Review of
Toxics Removal and Remediation Technologies

Department of Environmental Quality
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Executive Summary

Section 62.1-44.17:4 of the Code of Virginia directs the Department of Environmental Quality (DEQ) to review and report every five years to the General Assembly on any recent developments in new technologies for in-stream removal or remediation of toxic contamination that would cause DEQ to change any current strategies for dealing with contaminated waterbodies.

Efforts to remediate toxic contamination of waterbodies primarily focus on identification of active sources of the contaminant and elimination or control of those sources to reduce the input of the contaminant before the pollution can enter the waterbody. Once toxic contaminants are released into the aquatic environment, the chemicals become diluted in the water column and it is impractical to remove them from the entire volume of water; also, many toxic pollutants rapidly settle out of the water and end up in the sediment. In cases where control of on-shore sources of the toxic pollutant is insufficient to restore the waterbody and contaminated sediments in a waterbody are a significant continuing source of the toxic pollutant, instream remediation efforts must focus on the contaminated sediments.

Available options for dealing with contaminated sediments include:

1. Removal of the contaminated sediments - divert the stream channel away from the contaminated area, isolate the contaminated sediments from the waterbody by using dikes or casements, or dredge.

2. Monitor natural attenuation and recovery - the contaminated sediment is left in place and natural sedimentation processes are allowed to cover it with clean sediments. This isolates the toxic contamination from the water column and the aquatic life, reducing or eliminating the potential risk of toxic effects or bioaccumulation. This option involves periodic monitoring to ensure burial of the contaminated sediment progresses as expected.

3. Treatment of the contaminated sediments while they remain in place (in-situ) in the waterbody - capping the contaminated sediment with clean sediment or other materials; addition of materials (such as cement) to stabilize the sediment; and chemical or biological treatment methods.

More innovative technologies in natural water bodies such as in-situ chemical additions or bioremediation are generally not effective due to: problems with uneven distribution in the sediment of chemicals or biological material added to treat the contamination; sub-optimal temperature or anoxic conditions; and the variability of natural environmental conditions. In addition, these innovative treatment technologies are not commercially available or dependable for use in the field at the present time, especially in cases where the sediment contamination covers extensive areas.

In cases where a waterbody is impaired due to toxic contamination, DEQ, as a first step in remediation of the waterbody, routinely investigates the waterbody for active sources of input of the contaminant of concern. This effort is intended to identify the sources of the contaminant and to establish remediation goals through a Total Maximum Daily Load (TMDL) to bring the contamination under control and restore the waterbody. Control of on-shore sources of toxic pollutants to the water column is addressed by a variety of DEQ programs beginning with permits under the Virginia Pollutant Discharge Elimination System. When a TMDL study indicates the sediments are a significant source of the pollutant, an investigation of available treatment technologies is conducted as part of the course of action. In this manner, any new or innovative treatment methods to treat the contaminant will be identified and considered by DEQ as part of this process.

DEQ did not identify any new technology for treating contaminated sediment in-situ that was considered reliable or practical at the present time nor did it find sufficient developments in new or innovative remediation technologies to justify changes in any previous Board agreements. At this time, the DEQ will continue to rely upon source control as a primary mode of action for toxic remediation. In cases where contaminated sediments have been identified as a concern, the current DEQ Toxics Contamination Source Assessment Policy and the Total Maximum Daily Load process are adequate for investigating and identifying practical methods for remediating the sediment at each contaminated site.

REVIEW of TOXICS REMEDIATION TECHNOLOGY

I. Background

The General Assembly directed the Department of Environmental Quality (DEQ) to review and report every five years on any recent developments in new technologies for in-stream remediation of toxic contamination. The Code of Virginia section 62.1-44.17:4. Evaluation of toxics removal and remediation technology states that "The Board shall conduct a review of in-stream toxics removal or remediation technologies, a minimum of once every five years, to determine whether (i) new technologies for responding to toxic contamination will necessitate any changes in the selection of removal or remediation strategies previously included as provisions of Board agreements and (ii) any of the Department of Environmental Quality's current strategies for responding to toxic contamination need to be revised. (2000, cc.17, 1043.)".

