WD-16-04

NEW HAMPSHIRE DEPARTMENT OF ENVIRONMENTAL SERVICES

Guidance for Assessing and Managing Sediment Behind Dams/Barriers

November 2016

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Executive Summary

The NHDES Dam Removal and River Restoration Program is one of a number of programs within NHDES that provide dam owners with technical assistance and, in some cases, financial assistance for activities associated with the removal of dams and other channel barriers. NHDES has found that assessing and managing sediment can be one of the most challenging, time consuming and costly aspects of a dam/barrier removal project. In an effort to provide consistency to dam/barrier owners and their consultants, increase permitting efficiencies and minimize project costs, NHDES has developed guidance for assessing and managing sediment behind dams/barriers. Sections III, IV and V were prepared by a water resource engineering consulting team from Milone and MacBroom, Inc., in collaboration with NHDES, and with funding from the National Oceanic and Atmospheric Administration's Office for Coastal Management under the Coastal Zone Management Act in conjunction with the NHDES Coastal Program. The guidance is comprised of the following Sections:

- Section I - Dam/Barrier Removal Sediment Assessment & Management Protocol Flow Chart (Protocol)
- Section II - Dam/Barrier Removal Due Diligence Review (DDR) - Protocol Step #1
- Section III - Estimating Sediment Volume Behind a Dam/Barrier - Protocol Steps #1 & 2A
- Section IV - Estimating the Dominant Sediment Particle Size Behind a Dam/Barrier - Protocol Step #2B
- Section V - Estimating the Potentially Mobile Sediment Behind a Dam/Barrier - Protocol Step #4
- Section VI - Evaluation of Sediment Quantity From Dam/Barrier Removals White Paper
- Section VII - De Minimus Sediment Calculator - Protocol Step #5

Table 1 below provides the three most common sediment management alternatives for dam/barrier removal. The Protocol provides a process for determining the most appropriate sediment management alternative.

TABLE ES-1: Common Sediment Management Alternatives for Dam/Barrier Removal

Alternative	Description
No sediment removal	Allow the passive erosion of impounded sediment to take place when volume is low and anticipated impacts are expected to be limited and short-term.
Partial sediment removal (with or without stabilization of the remaining material)	The impounded sediment that is most prone to erosion (e.g., in the proposed channel) is removed while other material that may be associated with floodplains or pre-dam/barrier landforms that is unlikely to erode is left in place to self-vegetate or is stabilized. Short-term impacts are tolerable as the channel and floodplain adjust. This alternative includes partial dam/barrier removal where some sediment is left stabilized behind the remaining portion of the dam/barrier.
Full sediment removal	Removal of all of the impounded sediment where the likelihood of erosion following dam/barrier removal is high, the sediment is contaminated, or long-term impacts are anticipated.

The Protocol provides a process for assessing the risk to water quality and downstream resources and infrastructure from the release of impounded sediment and steps to manage that risk. In accordance with New Hampshire RSA 485-A:12 III,[1] no activity, including construction and operation, that requires a federal license or permit and which may result in a discharge to surface waters, may commence unless NHDES issues a Section 401 Water Quality Certification certifying that the discharge complies with state surface water quality standards[2]. The federal permit associated with most dam/barrier removal projects is the federal Clean Water Act Section 404 permit issued by the U.S. Army Corps of Engineers for the discharge of dredged or fill material. To help ensure that the project will comply with water quality standards, NHDES may require an approved Sediment Management Plan as a condition for Water Quality Certification or, in some cases, as a condition for another NHDES permit issued for the project (such as the NHDES Wetlands Permit). There are points during the process where the Protocol calls for consultation with NHDES. Because NHDES is ultimately the authority for determining if the proposed dam/barrier removal projects comply with water quality standards, **it is strongly recommended that NHDES be consulted at the points noted in the Protocol**.

Sections III, IV, and V are for estimating sediment volume, dominant particle size and the potentially mobile sediment volume and provide charts[3] for identifying the appropriate methods for each task. The methods must be approved by NHDES based on an initial reconnaissance-level estimate of the volume of impounded sediment and the level of risk posed by release of the impounded sediment.[4]

The information needed to determine a preliminary estimate of the level of risk includes:

- Results of the Due Diligence Review (DDR).
- Field measurements of the height of the dam/barrier[5].
- Initial reconnaissance-level estimate of the sediment volume[6].

For a preliminary assessment of what methods will be necessary for estimating sediment volume, sediment particle size and mobile sediment volume (Figure III-2, Figure IV-2 and Figure V-2), a draft response to the questions in the DDR will help assess the risk. It is reasonable to assume that if the answers to questions in the DDR are yes (i.e., yes there are known or potential sources of sediment contamination, yes there is infrastructure present that could be affected), then there is at least a moderate level of risk associated with the sediment. In addition, experience has shown that if the height of the dam/barrier exceeds eight feet, there is likely to be a higher volume of sediment in the impoundment. The final step in conducting a preliminary assessment of the risk of the impounded sediment is to perform a reconnaissance-level initial estimation of sediment volume, V_{RL}, as described in Section III. In general, the larger the volume of impounded sediment

[1] See http://www.gencourt.state.nh.us/rsa/html/L/485-A/485-A-12.htm.
[2] The NHDES Watershed Management Bureau administers the Water Quality Certification program. For more about water quality Certifications, see http://des.nh.gov/organization/divisions/water/wmb/section401/index.htm.
[3] See Figure III-2, Figure IV-2 and Figure V-2.
[4] The Due Diligence Review helps determine the level of risk posed by release of the impounded sediment by identifying downstream resources and infrastructure and potential sources of contamination.
[5] See Section III, Figure III-1. It may also be possible to obtain the height of the dam/barrier by contacting the NHDES Dam Bureau, see http://des.nh.gov/organization/divisions/water/dam/ .
[6] See Section III – INITIAL ESTIMATE OF SEDIMENT VOLUME.

the greater the risk to natural resources and infrastructure. With a preliminary assessment of the risk the charts in Figure III-2, Figure IV-2 and Figure V-2 can help identify what methods should be used.

Section VI provides a discussion of the comparison of the erodible sediment volume in an impoundment with the watershed annual sediment load. This comparison can be important because under some circumstances management of the sediment may be limited to passive erosion of impounded sediment. Section VII (Protocol Step #5) helps to provide an estimate of the watershed annual sediment load for that comparison.

Protocol Steps #1-5 will provide critical data and information for assessing the risk posed by sediment in an impoundment and managing the sediment for a dam/barrier removal project. Sections III – V help with the compilation of this data and information. Review of these Sections by a dam owner and/or a qualified engineering or water resources consultant can also provide a frame of reference for the level of effort for compiling the data and information needed to continue through the process of establishing of a NHDES-approved sediment management plan, if necessary.

For projects where approvals from NHDES will be required, consultation with NHDES to determine the appropriate methods can help avoid project delays and minimize the cost of assessing and managing sediment.

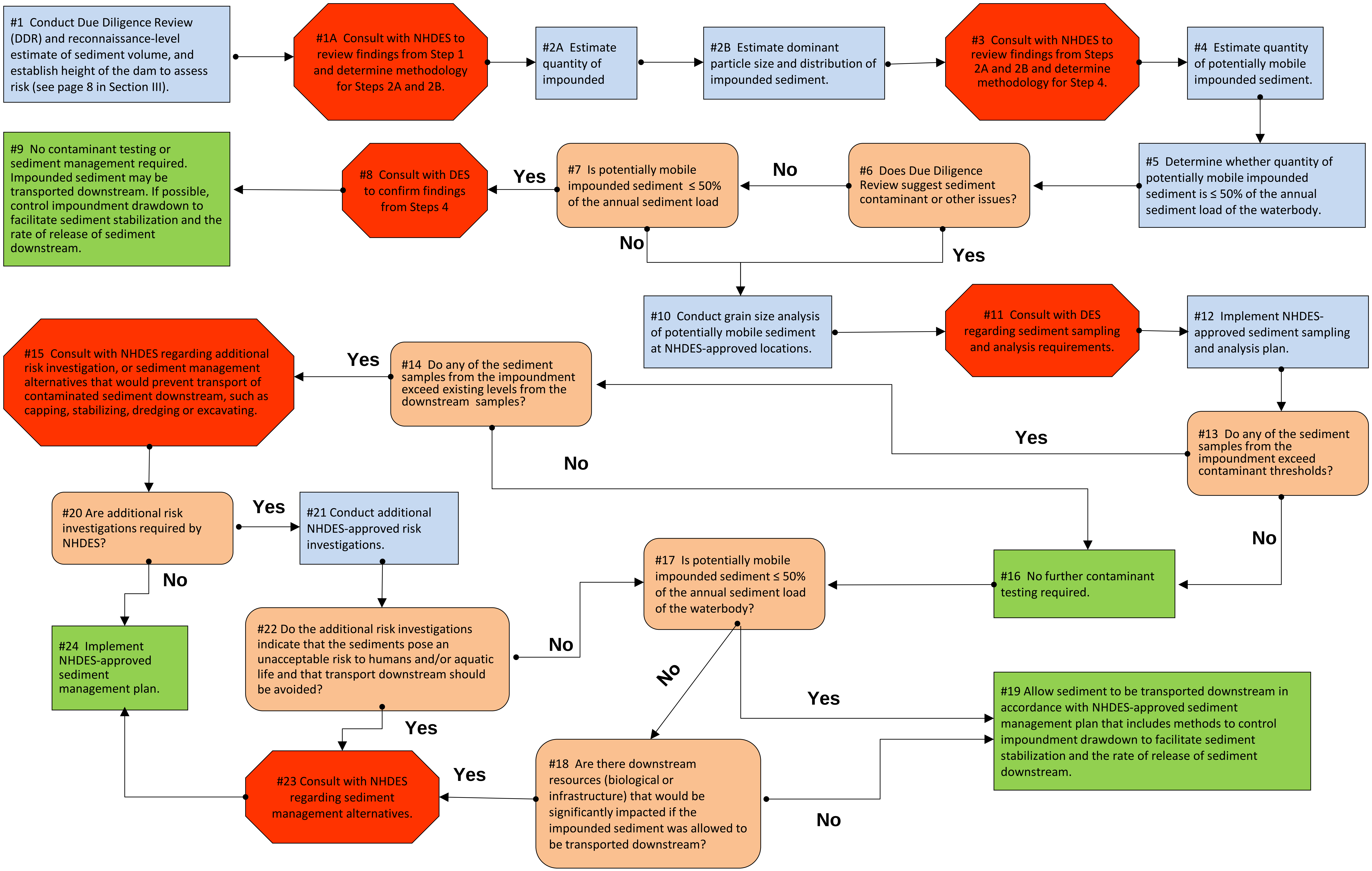
If you have questions about NHDES' Guidance for Assessing and Managing Sediment Behind Dam/Barriers, please contact the NHDES Dam Removal and River Restoration Program at (603) 271-3406.[7]

ACKNOWLEDGEMENTS:
Sections III, IV and V were prepared by Milone & MacBroom, Inc., in consultation with NHDES, and with funding assistance from the National Oceanic and Atmospheric Administration's Office for Coastal Management under the Coastal Zone Management Act in conjunction with the NHDES Coastal Program.

Sections VI and VII were prepared by Ken Edwardson of the NHDES Watershed Management Bureau, Water Quality Assessment Program.

[7] See also http://des.nh.gov/organization/divisions/water/dam/damremoval/index.htm.

I. Dam/Barrier Removal Sediment Assessment & Management Protocol Flow Chart



II. Dam/Barrier Removal Due Diligence Review (DDR)

Conducting a Due Diligence Review (DDR) is Step #1 of the NHDES Dam/Barrier Removal Sediment Assessment and Management Protocol Flow Chart (Protocol).

The purpose of the DDR is to provide a summary of <u>existing</u> information that will help NHDES assess the risk the impounded sediment may pose if the dam/barrier is removed by determining:

- If the impounded sediment is likely to be contaminated and if sediment testing should be required.
- The presence of critical (upstream and downstream) natural resources and infrastructure that might be impacted if the dam/barrier is removed.

To be considered complete, the DDR must include responses to all of the items A-D below. If an item is not applicable, please state so in your submittal. Please be aware that some level of sediment testing will likely be necessary unless the responses to the items below, combined with information obtained through completion of Steps #2-5 of the Protocol, demonstrate that testing of the sediment is not required.

It is intended that the information requested herein can be obtained primarily through a desktop review of existing sources, and not through extensive research or field work. A list of sources that may assist you in providing the requested information is included in the Sources of Information on page 7. **Should you have any questions, contact the NHDES Dam Removal and River Restoration Program at (603) 271-3406.**

A. Project Purpose & Status

Describe why the dam/barrier is proposed to be removed and where you are in the removal process (e.g., initial inquiry, feasibility study/impact analysis, design/engineering, permitting, other).

B. Known and/or Potential Sources of Sediment Contamination

Identify on a map (USGS or similar) and provide a summary all known and/or potential sources of contamination, including (but not limited to) those sources listed below, that could impact the quality of sediments within and upstream of the impoundment and downstream of the dam/barrier.

1. Aboveground storage tanks*
2. Auto salvage yards*
3. Hazardous materials and/or hazardous waste spill sites* (Initial Response Spill)
4. Hazardous waste generators*
5. Remediation sites*
6. Solid waste disposal sites*
7. Underground storage tanks*
8. National Pollutant Discharge Elimination System (NPDES) permitted outfalls
9. Stormwater outfalls
10. Current and historical land use activities (i.e., agricultural, industrial, residential, urban, etc.) at the site and in the watershed upstream and downstream of the dam/barrier?
11. Other known or potential sources of contamination
12. Previously collected sediment data from within the project area

* See NHDES OneStop Environmental Data and Information web page listed in Sources of Information on page 7.

C. Natural Resources Information

1. Are there state or federal rare, threatened, endangered species and/or species of special concern (e.g., dwarf wedge mussel, brook floater mussel, American brook lamprey, etc.) or exemplary natural communities, as identified by the New Hampshire Natural Heritage Bureau*, within the impoundment, and upstream/downstream of the dam/barrier.
2. Are shellfish (e.g., clams, mussels, oysters) or other natural resources commercially or recreationally harvested in the estuary or ocean below the dam/barrier (if head-of-tide dam/barrier)?
3. Please coordinate with the New Hampshire Fish & Game Department to identify any other aquatic and wildlife resources that might be of special concern (e.g., coldwater fisheries, etc.) within the impoundment, and upstream/downstream of the dam/barrier.

* See NHDES OneStop Environmental Data and Information web page listed in Sources of Information on page 7.

