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Physical Impact of Waterjet-Based Sediment Remediation on Benthic Organisms

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Adding activated carbon to sediments has been shown to be an effective means of reducing the bioavailability of certain contaminants. The current state of the practice is to mechanically mix activated carbon to a target concentration of 3 percent at depths of approximately 30 cm using a rotovator or similar construction equipment. Waterjets have been used to cut hard material using a mixture of water and an abrasive. If activated carbon is substituted for the abrasive, waterjets have the potential to use surface injection as a replacement for mechanical mixing during sediment remediation. A perceived benefit of waterjet-based sediment remediation is that there may be a reduced potential for benthic organism mortality related to amendment delivery. A set of waterjet parameters were identified that have the potential to achieve amendment placement goals, and a series of waterjet tests were conducted to evaluate the potential impact on the benthic community. The tests included mortality testing using a swimming macroinvertebrate and a burrowing invertebrate, benthic artifacts such as shells, and craft foam as a surrogate for living organisms. The results indicated that the immediate survivability was typically greater than 50 percent, and that empirical relationships between two variables (waterjet nozzle diameter and the water column height between the nozzle and the target) and the depth of cut in the foam could be established. Data are not available in the literature for direct comparison of organism survivability immediately after mechanical mixing, but the results of this study provide motivation for the further evaluation of waterjets on the basis of the low observed mortality rates. Future waterjet work may address field-scale characterization of mixing effectiveness, resuspension potential, technical feasibility, and cost. © 2011 Wiley Periodicals, Inc.

INTRODUCTION

Contaminated sediment is a problem that plagues not only every region in the United States, but most of the industrialized world. For example, in the U.S. Environmental Protection Agency's (EPA's) Contaminated Sediment Report to Congress, several of the major harbors and transportation routes were included under Tier 1, meaning they were probable causes of harm to humans and/or wildlife. These include the Mississippi River, Big Creek (Grays Harbor), San Francisco Bay, Puget Sounds, Elliot Bay, Hudson River, and Passaic River (U.S. EPA, 2004). Currently, there are limited options for sediment remediation, and remediation techniques may cause ecological damage despite that

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mitigating such damage is a primary project objective. Traditional sediment remediation processes include *dredging*, which is the removal of contaminated sediment; *capping*, where the contaminated sediment is covered with a layer of sand to inhibit contaminants from migrating into the water column; a combination of dredging and capping; or monitoring the contaminated site while pollutants naturally attenuate. Palermo et al. (1998) describe the first type of capping, which is now known as *passive capping*. This technique was essentially the addition of material to isolate the contaminated sediments through burial to prevent biouptake. Active caps, or caps containing amendments, have been shown to reduce bioavailability even further. Bioturbation or diffusion, which allowed contaminants to escape from a passive cap, is reduced by the chemical or physical attenuation of the contaminants with the amendments in the active caps (Knox et al., 2006; Reible et al., 2006).

Dredging and/or capping methods are detrimental to the benthic organisms that live along the streambed.

Dredging and/or capping methods are detrimental to the benthic organisms that live along the streambed. Qian et al. (2003) describe a study of sites that were capped with dredged material where at least three years were required for repopulation, and even then with a different proportion of species. These numbers vary with the degree of disturbance, which could carry more species into the affected area and reduce the time for repopulation. Carbines and Cole (2009) studied the effect that dredges used in industrial mollusk harvesting have on a population of benthic organisms. The harvesting dredge consists of a metal-wire-frame basket with a raking bar to scrape against the sediment bed, which, for the most part, leaves the sediment and is less intrusive relative to a standard dredge. Even so, it took four to seven years for the species to repopulate the site, and the new benthic organism species were different from those from before the harvesting.

Laboratory and field-testing using activated carbon to remediate sediment have been shown to reduce bioavailability of polychlorinated biphenyls (PCBs) and other hydrophobic organic contaminants (HOCs) (Cho et al., 2007, 2009). However, in field studies, the process used to mix the activated carbon into the contaminated sediment involved a barge-mounted rotovator system and a crawler-mounted activated carbon-slurry injector system, as described by Cho et al. (2009). The target depth of this application was 30 cm, which is the depth of the active biological layer. Pilot studies conducted by Ghosh et al. in 2011 demonstrated significant reduction of PCB bioavailability when the activated carbon (AC) was placed 10 to 30 cm deep into the contaminated sediment.

