CONTAMINATED SEDIMENT REMEDIATION GUIDANCE FOR HAZARDOUS WASTE SITES:

APPENDIX A: PRINCIPLES FOR MANAGING CONTAMINATED SEDIMENT RISKS AT HAZARDOUS WASTE SITES

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460
Feb. 12, 2002

OFFICE OF
SOLID WASTE AND EMERGENCY
RESPONSE

OSWER Directive 9285.6-08

MEMORANDUM

SUBJECT: Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites

FROM: Marianne Lamont Horinko ***/s/ Marianne Lamont Horinko***
Assistant Administrator

TO: Superfund National Policy Managers, Regions 1 - 10
RCRA Senior Policy Advisors, Regions 1 - 10

I. PURPOSE

This guidance will help EPA site managers make scientifically sound and nationally consistent risk management decisions at contaminated sediment sites. It presents 11 risk management principles that Remedial Project Managers (RPMs), On-Scene Coordinators (OSCs), and RCRA Corrective Action project managers should carefully consider when planning and conducting site investigations, involving the affected parties, and selecting and implementing a response.

This guidance recommends that EPA site managers make risk-based site decisions using an iterative decision process, as appropriate, that evaluates the short-term and long-term risks of all potential cleanup alternatives consistent with the National Oil and Hazardous Substances Pollution Contingency Plan's (NCP's) nine remedy selection criteria (40 CFR Part 300.430). EPA site managers are also encouraged to consider the societal and cultural impacts of existing sediment contamination and of potential remedies through meaningful involvement of affected stakeholders.

This guidance also responds in part to the recommendations contained in the National Research Council (NRC) report discussed below.

II. BACKGROUND

On March 26, 2001, the NRC published a report entitled *A Risk Management Strategy for PCB-Contaminated Sediments*. Although the NRC report focuses primarily on assessment and remediation of PCB-contaminated sediments, much of the information in that report is applicable to other contaminants. Site managers are encouraged to read the NRC report, which may be found at http://www.nrc.edu.

In addition to developing these principles, OSWER, in coordination with other EPA offices (Office of Research and Development, Office of Water, and others) and other federal agencies (Department of Defense/U.S. Army Corps of Engineers, Department of Commerce/National Oceanic and Atmospheric Administration, Department of the Interior/U.S. Fish and Wildlife Service, and others) is developing a separate guidance, *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (Sediment Guidance). The Sediment Guidance will provide more detailed technical guidance on the process that Superfund and RCRA project managers should use to evaluate cleanup alternatives at contaminated sediment sites.

While this directive applies to all contaminants at sediment sites addressed under CERCLA or RCRA, its implementation at particular sites should be tailored to the size and complexity of the site, to the magnitude of site risks, and to the type of action contemplated. These principles can be applied within the framework of EPA's existing statutory and regulatory requirements.

III. RISK MANAGEMENT PRINCIPLES

1. Control Sources Early.

As early in the process as possible, site managers should try to identify all direct and indirect continuing sources of significant contamination to the sediments under investigation. These sources might include discharges from industries or sewage treatment plants, spills, precipitation runoff, erosion of contaminated soil from stream banks or adjacent land, contaminated groundwater and non-aqueous phase liquid contributions, discharges from storm water and combined sewer outfalls, upstream contributions, and air deposition.

Next, site managers should assess which continuing sources can be controlled and by what mechanisms. It may be helpful to prioritize sources according to their relative contributions to site risks. In the identification and assessment process, site managers should solicit assistance from those with relevant information, including regional Water, Air, and PCB Programs (where applicable); state agencies (especially those responsible for setting Total Maximum Daily Loads (TMDLs) and those that issue National Pollutant Discharge Elimination

System (NPDES) permits); and all Natural Resource Trustees. Local agencies and stakeholders may also be of assistance in assessing which sources can be controlled.

Site managers should evaluate the potential for future recontamination of sediments when selecting a response action. If a site includes a source that could result in significant recontamination, source control measures will likely be necessary as part of that response action. However, where EPA believes that the source can be controlled, or where sediment remediation will have benefits to human health and/or the environment after considering the risks caused by the ongoing source, it may be appropriate for the Agency to select a response action for the sediments prior to completing all source control actions. This is consistent with principle #5 below, which indicates that it may be necessary to take phased or interim actions (e.g., removal of a hot spot that is highly susceptible to downstream movement or dispersion of contaminants) to prevent or address environmental impacts or to control human exposures, even if source control actions have not been undertaken or completed.

2. Involve the Community Early and Often.

Contaminated sediment sites often involve difficult technical and social issues. As such, it is especially important that a project manager ensure early and meaningful community involvement by providing community members with the technical information needed for their informed participation. Meaningful community involvement is a critical component of the site characterization, risk assessment, remedy evaluation, remedy selection, and remedy implementation processes. Community involvement enables EPA to obtain site information that may be important in identifying potential human and ecological exposures, as well as in understanding the societal and cultural impacts of the contamination and of the potential response options. The NRC report (p. 249) "recommends that increased efforts be made to provide the affected parties with the same information that is to be used by the decision-makers and to include, to the extent possible, all affected parties in the entire decision-making process at a contaminated site. In addition, such information should be made available in such a manner that allows adequate time for evaluation and comment on the information by all parties." Through Technical Assistance Grants and other mechanisms, project managers can provide the community with the tools and information necessary for meaningful participation, ensuring their early and continued involvement in the cleanup process.

Although the Agency has the responsibility to make the final cleanup decision at CERCLA and RCRA sites, early and frequent community involvement facilitates acceptance of Agency decisions, even at sites where there may be disagreement among members of the community on the most appropriate remedy.

Site managers and community involvement coordinators should take into consideration the following six practices, which were recently presented in OSWER Directive 9230.0-99 *Early* *and Meaningful Community Involvement* (October 12, 2001). This directive also includes a list of other useful resources and is available at http://www.epa.gov/superfund/pubs.htm.