D. Dam/Barrier and Other Infrastructure Information

1. What were the original and historical purposes of the dam/barrier and impoundment (e.g., flood control, water supply, hydropower, etc.)?
2. Is this a head-of-tide dam/barrier? (A head-of-tide dam/barrier is located at the upstream limit of water affected by the tide).
3. Is there infrastructure (e.g., bridges, culverts, dams, pipelines, roadways, utilities or other structures) upstream/downstream of the dam/barrier that could be impacted by dam/barrier removal? If so, please describe (size, distance from dam/barrier, etc.) and provide a map (USGS or similar) showing its location in reference to the dam/barrier.
4. Are there water intake structures, including dry hydrants, that could be impacted by dam/barrier removal? If so, please provide a map (USGS or similar) showing their location in reference to the dam/barrier.

Sources of Information

Local Department of Public Works (e.g., infrastructure)

Local Fire Department (e.g., dry hydrants or other fire suppression assets)

Local Board of Health / Town Health Officer

Local Historical Society (e.g., site history, photos, historic infrastructure, etc.)

New Hampshire Department of Agriculture

> Pesticide certification, licensing, registration);
> http://agriculture.nh.gov/divisions/pesticide-control/index.htm
> (603) 271-3550

NHDES

> NHDES OneStop Environmental Data and Information web page - http://www.des.nh.gov/onestop/index.htm (typical information needed: town/city name and/or site address, or tax map and lot number)
>
> Dam Removal and River Restoration Program/Dam Safety & Inspection Program
> http://des.nh.gov/organization/divisions/water/dam/damremoval/index.htm;
> http://des.nh.gov/organization/divisions/water/dam/index.htm; 603-271-3406
>
> Shellfish Program (e.g., maps of shellfish harvesting areas);
> http://des.nh.gov/organization/divisions/water/wmb/shellfish/index.htm; (603) 559-1509
>
> Waste Management Division (e.g., hazardous waste, solid waste, aboveground and underground storage tanks, etc.) http://des.nh.gov/organization/divisions/waste/index.htm; (603) 271-2900

New Hampshire Fish & Game Department

> Nongame & Endangered Program (e.g., state endangered and threatened species, and species of special concern)
> http://www.wildlife.state.nh.us/nongame/index.html; (603) 271-3211

U.S. Geological Survey (USGS)

> Maps (e.g., current and historic topographic maps, stream flow information)
> https://www.usgs.gov/products/maps/overview

III. Estimating the Sediment Volume Behind a Dam/Barrier

Dam/Barrier Removal Sediment Assessment and Management Protocol (Step #2A)

OBJECTIVES:

The objectives of this Section include:

- Computation of a reconnaissance-level initial estimation of the volume of impounded sediment.
- Preliminary assessment of the risk the sediment may pose when the dam/barrier is removed.
- Identification of the most appropriate method for computing the volume of impounded sediment based on risk and volume.
- Introduction to sediment volume estimation methods, data requirements, and necessary levels of effort and resources.

INITIAL ESTIMATION OF SEDIMENT VOLUME:

A reconnaissance-level initial estimation of sediment volume (V_{RL}) is recommended per Step #1 of the Dam/Barrier Removal Sediment Assessment and Management Protocol Flow Chart (Protocol). V_{RL} combined with a determination of sediment risk, will help to refine the sediment volume estimate using one of the three methods provided in this Section (see Figure III-2). This initial sediment volume calculation is made by estimating the impoundment area (A_I) dimensions from an aerial photograph (available from NH GRANITView http://granitview.unh.edu/) or a topographic map (available from the US Geological Survey), and estimating the sediment thickness as 1/3 of the dam/barrier height (H_D), as determined through field measurements. This reconnaissance-level estimate is used to determine the order of magnitude (e.g., 10s, 100s or 1,000s of cubic feet or cubic yards) of sediment volume in the impoundment prior to field observations and additional calculations.

$$V_{RL} = A_I \times (1/3\ H_D)$$

V_{RL} = reconnaissance-level initial estimation of sediment volume (cubic feet)
A_I = estimated impoundment area (square feet)
H_D = height of the dam/barrier on the downstream side (feet)

For reference, the amount of time for a dam owner to conduct a reconnaissance-level initial estimation of sediment volume using the resources referenced above is estimated to be 10 hours.

PRELIMINARY ASSESSMENT OF SEDIMENT RISK:

1. Due Diligence Review (DDR)
The first step in conducting a preliminary assessment of the risk the impounded sediment may pose when the dam/barrier is removed is to complete the Dam/Barrier Removal Due Diligence Review Guidance Document (DDR), as referenced in Step #1 of the Dam/Barrier Removal Sediment Assessment and Management Protocol Flow Chart (Protocol). The DDR will help identify known and potential sources of sediment contamination as well as natural resources and infrastructure that could be impacted by release of the sediment. If the results of the DDR indicate the presence of known or potential sources of contamination, and potentially impacted natural resources or infrastructure, it is likely that release of the sediment will pose at least a moderate level of risk.

2. Measure the Height of the Dam/Barrier
Once the DDR is complete, the next step in conducting a preliminary assessment of the risk of the impounded sediment is to measure the height of the dam/barrier on the downstream side. If the height of the dam/barrier exceeds eight feet, there is likely to be a large volume of sediment in the impoundment relative to the sediment load of the waterbody. Release of this sediment may pose at least a moderate level of risk.

3. Determine a Reconnaissance-Level Initial Estimation of Sediment Volume
The third and final step in conducting a preliminary assessment of the risk of the impounded sediment is to perform a reconnaissance-level initial estimation of sediment volume, V_{RL}, as described on page 8. In general, the larger the volume of impounded sediment the greater the risk to natural resources and infrastructure. At this point, consultation with NHDES is strongly recommended not only to review the dam/barrier height and V_{RL} calculations and the findings of the DDR but to determine the most appropriate method for estimating the volume of impounded sediment, per Table III-1 and Figure III-2.

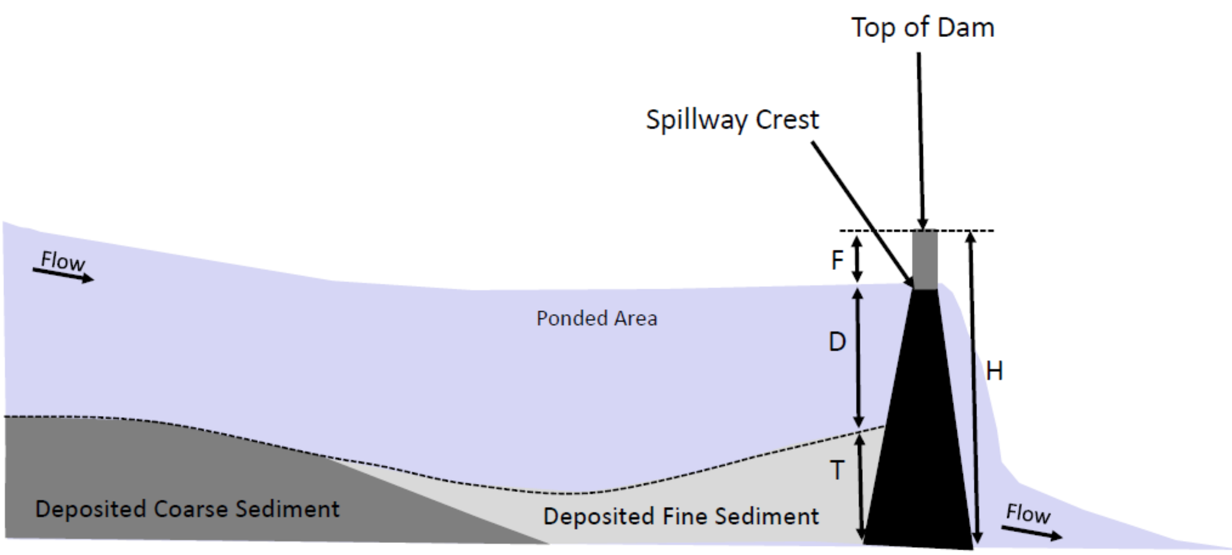


FIGURE III-1: Dam/Barrier Height on the Downstream Side (H), Water Depth (D), Freeboard (F), and Sediment Thickness (T)

TABLE III-1: Typical Sediment Volume Estimation Methods (See Figure III-2)

Method #	Description	Application	Accuracy
III-1	Field measurements of impoundment area dimensions and single thickness measurement at dam/barrier	Low risk and small to intermediate volume	± 100%
III-2	Probing at one or more locations to measure sediment thickness	Low risk and large volume; Moderate risk and small to intermediate volume; High risk and small volume	± 50%
III-3	Distributed probes or borings to determine sediment thickness and survey to measure dimensions of impoundment area	Moderate risk and large volume; High risk and intermediate to large volume	± 20%

VOLUME ESTIMATION METHODS

The three methods for estimating the sediment volume in the impoundment upstream of a dam/barrier described herein require basic data inputs such as aerial photographs, field observations and field measurements. Field measurements include, dam/barrier height, freeboard, water depth and sediment depth (see Figure III-1). The typical methods and anticipated level of accuracy, as described in Table III-1, are a function, in part, of the results of an initial sediment volume estimation and the level of project risk.[1]

Figure III-2 provides guidance on selecting the appropriate method for estimating sediment volume. A more detailed method may be requested by NHDES for impoundments where the level of risk and/or sediment volumes are determined to be moderate to high. It is strongly recommended that NHDES be consulted before selecting a method for estimating sediment volume.

[1] The level of risk (low, moderate, high) is derived from the Due Diligence Review and the height of the dam/barrier. Consult with NHDES for assistance with determining the level of risk for use with Table III-1 and Figure III-2.

ESTIMATE SEDIMENT VOLUME

The level of risk posed by the impounded sediment is determined from a Due Diligence Review, field measurements of the height of the dam/barrier, and an initial reconnaissance level estimate of sediment volume (Protocol Step #1). Consult with NHDES for an assessment of the level of risk and to determine the appropriate method for estimating sediment volume. For the same chart with additional technical detail regarding estimation of sediment volume and determination of risk, please see next page.