The toxicological and mechanical effects of these amendment techniques on benthic organisms have been investigated. Several studies have found decreased lipid content and growth rates when 4-week toxicity tests were used to examine the effects of activated carbon on common benthic organisms such as aquatic worms and polychaetes (Jonker et al., 2004, 2009). However, several others have found no decrease in lipid content, survival rate, or growth rate during similar tests of benthic organisms in the same or higher powdered or granular activated carbon–enriched sediments (Cornelissen, 2005; Millward, 2005). In 2009, Jonker et al. conducted an extensive field and laboratory study of the toxicological effects of activated carbon on two freshwater and one marine benthic organism (*Lumbriculus variegatus*, *Daphnia magna*, and *Corophium volutator*, respectively) (Jonker et al., 2009). Sediment with percent activated carbon by dry weight ranging from 0 to 25 percent was used. These tests were conducted using five different types of activated carbon, and survival, lipid content, and avoidance tests were each performed. The highest concentrations of activated carbon tested proved lethal to all organisms. However, at

15 percent activated carbon levels and higher, organisms avoided the activated carbon sediment during avoidance tests. During lipid content studies, at just 4 percent activated carbon, the lipid content decreased between 4 and 20 percent in different sediments. However, at both these activated carbon doses, there was no significant decrease in survivability. All of these results varied slightly with the type of activated carbon used.

The effects of mechanical mixing of sediments on the survival rate of benthic organisms have been tested by Cho et al. (2009). In the control plot of a full pilot study, the benthic community was surveyed before and after mixing without the addition of any activated carbon and no major significant change in the number or variation of species was found 6, 12, and 18 months after application. This pilot field test also studied the combined effects of mechanical mixing and toxicity due to activated carbon on the benthic community before and 6, 12, and 18 months after powdered activated carbon was added. Again, these results showed no significant change in the benthic community.

However, these tests do not show the immediate effects of mechanically mixing activated carbon into sediment on the current benthic community. Samples were taken six or more months after treatment of the sediment, which is enough time for the area to repopulate. No data are available to show the immediate physical damage that may occur with this mixing and delivery system.

Waterjets have been used to precisely cut a variety of media by adding abrasives to the water stream. Applications range from selective medical cutting to large-scale mining. Using waterjets to deliver amendments to contaminated sediment could potentially decrease the mortality rate of benthic organisms. The proposed technique of using a waterjet to deliver the amendments includes water ideally passing through the sediment and then fanning out at the layer that was contaminated. This would require less of the top five centimeters of sediment where most benthic organisms live undisturbed. The purpose of this study is to characterize the impact of a waterjet on the benthic community. The study focuses on physical damage instead of the more typical toxicological approach that is associated with mortality studies. Both invertebrate benthic organisms and surrogate organisms are used in the characterizations.

Using waterjets to deliver amendments to contaminated sediment could potentially decrease the mortality rate of benthic organisms.

This procedure is common in other types of studies involving invertebrates. In a study done by Samuelson (2007) testing for genes to produce insulin, *Caenorhabditis elegans* (nematodes) were put in Petri dishes, flooded, and prodded with a metal rod. If no movement was detected, the organisms were declared dead. This is similar to the EPA's standard toxicity procedures. In 2010, an experiment by Perron et al. testing the bioavailability of contaminants in a Texas bayou was carried out with *Ampelisca abdita* (amphipods) and *Americamysis bahia* (mysids) (Perron et al., 2010). The sediment used was canned with reconstituted seawater and gently aerated for 24 hours before. Ten of each of the test organisms were added to the jars and left for seven days. Afterward, the organisms were sieved from the sediment and assessed for mortality. Missing organisms were considered mortalities. Common freshwater organisms utilized included *Chironomus tentans* (midge larvae) and *Hyalella azteca* (sideswimmer).

MATERIALS AND METHODS

The potential impact of waterjets on benthic organisms was characterized in conjunction with ongoing work to quantify the amount of various amendments to saturated sediments.

