FEASABILITY OF LAND FARMING DREDGE SEDIMENTS FROM THE CHESAPEAKE BAY BASED ON A HUMAN HEALTH RISK ASSESSEMENT

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ABSTRACT

Risk assessment techniques were used to determine if land farming can be used safely to dispose of dredge sediments from shipping channel maintenance. These methods estimate the health implications of human exposure to a range of chemicals. In this project, data from chemical analysis of sediments were obtained from the Environmental Protection Agency's Chesapeake Bay Program and the open literature. This data was used to simulate land farming of dredged sediments for a typical plow depth. Existing soil chemical data was assumed to be equivalent to the state of Maryland's published background values. Sediment loading rates were determined for the maximum recommended nitrogen fertilizer additions in the Maryland Nutrient Management Program using a yield goal of 100 bu/ac grain corn. Risk was assessed for both residential and agricultural scenarios. The parameters and assumptions used were commonly used default values for a residential use and reasonable estimates for the agricultural scenario.

RÉSUMÉ

Des techniques d'évaluation des risques ont été employées pour déterminer si l'épendage agricole peut être employé sans risque pour se débarasser des sédiments de dragage de l'entretien de canal de navigation. Ces méthodes estiment les implications de santé de l'exposition humaine à une gamme de produits chimiques. Dans ce projet, des données d'analyses chimiques des sédiments ont été obtenues à partir du programme de Chesapeake Bay de la Environmental Protection Agency et de la littérature. Ces données ont été employées pour simuler l'épendage agricole des sédiments dragués pour une profondeur typique de charrue. On a assumé que les données chimiques des sols existants sont équivalentes aux valeurs de fond établies par l'état du Maryland. Des taux de chargement de sédiment ont été déterminés pour l'addition maximale recommandée d'engrais d'azote dans le Maryland Nutrient Management Program en utilisant un but de rendement de maïs de grain de 100 bu/ac. Le risque a été évalué pour les scénarios résidentiels et agricoles. Les paramètres et les hypothèses utilisées étaient généralement pour des valeurs par défaut d'usage résidentiel et des estimations raisonnables pour le scénario agricole.

1. INTRODUCTION

In 1608, Captain John Smith explored the Chesapeake Bay area and found an estuarine environment teeming with life. The water was clear enough to easily see the bottom in much of the bay showing a meadow of underwater grasses. The descriptions of his findings were so detailed that they are the standard used by the Chesapeake Bay Foundation to gauge the ecological health of the bay.

On a global scale, the Chesapeake Bay is considered large, in fact, the largest estuary in the world. Disregarding the tributaries, the Chesapeake Bay proper lies entirely within the states of Maryland and Virginia. It varies from 4 miles wide at Annapolis, MD to 30 miles wide at Smith Point, VA. It is 195 miles in length, from the mouth of the Susquehanna River to the southern end at Hampton Roads, VA.

For its size, the bay is shallow, averaging only 22 feet deep. While holes and channels are significantly deeper, it is the shallow parts that are important because they allow sunlight to reach bottom plant life and helps the estuary to stay relatively warm.

Impacts to the bay are also derived from the vast area contained in its watershed. Rain that falls over a 64000 square-mile area drains to the bay. The headwaters of the bay are in Otsego Lake in Cooperstown, NY where the Susquehanna River begins. Put fertilizer on your yard or fail to control erosion in Elmira, NY and it will eventually end up in the Chesapeake Bay. (www.sherpaguides.com/Chesapeake_bay/natural_history)

According to the USEPA Chesapeake Bay Program, which tracks the quality of the bay, the quality of the bay in the year 2000 was estimated at 28 (with the Chesapeake Bay that Captain John Smith described as being 100). This is barely more than one-quarter of its potential. This low estimate is primarily due to nutrient and sediment pollution reducing the survivability of the underwater grasses. Removal of sediments from specific areas of the bay is one method of improving water quality in both of these factors. Dredging has been identified as one of the most expedient methods of removing significant amounts of both sediment and nutrients from the bay if safe alternatives can be found for using the dredged material.

In this paper we present an evaluation technique to determine if land farming can be used as a beneficial end use of Chesapeake Bay sediment. We will start by determining how much sediment can be incorporated into the plow layer using the Nutrient Management Protocol used in the Maryland Department of Agriculture. Then health effects will be estimated using a risk assessment protocol used to determine the safety of human exposure to areas contaminated with industrial pollution.