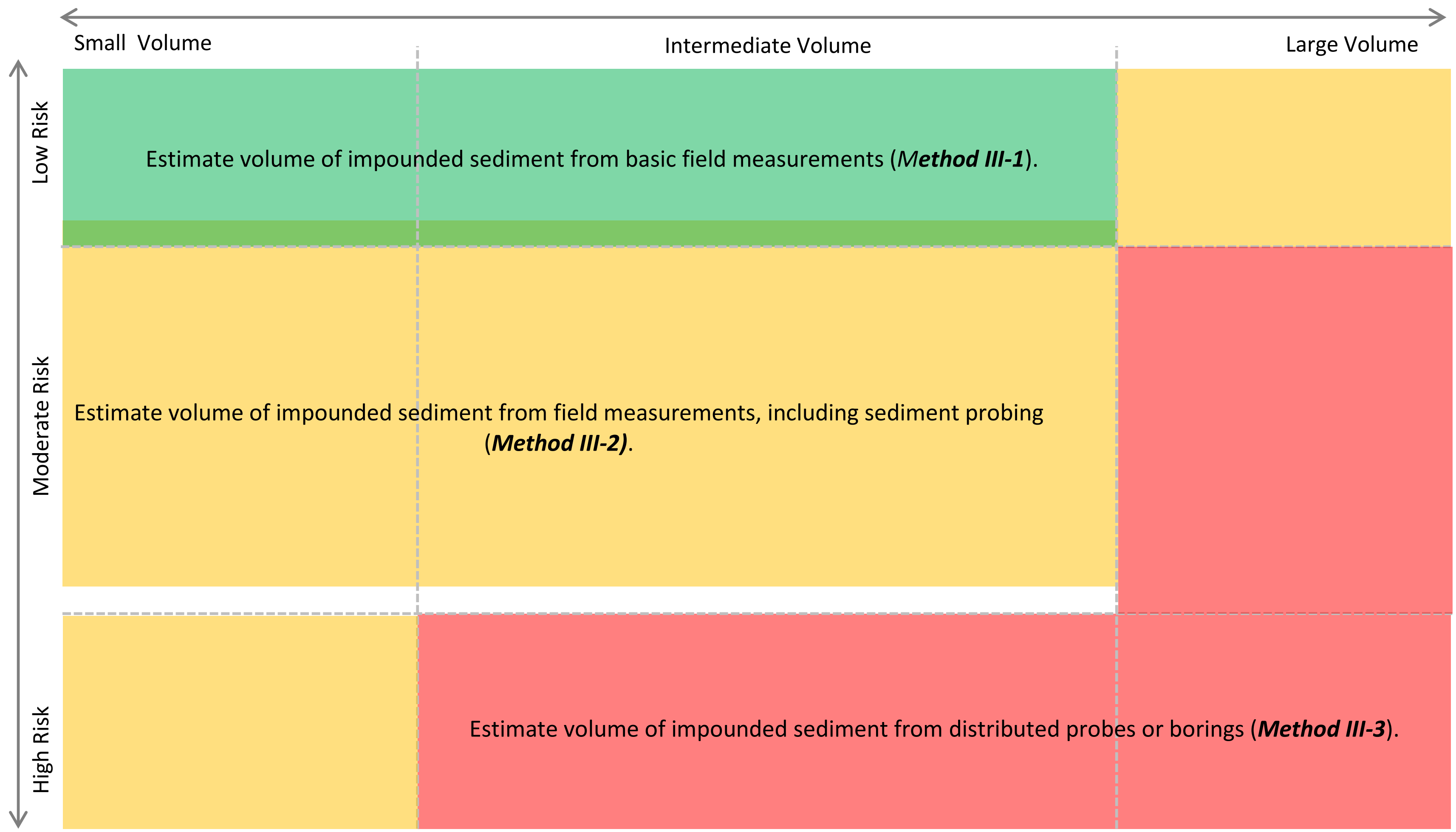


FIGURE III-2: Sediment Volume Typical Estimation Methods

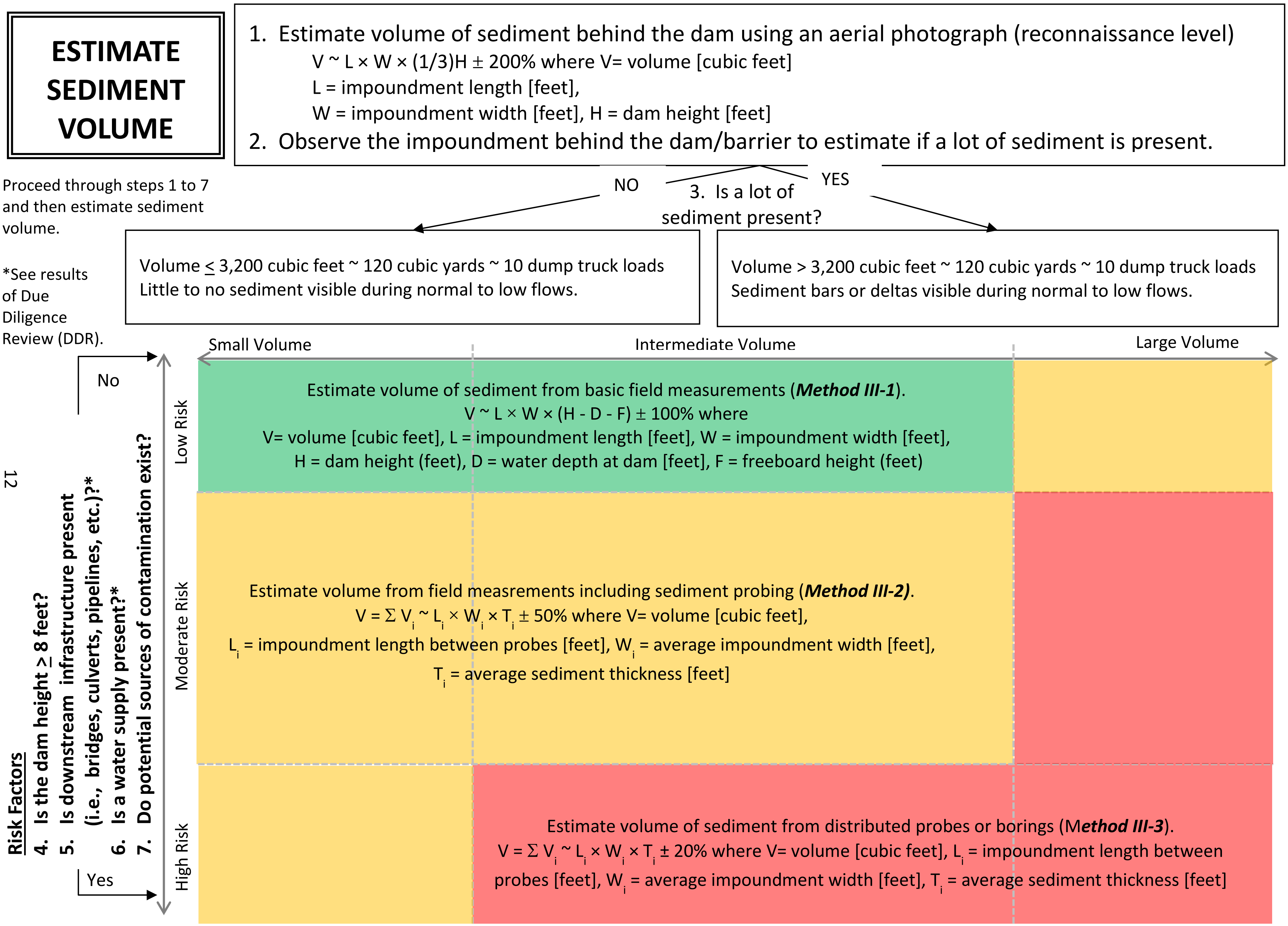


FIGURE III-2A Sediment Volume Typical Estimation Methods (Enhanced)

METHOD III-1: Basic Field Measurements (see also Figures III-1 and III-3)

TABLE III-2: Variables for the Basic Field Measurement Method

Variable	**Units**	**Measurement / Calculation**	**Example**
Impoundment Length (L)	Feet (ft)	Length from dam/barrier to upstream extent of impoundment area	L = 560 ft
Average Impoundment Width ($\overline{W}$)	Feet (ft)	Average impoundment width (Figure III-3)	W_1 = 30 ft, W_2 = 65 ft, W_3 = 25 ft $\overline{W} = 40$ ft
Dam/Barrier Height on Downstream Side (H)	Feet (ft)	Obtain downstream dam height from plans or field measurement (Figure III-1)	H = 15 ft
Water Depth (D)	Feet (ft)	Depth of water at upstream face of dam/barrier (Figure III-1)	D = 9 ft
Freeboard (F)	Feet (ft)	Distance between water surface and top of dam/barier (Figure III-1)	F = 3 ft
Estimated Sediment Thickness (T)	Feet (ft)	T = H – D – F	T = 3 ft
Volume (V)	Cubic Feet (CF) Cubic Yards (CY)	$V \sim L \times \overline{W} \times T \pm 100\%$	V~67,200 CF~2,489 CY $\pm 100\%$

NOTES:

- The Example in Table III-2 is provided solely for the purpose of demonstrating a computation using Basic Field Measurements (Method III-1).
- Cubic Yards (CY) = Cubic Feet (CF) ÷ 27.
- Measurements can be made with tape measure or laser range finder.
- Several width measurements should be averaged if impoundment shape is irregular (unlike a rectangle).
- Top of dam/barrier is upper most surface of the structure (e.g., abutment, road, walkway).
- This method often results in a conservative estimate of sediment volume since sediment thickness is often greatest at the dam/barrier.
- Method III-1 can be suitable for impoundments where the sediment has been determined to be low-risk and the sediment volume is estimated to be small to intermediate.
- For reference, the amount of time for a dam owner to compute sediment volume using Method III-1 is estimated to be 20 hours. This estimate is provided as a reference only, and can vary with the level of access by the dam owner to electronic resources that are available to compute the area of an impoundment. All dam/barrier removal projects vary in size, scope, complexity, and cost.

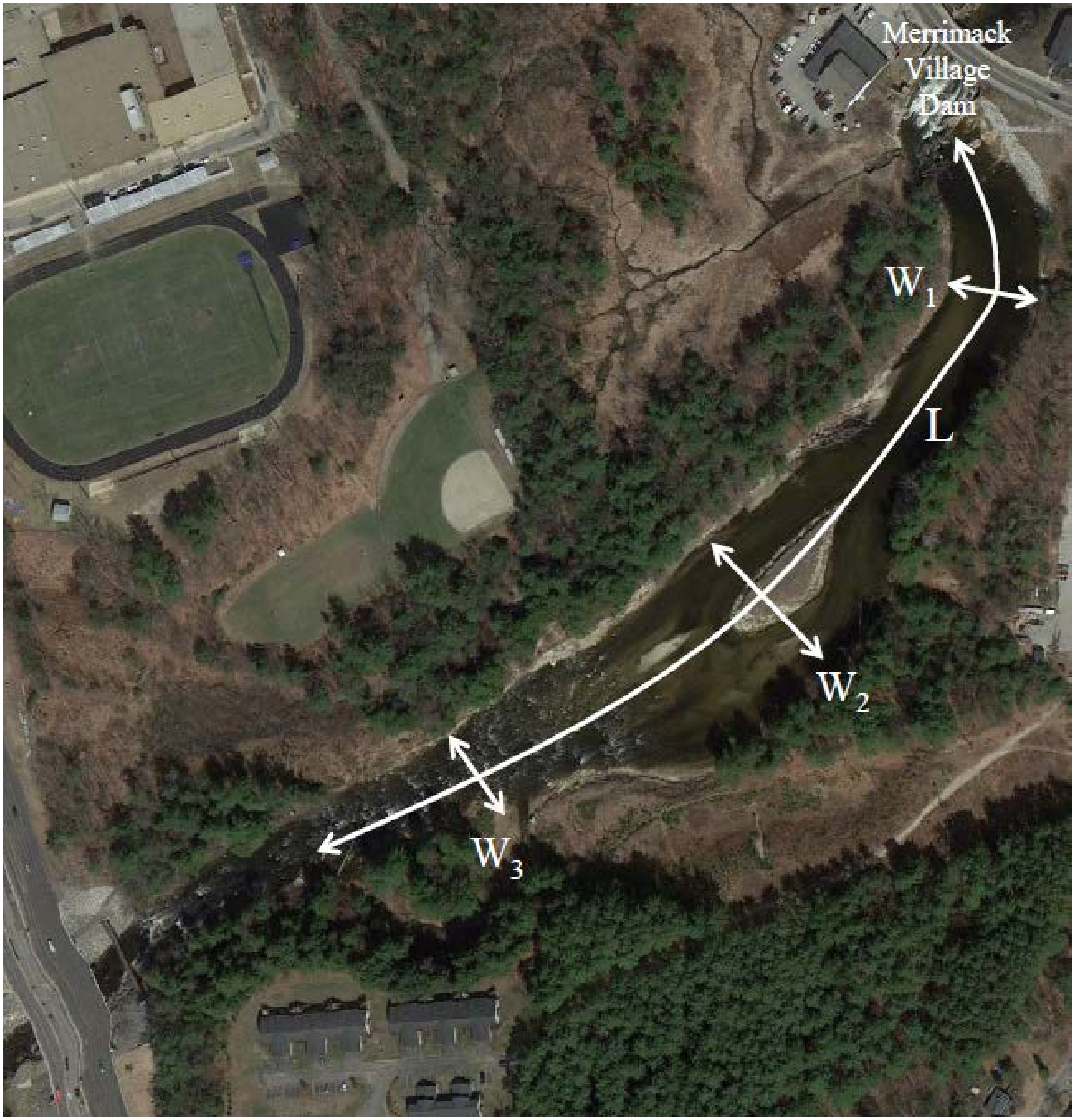


FIGURE III-3: Schematic of the Basic Field Measurement Method

METHOD III-2: Basic Sediment Probing (See Figures III-1 and III-4)

TABLE III-3: Variables for the Sediment Probing Method

Variable	**Units**	**Measurement / Calculation**	**Example**
Impoundment length (L_i)	Feet (ft)	Impoundment length between probe locations (Figure III-4)	$L_{1,2}$ = 300 ft, $L_{2,3}$ = 260 ft
Average Impoundment Width ($\overline{W}_i$)	Feet (ft)	Average impoundment width at adjacent probe locations (Figure III-4)	W_1 = 30 ft, W_2 = 65 ft, W_3 = 25 ft $\overline{W} = 40$ ft
Average Sediment Thickness ($\overline{T}_i$)	Feet (ft)	Average sediment thickness from adjacent probe locations (Figure III-4)	T_1 = 5 ft, T_2 = 3 ft, T_3 = 0 ft
Volume (V_i)	Cubic Feet (CF) Cubic Yards (CY)	Sediment volume between each probe location, $V_i \sim L_i \times \overline{W}\ i \times \overline{T}\ i$ (Figure III-4)	$V_{1,2} \sim$ 54,000 CF $\sim$ 2,000 CY $V_{2,3} \sim$ 19,500 CF $\sim$ 722 CY
Volume (V)	Cubic Feet (CF) Cubic Yards (CY)	$V \sim \sum V_i \pm 50\%$ (Figure III-4)	V $\sim$ 73,500 CF $\sim$ 2,722 CY $\pm 50\%$

NOTES:

- The Example in Table III-3 is provided solely for the purpose of demonstrating a computation using Basic Sediment Probing (Method III-2).
- Cubic Yards (CY) = Cubic Feet (CF) ÷ 27.
- Probing performed with rebar, PVC tube, stainless steel rods, or other sediment sampling devices. Drive sampler to refusal with sledge hammer or post-driver. Penetration distance equals sediment thickness.
- Several width measurements should be averaged if impoundment shape is irregular (unlike a rectangle).
- At least two probes per cross section are recommended.
- One cross section taken near the upstream face of the dam/barrier can be used when the sediment thickness and impoundment width are relatively uniform throughout the impoundment or for smaller impoundments (i.e., < 1 acre).
- More than two cross sections are typically necessary when sediment thickness is variable in the impoundment area, such as a long impoundment with a thick deposit near the dam/barrier and a thin deposit at the upstream end of the impoundment (Figure III-4). In such cases, cross sections should be taken near the upstream face of the dam/barrier and the inlet to the impoundment. When more than two cross sections are needed, cross section spacing typically ranges from 100 feet to one quarter of the length of the impoundment (whichever is less).
- The location of the probes can be identified by measuring the distance from the dam/barrier, marking on an aerial photograph, or using GPS coordinates.
- This method typically takes about two to four days for the dam owner to perform but can vary depending on the size and shape of the impoundment. This estimate is provided as a reference only, and can vary with the level of access by the dam owner to electronic resources that are available to compute the area of an impoundment and the ability to conduct the necessary field measurements and probes. All dam/barrier removal projects vary in size, scope, complexity and cost.