The impact study included several phases, such as the identification of representative waterjet parameters, establishing a methodology for quantifying mortality of representative benthic organisms, characterizing waterjet impacts on benthic organism artifacts, and characterizing waterjet impact on an inanimate surrogate for larger benthic organisms.

Waterjet Parameters

A *waterjet* is defined by several parameters, including pressure, flow rate, nozzle diameter and shape, and duration of the injection. The potential for a waterjet to penetrate contaminated sediment was evaluated using a 5.0-cm-diameter × 91-cm-length clear PVC tube filled with a saturated kaolinite clay mixture. A mass of 6.2 kg of kaolinite clay was mixed with every 3.79 L of water and used as a substitute for contaminated sediment. A slurry of 15 percent by weight WPH® powdered activated carbon from Calgon Cargon Corporation (Pittsburgh, Pennsylvania) and tap water were used to identify appropriate waterjet pumping systems. Electric and gasoline pressure washers developed for the residential market were shown to be unsatisfactory because the packing nature of the carbon would clog the internal orifices, causing the pump to fail immediately or shortly thereafter. However, a Graco Tradeworks (Minneapolis, Minnesota) 170 electric paint sprayer with a 466 W pump was able to handle the powdered activated carbon slurry without clogging. The paint sprayer has an adjustable pressure setting and delivers water at a rate of approximately 1.21 L/min. An electric footswitch was used to regulate the length of time of each injection into the clay. Standard paint sprayer nozzles were modified for use in the experiments by grinding off the terminal "fan" portion so that the nozzle consisted solely of a cylindrical tube. Two nozzles designated 313 and 515 were modified and evaluated for waterjet amendment. The nozzles consist of a tapered cylinder terminating in a fan shape. The fan shape was ground off of each nozzle, and the modified 313 nozzle had an exit diameter of 0.058 cm while the modified 515 nozzle had a final diameter of 0.066 cm. A pressure gage was mounted on the waterjet lance between the pump and the nozzle, and it was found that the sprayer delivered an initial 2.5-second pressure surge of 2,500 psi before rapidly declining to the preset steady pressure. Multiple injections into the clear PVC tubes with the 0.058 cm nozzle at a steady pressure of 700 psi resulted in a waterjet penetration of more than 30 cm, as shown in Exhibit 1. This was the depth targeted for mechanical mixing of powdered activated carbon with contaminated sediment in the field, as documented in Cho et al. (2007).

A device to maintain the height and angle of the waterjet lance above the benthic organism test bed was fabricated. A wooden beam with a collar to hold the waterjet lance in place was attached to a table, and the test bed was placed beneath the table. The beam was moved across the table and remained straight with the help of guides on either side of the table, and the nozzle was clamped at the prescribed height. The waterjet could then be moved across the test bed manually at a constant rate of 1 m/s.

Mortality Characterization Methodology

The procedure described in U.S. EPA (2000) to characterize freshwater sediment toxicity was modified to evaluate mortality rates from waterjetting. The standard toxicity test consists of placing 100 mL of the subject sediment in a 300 mL beaker along with 175 mL