(1) Energize the community involvement plan.
(2) Provide early, proactive community support.
(3) Get the community more involved in the risk assessment.
(4) Seek early community input on the scope of the remedial investigation/feasibility study (RI/FS).
(5) Encourage community involvement in identification of future land use.
(6) Do more to involve communities during removals.

3. Coordinate with States, Local Governments, Tribes, and Natural Resource Trustees.

Site managers should communicate and coordinate early with states, local governments, tribes, and all Natural Resource Trustees. By doing so, they will help ensure that the most relevant information is considered in designing site studies, and that state, local, tribal, and trustee viewpoints are considered in the remedy selection process. For sites that include waterbodies where TMDLs are being or have been developed, it is especially important to coordinate site investigations and monitoring or modeling studies with the state and with EPA's water program. In addition, sharing information early with all interested parties often leads to quicker and more efficient protection of human health and the environment through a coordinated cleanup approach.

Superfund's statutory mandate is to ensure that response actions will be protective of human health and the environment. EPA recognizes, however, that in addition to EPA's response action(s), restoration activities by the Natural Resource Trustees may be needed. It is important that Superfund site managers and the Trustees coordinate both the EPA investigations of risk and the Trustee investigations of resource injuries in order to most efficiently use federal and state resources and to avoid duplicative efforts.

Additional information on coordinating with Trustees may be found in OSWER Directive 9200.4-22A *CERCLA Coordination with Natural Resource Trustee*s (July 1997), in the 1992 ECO Update *The Role of Natural Resource Trustees in the Superfund Process* http://www.epa.gov/superfund/programs/risk/tooleco.htm), and in the 1999 OSWER Directive 9285.7-28 P *Ecological Risk Assessment and Risk Management Principles for Superfund Sites* (also available at the above web site). Additional information on coordinating with states and tribes can be found in OSWER Directive 9375.3-03P *The Plan to Enhance the Role of States and Tribes in the Superfund Program* (http://www.epa.gov/superfund/states/strole/index.htm).

4. Develop and Refine a Conceptual Site Model that Considers Sediment Stability.

A conceptual site model should identify all known and suspected sources of contamination, the types of contaminants and affected media, existing and potential exposure pathways, and the known or potential human and ecological receptors that may be threatened. This information is frequently summarized in pictorial or graphical form, backed up by site-specific data. The conceptual site model should be prepared early and used to guide site investigations and decision-making. However, it should be updated periodically whenever new information becomes available, and EPA's understanding of the site problems increases. In addition, it frequently can serve as the centerpiece for communication among all stakeholders.

A conceptual site model is especially important at sediment sites because the interrelationship of soil, surface and groundwater, sediment, and ecological and human receptors is often complex. In addition, sediments may be subject to erosion or transport by natural or man-made disturbances such as floods or engineering changes in a waterway. Because sediments may experience temporal, physical, and chemical changes, it is especially important to understand what contaminants are currently available to humans and wildlife, and whether this is likely to change in the future under various scenarios. The risk assessor and project manager, as well as other members of the site team, should communicate early and often to ensure that they share a common understanding of the site and the basis for the present and future risks. The May 1998 EPA *Guidelines for Ecological Risk Assessment* (Federal Register 63(93) 26846-26924, http://www.epa.gov/superfund/programs/risk/tooleco.htm), the 1997 Superfund Guidance *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments* (EPA 540-R-97-006, also available at the above web site), and the 1989 *Risk Assessment Guidance for Superfund (RAGS), Volume 1, Part A* (EPA 540-1-89-002, http://www.epa.gov/superfund/programs/risk/ragsa) provide guidance on developing conceptual site models.

5. Use an Iterative Approach in a Risk-Based Framework.

The NRC report (p. 52) recommends the use of a risk-based framework based on the one developed by the Presidential/Congressional Commission on Risk Assessment and Risk Management (PCCRARM, 1997, *Framework for Environmental Health Risk Management*, Vol. 1, as cited by NRC 2001). However, as recognized by the NRC (p. 60): "The framework is intended to supplement, not supplant, the CERCLA remedial process mandated by law for Superfund sites."

Although there is no universally accepted, well-defined risk-based framework or strategy for remedy evaluation at sediment sites, there is wide-spread agreement that risk assessment should play a critical role in evaluating options for sediment remediation. The Superfund program uses a flexible, risk-based framework as part of the CERCLA and NCP process to adequately characterize ecological and human health site risks. The guidances used by the

RCRA Corrective Action program (http://www.epa.gov/correctiveaction/resource/guidance) also recommend a flexible risk-based approach to selecting response actions appropriate for the site.

EPA encourages the use of an iterative approach, especially at complex contaminated sediment sites. As used here, an iterative approach is defined broadly to include approaches which incorporate testing of hypotheses and conclusions and foster re-evaluation of site assumptions as new information is gathered. For example, an iterative approach might include pilot testing to determine the effectiveness of various remedial technologies at a site. As noted in the NRC report (p. 66): "Each iteration might provide additional certainty and information to support further risk-management decisions, or it might require a course correction."

An iterative approach may also incorporate the use of phased, early, or interim actions. At complex sediment sites, site managers should consider the benefits of phasing the remediation. At some sites, an early action may be needed to quickly reduce risks or to control the ongoing spread of contamination. In some cases, it may be appropriate to take an interim action to control a source, or remove or cap a hot spot, followed by a period of monitoring in order to evaluate the effectiveness of these interim actions before addressing less contaminated areas.

The NRC report makes an important point when it notes (p. 256): "The committee cautions that the use of the framework or other risk-management approach should not be used to delay a decision at a site if sufficient information is available to make an informed decision. Particularly in situations in which there are immediate risks to human health or the ecosystem, waiting until more information is gathered might result in more harm than making a preliminary decision in the absence of a complete set of information. The committee emphasizes that a 'wait-and-see' or 'do-nothing' approach might result in additional or different risks at a site."