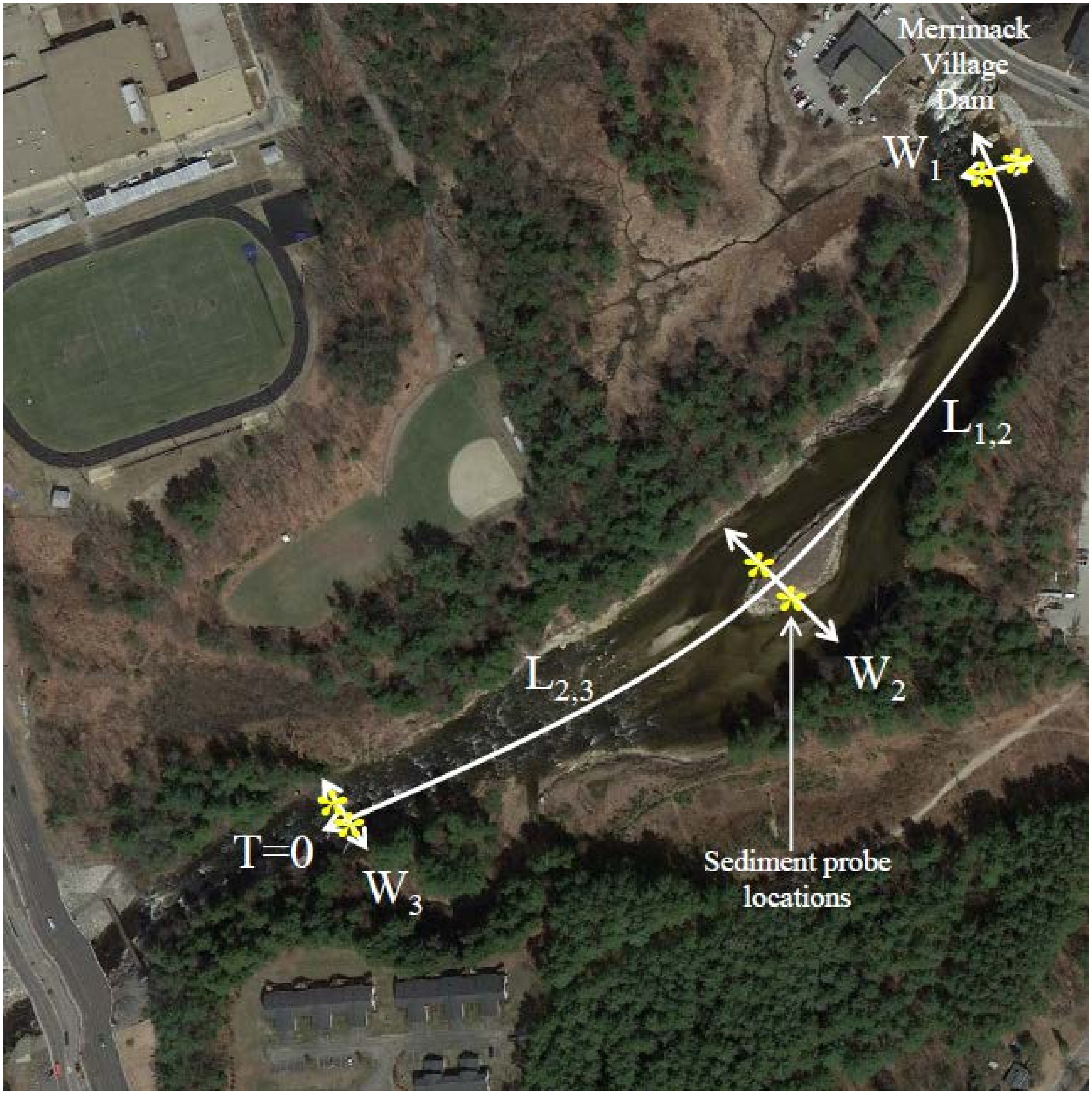


FIGURE III-4: Schematic of Sediment Probing at Several Cross Sections

METHOD III-3: Distributed Sediment Probing or Boring (See Figures III-1 and III-5)

TABLE III-4: Variables for the Distributed Sediment Probing or Boring Method

Variable	**Units**	**Measurement / Calculation**	**Example**
Impoundment Length (L_i)	Feet (ft)	Impoundment length between probe locations (Figure III-5)	$L_{1,2}$ = 170 ft, $L_{2,3}$ = 130 ft $L_{3,4}$ = 140 ft, $L_{4,5}$ = 120 ft
Average Impoundment Width ($\overline{W}_i$)	Feet (ft)	Average impoundment width at adjacent probe locations (Figure III-5)	W_1 = 35 ft, W_2 = 53 ft, W_3 = 65 ft W_4 = 40 ft, W_5 = 25 ft $\overline{W} = 43.6$ ft
Average Sediment Thikness ($\overline{T}_i$)	Feet (ft)	Average of the cross-sectional sediment thickness at adjacent probe locations	T_1 = 5 ft, T_2 = 4.5 ft, T_3 = 3.5 ft T_4 = 2 ft, T_5 = 0 ft $\overline{T} = 43.6$ ft
Volume (V_i)	Cubic Feet (CF) Cubic Yards (CY)	Sediment volume between each probe location, $V_i \sim L_i \times \overline{W}\ i \times \overline{T}\ i$ (Figure III-5)	$V_{1,2} \sim$ 35,530 CF $\sim$ 1,316 CY $V_{2,3} \sim$ 30,680 CF $\sim$ 1,136 CY $V_{3,4}$ $\sim$ 20,212 CF $\sim$ 749 CY $V_{4,5} \sim$ 3,900 CF $\sim$ 144 CY
Volume (V)	Cubic Feet (CF) Cubic Yards (CY)	$V \sim \sum V_i \pm 20\%$	V~90,322 CF~3,345 CY $\pm 20\%$

NOTES:

- The Example in Table III-4 is provided solely for the purpose of demonstrating a computation using Distributed Sediment Probing or Boring (Method III-3).
- Cubic Yards (CY) = Cubic Feet (CF) ÷ 27.
- Probing/boring should take place along the channel at regular intervals to measure changes in sediment thickness and volume for the entire length of the impoundment.
- At least four cross sections are recommended over the length of the impoundment.
- Probing/boring should take place along each cross section to measure changes in sediment thickness across the impoundment width. Three to five probes or borings are typically performed at each cross section.
- Cross sections should be taken near the upstream face of the dam/barrier and upstream end of the impoundment. Cross section spacing can range from 100 feet to one quarter of the length of the impoundment (whichever is less).
- If the impoundment shape deviates from a rectangle and high accuracy is required, consider calculating the sediment area at each probe cross section. The sediment volume between each cross section is calculated by multiplying the average sediment area at two adjacent cross sections by the length between the two sections. The total sediment volume is the sum of the volume between each cross section pair.
- This method usually requires a boring contractor and a professional river scientist or engineer. Track- or barge-mounted boring rigs are common, although probing can be performed with a tripod-mounted unit or by hand. The cost of borings will depend on the number of days necessary to keep the equipment on-site to conduct the borings.
- It is estimated that Method III-3 will approximately 10 hours of the dam owner's time to collect field measurements, approximately 36 hours of work by a professional water resource scientist or engineer, and two days (16 hours) to complete the borings. This estimate is provided as a reference only. All dam/barrier removal projects vary in size, scope, complexity and cost.

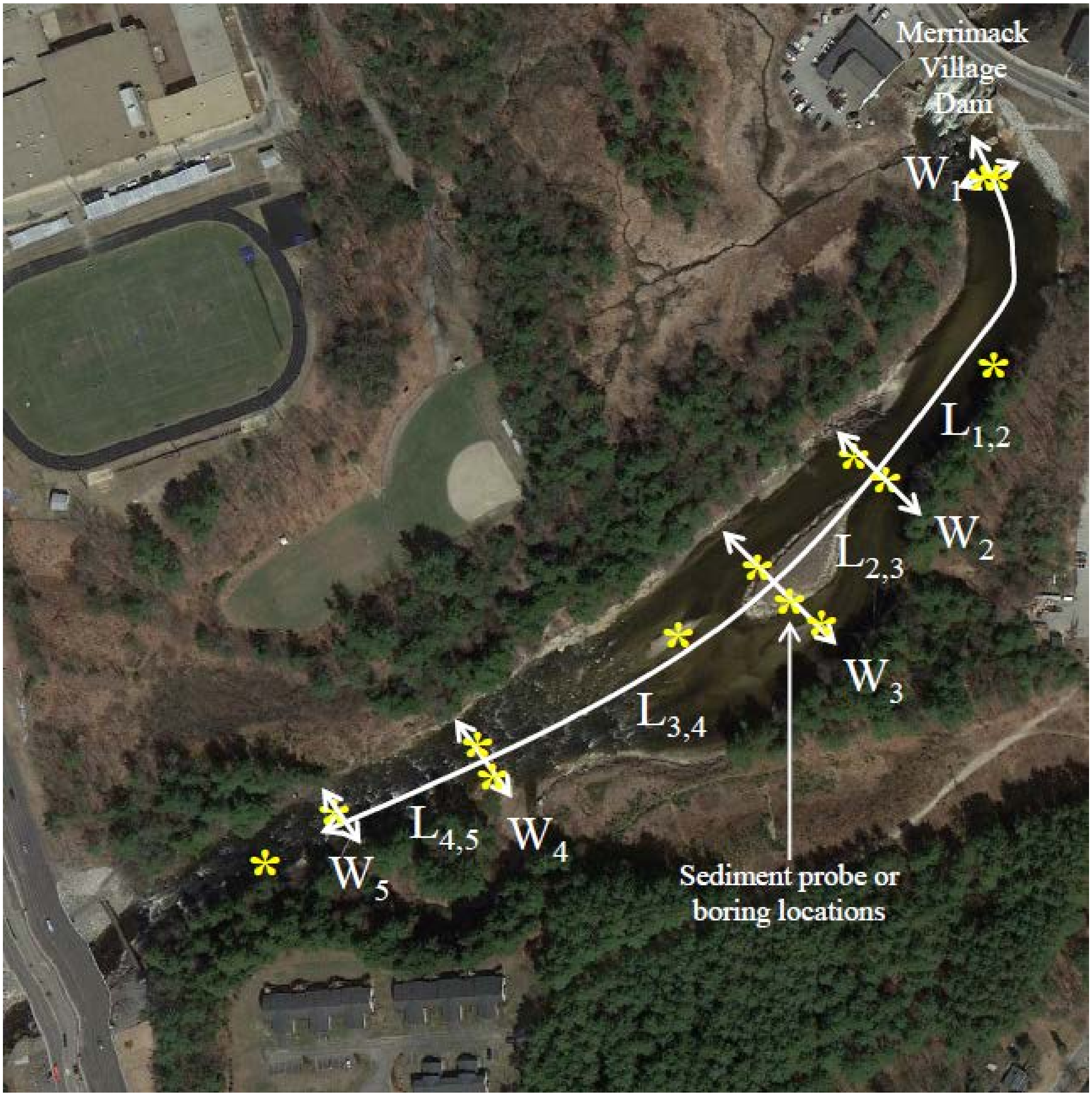


FIGURE III-5: Schematic of the Distributed Sediment Probing or Boring Method

SUMMARY: This Section was prepared to assist interested parties to better understand some common methods for estimating sediment volume in an impoundment, and how risk and other characteristics of the sediment affect the level of accuracy that will be required. The Due Diligence Review, a reconnaissance-level initial estimation of sediment volume, and field measurements of the dam/barrier height are used to help determine the level of risk of the impounded sediment. With that information, Figure III-2 helps identify which method for estimating sediment volume is most appropriate. To help avoid excess cost and project delays, it is recommended that applicants consult NHDES before selecting a method for estimating sediment volume. To save time, consider discussing which method for estimating dominant sediment particle size and distribution Section IV is most appropriate at the same time.

IV. Estimating the Dominant Sediment Particle Size and Distribution Behind a Dam/Barrier

Dam/Barrier Removal Sediment Assessment and Management Protocol (Step #2B)

OBJECTIVES:

The Objectives of this Section include:

- Computation of a reconnaissance level initial estimation of the dominant sediment particle size.
- Preliminary assessment of the risk the sediment may pose when the dam/barrier is removed.
- Identification of the most appropriate method for computing the volume of impounded sediment based on risk and volume.
- Introduction to sediment particle size estimation methods.
- Computation of sediment particle size.

The Barrier Removal Sediment Assessment and Management Protocol Flow Chart (Protocol) provides a process for assessing the risk to water quality and downstream resources and infrastructure from the release of impounded sediment and steps to manage that risk. Step #1 of the Protocol includes completion of a Due Diligence Review while Step #2A involves estimating the volume of impounded sediment. Once those two steps have been completed, the dominant sediment particle size in the impoundment upstream of a dam/barrier is estimated, per Step #2B of the Protocol. The sediment particle size estimation can be used to help understand the potential risks associated with a dam/barrier removal project or dam/barrier failure including impacts to water quality, instream habitat, biological communities and channel stability. Following completion of Step #2B, consultation with NHDES is strongly recommended before proceeding further with the Protocol.

INITIAL ESTIMATION OF DOMINANT PARTICLE SIZE:

A reconnaissance-level initial estimation of the dominant particle size is recommended for all projects prior to refining the estimation with one of the three methods listed in Table IV-1. The initial estimation is made by observing the surface sediment in the impoundment during low flow. Handfulls of sediment are collected to identify areas of mud (clay, silt, fine sand), sand, gravel, cobbles or boulders. Mud will be sticky, squeezable and full of water. Sand is what you typically associate with a beach. A grain of gravel is larger than the head of a match but smaller than a tennis ball. A cobble is roughly between the size of a tennis ball and a basketball, while boulders are larger than basketballs. Bedrock is often larger than a small car and often occurs as outcrops or slabs.

PRELIMINARY ASSESSMENT OF SEDIMENT RISK:

A methodology for preliminarily assessing the risk that the impounded sediment may pose when the dam/barrier is removed is described in Section III. The methodology involves completion of the Due Diligence Review (DDR), measurement of the dam/barrier height and calculation of a reconnaissance-level initial estimation of sediment volume (V_{RL}). This initial understanding of potential risk is improved using the reconnaissance-level initial estimation of the dominant particle size described above. While it is possible that a high bedload of coarse material could erode and create risk to nearby infrastructure, in general, for a given sediment volume, coarser sediment, such as gravel and cobble, tends to pose less risk to downstream aquatic resources, since it is less mobile during a given flow and less likely to contain contaminants. However, fine sediment, such as sand and silt, is more mobile and can lead to habitat and water quality impacts downstream, especially if a high volume of fine material has accumulated behind the dam/barrier.

The results of the reconnaissance-level estimation of the dominant particle size and DDR, combined with the dam/barrier height and V_{RL} calculations, are used to determine the most appropriate method for estimating the dominant sediment particle size (Table IV-1 and Figure IV-1). Consultation with NHDES is strongly recommended to determine the most appropriate method for estimating the dominant particle size in the impoundment.

SEDIMENT PARTICLE SIZE ESTIMATION METHODS: Three methods of estimating the dominant sediment particle size upstream of a dam/barrier that require basic field observations and measurements are described herein. The typical methods and anticipated level of accuracy (Table IV-1) are a function of the results of an initial sediment particle size estimation and the level of project risk (Figure IV-1), and are linked to the sediment volume estimation calculated in Section III. A more detailed method of estimating the dominant sediment particle size may be requested by NHDES based on an increased level of risk or a higher anticipated sediment volume than initially estimated for the site. It is strongly recommended that NHDES be consulted before selecting a method for estimating dominant sediment particle size.

TABLE IV-1: Typical Sediment Particle Size Estimation Methods (see also Figure IV-1)

Method #	Description	Application (by project risk)	Accuracy
IV-1	Estimate dominant particle size of surface material at several points in the impoundment from field observations	Low risk and intermediate to coarse texture sediments	± 50%
IV-2	Estimate dominant particle size of surface and sub-surface sediment from field observations, sediment probing, and samples	Low risk and fine texture sediments; Moderate risk and intermediate to coarse texture sediments; High risk and coarse texture sediments	± 25%
IV-3	Calculate texture from laboratory analysis of samples collected at various depths	Moderate risk and fine texture sediments; High risk and fine to intermediate texture sediments	± 10%

ESTIMATE SEDIMENT SIZE

The level of risk posed by the impounded sediment is determinied from a Due Diligence Review, field measurements of the height of the dam/barrier, initial reconnaissance level estimate of sediment volume (Protocol Step #1), and an initial reconnaissance level estimate of the dominant particle size (Protocol Step #2B). Consult with NHDES for an assessment of the level of risk and to determine the appropriate Method for estimating sediment particle size. For the same chart with additional technical detail regarding estimation of sediment size and determination of risk, please see next page.