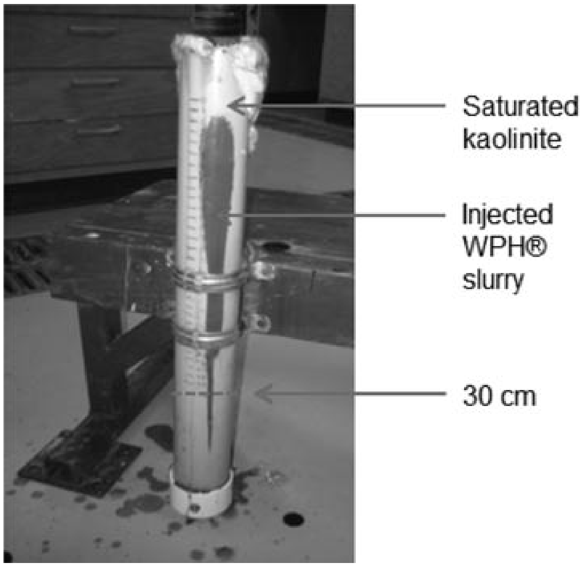

Exhibit 1. Amendment placement characterization results

of water from the subject body of water. Eight replicates were conducted, and each consisted of 10 amphipods that were 7 to 14 days old. Each beaker was dosed with 1 mL of yeast, cerophyl, and trout chow (YCT) food. The beakers were kept at a constant 23 degrees Celsius under a 16-hour light/8-hour dark cycle for 10 days. After 10 days, the sediment was sieved and the organisms were placed on a Petri dish and counted using a dissection microscope. Organisms that were observed to move under the microscope were counted as living, and those that did not move were counted as dead.

Modifications of this procedure are common in other types of studies involving invertebrate mortality. Samuelson (2007) studied insulin-producing genes using *Caenorhabditis elegans* (nematodes), which were put in Petri dishes, flooded, and prodded with a metal rod. If no movement was detected, the organisms were declared dead. Perron et al. (2010) tested the bioavailability of contaminants in a Texas bayou sediment using *C. tentans* (midge larvae) and *H. azteca* (sideswimmer) in freshwater. Again, the organisms were sieved from the sediment and assessed for mortality based on movement. Missing organisms were classified as dead.

Based on these studies, two invertebrate benthic organisms were selected for this study. *Chironomus tentans* is a midge from the Chironomidae family; this family is found worldwide and has over 5,000 species. They spend most of their life as larvae and spend less than a week as a flying midge and do not even have a functioning digestive system at this life stage. *C. tentans* is found worldwide in temperate climates. Eggs hatch after approximately three weeks; two weeks are spent as larvae and three to four days as pupae, before the organisms emerge as adults (U.S. EPA, 2000). Dawson et al. (2000) found that a density of 600 eggs per 15 L of aquarium volume provided the maximum egg emergence with a ratio of 7 L of water to 200 mL of sand. These ratios were translated for use with the 3.8 L aquarium that was used to grow organisms from eggs for the waterjet study. The *C. tentans* eggs were obtained from the U.S. Geological Survey Columbia Environmental Research Center (CERC) located in Columbia, Missouri. The sand used in the experiments was an underground silica provided by U.S. Silica (Pacific, Missouri).

Hyalella azteca is an amphipod crustacean that is common throughout the freshwaters of the Americas. Its other names include *H. knickerbocker* and *H. dentata*. These amphipods live in the sediment of lakes, rivers, and streams, and they molt several times throughout their life cycle. Young *H. azteca* are around 1 mm long, and they grow to be 7 mm (Othman & Pascoe, 2000). Temperature affects the growth rate of these amphipods, and cooler temperatures (19 to 21 degrees Celsius) produce lower growth rates, but larger organisms. Warmer temperatures (22 to 24 degrees Celsius) allow for faster growth rates and smaller animals. Seven-day-old *H. azteca* were also obtained from CERC for the waterjet experiments. They were kept in 30 L of untreated groundwater that was maintained at 22 degrees Celsius throughout the experiments.

Each set of experiments included a control group of organisms that was placed in a separate aquarium at the same time that the other organisms were placed in the waterjet testing apparatus.

The method used to assess the mortality rate of the waterjet was the same for each organism. A 5.08 cm layer of sand was placed in the bottom of a 36.5 cm × 20.3 cm × 15.2 cm container and was covered with standing untreated groundwater to a specified height to form the test bed. In each experiment, 20 benthic organisms were added to a test bed and allowed to acclimate for 3 hours. The waterjet with the 0.058 cm nozzle was passed one time along the center of the test bed lengthwise, and the water column was decanted. Following U.S. EPA (2000), the organisms were collected from the decanted water using a #40 U.S. Standard Sieve. Organisms were removed from the sand by spraying gently with water as it passed through the sieve. The organisms collected on the sieve were assessed for mortality using the previously described movement test.

Each set of experiments included a control group of organisms that was placed in a separate aquarium at the same time that the other organisms were placed in the waterjet testing apparatus. At the end of the waterjet experiments, the control groups were counted to evaluate both mortality rate and organism location (water or sand).