6. Carefully Evaluate the Assumptions and Uncertainties Associated with Site Characterization Data and Site Models.

The uncertainties and limitations of site characterization data, and qualitative or quantitative models (e.g., hydrodynamic, sediment stability, contaminant fate and transport, or food-chain models) used to extrapolate site data to future conditions should be carefully evaluated and described. Due to the complex nature of many large sediment sites, a quantitative model is often used to help estimate and understand the current and future risks at the site and to predict the efficacy of various remedial alternatives. The amount of site-specific data required and the complexity of models used to support site decisions should depend on the complexity of the site and the significance of the decision (e.g., level of risk, response cost, community interest). All new models and the calibration of models at large or complex sites should be peer-reviewed consistent with the Agency's peer review process as described in its Peer Review Handbook (EPA 100-B-00-001, http://www.epa.gov/ORD/spc/2peerrev.htm).

Site managers should clearly describe the basis for all models used and their uncertainties when using the predicted results to make a site decision. As recognized by the NRC report (p. 65), however, "Management decisions must be made, even when information is imperfect. There are uncertainties associated with every decision that need to be weighed, evaluated, and communicated to affected parties. Imperfect knowledge must not become an excuse for not making a decision."

7. Select Site-specific, Project-specific, and Sediment-specific Risk Management Approaches that will Achieve Risk-based Goals.

EPA's policy has been and continues to be that there is no presumptive remedy for any contaminated sediment site, regardless of the contaminant or level of risk. This is consistent with the NRC report's statement (p. 243) that "There is no presumption of a preferred or default risk-management option that is applicable to all PCB-contaminated-sediment sites." At Superfund sites, for example, the most appropriate remedy should be chosen after considering site-specific data and the NCP's nine remedy selection criteria. All remedies that may potentially meet the removal or remedial action objectives (e.g., dredging or excavation, in-situ capping, in-situ treatment, monitored natural recovery) should be evaluated prior to selecting the remedy. This evaluation should be conducted on a comparable basis, considering all components of the remedies, the temporal and spatial aspects of the sites, and the overall risk reduction potentially achieved under each option.

At many sites, a combination of options will be the most effective way to manage the risk. For example, at some sites, the most appropriate remedy may be to dredge high concentrations of persistent and bioaccumulative contaminants such as PCBs or DDT, to cap areas where dredging is not practicable or cost-effective, and then to allow natural recovery processes to achieve further recovery in net depositional areas that are less contaminated.

8. Ensure that Sediment Cleanup Levels are Clearly Tied to Risk Management Goals.

Sediment cleanup levels have often been used as surrogates for actual remediation goals (e.g., fish tissue concentrations or other measurable indicators of exposure relating to levels of acceptable risk). While it is generally more practical to use measures such as contaminant concentrations in sediment to identify areas to be remediated, other measures should be used to ensure that human health and/or ecological risk reduction goals are being met. Such measures may include direct measurements of indigenous fish tissue concentrations, estimates of wildlife reproduction, benthic macroinvertebrate indices, or other "effects endpoints" as identified in the baseline risk assessment.

As noted in the NRC report (p. 123), "The use of measured concentrations of PCBs in fish is suggested as the most relevant means of measuring exposures of receptors to PCBs in contaminated sediments." For other contaminants, other measures may be more appropriate.

For many sites, achieving remediation goals, especially for bioaccumulative contaminants in biota, may take many years. Site monitoring data and new scientific information should be considered in future reviews of the site (e.g., the Superfund five-year review) to ensure that the remedy remains protective of human health and the environment.

9. Maximize the Effectiveness of Institutional Controls and Recognize their Limitations.

Institutional controls, such as fish consumption advisories and waterway use restrictions, are often used as a component of remedial decisions at sediment sites to limit human exposures and to prevent further spreading of contamination until remedial action objectives are met. While these controls can be an important component of a sediment remedy, site managers should recognize that they may not be very effective in eliminating or significantly reducing all exposures. If fish consumption advisories are relied upon to limit human exposures, it is very important to have public education programs in place. For other types of institutional controls, other types of compliance assistance programs may also be needed (e.g., state/local government coordination). Site managers should also recognize that institutional controls seldom limit ecological exposures. If monitoring data or other site information indicates that institutional controls are not effective, additional actions may be necessary.

10. Design Remedies to Minimize Short-term Risks while Achieving Long-term Protection.

The NRC report notes (p. 53) that: "Any decision regarding the specific choice of a risk management strategy for a contaminated sediment site must be based on careful consideration of the advantages and disadvantages of available options and a balancing of the various risks, costs, and benefits associated with each option." Sediment cleanups should be designed to minimize short-term impacts to the extent practicable, even though some increases in short-term risk may be necessary in order to achieve a long-lasting solution that is protective. For example, the long-term benefits of removing or capping sediments containing persistent and bioaccumulative contaminants often outweigh the additional short-term impacts on the already-affected biota.

In addition to considering the impacts of each alternative on human health and ecological risks, the short-term and long-term impacts of each alternative on societal and cultural practices should be identified and considered, as appropriate. For example, these impacts might include effects on recreational uses of the waterbody, road traffic, noise and air pollution, commercial fishing, or disruption of way of life for tribes. At some sites, a comparative analysis of impacts such as these may be useful in order to fully assess and balance the tradeoffs associated with each alternative.

11. Monitor During and After Sediment Remediation to Assess and Document Remedy Effectiveness.

A physical, chemical, and/or biological monitoring program should be established for sediment sites in order to determine if short-term and long-term health and ecological risks are being adequately mitigated at the site and to evaluate how well all remedial action objectives are being met. Monitoring should normally be conducted during remedy implementation and as long as necessary thereafter to ensure that all sediment risks have been adequately managed. Baseline data needed for interpretation of the monitoring data should be collected during the remedial investigation.

Depending on the risk management approach selected, monitoring should be conducted during implementation in order to determine whether the action meets design requirements and sediment cleanup levels, and to assess the nature and extent of any short-term impacts of remedy implementation. This information can also be used to modify construction activities to assure that remediation is proceeding in a safe and effective manner. Long-term monitoring of indicators such as contaminant concentration reductions in fish tissue should be designed to determine the success of a remedy in meeting broader remedial action objectives. Monitoring is generally needed to verify the continued long-term effectiveness of any remedy in protecting human health and the environment and, at some sites, to verify the continuing performance and structural integrity of barriers to contaminant transport.