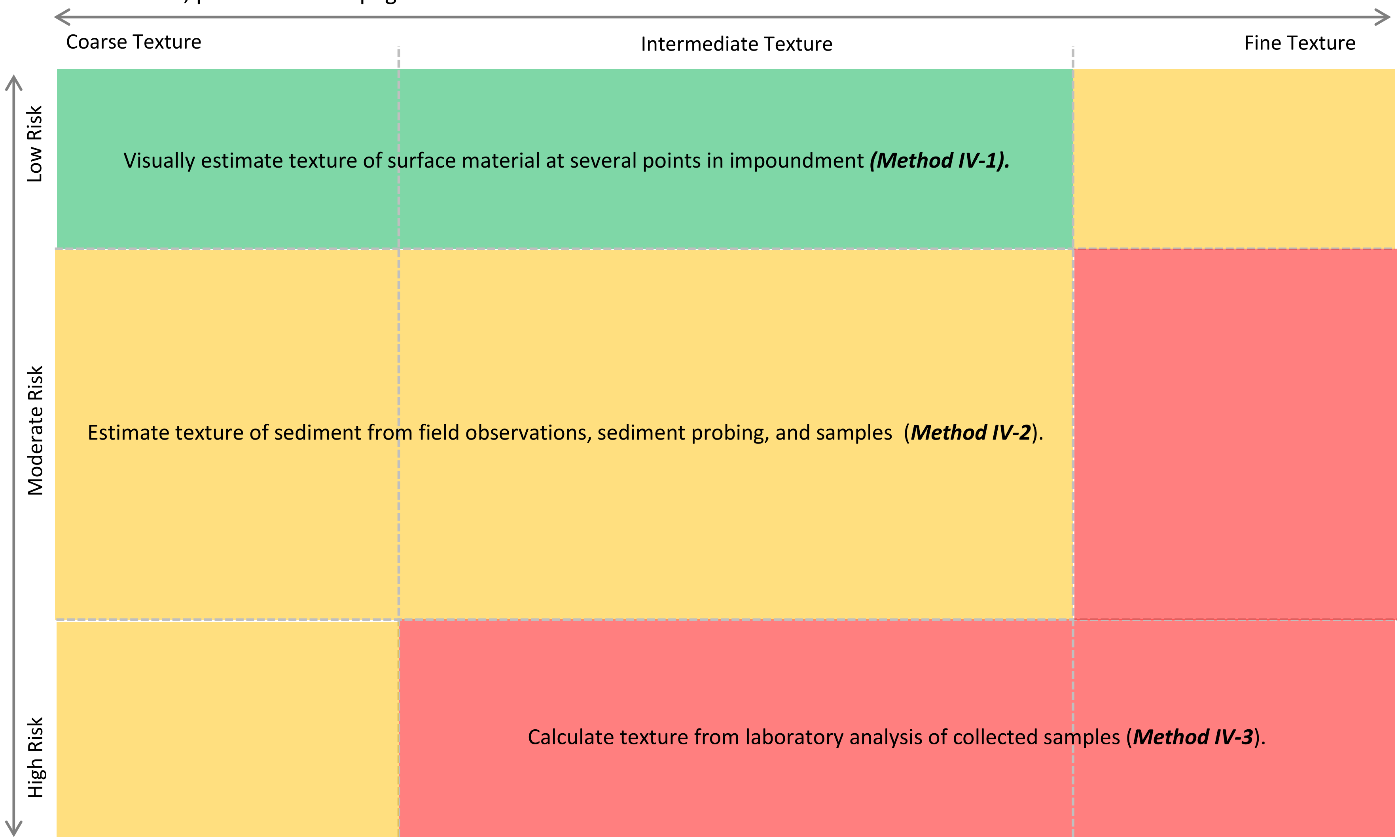


FIGURE IV-1: Sediment Size Typical Estimation Methods

ESTIMATE SEDIMENT SIZE

1. Is sediment in impoundment mud, sand, gravel, cobble, or boulder (*reconnaissance level*)?
Mud (clay, silt, fine sand) will be squeezable and full of water, sand is what you typically associate with a beach, gravel is larger than the head of a match, cobble is the size of a softball or larger, boulders are larger than basketballs.
2. Observe the impoundment behind the dam/barrier to estimate if a lot of sediment is present.

Proceed through steps 1-7 and then estimate sediment texture.

*See results of Due Diligence Review (DDR).

3. Is sediment texture fine, intermediate or coarse?

NO → Coarse (gavel, cobbles, boulders)
Little to no sediment visible during normal to low flows.

YES → Fine (e.g., clay, silt) or intermediate (e.g., sand)
Sediment bars or deltas visible during normal to low flows.

Risk Factors

4. Is the dam height ≥ 8 feet?
5. Is downstream infrastructure present (i.e., bridges, culverts, pipelines, etc.)?*
6. Is a water supply present?*
7. Do potential sources of contamination exist?*

No → Low Risk; Yes → High Risk

Risk	Coarse Texture	Intermediate Texture	Fine Texture
Low Risk	Visually estimate texture of surface material at several points in impoundment (***Method IV-1***).	Visually estimate texture of surface material at several points in impoundment (***Method IV-1***).	Estimate texture of sediment from observations, sediment probing, and samples (***Method IV-2***).
Moderate Risk	Estimate texture of sediment from observations, sediment probing, and samples (***Method IV-2***).	Estimate texture of sediment from observations, sediment probing, and samples (***Method IV-2***).	Calculate texture from laboratory analysis of collected samples (***Method IV-3***).
High Risk	Estimate texture of sediment from observations, sediment probing, and samples (***Method IV-2***).	Calculate texture from laboratory analysis of collected samples (***Method IV-3***).	Calculate texture from laboratory analysis of collected samples (***Method IV-3***).

METHOD IV-1: Visual Field Observations (See Figure IV-2)

Field observations are made around the impoundment where sediment is accessible. Sediment samples are retrieved by hand or shovel and the texture is felt to estimate the particle size. Findings are typically sketched on an aerial photograph or topographic map to show the distribution of surface sediment sizes (Figure IV-2).

NOTES:

- Collect samples by hand, trowel or shovel for texture identification in the field for fine sediment.
- Note texture on map.
- Draw approximate boundaries to separate areas of different dominant particle size.
- To assist with identifying the dominant particle size for fine sediment, place a small sediment sample in a mason jar, fill with water, place lid on jar, and shake. The sediment will settle and layer from coarse to fine starting on the bottom. Gravel and sand will settle in seconds. Fine sand will stay in suspension for a few minutes. Silt and clay will remain in the water for hours to days. The thickest layer is likely the dominant particle size (Figure IV-3).
- Estimate the distribution (Figure IV-4) and measure (Figure IV-5) the dominant particle size in a 1-meter square quadrat for coarse material.
- It is estimated that this method will take the dam owner approximately 4 hours to perform.

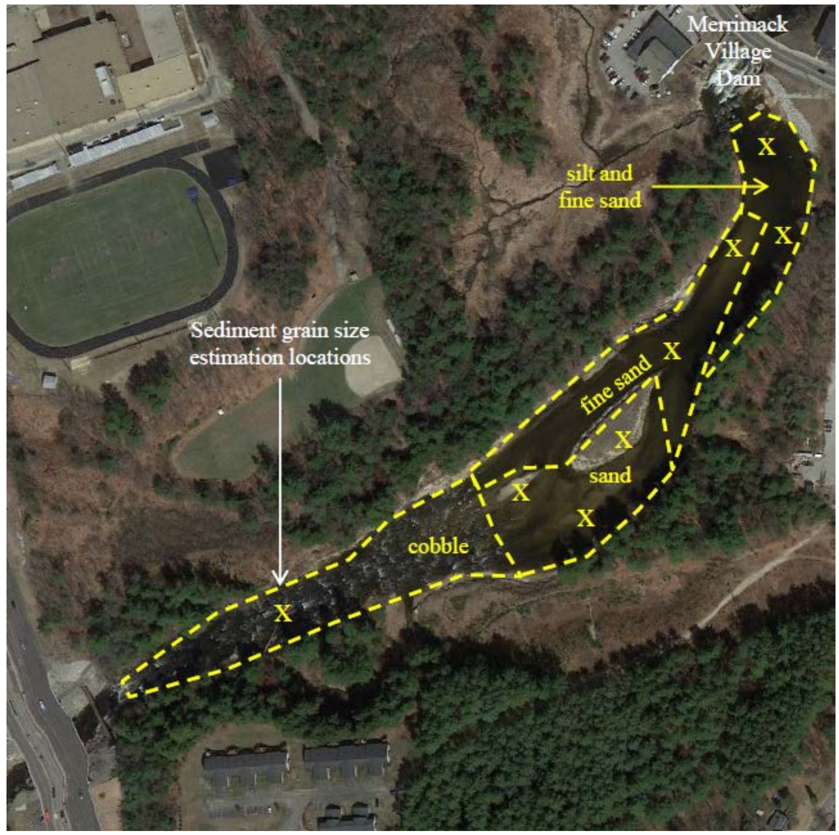


FIGURE IV-2: Map of Sediment Size Distribution

FIGURE IV-3: Jar Test to Estimate Dominant Particle Size

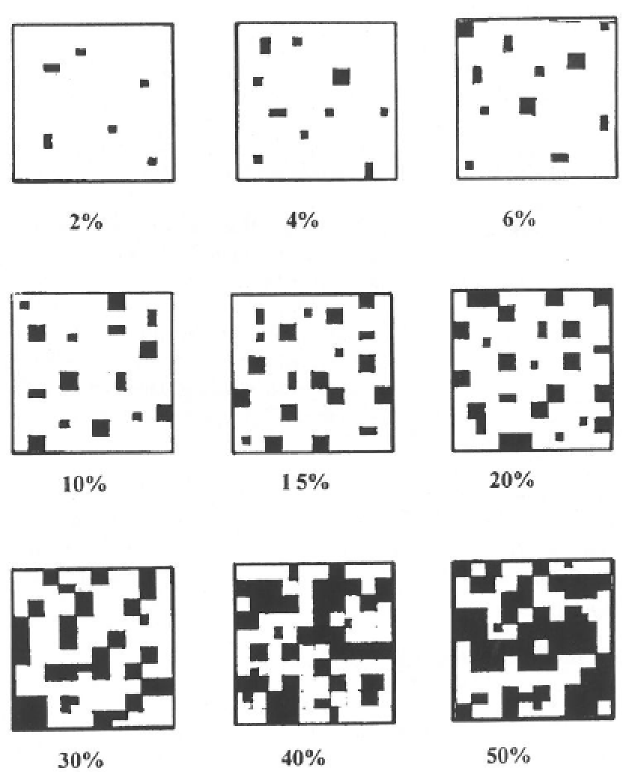


FIGURE IV-4: Visual Representation of Percent Cover (of Dark Areas) Used to Estimate Area and Dominant Particle Size with the Highest Percent Cover

	Size Limits (mm)		
Particle Name	**Lower**	**Upper**	**Texture Group**
silt/clay	0	**0.063**	Fine
very fine sand	0.063	**0.125**	Intermediate
fine sand	0.125	**0.250**	
medium sand	0.250	**0.500**	
coarse sand	0.500	**1**	
very coarse sand	1	**2**	
very fine gravel	2	**4**	Coarse
fine gravel	4	**5.7**	
fine gravel	5.7	**8**	
medium gravel	8	**11.3**	
medium gravel	11.3	**16**	
coarse gravel	16	**22.6**	
coarse gravel	22.6	**32**	
very coarse gravel	32	**45**	
very coarse gravel	45	**64**	
small cobble	64	**90**	
medium cobble	90	**128**	
large cobble	128	**180**	
very large cobble	180	**256**	
small boulder	256	**362**	
small boulder	362	**512**	
medium boulder	512	**1024**	
large boulder	1024	**2048**	
very large boulder	2048	**4096**	
bedrock	4096	**-**	

FIGURE IV-5: Particle Size Definitions (Souce: Adapted from Wentworth, 1922)

METHOD IV-2: Basic Sediment Collection

Estimating the dominant particle size using basic sediment collection builds on the visual observations of Method IV-1. Samples of sediment that consist of gravel or finer materials are collected with a trowel, shovel or bucket. A coffee can screwed onto the end of an expandable painters rod is a suitable sediment sampler that can take the place of more expensive samplers such as a ponar dredge.

Once a sediment sample is collected, the location is recorded on a field map or with GPS. The dominant particle size of a sample that is comprised of gravel, sand, silt and clay can be determined by feeling the sediment, by shaking the sample in water to perform a jar test (Figure IV-3) or by passing the sediment through a series of stacked field sieves (Figure IV-6).

FIGURE IV-6: Field Sieves

Each sieve should be weighed before passing sediment through to determine the weight of the sieve without material in it. After passing sediment through the stack of sieves using river water, the sieves are weighed again to determine the weight of sediment within each particle size class. A plot of particle size by weight will identify the size of the dominant particle (Figure IV-7).

For coarse sediment with sizes of gravel or larger, Wolman pebble counts are typically performed to count particles and determine the dominant particle size (Wolman, 1954; Bunte and Abt, 2001). The most common approach is to measure the intermediate axis (Figure IV-7) of each particle encountered on each step as the observer follows a zigzag pattern through a riffle area in the bankfull channel. A riffle is an area with shallow, turbulent flow where water is rushing over sediment particles. The bankfull channel is within the top of banks where the channel can spill onto the floodplain or approximately to the limits of perennial vegetation for a channel that has cut down (i.e., incised) from its floodplain. Particle size distribution and histogram plots (Figure IV-8) are made with pebble count data versus count number rather than mass. Typically, 100 particles are collected in each sample area. Particles are measured with a ruler or passed through a gravelometer (e.g., an aluminum plate with different sized holes to identify their size).