This 2007 report has been prepared to provide the status of toxic remediation technologies and whether there is a need to revise any of the strategies currently being deployed by DEQ in response to water bodies contaminated with toxic chemicals. As a first step DEQ investigated work that was still underway at the time of the first report to the General Assembly in 2002. The 2002 report concluded that source controls should be the main mode of action for remediation of toxic pollution, along with investigations of sediment remediation technologies. That report also noted DEQ was working with an interstate workgroup investigating remediation options for contaminated sediments. However, the interstate workgroup did not identify any new practical treatment method for contaminated sediment.

When toxic chemicals are released into a natural waterbody, many toxic pollutants settle out into the sediment and become highly diluted in the water column which makes removal of the contaminants in the water column very difficult or impossible. In-stream treatment for removal of very low concentrations of toxic chemicals from the water column would require waste treatment of the entire volume of the waterbody which becomes impractical. In the various materials reviewed for this report, DEQ did not find any case where treatment of the entire water body was recommended or any technology was considered practical for treating large volumes of water contaminated with very low levels of toxic contaminants.

The most practical approach to dealing with toxic contamination of waterbodies is the identification and control of any active sources of the contamination, thus preventing the pollution from entering the waterbody in the first place. Many toxic pollutants, especially those that bioaccumulate in fish and pose the greatest risk to human consumers, are not very soluble in water and are found in very low concentrations in the water column, but these chemicals are more often found in sediments. In water bodies where contaminated sediment is an ongoing source of the contamination, all available options for removing or reducing exposure of the aquatic life to the contamination must be considered. The available options involve either removal of the sediments from the waterbody, or remediation of contaminated sediments.

DEQ reviewed recent reports and studies identified by using web sites maintained by the US Environmental Protection Agency (EPA), the National Academy of Sciences (NAS), the US Army Corp of Engineers, the National Oceanic and Atmospheric Administration (NOAA), the Interstate Technology and Regulatory Council (ITRC), the Minnesota Pollution Control Agency - Contaminated Sediments, Wisconsin's Contaminated Sediment Program, Los Angeles Basin Contaminated Sediments Task Force, Washington Department of Ecology Sediment Management Program , Environment Canada (Sediments), as well as internet searches and several other sources. Special focus was placed on reports on new or innovative treatment methods for treating toxic contaminants in sediment while the sediments remain in place in the water body, referred to as in-situ (in place) treatment, as this corresponds to the intent of §62.1-44.17:4 to investigate "in-stream toxics removal or remediation technologies".

Waterbodies contaminated by toxic pollutants could pose potential risks to human health due to two potential exposure pathways: via drinking the contaminated water or by eating fish that have bioaccumulated the toxic chemical from the waterbody. The potential risk via direct ingestion of the water is low because many toxic pollutants are not very soluble in water and rarely approach concentrations that could pose a risk to the consumer by direct ingestion of water. Also, municipal drinking water is treated to remove toxic pollutants and provide drinking water that meets all necessary standards; so consumers of municipal drinking water are assured of a safe product. However, many toxic pollutants have the potential for being accumulated by fish that live in a contaminated waterbody. Often the fish may contain thousands of times higher concentrations of the toxic pollutant than what is found in the water itself. The fish are exposed to the contaminant in the water, in the sediment and in the insects and other fish that they consume in the contaminated waterbody. The vast majority of the waterbodies classified as impaired due to concerns for potential risks to human health are due to contaminated fish. Since much of the concern involving potential risks to human health due to toxic contaminants are from the potential risk of consumption of contaminated fish, this was one of the main topics investigated. With the exception of one old advisory for kepone, all of the fish consumption advisories issued by the Virginia Department of Health are due to contamination by two toxic contaminants, polychlorinated biphenyls (PCBs) or mercury, so particular attention was placed on investigating any recent innovations in remediation technologies involved with these pollutants.