IV. IMPLEMENTATION

EPA RPMs, OSCs, and RCRA Corrective Action project managers should immediately begin to use this guidance at all sites where the risks from contaminated sediment are being investigated. EPA expects that Federal facility responses conducted under CERCLA or RCRA will also be consistent with this directive. This consultation process does not apply to Time-Critical or emergency removal actions or to sites with only sediment-like materials in wastewater lagoons, tanks, storage or containment facilities, or drainage ditches.

Consultation Process for CERCLA Sites

To help ensure that Regional site managers appropriately consider these principles *before* site-specific risk management decisions are made, this directive establishes a two-tiered consultation procedure that will apply to most contaminated sediment sites. The consultation process applies to all proposed or listed NPL sites where EPA will sign or concur on the ROD, all Non-Time-Critical removal actions where EPA will sign or concur on the Action Memorandum, and all "NPL-equivalent" sites where there is or will be an EPA-enforceable agreement in place.

Tier 1 Process

Where the sediment action(s) for the entire site will address more than 10,000 cubic yards or five acres of contaminated sediment, Superfund RPMs and OSCs should consult with their appropriate Office of Emergency and Remedial Response (OERR) Regional Coordinator at least 30 days before issuing for public comment a Proposed Plan for a remedial action or an Engineering Evaluation/Cost Analysis (EE/CA) for a Non-Time-Critical removal action.

This consultation entails the submission of the draft proposed plan or draft EE/CA, a written discussion of how the above 11 principles were considered, and basic site information that will assist OERR in tracking significant sediment sites. If the project manager has not received a response from OERR within two weeks, he or she may assume no further information is needed at this time. EPA believes that this process will help promote nationally consistent approaches to evaluate, select and implement protective, scientifically sound, and cost-effective remedies.

Tier 2 Process

This directive also establishes a new technical advisory group (Contaminated Sediments Technical Advisory Group–CSTAG) that will monitor the progress of and provide advice regarding a small number of large, complex, or controversial contaminated sediment Superfund sites. The group will be comprised of ten Regional staff and approximately five staff from OSWER, OW, and ORD. For most sites, the group will meet with the site manager and the site team several times throughout the site investigation, response selection, and action implementation processes. For new NPL sites, the group will normally meet within one year after proposed listing. It is anticipated that for most sites, the group will meet annually until the ROD is signed and thereafter as needed until all remedial action objectives have been met. The specific areas of assistance or specific documents to be reviewed will be decided by the group on a case-by-case basis in consultation with the site team. For selected sites with an on-going RI/FS or EE/CA, the group will be briefed by the site manager some time in 2002 or 2003. Reviews at sites with remedies also subject to National Remedy Review Board (NRRB) review will be coordinated with the NRRB in order to eliminate the need for a separate sediment group review at this stage in the process.

Consultation Process for RCRA Corrective Action Facilities

Generally, for EPA-lead RCRA Corrective Action facilities where a sediment response action is planned, a two-tiered consultation process will also be used. Where the sediment action(s) for the entire site will address more than 10,000 cubic yards or five acres of contaminated sediment, project managers should consult with the Office of Solid Waste's Corrective Action Branch at least 30 days before issuing a proposed action for public comment. This consultation entails the submission of a written discussion of how the above 11 principles were considered, and basic site information that will assist OSW in tracking significant sediment sites.

If the project manager has not received a response from OSW within two weeks, he or she may assume no further information is needed. States are also encouraged to follow these procedures. For particularly large, complex, or controversial sites, OSW will likely call on the technical advisory group discussed above.

EPA also recommends that both state and EPA project managers working on sediment contamination associated with Corrective Action facilities consult with their colleagues in both RCRA and Superfund to promote consistent and effective cleanups. EPA believes this consultation would be particularly important for the larger-scale sediment cleanups mentioned above.

EPA may update this guidance as more information becomes available on topics such as: the effectiveness of various sediment response alternatives, new methods to evaluate risks, or new methods for characterizing sediment contamination. For additional information on this guidance, please contact the OERR Sediments Team Leader (Stephen Ells at 703 603-8822) or the OSW Corrective Action Programs Branch Chief (Tricia Buzzell at 703 308-8632).

NOTICE: This document provides guidance to EPA Regions concerning how the Agency intends to exercise its discretion in implementing one aspect of the CERCLA and RCRA remedy selection process. This guidance is designed to implement national policy on these issues. Some of the statutory provisions described in this document contain legally binding requirements. However, this document does not substitute for those provisions or regulations, nor is it a regulation itself. Thus it cannot impose legally binding requirements on EPA, states, or the regulated community, and may not apply to a particular situation based upon the circumstances. Any decisions regarding a particular situation will be made based on the statutes and regulations, and EPA decision-makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance where appropriate. Interested parties are free to raise questions and objections about the substance of this guidance and the appropriateness of the application of this guidance to a particular situation, and the Agency welcomes public input on this document at any time. EPA may change this guidance in the future.

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CONTAMINATED SEDIMENT REMEDIATION GUIDANCE FOR HAZARDOUS WASTE SITES:

APPENDIX B: USGS 100-YEAR FLOOD FACT SHEET

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Fact Sheet 229-96

The "1OO-Year Flood"

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Photo by Geff Hinds, Tacoma News Tribune

Flood designations are based on statistical averages, *not* on the number of years between big floods.

The estimates are only as good as the available data. Flood designations are updated as more data are collected or when the conditions change in a river basin.

BIG FLOODS COULD HAPPEN AGAIN IN WASHINGTON DURING ANY YEAR

Rivers across the Nation seem to be rising to record flood levels almost every year. In Washington, more than one 100-year flood has happened on a few rivers in just the past several years. How can 100-year floods happen so often?

WHY DON'T THESE FLOODS HAPPEN EVERY 100 YEARS?

The term "100-year flood" is misleading because it leads people to believe that it happens only once every 100 years. The truth is that an uncommonly big flood can happen any year. The term "100-year flood" is really a statistical designation, and there is a **1-in-100 chance** that a flood this size will happen during any year. Perhaps a better term would be the "1-in-100 chance flood."