2. METHODOLOGY

2.1 Nutrient Management Plans.

Concerns regarding declining water quality in the Bay and its tributaries led in 1976 to a 6-year study of water quality in the Bay. About 40 research projects, coordinated by the U.S. Environmental Protection Agency (EPA), documented declining water quality and reduction in the numbers and diversity of fish, shellfish and submerged aquatic vegetation (SAV). Eutrophication and turbidity caused by soil sediments and an increase in plant nutrient inputs were considered to be the main causes of these changes. Nutrient reduction was therefore considered to be the major factor in improving habitat for benthic organisms and fish by reducing algal blooms and increasing light penetration to SAV. In 1987 the Chesapeake Bay Agreement was signed by the states of Maryland, Virginia, Pennsylvania, the District of Columbia, as well as by the EPA and the Chesapeake Bay Commission adopting a 40% nutrient reduction goal by the year 2000. One option identified as being able to play a major role in the reduction of nutrients from agricultural non-point sources is nutrient management planning.

Nutrient management planning is a series of best management practices (BMPs) aimed at reducing nutrient pollution by balancing nutrient inputs with crop nutrient requirements. Nutrient management plans are documents, which incorporate soil test results, yield goals and estimates of residual nitrogen to generate field-by-field nutrient recommendations. The current effort makes several assumptions:

- the field will be used for conventionally tilled field corn;
- the yield goal is set at 100 bushels/acre;
- nutrient recommendations are nitrogen-based;
- anthropogenic pollutant concentrations are as defined by the Maryland Department of the Environment.

2.2 Focused Risk Assessment Method.

As the title implies, a focused risk assessment is performed to evaluate the health implications from a specific suspected source or affected receptor type. This focused risk assessment provides an understanding of the potential threats that may be posed by exposure to chemicals in dredged sediment used for land farming.

The risk assessment will follow the same methods used for baseline risk assessments at USEPA hazardous waste sites with the exceptions that the evaluation will be limited to those risks involving the direct contact with the soil.

A risk assessment contains four major subsections, as follows:

- Identification of Chemicals of Concern
- Exposure Assessment
- Toxicity Assessment
- Risk Characterization

2.2.1 Identification of chemicals of concern

Data obtained through the literature were evaluated for suitability of use in the risk assessment as discussed in Risk Assessment Guidance for Superfund (EPA, 1989a). Data suitability was based on quantitation limits, qualifiers, and blank chemical concentrations. The Upper 95th confidence limit concentration for each chemical in the database was used as the exposure point concentration. Analysis of analytical blanks were used to evaluate whether the chemicals in the site data set resulted from the analysis and were not related to site activities. Chemicals that are retained for further evaluation are referred to as chemicals of potential concern (COPC).

2.2.2 Exposure assessment

The objective of the exposure assessment is to estimate the type and magnitude of exposures to the COPC at the site. The exposure assessment consists of three steps (EPA, 1989a):

(a) **Characterize Exposure Setting:** This is general information concerning the physical characteristics of the site as it pertains to potential considerations affecting exposure. The physical setting involves climate and vegetation. All potentially exposed populations and subpopulations (receptors) are assessed relative to their potential for exposure.

(b) **Identify Exposure Pathways:** Exposure points of human contact and exposure routes for this study consist of the incidental ingestion of soil and fugitive dust by a current site worker (agricultural) and a future residential receptor.

(c) **Quantify Exposure:** In this final process, the exposure levels (COPC intakes) are calculated for each exposure pathway and receptor. The equation for intake is as follows (EPA 1989a):

$$\textbf{Intake (mg/kg-day)} = \frac{\underline{\textbf{CS x IR x CF x EF x ED}}}{\textbf{BW x AT}}$$

Where:
CS = Chemical Concentration in Soil (mg/kg)
IR = Ingestion Rate (mg soil/day)
CF = Conversion Factor (1 Kg/10^6 mg)
EF = Exposure Frequency (days/years)
ED = Exposure Duration (years)
BW = Body Weight (kg)
AT = Averaging Time (period over which exposure is averaged -- days)

2.2.3 Toxicity assessment

The objective of the toxicity assessment is to weigh available evidence regarding the potential of the chemicals to cause adverse effects in exposed individuals, and to provide, where possible, an estimate of the relationship between the extent of exposure to a chemical and the increased likelihood and/or severity of adverse effects. The types of toxicity information considered in this assessment include the reference dose (RfD) used to evaluate noncarcinogenic effects, and the slope factor or unit risk to evaluate carcinogenic potential. Most toxicity information used in this evaluation was obtained from the Integrated Risk Information System (IRIS). If values were not available from IRIS, the *Health Effects Assessment Summary Tables* (HEAST) (EPA, 1993b) were consulted.