II. Prevention and Restoration Approaches

The management of toxic pollution of aquatic ecosystems has traditionally focused on contaminants dissolved in the water column. DEQ implements the Virginia Pollutant Discharge Elimination System (VPDES) which is designed to control direct discharges of toxic pollutants into Virginia's water bodies. A goal of the VPDES program is to prevent direct toxic effects to aquatic life and the bioaccumulation of the toxicant in fish tissue to levels that could pose a risk to human consumers. These control strategies are aimed at treatment and removal of toxic contaminants before they can be released into the aquatic environment and while the contaminants are still relatively concentrated in the wastewater and are more efficiently treated. Once toxic pollutants have entered the aquatic environment, they often become trapped in bottom sediments and can be a

continuing source of the contaminant which can dissolve back into the water column where it can cause toxic effects, or the toxic contaminant can affect aquatic life living in the sediment.

Once a waterbody is classified as impaired due to contamination by toxic pollutants, DEQ begins a process of identifying the sources of the contamination and then initiates the development of a Total Maximum Daily Load (TMDL) to control the sources of the pollution and try to alleviate the contamination to an acceptable level. In this way, each contaminated waterbody is investigated to identify the causes of the pollution and all options for remediation are identified and considered before determining the most effective course of action for any particular site.

To addresses remediation of waterbodies impaired due to PCB contamination, the DEQ developed a PCB Strategy which can be found at **http://www.deq.virginia.gov/fishtissue/pcbstrategy.html.** This PCB Strategy integrates the agency's Toxics Contamination Source Assessment Policy with the requirements of the Total Maximum Daly Load program. A similar approach can be taken for other toxic contaminants, with some modifications based on the specific toxic contaminant involved. In this approach emphasis is placed on identification and control of all active sources of the pollutant to the water body, including identification of hot spots of contaminated soil and sediments.

III. Removal Methods Currently Considered

Although not technically an in-stream technology, removal is one of the standard options considered for remediation of contaminated sediments. Available methods regularly considered by DEQ include the following:

A. Wet Dredging: Wet dredging refers to the excavation of sediment from a waterway. Removed sediment will require subsequent management and disposal. Benefits include the fact that it permanently removes contaminated sediment from the aquatic environment. Disadvantages include the possibility of spreading the contamination to other areas of the waterbody during dredging operations, disturbance to the benthic habitat, the cost of removal and the need to properly treat and dispose of the contaminated sediment. One of the largest dredging operations being undertaken is in the Hudson River in New York to remove PCBs from known hot spots in the sediment.

B. Dry Excavations: Dry excavation refers to the removal of sediment following significant dewatering in conjunction with diversion of a surface water body. The removed sediment requires subsequent management and disposal. Typical process options include area dewatering, construction of casements or cofferdams, and bypass pumping/siphoning. Benefits include the permanent removal of the contaminated sediment from the aquatic environment. In some cases, where the contaminated sediment is located near-shore and in shallow water, this can be a practical approach. Disadvantages include: not practical in some situations such as deeper waters,

disturbance to the benthic habitat, possibility of spreading the contamination further, the cost of removal and the need to properly treat and dispose of the contaminated sediment.

C. Hydraulic Modifications: Hydraulic modification refers to the physical alteration of an existing waterbody to help control the movement/release of contaminated sediments and/or promote deposition of clean sediments. Typical process options include rechannelization, damming, sediment basins, and subsurface structures.

IV. In-Situ Methods Currently Considered

In-situ remediation of contaminated sediments refers to methods used to reduce risks to human health and the environment from toxic contaminants in sediments when the sediments are left in-situ in the waterbody. Methods considered by DEQ for in-situ remediation of contaminated sediment that have proven to be effective can be divided into several general categories: natural attenuation and recovery, capping the contaminated sediment with clean sediment or other materials, addition of materials (such as cement) to stabilize the sediment, or other means of isolating the contamination from the aquatic biota.

A. Natural Attenuation and Recovery: Natural attenuation involves leaving the sediments in place and allowing natural processes such as dispersion, burial, chemical degradation, or microbial degradation to operate to reduce the risk posed by the contamination. This is complimented with a monitoring program to measure and document the expected reduction in risk over time. If expected recovery is not demonstrated by the monitoring effort, other alternatives are then considered.