The actual number of years between floods of any given size varies a lot. Big floods happen irregularly because the climate naturally varies over many years. We sometimes get big floods in successive or nearly successive years with several very wet years in a row.

HOW ARE FLOODS DESIGNATED?

Scientists collect data and study past floods to get a minimum of 10 years of information about the river;

a longer record provides a better estimate of the "1-in-100 chance flood." Scientists use statistics and observe how frequently different sizes of floods occurred, and the average number of years between them, to determine the probability that a flood of any given size will be equalled or exceeded during any year.

MANY FLOOD DESIGNATIONS WILL CHANGE OVER TIME

As more data are collected, or when a river basin is altered in a way that affects the flow of water in the river, scientists re-evaluate the frequency of flooding. Dams and urban development are examples of some man-made changes in a basin that affect floods.

THE USGS COLLECTS ESSENTIAL DATA FOR UNDERSTANDING FLOODS

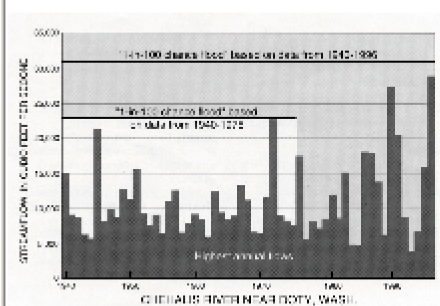
Scientists at the USGS measure streamflow in rivers across the State during every major flood. After flood waters recede, the USGS may be funded to locate and survey "high-water marks" where debris and mud lines indicate the highest extent of flood waters. These post-flood surveys are used to estimate maximum flows at sites that could not be reached during the floods and also to map the areas covered by the floods.

Streamflow data that have been collected since 1975 on the Chehalis River near Doty indicate that the estimated streamflow of "1-in-100 chance flood" is higher than it was 20 years ago.

The eariler flood designation was accurate on the basis of the data that were available at the time; more large floods happened after 1975 than from 1940-1975.

The change in the flood designation after 20 years of additional data collection highlights the importance of continued river monitoring.

Annual peak flow data for 1995 and 1996 are provisional and may change.



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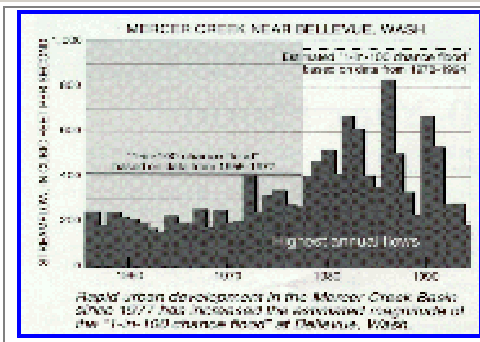

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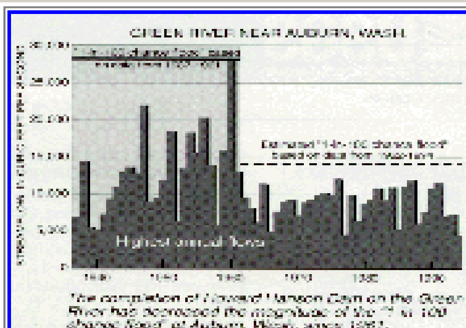
Rapid urban development in the Mercer Creek Basin since 1977 has increased the estimated magnitude of the "1-in-100 chance flood" at Bellevue, Wash.



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The completion of Howard Hanson Dam on the Green River has decreased the magnitude of the "1-in-100 chance flood" at

	Auburn, Wash. since 1961.

DO YOU LIVE ON THE FLOODPLAIN?

The areas affected by past floods have been mapped by the Federal Emergency Management Agency and many other government agencies. Because of continuing changes in river channels and land use in many basins, the maps may not reflect current information for your area. Inquire at your City or County Building or Planning Department.

If you live on the designated floodplain, the chances are about 1 in 2 that you will experience a flood during your lifetime. Prepare for a flood as you would for any natural disaster, and make evacuation plans for your family.

FLOODS WILL CONTINUE TO HAPPEN

Although we can lessen effects of some floods, they are part of the natural cycle of every river and benefit instream habitats by moving material downstream and renewing streambeds. As floods get bigger and spread farther, flood waters slow and deposit sediment on the floodplain. This natural process created valuable farmlands in river valleys of the Pacific Northwest over thousands of years.

Glossary of Flood Terms

A **flood** is any relatively high streamflow that overtops the natural or artificial banks of a river.

Discharge is another term for streamflow; it is the measured volume of water that moves past a point in the river in a given amount of time. Discharge is usually expressed in cubic feet per second.

One **cubic foot per second** (cfs) is about 450 gallons per minute. The average discharge of the Columbia ~ River in September at The Dalles, Oregon, is about 120,000 cfs, which would fill the Seattle Kingdome in less than 10 minutes. The average discharge of the Puyallup River in September is about 1,700 cfs at Puyallup, Wash.

The **floodplain** is the relatively flat lowland that borders a river, usually dry but subject to flooding. Floodplain soils actually are former flood deposits.

The *average* number of years between floods of a certain size is the **recurrence interval** or **return period.** The *actual* number of years between floods of any given size varies a lot because of the naturally changing climate.

A **hydrograph** is a graph that shows changes in discharge or river stage over time. The time scale may be in minutes, hours, days, months, years, or decades.

The **river stage** is the height of the water in the river, measured relative to an arbitrary fixed point.