(a) Noncarcinogenic Effects

For chemicals that exhibit noncarcinogenic (i.e., systemic) effects, authorities consider organisms to have repair and detoxification capabilities that must be exceeded by some critical concentration (threshold) before the health effect is manifested. This threshold view holds that a range of exposures from just above zero to some finite value can be tolerated by the organism without an appreciable risk of adverse effects.

Health criteria for chemicals exhibiting noncarcinogenic effects for use in risk assessment are generally developed using USEPA RfDs. In general, the RfD is an estimate of an average daily exposure to an individual (including sensitive individuals) below which there will not be an appreciable risk of adverse health effects. The RfD is derived using uncertainty factors (e.g., to adjust from animals to humans and to protect sensitive subpopulations) to ensure that it is unlikely to underestimate the potential for adverse noncarcinogenic effects to occur. The purpose of the RfD is to provide a benchmark against which an intake from human exposure to various environmental conditions might be compared. Intakes of doses that are significantly higher that the RfD may indicate that an inadequate margin of safety could exist for exposure to that substance.

(b) Carcinogenic Effects

For chemicals that exhibit carcinogenic effects, most authorities recognize that one or more molecular events can evoke changes in a single cell or a small number of cells that can lead to tumor formation. This is the non-threshold theory of carcinogenesis that purports that any level of exposure to a carcinogen can result in some finite possibility of generating the disease. Generally, regulatory agencies assume the non-threshold hypothesis for carcinogens in the absence of information concerning the mechanisms of action for the COPC.

USEPA's Carcinogen Risk Assessment Verification Endeavor (CRAVE) has developed slope factors and unit risks (i.e., dose-response values) for estimating excess lifetime cancer risks associated with various levels of lifetime exposure to potential human carcinogens. The carcinogenic slope factors can be used to estimate the lifetime excess cancer risk associated with exposure to a potential carcinogen. Risks estimated using slope factors are considered unlikely to underestimate actual risks, but they may overestimate actual risks. Excess lifetime cancer risks are generally expressed in scientific notation. An excess lifetime cancer risk of 1×10^{-6} (one in a million), for example, represents the probability of an individual developing cancer over a lifetime as a result of exposure to the specific carcinogenic chemical. USEPA considers total excess lifetime cancer risks within the range of 10^{-4} (one in ten thousand) to 10^{-6} (EPA, 1989a) to be acceptable when developing remedial alternatives for cleanup of Superfund Sites.

2.2.4 Risk characterization

To characterize risk, toxicity and exposure assessments were summarized and integrated into quantitative and qualitative expressions of risk. To characterize potential noncarcinogenic effects, comparisons were made between projected intakes of substances and toxicity values. To characterize potential carcinogenic effects, probabilities that an individual will develop cancer over a lifetime of exposure are estimated from projected intakes and chemical-specific dose-response information. Major assumptions, scientific judgments, and, to the extent possible, estimates of the uncertainties embodied in the assessment are also presented.

(a) Noncarcinogenic Effects

The potential for noncarcinogenic effects is evaluated by comparing an exposure level over a specified time period with an RfD derived for a similar exposure period. This ratio of exposure to toxicity is called a hazard quotient according to the following equation:

Noncancer Hazard Quotient = E/RfD

Where:
E = Exposure level or intake (mg/kg-day), and
RfD = Reference Dose (mg/kg-day)

The noncancer hazard quotient assumes that there is a level of exposure (i.e., an RfD) below which it is unlikely for even sensitive populations to experience adverse health effects.

To assess the overall potential for noncarcinogenic effects posed by more than one chemical, a hazard index (HI) approach has been developed which assumes that the magnitude of simultaneous exposures to several chemicals will be proportional to the sum of the hazard quotients for each chemical. This assumption of additivity reflected in the HI is best applied to compounds that induce the same effects by the same organ and mechanism.