U.S. EPA recognizes monitored natural attenuation and recovery as an appropriate option that can be selected on a case-by-case basis if leaving sediments in place poses lower risks to the environment than removal. Long-term biological and chemical monitoring should be established to measure any change in contaminant levels over time. Natural attenuation and recovery can be "enhanced" by the addition of a thin layer of clean sediment over the contaminated area. Placement of a thin layer (several inches) of clean material will help to mitigate chemical flux to the water column and enhance natural attenuation process.

An example of the use of monitored natural attenuation and recovery in Virginia is the contamination of the lower James River by the pesticide kepone in the mid 1970s. This resulted in elevated levels of kepone detected in many species of fish in this waterbody and a fish consumption advisory affecting the James River from Richmond to its mouth. Of the several options that were considered for addressing this contamination, monitored natural attenuation and recovery was selected. Over time, the contaminated sediment has been covered with relatively clean sediment. Continued monitoring of the concentrations of kepone in the fish in the river showed that after twenty years the levels of kepone in fish have dropped to below the level of concern used by the Virginia Department of Health.

B. Capping: Capping technologies are applicable for both organic compounds (i.e. PCBs) and for metals and metalloids (i.e. mercury). Capping involves covering the contaminated sediment with clean material such as sediment, clay, sand or gravel, or even woven synthetic fabric, or a combination of these layers. This technique buries the contamination to a depth where it is no longer likely to come in contact with aquatic life that live or burrow into the sediment. In-situ capping can be a relatively effective and economical alternative at sites that are not subject to navigational dredging and the stability of the cap can be assured. Capping remedies, as both a stand-alone remedy and in combination with other remedial approaches, have been successfully implemented at a number of sites both in the United States and worldwide.

Similar to capping, stabilization methods involve adding cements or chemicals to help stabilize or solidify the sediment and reduce the ability of the toxic components in the sediment to become dissolved into the water column, or to prevent aquatic organisms from burrowing into the sediment and becoming contaminated or redistributing and resuspending the contaminated sediment. Although this is similar to the process of capping with clean sediments, in theory, stabilization will encapsulate the contaminated sediments in a more stable and more permanent form.

C. Confined Aquatic Disposal (CAD) and Confined Disposal Facility (CDF): Confined Aquatic Disposal (CAD) is the process where contaminated sediment is dredged, moved and re-deposited at another in-water site and covered over with a cap of clean material to isolate the contaminants from the waterbody. If carefully engineered and completed, CADs can isolate the contaminants from the aquatic environment and remediate the site.

A Confined Disposal Facility (CDF) is a near-shore or on-shore disposal area where the dredged sediments are placed for disposal or remediation. The CDF is separated from the waterbody by dikes or some other isolating barriers, or on-shore excavated pits are used as receptacles for the dredged material. CDFs are sometimes temporarily used as disposal areas near the waterbody until final remediation treatment or removal can be accomplished.

V. Review of In-Situ Remediation Methods and Technologies

DEQ reviewed the current literature and remediation guidelines to determine if any methods, other than those discussed above, had recently been developed and shown to be effective for in-situ remediation of contaminated sediments. A variety of innovative treatment technologies have been proposed in recent years as possible methods for treating toxic contaminated sediments in-situ. Most of these involve the addition of chemicals or biological microbes that will enhance the breakdown and degradation of the toxic pollutant without removing the sediment from the waterbody. However, technical limitations have been encountered when these treatment methods have been applied under actual field conditions.

Chemical or biological treatment methods involve adding chemicals or microorganisms to the sediment to enhance the breakdown or conversion of the toxic pollutants into less toxic or less bio-available forms. While there has been considerable interest in the potential for these types of treatments, at this time these do not appear to be practical treatment methods in most large scale sediment remediation scenarios. For instance, these types of treatments were not selected in either of the two most studied PCB-sediment contamination superfund sites (the Hudson River, NY and the Fox River, WI). Although several innovative proposals for in-stream treatment of the contaminated sediment were considered in these rivers, ultimately none of these alternatives were considered practical. Several issues prevent these methods from being practical for in-stream treatments due to limitations which include the following:

- In order to be effective, the added chemical or biological agents have to be uniformly mixed with the contaminated sediments. This is difficult to do in a natural setting and often involve the risks of re-suspension of the contaminants into the water column and redistribution of the contaminated sediments to other sections of the water body.