Characterization Using Artifacts

Potential waterjet impacts on larger benthic organisms were characterized using empty chicken egg shells, mussel shells (including round pigtoes, paper pondshells, and yellow sandshells) collected from a stream near Rolla, Missouri, food-grade New Zealand green-lipped mussel shells, and food-grade New England Blue Mussel shells. The artifacts were held stationary in the test bed, and the waterjet was passed over each type of artifact at pressures varying from 200 to 2,000 psi using the 0.058 cm nozzle.

Inanimate Surrogate Study

An inanimate surrogate study was conducted to evaluate the effects waterjet delivery would have on less mobile organisms, such as shellfish. Dow Styrofoam$^{\text{TM}}$ 21.3-cm-thick Floral & Craft Edge Trim Extruded Billet, commonly known as craft foam, was cut into 12.7-cm-wide sheets and placed on a layer of sand in the test bed that was used with the *C. tentans* and *H. azteca* testing. The waterjet was passed over the foam at varying pressures, and various water column heights were also evaluated. Two waterjet nozzle diameters were tested: 0.058 cm and 0.066 cm. The depth of the resulting cut into the foam was measured every centimeter and the average depth for each trial was recorded. It was found that the strength of each individual piece of foam varied, so modulus of elasticity was measured for each piece using an Instrong 4469 testing machine.

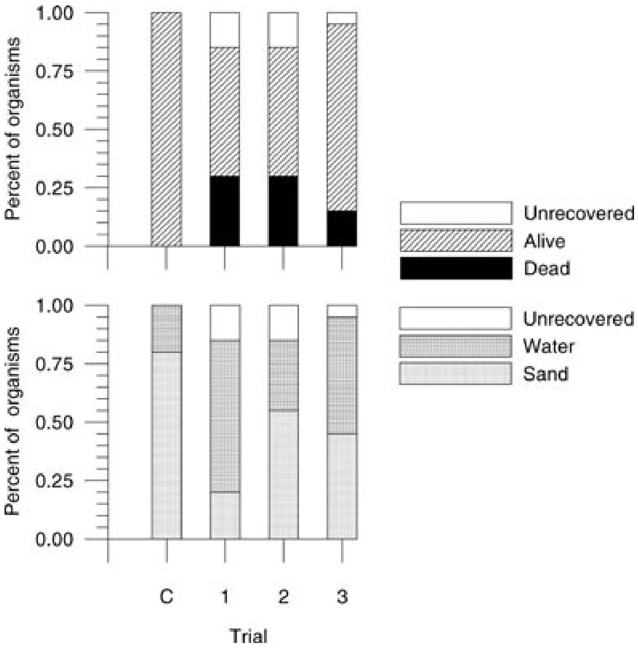

Exhibit 2. *C. tentans* mortality characterization results

RESULTS AND DISCUSSION

Mortality Characterization

The recovery of the subject macroinvertebrates was always 90 percent or higher. This is an acceptable recovery rate for a standard toxicity test according to U.S. EPA (2000). Exhibit 2 shows the results of the *C. tentans* mortality testing. The average survival rate was 63 percent with a 14 percent standard deviation. The coefficient of variation (COV) was 0.23, which indicates that the survival rates were relatively consistent between trials. The survival rate for the control group was 100 percent. The location count results showed that 80 percent of the organisms were found in the sand, which is consistent with the burrowing behavior associated with *C. tentans*. However, the waterjet did displace roughly 20 percent of the burrowed organisms. Approximately 60 percent of the recovered organisms were found in the sand, and the COV of 0.58 indicated that there was moderate variability in the location of the organisms between trials.

The *H. azteca* results are shown in Exhibit 3. The survival rate was high, with an average of 93 percent, and the variability between trials was low, with a COV of 0.031. Unlike *C. tentans*, *H. azteca* prefer the water interface, but the displacement rate was about the same for recovered *H. azteca* organisms at 27 percent with a COV of 0.12. In the control tests for both species, 100 percent of the organisms were recovered alive. *H. azteca* are swimmers and, therefore, had a greater ability to avoid the waterjet's concentrated stream relative to the burrowing *C. tentans*. Although the incremental percent transferred from one media to another was higher for the *H. azteca* than the *C. tentans*, the *H. azteca* experienced a significantly higher survival rate.