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from U.S. Department of the Interior, U.S. Geological Survey, Fact Sheet FS-229-96

For more information contact any of the following:

The U.S. Geological Survey has served the public and Federal, State, and local goverments since 1879 by collecting, analyzing, and publishing detailed information about the Nation's mineral, land, and water resources. The USGS has been studying the water resources of Washington State since the turn of the century. This information is in a variety of map, book, electronic, and other formats and is available by contacting:

U.S. Geological Survey
1201 Pacific Ave., #600
Tacoma, WA 98402
(206) 593-6510
Fax: (206) 593-6514
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Selected data and interpretive reports are available on the USGS Washington "home page" on the World Wide Web at http://wwwdwatcm.wr.usgs.gov/

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CONTAMINATED SEDIMENT REMEDIATION GUIDANCE FOR HAZARDOUS WASTE SITES:

APPENDIX C: RADIOMETRIC DATING OF SEDIMENT

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RADIOMETRIC DATING OF SEDIMENT

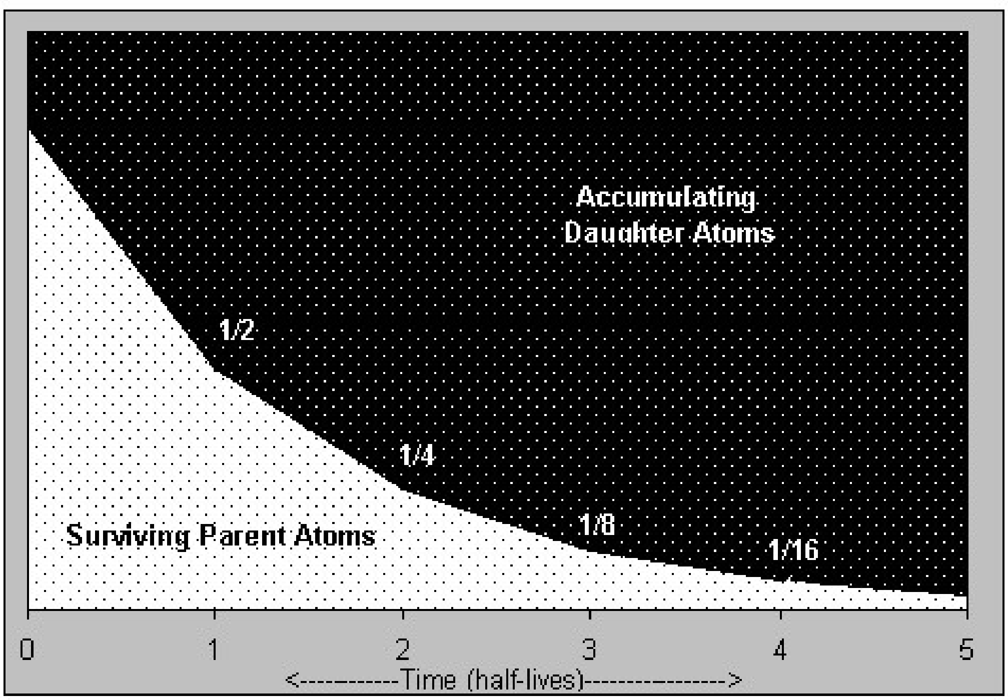
C.1 BACKGROUND

Radiometric dating is a technique that has been in use for decades in fields as diverse as geology and archeology. This technique relies on measuring the known rate of isotope decay, or half-life, as a function of time and depth of sampling. Briefly stated, when the half-life of a radionuclide is known, then observing the distribution of the radionuclide and its breakdown products along a sample core can provide significant insight into the chronology of soil formation within the sample core.

C.2 RADIOMETRIC DATING

The purpose of this section is to describe the process of radioactive decay and its relationship to radiometric dating. Highlight D-1 depicts the decay of a hypothetical parent isotope and the formation of a radiogenic daughter. With time, the decay of a radioactive parent produces radiogenic daughter atoms within the material in which the isotope resides (i.e., soil, sediment, etc). Knowing the decay rate of the parent, the time since the parent material was formed can be measured in terms of the ratio of daughter and parent nuclides in the material. In Highlight D-1, it can be seen that this ratio is unique for any point in time.

Highlight C-1: Radioactive Decay of a Parent Isotope and Radiogenic Formation of a Daughter Isotope



The accuracy of this method of dating relies on two assumptions. First, the system in which radioactive decay occurs must be closed. In order for this method to produce accurate assessments of time, it is important that neither parent nor daughter atoms have been introduced or removed by factors other than radioactive decay. This assumption is more important when daughter atoms have been introduced from outside the system, than when parent atoms have an external origin. When daughter atoms are introduced from sources outside of the system, the ratio of daughter to parent isotopes increases and estimates of the age of material will be too large. The violation of this assumption and its resolution will play an important role in estimating sedimentation rates and is discussed in detail in the next section. The second assumption is that no daughter atoms were present in the system when the parent isotope was formed. Again, the failure of this assumption would result in dating estimates that were larger than the actual age of the material.

There are three major systems of radioactive decay that have been used for radiometric dating (Eicher 1976). A system is usually identified by its parent-daughter (or granddaughter) relationship, such as the potassium-argon, rubidium-strontium, and uranium-lead. Within each system, different isotopes may be used as geochronometers, such as potassium-40, rubidium87, uranium-235 and uranium-238 and the daughter products may be chosen based on physical characteristics, such as solubility and half-life.

There are a large number of unstable isotopes that could be used for radiometric dating of sediments, but many may be unsuitable for such an application. Some of the reasons for unsuitability include very long or short half-lives, ubiquity in nature, solubility in water, or poor understanding of their physical characteristics. The selection of a radionuclide for radiometric dating should depend on the following five requirements (USGS 1998):