- Biological agents (bacteria that can breakdown the toxic chemical into a less toxic form) are limited in their ability to perform efficiently in the often anaerobic sediments.

DEQ participated in an Interstate Technology and Regulatory Council (ITRC) "Contaminated Sediment" Work Group which produced a final draft document, *Overview of Contaminated Sediments (March 2005)*. This document provides summary information on the state of the science regarding methods currently available or under development for the treatment and remediation of contaminated sediments. This ITRC report offers caution on in-situ treatment and management. In particular, the report concludes that the primary remediation used to date for in situ sediments has been long-term management with capping. The report indicates that most in-situ treatment methods are still in the evaluation / pilot testing phase.

In-situ bioremediation is of limited effectiveness due to the complexity of the sediment-water ecosystem. The report concludes that the best prospects for successful bioremediation of sediments are ex-situ engineered treatment systems in which environmental conditions can be carefully controlled and adjusted as the biotransformation processes progress with time where engineered treatment systems are used to carefully control environmental conditions.

EPA, in their report, *Treatment Technologies for Mercury in Soil, Waste, and Water* (August 2007), noted that several potential treatments are under development and several pilot applications of the more promising technologies are being conducted. However, they indicate there are significant technical limitations for many of the treatment technologies and that most techniques for in-situ treatment of sediment are in the early stages of development, and few methods are currently commercially available. EPA did identify four potentially

promising studies underway involving innovative remediation technologies. DEQ further investigated these studies and determined two of the studies were for phytoremediation of dredged sediment removed from the waterbody and planted with vegetation such as corn and therefore not pertinent to treatment of in-place sediments in river bottoms. A third study involving electrochemical oxidation of metals and organic chemicals was unsuccessful in reducing the concentrations of the toxic chemicals.

For the fourth study, a final report is currently under preparation on multiple reactive caps to treat metals, PCBs and other organic chemicals for a site in the Anacostia River, in Washington D.C. This study tests the effectiveness of several different capping technologies on sediment, including Aquablock, rock/gravel with a clay cap, addition of activated carbon, organo-modified clay, ambersorb, XAP-2, and coke. Once this study is completed, it may provide useful information on the effectiveness of various capping techniques in sequestering different classes of contaminants.

EPA's website on the Great Lakes Contaminated Sediments provides a document on cleaning up contaminated sediments. This document describes the various options available for dealing with contaminated sediment including "non-removal technologies" which equates to in-stream treatment and remediation technologies. The guidance and recommendations supplied by EPA regarding the sediment contamination at sites in the Great Lakes are comparable with general guidance for other sites; the basic recommended methods of dealing with contaminated sediment involve removal or capping methods, and innovative in-situ treatment technologies are still in the developmental stages at the present time

Overall, in the numerous studies reviewed involving innovative chemical or bioremediation methods for in-situ treatment of contaminated sediments, significant issues prevented the use of in-situ bioremediation from being considered. These treatments proved unreliable under field conditions for a variety of reasons, mostly due to problems with ensuring the added material was distributed evenly, sub-optimal temperature, anoxic conditions as well as other factors inherent to variability of natural environmental conditions.

VI. Conclusion

Section 62.1-44.17:4 of the Code addresses two questions: (1) do any of the current DEQ strategies for responding to toxic contamination need to be revised and (2) do new technologies for responding to toxic contamination necessitate changes in the selection of removal or remediation strategies previously included as provisions of Board agreements?

At this time, the DEQ will continue to rely upon source control as a main mode of action for toxic remediation and will carefully investigate on a site specific basis in-situ remediation technologies in cases where sediment contamination proves to be a significant source of the contamination and cause of the impairment. Once a water body

is designated as impaired and scheduled for the development of a Total Maximum Daily Load to restore its beneficial use, all sources of the contaminant are assessed and identified. If sediment is a significant source of the contaminant, methods are investigated for remediating the sediment. In this process, on a site-specific basis, all potential remediation options are investigated and considered, including any new or developing treatment technologies that may have become available recently. In this way DEQ will continue to consider all potential options for remediation, including any new, innovative treatment technologies. However, at this time DEQ has not found sufficient advances in new or innovative remediation technologies to justify changes to any previous Board agreements.