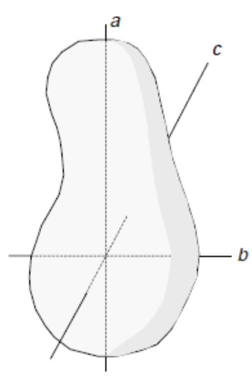
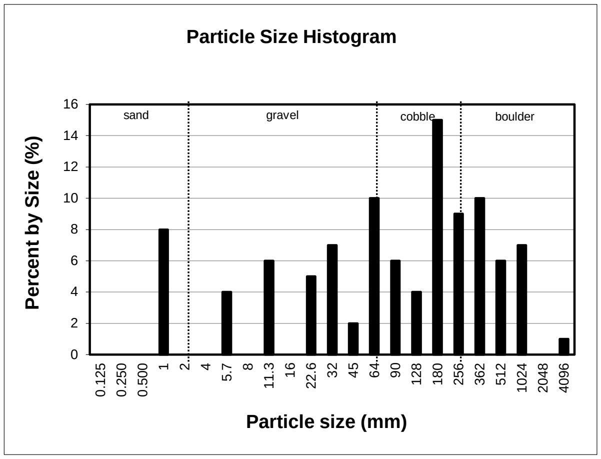
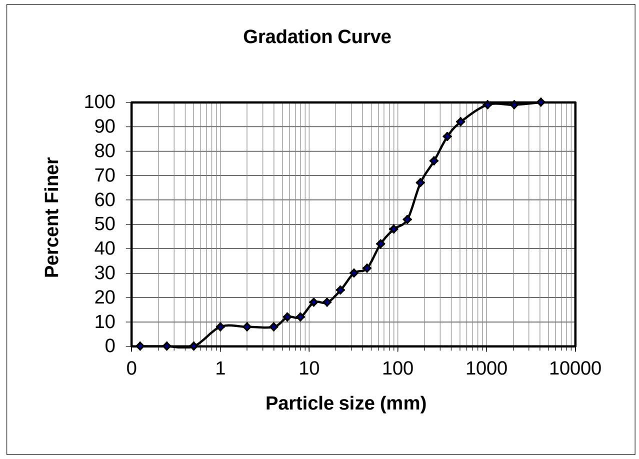


FIGURE IV-7: The dimensions of a sediment particle showing the longest axis (a), the intermediate axis often used for pebble counting (b), and the shortest axis (c) (Source: Bunte and Abt, 2001).





NOTES:

FIGURE IV-8: Finer Sediment Particle Size Distribution and Histogram

- Sediment sampling is performed by hand, trowel, shovel, a can attached to a rod or ponar dredge.
- Samples are typically collected for particle size analysis at each sediment probe location. At least two samples per probe are recommended.
- The location of the samples can be identified by measuring the distance along the cross section of the impoundment, marking on an aerial photograph or collecting GPS coordinates.
- It is estimated that this method will take about 30 minutes to one hour <u>per sample</u> to perform.

METHOD IV-3: Laboratory Analysis

For higher risk sites and larger sediment volume sites, distributed probing is often accompanied by sediment sampled for particle size analysis by a certified testing laboratory (see Section III, Method III-3). Samples are typically collected by a boring contractor using a split spoon sampler at 5- or 10-foot depth intervals. Samples are placed in jars, plastic containers or bags for delivery to the laboratory. Sediment particle size distribution and particle size histograms are provided by the laboratory for each sample.

NOTES:

- Sediment collection sites are distributed throughout the impoundment and sediment is collected at various depths based on the probing and boring program that is established when estimating the volume of sediment behind the dam/barrier (Section III).
- Samples may be combined into two composites – one from the surface sediments (0-10 feet) and one from deeper sediments (>10 feet).
- Method IV-3 will typically require hiring a boring contractor and a professional water resource scientist or engineer to assist with sample collection, and costs associated with laboratory analysis of the samples.

SUMMARY:

This Section was prepared to assist interested parties to better understand some common methods for estimating the dominant sediment particle size and distribution in an impoundment, and how risk and other characteristics of the sediment affect the level of accuracy that will be required. Once a preliminary assessment of the risk that the sediment in an impoundment poses has been made and an estimate of the sediment volume (Section III) has been determined, Figure IV-1 helps identify which Method for estimating dominant sediment particle size and distribution is most appropriate for an impoundment. To help avoid excess cost and project delays, it is recommended that applicants consult NHDES before selecting a Method for estimating dominant particle size and distribution.

References

Bunte, K. and S. R. Abt, 2001. Sampling Surface and Subsurface Particle-Size Distributions in Wadeable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring. RMRS-GTR-74. Rocky Mountain Research Station, Fort Collins, CO.

Wentworth, C. K., 1922. A Scale of Grade and Class Terms for Clastic Sediments. The Journal of Geology 30(5):377-392.

Wolman, M. G., 1954. A Method of Sampling Coarse River-Bed Material. Transactions of American Geophysical Union 35:951-956.

V. Estimating the Volume of Potentially Mobile Sediment Behind a Dam/Barrier

Dam/Barrier Removal Sediment Assessment & Management Protocol (Step #4)

OBJECTIVES:

The Objectives of this Section include:

- Computation of a reconnaissance-level initial estimation of potentially mobile impounded sediment.
- Assessment of the risk the sediment may pose when the dam/barrier is removed.
- Identification of the most appropriate method for computing the volume of potentially mobile. impounded sediment behind a dam/barrier.
- Introduction to potentially mobile sediment estimation methods.

The Barrier Removal Sediment Assessment and Management Protocol Flow Chart (Protocol) provides a process for assessing the risk to water quality and downstream resources and infrastructure from the release of impounded sediment and steps for managing that risk. Step #1 of the Protocol includes completion of a Due Diligence Review, Step #2A involves estimating the volume of impounded sediment and Step #2B involves estimating the dominant particle size and distribution of impounded sediment. Once those three steps have been completed, and following consultation with NHDES, the volume of potentially-mobile impounded sediment is estimated, per Step #4 of the Protocol.

The potentially-mobile sediment estimation can be used to help understand the potential risks associated with a dam/barrier removal project or dam/barrier failure including impacts to water quality and instream habitat, ecological risk and channel stability. The information obtained through completion of Steps #1, 2A, 2B and 4 of the Protocol, in conjunction with consultation from NHDES, is used to identify sediment management alternatives (Table V-1).

TABLE V-1: Common Sediment Management Alternatives for Dam/Barrier Removal

Alternative	Description
No sediment removal	Allow the passive erosion of impounded sediment to take place when volume is low and anticipated impacts are expected to be limited and short-term.
Partial sediment removal (with or without stabilization of the remaining material)	The impounded sediment that is most prone to erosion (e.g., in the proposed channel) is removed while other material that may be associated with floodplains or pre-dam landforms that is unlikely to erode is left in place to self-vegetate or is stabilized. Short-term impacts are tolerable as the channel and floodplain adjust. This alternative includes partial dam/barrier removal where some sediment is left stabilized behind the remaining portion of the dam/barrier.
Full sediment removal	Removal of all of the impounded sediment where the likelihood of erosion following dam/barrier removal is high, the sediment is contaminated, or long-term impacts are anticipated.

INITIAL ESTIMATION OF THE VOLUME OF POTENTIALLY MOBILE SEDIMENT:

A visual reconnaissance-level initial estimation of sediment mobility is recommended for all projects prior to refining the estimate with one of the three methods described in Table V-2. This initial estmation is made by comparing the slope of the channel with the slope of the impoundment, and by gaining an understanding of how much the channel curves as it travels down its valley (i.e., sinuosity).

The channel slope is the change in elevation over a given channel length:

$$S = \Delta E / L \times 100$$

S = slope [%]
ΔE = change in elevation [feet]
L = channel length [feet]

Slope can be estimated using a topographic map (available from the US Geological Survey), measured on a plan or measured in GIS using existing digital contours often derived from light detection and ranging (LiDAR) data. Slope can also be measured in the field using land surveying equipment. Calculate the slope in the upstream channel, in the impoundment and in the downstream channel. Steeper channels (i.e., $S > 1\%$) transport more (and coarser) sediment. Also, the more the (upstream or downstream) channel slope exceeds the impoundment slope, the more sediment is likely to mobilize following dam/barrier removal. The upstream slope is influenced by the size of the sediment being delivered to the impoundment at the dam/barrier, while the downstream slope is influenced by the size of the sediment that can be transported away from the impoundment.

Sinuosity is the curvature of the channel moving downstream that is calculated by dividing the channel length by the valley length ($Sin = L_{channel} / L_{valley}$ where Sin = sinuosity , $L_{channel}$ = channel length along its centerline as it winds down the valley [feet], L_{valley} = straight line valley length [feet]). Sinuosity can be calculated using an aerial photograph (available from NH GRANITView http://granitview.unh.edu/) or a topographic map (available from the US Geological Survey). Sinuosity can also be measured in the field with a tape measure. Steeper channels are straighter (i.e., less sinuous) while channels with shallower slopes are generally more sinuous. Channels with low sinuosity (i.e., Sin < 1.2) tend to transport less sediment following dam/barrier removal since only the channel area is likely to erode. For a highly sinuous channel (i.e., Sin > 1.5), more sediment is likely to mobilize following dam/barrier removal since the channel will meander through the impoundment and mobilize sediment in both the channel and floodplain.

If the limits of a sinuous channel extend to the edges of the impoundment and the channel is steeper than the impoundment, all or most of the impounded sediment will likely erode. If the channel and impoundment slope are similar, then half or less of the impounded sediment could erode. This reconnaissance-level estimate is used to get the order of magnitude (e.g., 10s, 100s or 1,000s of cubic feet/yards) of sediment mobility prior to field observations and additional calculations.

PRELIMINARY ASSESSMENT OF SEDIMENT RISK:

A methodology for preliminarily assessing the risk that the impounded sediment may pose when the dam/barrier is removeded is described in Section III. The methodology involves completion of the Due Diligence Review (DDR), measurement of the dam/barrier height and calculation of a reconnaissance-level initial estimation of sediment volume (V_{RL}). This initial understanding of potential risk is improved using the reconnaissance-level initial estimation of the dominant particle size, as described in Section IV. While it is possible that a high bedload of coarse material could erode and create risk to nearby infrastructure, in general, for a given sediment volume, coarser sediment, such as gravel and cobbles, tends to pose less risk to downstream aquatic resources, since it is less mobile during a given flow and less likely to contain contaminants. However, fine sediment, such as sand and silt, is more mobile and can lead to habitat and water quality impacts downstream, especially if a high volume of fine material has accumulated behind the dam/barrier. Further refinement of the methodology can be achieved by using the results of the reconnaissance-level initial estimation of sediment mobility, as described above.

The results of the reconnaissance-level estimations of sediment volume, dominant particle size and sediment mobility, combined with the results of the DDR, are used to determine which method for estimating the volume of potentially mobile impounded sediment is most appropriate (Table V-2 and Figure V-1). Consultation with NHDES is strongly recommended to determine the most appropriate method for estimating the volume of potentially mobile sediment in the impoundment.

METHODS TO ESTIMATE THE AMOUNT OF MOBILE SEDIMENT:

Three methods of estimating the amount of mobile sediment upstream of a dam/barrier are described herein, two of which require basic data inputs such as topographic maps, field observations and field measurements, and one modeling approach that requires more detailed data collection. The typical methods and anticipated level of accuracy, as described in Table V-2, are a function of the results of an initial sediment mobility prediction, previous sediment volume and particle size estimates (see Sections III and IV), and the anticipated level of project risk (Figure V-1). A more detailed method may be requested by NHDES based on an increased level of risk or a higher anticipated sediment volume than initially estimated for the site. It is strongly recommended that NHDES be consulted before selecting a method for estimating the volume of potentially mobile sediment.

TABLE V-2: Typical Sediment Mobility Estimation Methods (see also Figure V-1)

Method #	Description	Application	Accuracy
V-1	Field observations to compare the channel slope, channel confinement, and dominant particle size between the channel and impoundment.	Low risk and minimum to intermediate predicted transport potential.	± 100%
V-2	Flow velocity estimation and comparison to the allowable velocity of the dominant particle size. Velocity can be computed by comparing to walking/running speeds of humans, floating and timing with an object (i.e., tennis ball), or calculation using a uniform flow equation.	Low risk and maximum predicted transport potential; Moderate risk and minimum to intermediate predicted transport potential; High risk and minimum predicted transport potential.	± 75%
V-3	Hydraulic modeling and possible sediment transport analysis	Moderate risk and maximum predicted transport potential; High risk and intermediate to maximum predicted transport potential.	± 50%

METHOD V-1: Field Observations

This field observation method builds on the reconnaissance-level information as well as the previously estimated sediment volume and dominant particle size in the impoundment (see Sections III and IV). Field observations are made in the upstream channel, around the impoundment and in the downstream channel. Sediment deposits, channel features and dominant particle size are compared between the channel and impoundment.

This method begins with observations of the dominant particle sizes of the channel features and sediment deposits in the upstream and downstream channel. Observe the channel and determine the dominant particle size in the steepest areas where water is visibly moving, such as over riffles or runs. Dominant particle size is often estimated by measuring the most abundant particle in a square meter. This method is described in further detail in Section IV. If the dominant particle size in the impoundment is smaller than in the channel, the material will be prone to transport once the dam/barrier is removed. If the dominant particle size in the channel and in the impoundment are the same, sediment transport downstream following dam/barrier removal is less likely.

Confinement is the number of channel widths that can fit in the valley:

$$C = W_{valley} / W_{channel}$$

C = confinement
W_{valley} = width of the valley [feet]
$W_{channel}$ = bankfull channel width [feet]

Confinement indicates how concentrated flows are likely to be. In a more confined valley(lower confinement values) the tendency is for increased sediment transport. In many cases, a road or railroad embankment permanently exists along the edge of a valley so the width is narrower than the full natural valley width. Bankfull channel width is the distance between the top of the banks on channels that are connected to their floodplains. For channels that are incised, bankfull indicators include the limits of woody vegetation, a level shelf of recently deposited sediment, and the top of a sediment point bar.

In a confined setting where the impoundment has a small width assume all of the impounded sediment will erode (Table V-3). In an unconfined, broad setting where the impoundment has a larger width, $3 \text{ to } 6 \times \mathrm{A_{channel}}$ of the impounded sediment will typically erode. For impoundments with a large volume of sediment where the dominant particle size is fine-grained, the volume of potentially mobile sediment may be higher. To predict the volume of potentially mobile sediment, multiply the estimated cross-sectional area of erosion by the impoundment length.

TABLE V-3: Sediment Erodability Predictions Based on Confinement, Channel Width and Impoundment Width

Channel Confinement*	Impoundment Width	Impounded Sediment Potential Erosion Cross Sectional Area**
Confined (< 6)	< 3 x $W_{channel}$	All will likely erode
Confined (< 6)	> 3 x $W_{channel}$	3 x $A_{channel}$ in short-term, 3-6 x $A_{channel}$ in long-term
Broad (>6)	< 3 x $W_{channel}$	3 x $A_{channel}$ in short-term, 3-6+ x $A_{channel}$ in long-term
Broad (>6)	> 3 x $W_{channel}$	3 x $A_{channel}$ in short-term, 3-6+ x $A_{channel}$ in long-term

*Confinement = valley width / bankfull channel width

**Multiply the estimated erosion cross sectional area by the impoundment length to get the volume of potentially eroded sediment.

