots. Prepared on behalf of Lower Duwamish Waterway Group, Seattle, Washington. November.

_____. 2017. Quality Assurance Project Plan Addendum 2, Enhanced Natural Recovery/Activated Carbon Pilot Study, Lower Duwamish Waterway, Laboratory Bioaccumulation Study. Prepared on behalf of Lower Duwamish Waterway Group, Seattle, Washington. May.

_____. 2018a. Quality Assurance Project Plan Addendum 3, Enhanced Natural Recovery/Activated Carbon Pilot Study, Lower Duwamish Waterway, Analytical Methods for Carbon Analysis and Sieving of Gravelly Sand ENR Substrate. Prepared on behalf of Lower Duwamish Waterway Group, Seattle, Washington. January.

_____. 2018b. Construction Report, Enhanced Natural Recovery/Activated Carbon Pilot Study, Lower Duwamish Waterway. Prepared on behalf of Lower Duwamish Waterway Group, Seattle, Washington. June.

Conder, J.M., La Point, T.W., Lotufo, G.R., and Steevens, J.A., 2003. Nondestructive, minimal disturbance, direct-burial solid phase microextraction fiber technique for measuring TNT in sediment. Environ. Sci. Technol. 37:1625-1632.

Grossman, A., and Ghosh, U., 2009. Measurement of activated carbon and other black carbons in sediments. Chemosphere 75:469-475.

Gustafsson, O., Haghseta, F., Chan, C., MacFarlane, J., and Gschwend, P.M., 1997. Quantification of the dilute sedimentary soot phase: Implications for PAH speciation and bioavailability. Environ. Sci. Technol. 31: 203-209.

Lu, X., Skwarski, A., Drake, B., and Reible, D.D., 2011. Predicting bioavailability of PAHs and PCBs with porewater concentrations measured by solid-phase microextraction fibers. Environ. Toxicol. Chem. 30: 1109-1116.

Oen, A.M.P., Janssen, E.M.L., Cornelissen, G., Breedveld, G.D., Eek, E., and Luthy, R.G., 2011. In situ measurement of PCB pore water concentration profiles in activated carbon-amended sediment using passive samplers. Environ. Sci. Technol. 45: 4053–4059.

USEPA, 2014a. National Functional Guidelines for Inorganic Superfund Data Review.

_____. 2014b. National Functional Guidelines for Superfund Organic Methods Data Review.

_____. 2016. National Functional Guidelines for High Resolution Superfund Methods Data Review.

Windward Environmental LLC (Windward). 2018. Baseline Surface Water Collection and Chemical Analyses Data Report, Draft. Submitted to EPA on December 3, 2018. Lower Duwamish Waterway Pre-Design Studies. Windward Environmental LLC, Seattle, Washington.

Yang, Z., Maruya, K.A., Greenstein, D., Tsukada, D., and Zeng, E.Y., 2008. Experimental verification of a model describing solid phase microextraction (SPME) of freely dissolved organic pollutants in sediment porewater. Chemosphere 72: 1435-1440.

You, J., Pehkonen, S., Landrum, P.F., and Lydy, M.J., 2007. Desorption of hydrophobic compounds from laboratory-spiked sediments measured by Tenax absorbent and matrix solid-phase microextraction. Environ. Sci. Technol. 41: 5672-5678.