There was never more than 5 percent mortality directly after the waterjet was used. The one *H. azteca* found dead immediately after the waterjet was applied to the test bed

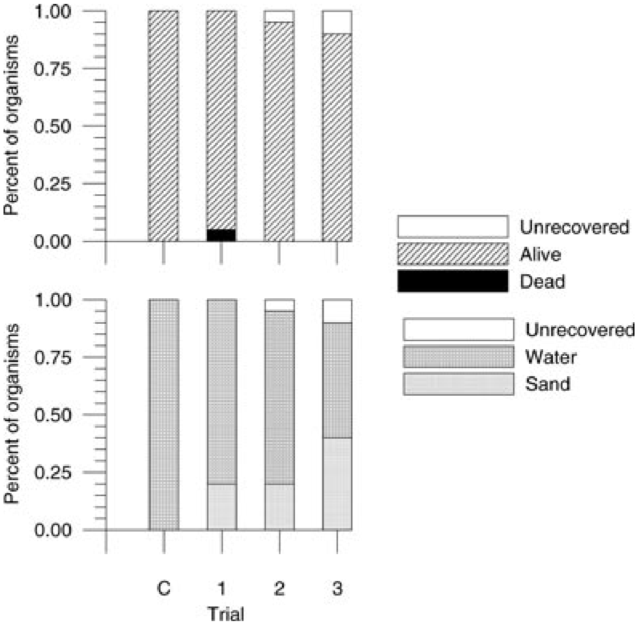

Exhibit 3. *H. azteca* mortality characterization results

did not move under the microscope and, under further examination, it was shown that it had lost its head from the waterjet.

Characterization Using Artifacts

Weathered mussel shells collected from a Missouri Ozarks stream were undamaged when subjected to pressures of 1,500 psi or lower. At 2,000 psi, one of the three paper pondshells cracked and a round pigtoe's periostracum was removed after about 3 seconds of constant waterjet exposure. Empty chicken egg shells were tested as a potential surrogate, but they were too delicate and broke under pressures as low as 500 psi. Cooked New Zealand green-lipped mussel shells were tested, but the maximum pressure failed to damage any of the shells. Fresh raw food-grade New England Blue Mussels were sprayed with the nozzle of the waterjet right above the shell at 2,000 psi, but no detrimental effects were observed. The soft tissue from the mussels was tested raw, and the tissue was physically deformed and blown out of its shell at the minimum pressure tested, 200 psi.

Inanimate Surrogate Study

The compression testing showed that there was significant variability in the strength of the foam sample, and variability was observed between samples originating from a single sheet of foam. The cut depth observed for each sample was divided by the corresponding modulus of elasticity for that sample to account for the varying foam strength. Exhibits 4 and 5 show that there was an approximately linear relationship between the normalized depth of cut and the height of the water column between the waterjet nozzle and the foam.

The equation for the 0.058 cm nozzle best-fit line was $y = -0.00025x + 0.00044$ while the larger 0.066 cm nozzle had a flatter slope with $y = -0.00016x + 0.00024$. The goodness-of-fit was approximately the same for both nozzles. The larger-diameter