NOTES:

- See the "White Paper: River Restoration and Fluvial Geomorphology" (Schiff et al., 2006) for information on bankfull width and sinuosity. http://des.nh.gov/organization/commissioner/pip/publications/wd/documents/r-wd-06-27.pdf
- Geologic mapping may be helpful to improve sediment erosion prediction to determine if features, such as terraces that may be less inclined to erode, exist in the impoundment next to or under more recently deposited sediment.
- It is estimated that this method will take about 4 hours to perform.

ESTIMATE ERODABLE SEDIMENT

The level of risk posed by the impounded sediment is determinied from a Due Diligence Review, field measurements of the height of the dam/barrier, an initial reconnaissance level estimate of sediment volume (Protocol Step #1), an initial reconnaissance level estimate of the dominant particle size (Protocol Step #2-B), and an initial reconnaissance level estimate of sediment mobility (Protocol Step #4). Consult with NHDES for an assessment of the level of risk and to determine the appropriate Method for estimating the volume of potentially mobile sediment. For the same chart with additional technical detail regarding estimation of sediment size, please see next page.

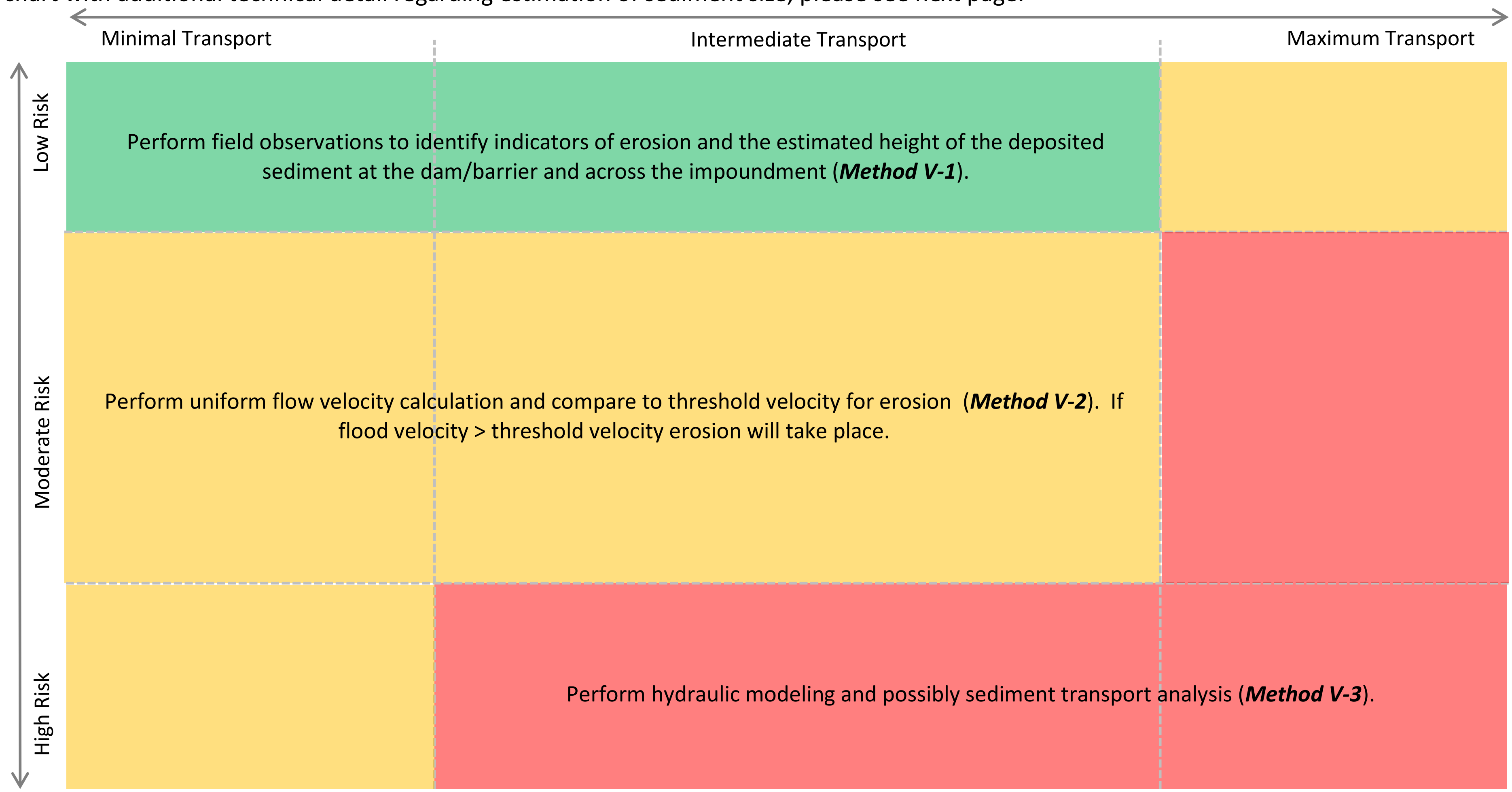


FIGURE V-1: Erodable Sediment Volume Typical Estimation Methods

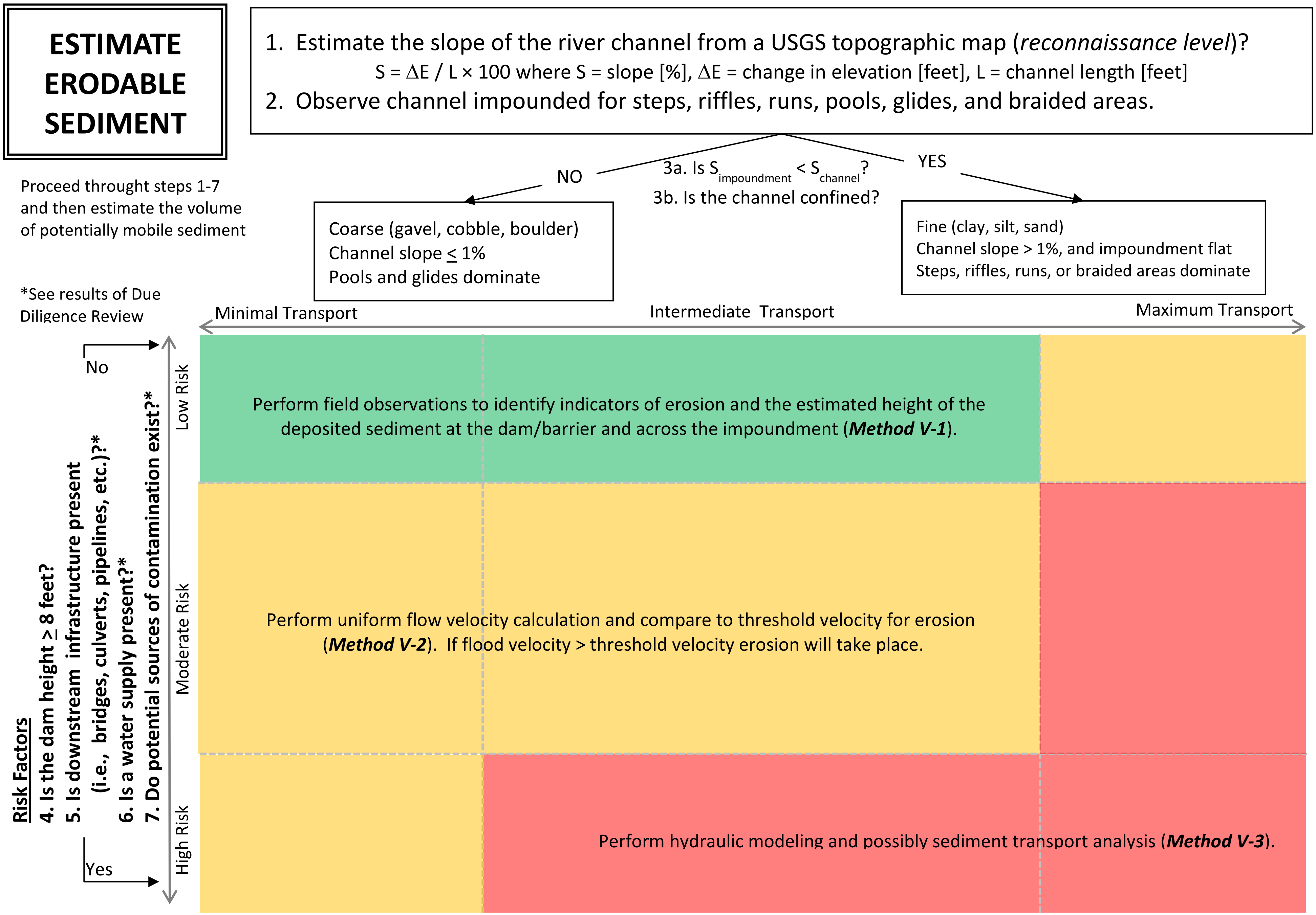


FIGURE V-1A: Erodable Sediment Volume Typical Estimation Methods (Enhanced)

METHOD V-2: Allowable Velocity

This method consists of comparing the allowable velocity (i.e., the flow velocity occurring just before the onset of sediment transport, also known as the threshold or critical velocity for movement with a factor of safety) of the dominant particle size in the impoundment and channel with an estimate of the flow velocity. The velocity is typically estimated at two flows: 1. The bankfull flow that represents the effective discharge that transports the most sediment over time (Emmett and Wolman, 2001); and, 2. A large flood flow, such as the 100-year flood, that represents an extreme event.

The allowable velocity for the dominant particle size in the impounded sediment is readily obtained from tabulated empirical data (Table V-4). Equations also exist for allowable velocity based on sediment particle size, including those used by the U.S. Bureau of Reclamation, where $\mathrm{V} = 0.64 \times \mathrm{d}^{\frac{4}{9}}$ for $\mathrm{d} < 6$ and $\mathrm{V} = 0.5 \times \mathrm{d}^{\frac{1}{2}}$ for $\mathrm{d} > 6$ where V = allowable velocity (feet per second) and d = sediment particle size (millimeters).

TABLE V-4: Allowable Velocity Based for Non-Cohesive Sediment (NRCS, 2007)

Channel material	Mean channel velocity (ft/s)	(m/s)
Fine sand	2.0	0.61
Coarse sand	4.0	1.22
Fine gravel	6.0	1.83
Earth		
Sandy silt	2.0	0.61
Silt clay	3.5	1.07
Clay	6.0	1.83
Grass-lined earth (slopes <5%)		
Bermudagrass		
Sandy silt	6.0	1.83
Silt clay	8.0	2.44
Kentucky bluegrass		
Sandy silt	5.0	1.52
Silt clay	7.0	2.13
Poor rock (usually sedimentary)	10.0	3.05
Soft sandstone	8.0	2.44
Soft shale	3.5	1.07
Good rock (usually igneous or hard metamorphic)	20.0	6.08

Bankfull flow velocity can be estimated by observation and comparison to a person's walking or running speed. Water moving at the speed of a slow walk will mobilize loose silt and clay. Water flowing at the pace of a fast walk mobilizes sand, while water travelling at running speed will mobilize gravel.

Another way to estimate flow velocity is to float an object, such as an orange or tennis ball, over a known distance and record the travel time. Dividing the travel distance (feet) by the time of travel (seconds) results in the flow velocity (feet per second).

Flow velocity is often estimated by professional water resource engineers using the Manning's equation and the continuity equation. Flow estimates are obtained from U.S. Geological Survey stream gauges, if they exist, or they can be estimated using the U.S. Geological Survey StreamStats web application (Olson, 2009).

http://water.usgs.gov/osw/streamstats/new_hampshire.html

Once the flow is determined, the velocity is calculated using the Manning's equation. Web applications exist to simplify the math.

e.g., http://www.eng.auburn.edu/~xzf0001/Handbook/Channels.html

The Manning's equation in conjunction with the continuity equation is needed to convert between flow and velocity and is:

$$Q = V \times A = \left(\frac{1.49}{n}\right) AR^{\frac{2}{3}}\sqrt{S}$$

where Q = flow (cubic feet per second), V = velocity (feet per second), A = cross sectional flow area (square feet), n = Manning's roughness coefficient that indicates how rough the surface that the water flows over is (Chow, 1959), R = hydraulic radius which is the area (A) divided by the wetted perimeter of the channel (W) (feet), S = channel slope (feet /foot). An estimation of the water depth and cross sectional dimensions are thus needed to determine the velocity, along with an indication of the hydraulic roughness (used to select Manning's roughness coefficient). The hydraulic roughness can be determined from a combination of field observations and catalogued photographs (http://wwwrcamnl.wr.usgs.gov/sws/fieldmethods/Indirects/nvalues/).

If the predicted velocity for the bankfull flow is larger than the allowable velocity of the dominant particle size of the impounded sediment most of the sediment will likely erode in the near term (i.e., 1 to 5 years). If the predicted velocity for the 100-year flow is larger than the allowable velocity of the dominant particle size of the impounded sediment most of the material will likely erode in the long term (i.e., 50 to 100 years). If the allowable velocity is larger than the predicted velocity, then most of the sediment outside of the immediate flow path is likely to remain in place over the long term.

NOTES:

- Some areas outside of the likely future main flow area (channel) may not erode even if the allowable velocity is exceeded. These areas may be landforms or soil types that are linked more to glacial action than river action. For example, a terrace of material that is relatively coarse and compacted compared to material deposited by the river (i.e., alluvium) may remain in place longer. These areas should be sketched on a map during field observations and the estimated volume in these areas removed from the calculation of potentially mobile sediment.
- The channel cross-sectional area can be estimated assuming a rectangular or trapezoidal channel shape to simplify measurements of width, depth, and side slopes. Land surveying equipment can be used to record the shape of an irregular cross section where more detail is needed.
- Some assistance will likely be needed by a professional water resource scientist or engineer to estimate the flow using the Manning's equation, record channel dimensions, and complete the calculations.

METHOD V-3: Hydraulic Modeling

For higher risk sites and higher sediment volume sites, hydraulic modeling, and possibly sediment transport analyses are recommended. The modeling which can be performed using public domain software such as the Hydrologic Engineering Center's – River Analysis System (HEC-RAS, U.S. Army Corps of Engineers, 2010), will establish a more accurate velocity estimate to compare to allowable velocities. Hydraulic modeling will also generate estimates of shear stress (i.e., the force of water on the bed that causes erosion) and stream power (i.e., the ability of the channel to do work) that allow for additional predictions of how much of the impounded sediment will erode. These methods are best performed by a professional water resource scientist or engineer.