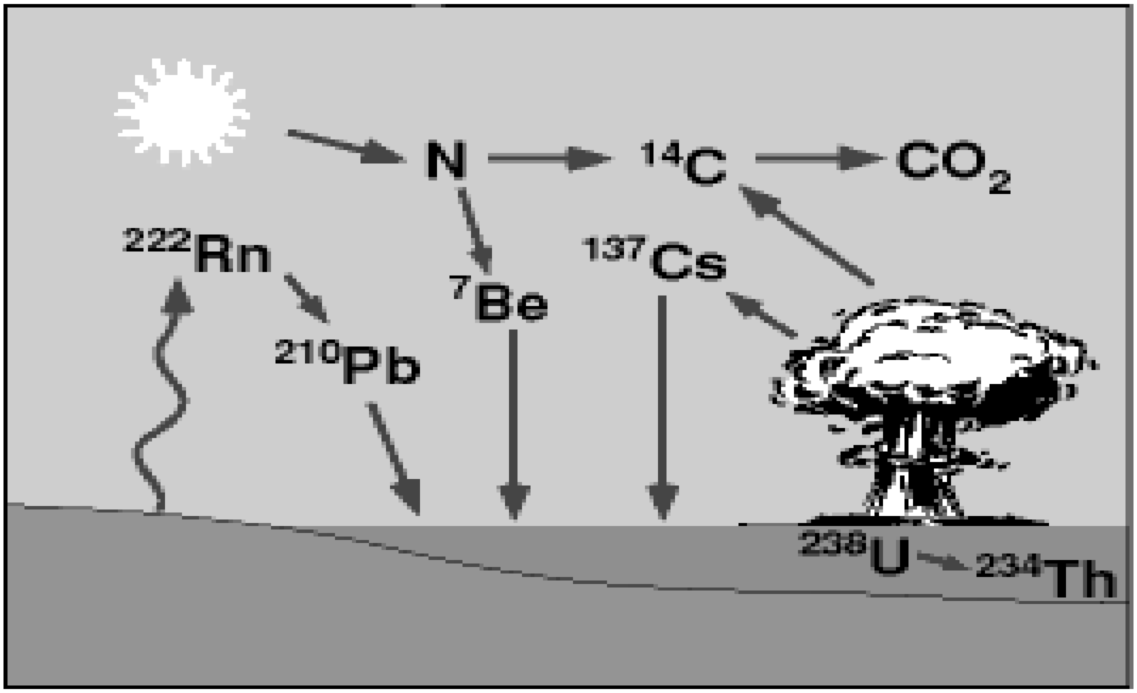
- The chemistry of the isotope (element) is known;
- The half-life is known;
- The initial amount of the isotope per unit of substrate is known or accurately estimated;
- The only change in concentration of the isotope is due to radioactive decay; and
- In order to be useful, it must be relatively easy to measure.

Given these requirements, four isotopes are commonly used to measure sedimentary dynamics over a time period from 100 to 150 years: Beryllium-7 (^{7}Be), Carbon-14 (^{14}C), Cesium-137 (^{137}Cs), and Lead-210 (^{210}Pb). The following sections describe each of these radionuclides and their use in radiometric dating of sediments (USGS 1998). Highlight C-2 presents a graphical representation of the radioactive decay chains for each of these isotopes.

Beryllium-7

^{7}Be is a naturally produced radioisotope that is formed by cosmic ray bombardment of atmospheric nitrogen (N) and oxygen (O). It is removed from the atmosphere through precipitation. Beryllium is a highly reactive element and becomes rapidly and tightly bound to sediments. ^{7}Be has a half-life of 53 days, which makes it effective for dating sediments of an age of about 1 year. Detection of its presence is a reliable indicator that the substance was in contact with the atmosphere within the past

Highlight C-2: Radioactive Decay of Common Isotopes



year. This information is important, as it can be used to calibrate other radiometric dating methods to date and define sedimentary behavior.

<u>Carbon-14</u>

^{14}C is produced in the Earth's atmosphere by the interaction of cosmic ray particles with nitrogen (N), oxygen (O), and carbon (C). Of these elements, nitrogen is the most important in terms of the amount of ^{14}C produced. ^{14}C was also produced by thermonuclear activity (bomb testing), which contributed significantly to ^{14}C levels in the atmosphere, reaching a peak in 1963 (Northern Hemisphere) and 1964 (Southern Hemisphere). All ^{14}C produced is rapidly oxidized to CO_2 and is assimilated into the carbon cycle. ^{14}C has a half-life of 5,730 years and has an effective range of applicability of 100 to 70,000 years for dating organic material. The amount of bomb-produced carbon is determined by comparing present radiocarbon activity to 1950 carbon activity, the date established by convention as the baseline for all radiocarbon dating. Post-1952 carbon values are reported as a percentage of modern (that is, 1950) carbon, and denoted as ^{14}C.

<u>Cesium-137</u>

Cesium has only one naturally occurring stable isotope, ^{133}Cs. The radiogenic isotope ^{137}Cs has been used in hydrologic studies. ^{137}Cs is produced from detonation of nuclear weapons and emissions from nuclear power plants. Beginning in 1954 with the commencement of nuclear testing, ^{137}Cs was released into the atmosphere where it is absorbed readily into solution and returns to earth in the form of precipitation. Once ^{137}Cs enters the ground water, it is deposited on soil surfaces and is removed from the landscape primarily by particle transport. As a result, the input function of these isotopes can be estimated as a function of time. The resulting activities of ^{137}Cs in sediments can thus be used to understand the history of sediments by dating cores and estimating rates of sediment deposition and thus erosion within the watershed.

^{134}Cs and ^{135}Cs have also been used in hydrology as a measure of cesium output by the nuclear power industry. This isotope is used because, while it is less prevalent than either ^{133}Cs or ^{137}Cs, both are be produced solely by nuclear reactions.

<u>Lead-210</u>

^{210}Pb, with a half-life of 22.3 years, is ideal for most ecosystem studies. A member of the ^{238}U series, ^{210}Pb forms by the decay of its intermediate gaseous parent, radon-222. ^{222}Rn, formed by the decay of radium, escapes into the atmosphere by recoil or by diffusion, and rapidly decays to form ^{210}Pb. This isotope has a residence time in the atmosphere of about 10 days before it is removed by precipitation. The highly reactive lead is then rapidly adsorbed to and incorporated into the depositing sediment. ^{210}Pb is also formed within sediments by the decay of ^{226}Ra. Dates of sediment deposition are calculated by determining the decrease in ^{210}Pb activity at each selected sediment interval; this decrease is a function of time. If the initial concentration of ^{210}Pb is known, or is estimated using ^{7}Be data, then the "age" of a sediment interval can be calculated.