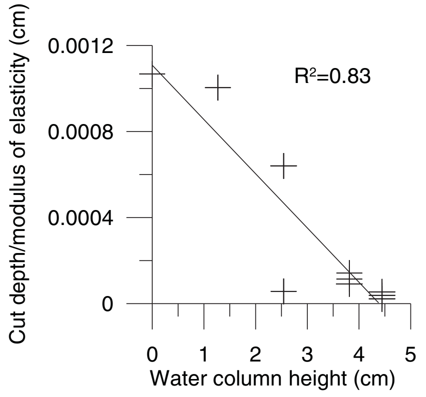

Exhibit 4. Surrogate study results for 0.058-cm-diameter waterjet nozzle

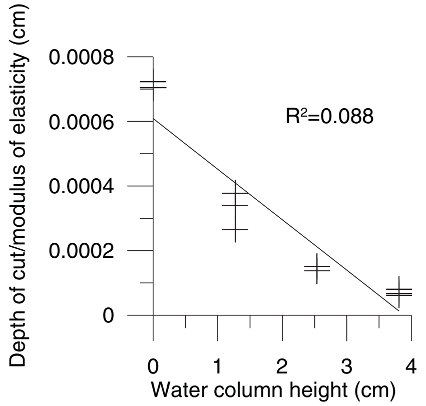

Exhibit 5. Surrogate study results for the 0.066-cm-diameter waterjet nozzle

nozzle created a smaller cut depth relative to the smaller-diameter nozzle, and the difference in cut depths increased with increasing water column height as indicated by the difference in the slope values for the best-fit lines. For example, at a water column height of 1.3 centimeters, the normalized depth of cut for the 0.058 cm nozzle was twice the normalized cut depth for the 0.066 cm nozzle. However, with 2.6 cm of water between the nozzle discharge and the foam, the 0.058 cm nozzle normalized cut depth was 2.4 times the normalized cut depth for the 0.066 cm nozzle. This phenomenon can be conceptualized by evaluating the volume of water displaced by the waterjet. If the waterjet is assumed to be cylindrical between the nozzle and the foam, the displaced volume increases as the cylinder height (distance between the nozzle and the foam) increases and as the cylinder diameter (waterjet nozzle diameter) increases.

CONCLUSIONS

The work examined in this article presents preliminary results regarding the potential impact of waterjets on organisms living in the benthic community. Both swimming and burrowing organisms were evaluated using tests that were developed from standard toxicity tests. Waterjets similar to those that would be reasonable to use to deliver an amendment to contaminated sediments were used in the testing, and the results indicated that the survival rates for both organisms immediately after being exposed to the waterjet were greater than 50 percent. This means that there is a good chance that repopulation will occur relatively rapidly for these benthic organisms. It is reasonable to assume that *C. tentans* eggs, larvae, and pupae would have survival rates on the order of the 63 percent survival rate characterized for adults in this study, and that repopulation would be complete in a single 40-day cycle. A similar argument can be made for *H. azteca*, which had a 93 percent survival rate in this study. This organism takes approximately 100 days to go from hatched egg to a sexually mature adult. The literature review showed that others have characterized that the toxicity associated with activated carbon amendments is relatively low, and that mechanical-mixing mortality is also generally acceptable after there has been the potential for repopulation over a period of months. However, this study shows that immediate survivability after waterjetting is relatively high. The artifacts testing also showed that there was little potential that the waterjet would cause physical damage to a shellfish unless an open shell was struck. It is difficult to predict how this information would correlate to mortality rates, but it provides a point of comparison for future studies. Likewise, the systemic characterization of depth of cut as a function of the height of the water column between the waterjet and the target provides basic information for researchers who are interested in characterizing the effect of waterjets on benthic organism mortality.

Finally, this work establishes the motivation for further evaluation of the use of waterjets to place amendments in contaminated saturated sediments because it indicates that survivability rates are acceptable relative to application by rotovator. Future waterjet work may address field-scale characterization of mixing effectiveness, resuspension potential, technical feasibility, and cost.

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REFERENCES

Carbines, G., & Cole, R. G. (2009). Using a remote drift underwater video to examine dredge impacts on demersal fishes and benthic habitat complexities in Foveaux Strait, Southern New Zealand. Fisheries Research, 96, 230–237.

Cornelissen, G. Gustafsson, Ö., Bucheli, T. D., Jonker, M. T. O., Koelmans, A. A., & van Noort, P. C. M. (2005). Extensive sorption of organic compounds to black carbon, coal, and kerogen in sediments and soils: Mechanisms and consequences for distribution, bioaccumulation, and biodegradation. Environmental Science & Technology, 39(18), 6881–6895.

Cho, Y.-M., Ghosh, U., Kennedy, A. J., Grossman, A., Ray, G., Tomaszewski, J. E., & Smithenry, D. W. (2009). Field application of activated carbon amendment for in-situ stabilization of polychlorinated biphenyls in marine sediment. Environmental Science & Technology, 43, 3815–3823.