(b) Carcinogenic Effects

For carcinogens, risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen (i.e., excess individual lifetime cancer risk). The slope factor converts estimated daily intakes averaged over a lifetime of exposure directly to incremental risk of an individual developing cancer. It can generally be assumed that the dose-response relationship will be linear in the low-dose portion of the multistage model dose-response curve. Under this assumption, the slope factor is a constant, and risk will be directly related to intake. Thus, the following linear equation was used in this assessment:

Risk = CDI x SF

Where:
Risk = A unitless probability of developing cancer,
CDI = Chronic Daily Intake over 70 years (mg/kg-day),
SF = Slope Factor $(mg/kg\text{-}day)^{-1}$

For simultaneous exposure to several carcinogens, the USEPA assumes that the risks are additive.

3. DISCUSSION

3.1 Sediment Data

Sediment data was used by permission from sediment monitoring data and research reports from references 5a, 5b, and 5c. While this limited our study to metal, hydrophobic organic, PCB, and polycyclic aromatic hydrocarbon chemicals, we believe that these are the major chemical constituents which would persist in the sediments and limit its use for land farming. Sediment data was divided into areas representing the northern bay, middle bay and southern bay. The explanation of these areas can be found in reference 5b.

3.2 Dilution Factor

The final concentration of any chemical in the soil after an addition of dredged sediments involves mixing the native soil with the sediments to a prescribed depth (usually 8 inches). This mixing results in a chemical concentration that is a weighted average of the concentrations of both the soil and the sediment. An 8-inch depth of soil weighs approximately $2X10^6$ pounds ($9X10^8$ grams) per acre.

3.3 Applied Sediment

The amount of sediment allowed in the land farming operation is usually dictated by the crop’s nitrogen requirement. For a corn grain crop with a yield goal of 100 bu/acre the total nitrogen recommendation is 100 lbs/acre. For this project, we are assuming that all of the nitrogen is applied at the beginning of the crop year, ignoring the usual recommendation to side dress 50-70% of the nitrogen later in the crop’s life. With nitrogen 95UCL percentages ranging from 0.16 to 0.40 and an annual mineralization rate for the organic nitrogen of 10%, the amount of sediments added to the land farming fields were: 168 T/A for the north bay sediments; 122 T/A for the middle bay sediments; and 294 T/A for the southern bay sediments based on the weight of dry sediments. While these are amounts that may be difficult to actually land farm or even dewater adequately due to the 50-85% water contents in these sediments. However, we will carry the calculations through to the conclusion.

3.4 Risk Assessment.

3.4.1 Potentially Exposed Populations

For purposes of this assessment, three potentially exposed populations were considered: adult agricultural worker, adult resident, and child resident.

Workers are assumed to work 40 hours/week, 50 weeks a year and 25 years of continuous employment at the site. The residents whether child or adult are assumed to be live on site, 24 hours a day, 350 days a year for 6 years (child) and 30 years (adult). Other factors defining the exposure of an individual reflect current default values determined by the US Environmental Protection Agency (Ref 5d).

3.4.2 Identification of Exposure Pathways

Exposures are estimated only for plausible completed exposure pathways. A completed exposure pathway has the following four elements:

- a source and mechanism for chemical release,
- an environmental transport medium,
- an exposure point, and
- a human receptor and a feasible route of exposure at the exposure point (ingestion).

A pathway cannot be completed unless each of these elements is present. For this study, we assume that the only complete pathway is soil ingestion.

3.4.3 Quantification of Exposure

In this section, each receptor's potential exposures to the COPC’s are quantified for each of the exposure pathways. In each case, the exposures are calculated following methods recommended in EPA guidance documents, such as the Risk Assessment Guidance for Superfund (Ref 5d). These calculations generally involve two steps. First, representative chemical concentrations in the environment, or exposure point concentrations (EPCs), are determined for each pathway and receptor. For this study, the upper 95th confidence limit percentile of the arithmetic mean was used as an estimate of the EPC for each chemical. From these EPC values, the amount of chemical, which an exposed person may take into his/her body, is then calculated. This value is referred to as the Human Intake.

Estimates of pathway-specific human intakes for each COPC involve assumptions about patterns of human exposure to the media being evaluated. These assumptions are integrated with the EPCs to calculate intakes. Intakes are normally expressed as the amount of chemical at the environment-human receptor exchange boundary in milligrams per kilogram of body weight per day (mg/kg-day), which represents an exposure normalized for body weight over time. The total exposure is divided by the time period of interest to obtain an average exposure. The averaging time is a function of the health endpoint: For noncarcinogenic effects, it is the exposure time (specific to