C.3 RADIOMETRIC DATING FOR ESTIMATING SEDIMENTATION RATES

Radiometric dating in a lacustrine, estuarine, or marine setting is marked primarily for its violation of one of the primary assumptions, that the "system" is closed and there is no introduction nor loss of daughter products through other than radiogenic transformation of the parent material already present in the material. The system is defined as that area of sediments which are under evaluation. Such an area may be a river reach, a tidal wetland, or any other natural hydrologic catchment area. The accumulation of sediments in any such area will involve the introduction of both parent and daughter isotopes which were formed upstream in the migratory sediments' original location. Thus, when a core is taken from an area of interest, the core will contain not only the isotopes that were deposited through aerial deposition within the catchment area but also isotopes that were transported into the area as a result of sedimentary deposition. Some isotopes also form within the material of interest, itself, as a result of radiogenic decay of parent material that was already present in the material of interest. For example, ^{210}Pb can be deposited in sediments as precipitation, but it also forms as a daughter product from the radiogenic decay of ^{226}Ra within the sediments. Thus, within a system in which ^{210}Pb is used as a geochronometer there are two original sources of ^{210}Pb, and then the ^{210}Pb that has been introduced into the system as a result of sedimentation. Dating such cores requires integrating information from multiple sources or making a series of assumptions. The accuracy of the effort will be sensitive to any assumptions that are made, and independent verification of the radiometric dating will greatly improve its accuracy.

Methods have been developed, primarily by the U.S. Geologic Survey (USGS), to inventory, or separate out the various contributing sources of isotopes to a natural catchment area. First, there are multiple sources of data related to the rates of aerial deposition of many isotopes. Depending on the isotope, institutions such as universities or government agencies, have performed many studies, some long-term, directed at measuring rates of aerial deposition of radioactive isotopes. For instance, in the South Florida area, the University of Miami has tracked aerial deposition of ^{210}Pb and ^{137}Cs for nearly a decade. Under the 1996 Comprehensive Test Ban Treaty, several organizations collect and monitor information on ^{137}Cs deposition at numerous sites in the U.S. Other organizations are interested in radiometric dating to support archeological and paleontological investigations. These sources of information may be used to establish rates of aerial deposition of the isotope to be used in the radiometric dating of sediments.

The second source of an isotope maybe its formation within the sediments of concern. In such cases, the parent material can be directly measured. Using known rates of radioactive decay, an estimate of the amount of daughter product that would be produced by the radiogenic decay of the parent can be generated. This level of daughter product material is often called the "supported" amount of the isotope, or the amount of an isotope that should be present given the amount of the parent material present.

The final source of an isotope within a natural catchment area is that which is introduced through sedimentation, or transported into the system from sources upstream. This is the amount of sediment that is most of interest to site managers at sites whose remedies include natural capping. The amount of sediment being transported into a system can be measured by the amount of isotope that is present but could not have been produced within the system, given the amount of parent material present. Often, this amount is called the "unsupported" amount of the isotope.

Radiometric dating of a catchment system requires establishing an inventory of the isotope present and the related daughter products and determining the amount of the inventory that can be attributed to 1) aerial deposition, 2) in situ formation, and 3) sedimentary transport. Given that the first two can be either estimated based on studies of the local area or directly measured, the amount of the third component can only be attributed to sedimentation.

Important Considerations

There are some factors of which investigators using radiometric dating methods should be aware. Some to consider will include the following:

- First, if no studies are available to establish rates of aerial deposition, then assumptions should be made. Such assumptions should be based on as much relevant information as possible, and the accuracy of the dating method will be sensitive to the validity of those assumptions. For instance, if the assumption underestimates the rate of aerial deposition, then the radiometric dating method will overestimate the amount of sediment being transported into the catchment area and the estimated rate of sedimentation will be too high;

- Second, investigators should be aware that sediment deposition is a dynamic process that reflects not only hydrologic events but also is influenced by man-made events. Furthermore, sedimentation occurs not as a homogeneous, continuous process, but in pulses over time. Therefore, extrapolating results across event short periods of time may result in inaccurate results. For example, in a rapid depositional environment, such as portions of the Chesapeake Bay where rapid urban development is clearing large tracts of land quickly, sedimentation rates may fluctuate significantly over periods as short as one to two years. Therefore, the core intervals that are used for dating should be small enough to account for such variations, usually one to five centimeters;

- Third, relying solely on measurements of isotope activity without taking into account the quality and characteristics of the sediments in which the measurements are made can significantly influence the radiometric dating results. For example, in catchment areas with little or no mixing of sediments, fine-grained sediments settle into fine laminate structures. Concentrations of isotopes within these fine laminate structures may be significantly higher than within laminates of coarser-grained materials, such as sand, and radioactive measurements will also be higher. Thus, without taking into account that material in which the isotope has been deposited, the radiometric method will underestimate the age of the sediments; and

- Fourth, information about significant geologic, ecological, or anthropogenic events should be considered and integrated into the radiometric dating when appropriate. Large-scale housing or industrial construction over extended periods of time can introduce significant quantities of recently-deposited isotopes into the system as a result of erosion of unprotected soils. Similar information can used to benchmark ^{137}Cs levels in sediments. Knowledge of the half-life of ^{137}Cs, and that ^{137}Cs was introduced into the environment as a result of atomic bomb testing in the mid-1950s can be used to validate date estimates using ^{210}Pb as a chronometer. For example, during a study conducted by the USGS in Lake Ponchatrain, Louisiana, using ^{210}Pb as the geochronometer, the method showed that the bottom of the cores taken near the input from the Mississippi River were of about 150 years of age. However, additional testing of the material at the bottom of the cores indicated the presence of ^{137}Cs, which has only been present in the environment since the mid-1950s. A USGS study of the South Florida Bay area used the introduction of the Australian Pine to benchmark ^{210}Pb levels in core samples taken in peat soils. The introduction of the Australian Pine occurred during the early 1900s. Because of the minimal mixing that can be expected in such soils, investigators were able to establish appropriate rates of supported isotope activity with a significant degree of accuracy.

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CONTAMINATED SEDIMENT REMEDIATION GUIDANCE FOR HAZARDOUS WASTE SITES:

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