Cho, Y.-M., Smithenry, D. W., Ghosh, U., Kennedy, A. J., Milward, R.N., Bridges, T. S., & Luthy, R. G. (2007). Field methods for amending marine sediment with activated carbon and assessing treatment effectiveness. Marine Environmental Research, 64, 541–555.

Cornelissen, G., Breedveld, G. D., Naes, K., Oen, A. M. P., & Ruus, A. (2006). Bioaccumulation of native polycyclic aromatic hydrocarbons from sediment by a polychaete and a gastropod: Freely dissolved concentrations and activated carbon amendment. Environmental Toxicology & Chemistry, 25, 2349–2355.

Dawson, T. D., Jenson, J. J., & Norberg-King, T. J. (2000). Laboratory culture of Chironomus tentans for use in toxicity testing: Optimum initial egg-stocking densities. Hydrobiologia, 439, 251–256.

Ghosh, U., Luthy, R. G., Cornelissen, G., Werner, D., & Menzie, C. A. (2011). In-situ sorbent amendments: A new direction in contaminated sediment management. Environmental Science & Technology, 45(4), 1163–1168.

Jonker, M. T. O., Hoenderboom, A. M., & Koelmans, A. A. (2004). Effects of sedimentary soot-like materials on sorption and bioaccumulation of polychlorinated biphenyls. Environmental Toxicology & Chemistry, 23, 2563–2570.

Jonker, M. T. O., Suijkerbuijk, M. P. W., Schmitt, H., & Sinnige, T. (2009). Ecotoxicological effects of activated carbon addition to sediments. Environmental Science & Technology 43, 5959–5966.

Knox A. S., Kaplan, D. I., & Paller, M. H. (2006). Natural phosphate sources and their suitability for remediation of contaminated media. Science of the Total Environment, 357, 271–9.

Millward, R. N., Bridges, T. S., Ghosh, U., Zimmerman, J. R., & Luthy, R. G. (2005). Addition of activated carbon to sediments to reduce PCB bioaccumulation by a polychaete (*Neanthes arenaceodentata*) and an amphipod (*Leptocheirus plumulosus*). Environmental Science & Technology, 39(8), 2880–2887.

Othamn, M. S., & Pascoe, D. (2001). Growth, development and reproduction of Hyalella azteca (Saussure, 1858) in laboratory culture. Crustaceana, 74(2), 171–181.

Palermo, M., Maynord, S., Miller, J., & Reible, D. (1998). Guidance for in-situ subaqueous capping of contaminated sediments. EPA 905-B96-004. Great Lakes National Program Office.

Perron, M. M., Burgess, R. M., Kay, T. H. O., Pelletier, M. C., Cantwell, M. G., & Shine, J. P. (2010). Bioavailability assessment of contaminated field sediment from Patrick Bayou, Texas, USA: Toxicity identification evaluation and equilibrium partitioning. Environmental Toxicology & Chemistry, 29, 742–750.

Qian, P. Y., Qiu, J. W., Kennish, R., & Reid, C. A. (2003). Recolonization of benthic infauna subsequent to capping of contaminated dredged material in East Sha Chau, Hong Kong. Estuarine Coastal and Shelf Science, 56, 819–831.

Reible, D. D., Lampert, D., Constant, W. D., Mutch, R. D., Zhu, Y. (2006). Active capping demonstration in the Anacostia River, Washington, DC. Remediation, 17(1), 39–53.

Samuelson, A. V., Carr, C. E., & Ruvkun, G. (2007). Gene activities that mediate increased life span of *C. elegans* insulin-like signaling mutants. Genes & Development. 22, 2976–2994.

U.S. Environmental Protection Agency. (2000). Methods for measuring the toxicity and bioaccumulation of sediment associated contaminants with freshwater invertebrates (2nd ed.). EPA document No. 600-R-99-064. Office of Research and Development Mid-Continental Ecology Division. Duluth, Minnesota.

U.S. Environmental Protection Agency. (2004). The incidence and severity of sediment contamination in surface waters of the United States: National sediment quality survey (2nd ed.). EPA document No. 823-R-04-007. Washington, DC.

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