Table 1. Risk Calculation Results

	Adult		child	adult		Notes
Parameter	Residential (carc)	(noncarc)	Residential (noncarc)	Agricultural (carc)	(noncarc)	Major chemical contr butors Noncarc/carc
North Bay Sediments						
Total pcb	5.9E-08			2.0E-07		
Total PAH	1.3-06	1.8E-05	1.4E-04	4.3E-06	6.1E-05	Fluoanthene,pyrene/BaP, BeP, Dibenzo[ah] anthracene
Total Metals	5.9E-06	0.079	0.633	2.0E-05	0.270	Cr, Al, As/As
North Bay Total Risk	7.2E-06	0.079	0.633	2.5E-05	0.270	
Middle Bay Sediments						
Parameter						
Total pcb	5.1E-09			1.8E-08		
Total PAH	1.1E-07	2.3E-06	1.8E-05	3.8E-07	78E-06	Fluoanthene,pyrene/BaP, BeP, Dibenzo[ah] anthracene
Total Metals	4.6E-06	0.067	0.539	1.6E-05	0.230	Cr, Al, As/As
Middle Bay Total Risk	4.7E-06	0.067	0.539	1.6E-05	0.230	
South Bay Sediments						
Parameter						
Total pcb	1.9E-09			6.5E-09		
Total PAH	2.7E-08	3.6E-07	2.9E-06	9.1E-08	1.2E-06	Fluoanthene,pyrene/BaP, BeP, Dibenzo[ah] anthracene
Total Metals	5.9E-06	0.083	0.669	2.0E-05	0.285	Cr, Al, As/As
South Bay Total Risk	5.9E-06	0.083	0.669	2.0E-05	0.285	
Background Soils						
Parameter						
Total Risk (Metals)	4.3E-06	0.063	0.503	1.5E-05	0.215	Cr, Al, As/As

the scenario being assessed) and for carcinogenic effects, it is lifetime (70 years).

3.4.4 Risk Calculation Results

Table 1 shows the results of the risk calculations for land farming sediment from the three regions of the bay and for background soil data used by the State of Maryland for evaluating risk from natural soil. In the “Notes” column, we have identified the chemicals that contributed to the majority of the calculated risk.

The risks to all the receptors in this evaluation are within the acceptable range as defined by the USEPA. This indicates that the use of dredge sediments from the Chesapeake Bay could be safely used for land farming. It should be noted that this evaluation draws this observation from the affects of chemicals in the sediment on human health only. Other important factors have to be considered before such a recommendation should actually occur. While overall, the risks in this evaluation are within the acceptable range, several other observations can be made from the data.

The calculated risks are similar and not dependent on the location the sediment was collected. Both the types of constituent that are major contributors and the magnitudes of the contributions are independent of the sample locations. For the organic chemicals, one would expect that both the number of species and concentrations of chemicals in the sediments would increase as they move through the system. Even after passing the industrialized area around Baltimore City, the sediment data does not show a significant change in the species or concentration of chemicals that drive the risk. This suggests that the largest contributor to chemicals in the bay sediments is the general urbanization of the area.

Metal concentrations show a similar pattern. Middle bay sediments (where flow from the Baltimore City area would enter the bay) actually show a decrease in risk as compared to either North Bay or south bay sediments. However, this risk may not be due to additions from the urban areas surrounding the bay.

Risks from using bay sediments in land farming all show an increase as compared to the background soil values, but most of the total risk can be attributed to the concentration of metals in the background soil.

4. CONCLUSIONS

The evaluation presented here used several conservative assumptions to attempt to provide a worst-case estimate of using Chesapeake Bay sediment to supply the nitrogen requirements of an agricultural crop. One group of chemicals that are notably missing is the pesticides. No data concerning these chemicals could be found thus they were not included in the evaluation. Due to the inherent toxicity of this group of chemicals, their inclusion into this evaluation could hypothetically alter the conclusions of this study. Several conclusions can be drawn from the evaluation presented here:

- Based on human health, the land farming of sediments from the Chesapeake Bay should not pose a health risk, which would be unacceptable for the remediation of a hazardous waste site.

- The risk that was calculated was due to exposure to both organic and inorganic chemicals.

- The concentrations of organic chemicals in the sediments appears to be due to the general urbanization of the land around the bay and not concentrated around the industrialized areas of the bay.

- The majority of the concentrations of inorganic chemicals found in the sediment appear to be due to erosion of the natural soil.

- Because of the limitations and assumptions used in this evaluation, it must not be used as an absolute determination of the probability of health effects from the chemicals at these sites.

5. REFERENCES

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