For the highest risk sites, sediment transport analyses are often performed. A comparison of equilibrium channel slope for the given sediment particle size can be performed to estimate the predicted channel profile and how much material will be transported downstream. The equilibrium channel slope (S) can be calculated using Shield's equation for incipient motion:

$$\tau = \gamma \times \mathrm{R} \times \mathrm{S} \times 304 = 5 \times d_{50}$$

where γ = weight of water (62.4 pounds per cubic foot), R is the hydraulic radius = cross section area of the channel divided by wetted perimeter (feet), S is the equilibrium channel slope (feet per foot), and d_{50} is the median particle grain size (millimeters). The channel width, depth, and slope for a given sediment particle size may also be determined from empirical data plots in stable channel design guidance using the bankfull flow (e.g., USACE, 1994).

Sediment transport modeling such as available in HEC-RAS (e.g., Copeland, 1994) can predict the bed level change following dam/barrier removal and the anticipated stable channel dimensions. This modeling further refines the sediment transport prediction, and is reserved for professionals to perform on higher risk sites.

NOTES:

- Detailed surveys using more precise methods must be performed to determine channel cross sections and the profile in the upstream channel, impoundment, and downstream channel.
- A professional water resource scientist or engineer is needed to perform hydraulic modeling while a surveyor is needed to collect the required information.

SUMMARY: This Guidance Document was prepared to assist interested parties to better understand some common methods for estimating the potentially mobile sediment volume in an impoundment, and how risk and other characteristics of the sediment impact the level of accuracy that will be required. Using Sections III and IV, estimates of the sediment volume and the dominant particle size and distribution can be obtained. Following consultation with NHDES, per Step 3 of the Protocol, Figure V-1 helps identify which Method for estimating the volume of potentially mobile sediment is most appropriate. In most instances, a professional water resource scientist or engineer will be needed to assist with identifying the most appropriate Method for estimating the volume of potentially mobile sediment.

References

Chow, V. T., 1959. Open-Channel Hydraulics, McGraw-Hill Book Company, New York, NY.

Copeland, R. R., 1994. Application of Channel Stability Methods - Case Studies. TR-HL-94-11. US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Emmett, W. W. and M. G. Wolman, 2001. Effective Discharge and Gravel-Bed Rivers. Earth Surface Processes and Landforms 26(13):1369-1380.

NRCS, 2007. Stream Restoration, Part 654 of the National Engineering Handbook. 210–VI–NEH, August 2007. Natural Resources Conservation Service, U.S. Department of Agriculture, Washington, DC.

Olson, S., 2009. Estimation of Flood Discharges at Selected Recurrence Intervals for Streams in New Hampshire. Scientific Investigations Report 2008-5206. U.S. Geological Survey, Pembroke, NH.

Schiff, R., J. G. MacBroom, and J. Armstrong Bonin, 2006. River Restoration and Fluvial Geomorphology White Paper. R-WD-06-27. Prepared by Milone & MacBroom, Inc. for the New Hampshire Department of Environmental Services and the New Hampshire Department of Transportation, Concord, NH.

USACE, 1994. Channel Stability Assessment for Flood Control Projects. EM 1110-2-1418. http://www.publications.usace.army.mil/USACE-Publications/Engineer-Manuals/udt_43544_param_page/6/. United States Army Corps of Engineers, Washington, DC.

USACE, 2010. Hydrologic Engineering Center River Analysis System (HEC-RAS) (V. 4.1). U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA.

VI. WHITE PAPER - EVALUATION OF SEDIMENT QUANTITY FROM DAM REMOVALS

BACKGROUND

This paper sets forth the N.H. Department of Environmental Services' thoughts on the release of sediment for the application of Surface Water Quality Standards to freshwater, estuarine, and marine systems. The narrative standards of Env-Wq 1703.03 *General Water Quality Criteria,* Env-Wq 1703.08 *Benthic Deposits,* and Env-Wq 1703.19 *Biological and Aquatic Community Integrity* are applicable to sediment habitat and biology as well as its relationship to recreational activities. This paper solely addresses sediment quantity. Sediment quality is addressed in due diligence reviews and the sediment triad approach.

Sediments found in streams, rivers, lakes and estuaries are habitat for many forms of aquatic life. This bottom-dwelling aquatic life is intimately linked via nutrient and energy exchange webs to additional ecological resources including finfish, shellfish, birds, and other wildlife associated with surface water ecosystems. The flora and fauna in aquatic systems are adapted to a natural range of sediment movement with periods of aggregation and degradation. A deviation in the natural sediment yield within that natural range that is limited in duration is an event to which the flora and fauna will easily recover. Large deviations outside the natural range may result in lasting degradation to aquatic systems.

Sediment quantity is addressed as narrative in Surface Water Quality Regulations Env-Ws 1700. This paper sets out to describe a *de minimis* numeric translator for the acceptable volumes of sediment that can be released during dam removal activities that is not likely to cause degradation to the physical or biological qualities of the impacted aquatic systems. Site level conditions may dictate that more or less sediment can be released without adverse impacts.

APPLICABLE LAWS / REGULATIONS

Env-Wq 1703.03 General Water Quality Criteria

(c) The following physical, chemical and biological criteria shall apply to all surface waters:

(1) All surface waters shall be free from substances in kind or quantity which:

a. Settle to form harmful deposits;

Env-Ws 1703.08 Benthic Deposits

(a) Class A waters shall contain no benthic deposits, unless naturally occurring.

(b) Class B waters shall contain no benthic deposits that have a detrimental impact on the benthic community, unless naturally occurring.

Env-Ws 1703.19 Biological and Aquatic Community Integrity

(a) The surface waters shall support and maintain a balanced, integrated, and adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of similar natural habitats of a region.

(b) Differences from naturally occurring conditions shall be limited to non-detrimental differences in community structure and function.

DERIVATION OF 'NATURAL' SEDIMENT LOAD

There are no estimates of annual sediment loads for New Hampshire rivers. However, in February 2011 the NH Geological Survey –NHDES (Shane Csiki) compiled measured annual sediment load data from 47 sites in the United States that may be considered roughly comparable to New Hampshire rivers. Two additional sites from Connecticut and two sites from Vermont have since been added to the dataset. While not 'reference' conditions, the researched sites represent the best available set of measured conditions that could be found. The 51 sites are provided below in Table VII-1. The analysis within this paper assumes that the 51 sites represent a 'natural' condition.

TableVII-1: Sites with measured annual sediment loads.

State-River (site)	Watershed Area (sq mi)	Sediment Load (tons/day)	Sediment Load (tons/year)
ID-Horse Creek (16)	0.08	0.01	5.27
ID-Silver Creek (5)	0.09	0.01	3.31
ID-Horse Creek (9)	0.09	0.01	1.98
ID-Horse Creek (2)	0.22	0.01	4.16
ID-Horse Creek (14)	0.24	0.01	4.65
ID-Horse Creek (10)	0.25	0.02	6.44
ID-Horse Creek (12)	0.32	0.02	6.81
ID-Horse Creek (6)	0.39	0.01	3.30
ID-Silver Creek (4)	0.42	0.03	11.99
ID-Silver Creek (6)	0.42	0.09	33.00
ID-Silver Creek (2)	0.46	0.04	15.84
ID-Silver Creek (3)	0.50	0.03	11.57
ID-Horse Creek (4)	0.54	0.01	4.90
ID-Tailhot C	0.54	0.05	19.18
ID-Horse Creek (8)	0.58	0.05	16.50
ID-Silver Creek (1)	0.62	0.04	14.88
ID-Tailhot B	0.62	0.06	23.36
ID-Tailhot A	0.85	0.07	24.20
ID-Circle End Main	1.47	0.07	24.70
ID-Tailhot Main	2.55	0.25	92.40
WY-East Fork Encampment Creek	3.50	0.02	9.10
MD-Watts Branch	4.00	2.49	908.0
CO-Lower Trap	5.00	0.05	20.0
ID-Horse Creek (East Fork)	5.41	0.10	35.0
WY-Coon Creek	6.50	0.30	110.5

State-River (site)	Watershed Area (sq mi)	Sediment Load (tons/day)	Sediment Load (tons/year)
ID-Horse Creek (West Fork)	6.56	0.23	85.0
ID-Trapper Creek	7.72	0.54	196.0
VT-Rock River	11.30	0.28	101.6
CO-Little Beaver	12.00	0.33	120.0
WY-Little Granite Creek	21.10	12.20	4,452
CO-Middle Boulder	29.00	1.11	406.0
ID-South Fork Red River	37.84	2.15	784.0
CT-Coginchang River	38.70	2.39	872.0
ID-Upper Red River	49.81	3.57	1,302.9
CO-Left Hand Creek	52.00	5.70	2,080.0
CO-South Fork, Cache la Poudre	88.00	3.13	1,144.0
ID-Johns Creek	113.1	6.10	2,226.8
CT-Salmon River	150.00	75.3	27,500.0
VT- Barton River	152.83	15.87	5,791.00
ID-South Fork Clearwater River	829.7	44.8	16,332.4
ID-Lochsa River	1,179.5	220.1	80,346.5
ID-Selway River	1,909.3	331.9	121,152.5
IL-Iroquois (1)	2,091	255.2	93,131.0
IL-Iroquois (2)	2,091	189.9	69,298.0
PA-Juniata	3,354	2,435	888,810
IL-Kankakee	5,150	2,470	901,501
NJ/PA-Delaware	6,780	5,015	1,830,600
ID-Salmon River	13,544	1,317	480,582
WY-Bighorn River	15,900	4,966	1,812,600
UT-Colorado (Cisco, Utah)	24,100	53,350	19,472,800
UT-Green	40,600	58,953	21,518,000

Demissie, M., Bhowmik, N.G., Adams, J.R. 1983. Hydrology, hydraulics, and sediment transport, Kankakee and Iroquois Rivers. Champaign, Ill.: Illinois State Water Survey, Report of Investigation 103.

Leopold, L.B. 2006. A View of the River. Cambridge, Mass.: Harvard University Press.

Kulp, K.P. 1983, Suspended sediment characteristics of the Yantic River at Yantic, Connecticut: Connecticut Water Resources Bulletin 39, 34p.

USGS FS 129-98. Suspended-Sediment Loads and Yields in the Salmon and Coginchaug River Basins, Central Connecticut.

Personal communications on work done for; Schuett, E. and Bowden, W.B. 2014. Use of Acoustic Doppler Current Profiler data to estimate sediment and total phosphorus loads to Lake Champlain from the Rock River. Final Report to the Vermont Agency of Natural Resources, Department of Environmental Conservation. 27 October 2014

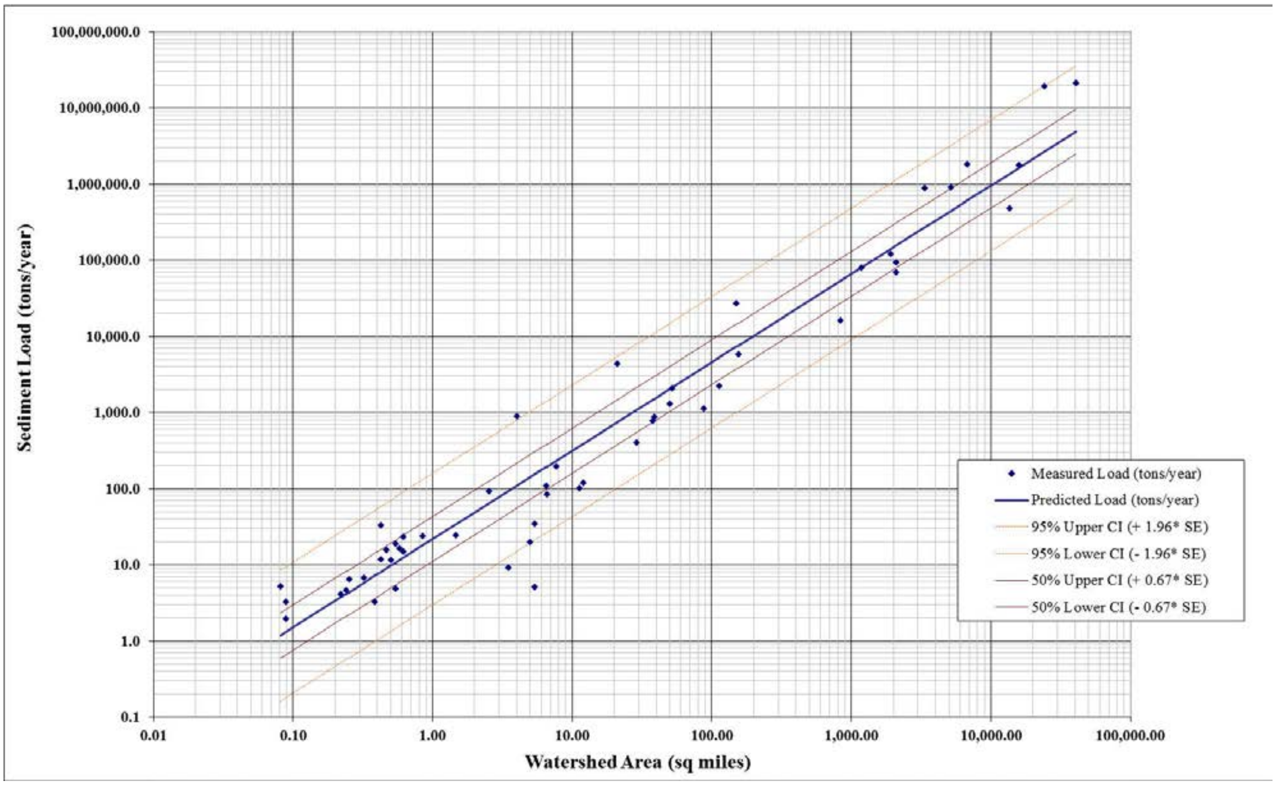
Personal communications and additional calculations on the raw data from; Medalie, Laura, Chalmers, A.T., Kiah, R.G., and Copans, Benjamin, 2014, Use of acoustic backscatter to estimate continuous suspended sediment and phosphorus concentrations in the Barton River, northern Vermont, 2010–2013: U.S. Geological Survey Open-File Report 2014–1184, 29 p., 4 appendixes, http://dx.doi.org/10.3133/ofr20141184.

From the above dataset it is possible to predict the tons of sediment per year from the watershed area in square miles with an adjusted R^2 of 0.95 by using the following equation;

Predicted Load (tons/year) = (21.741*[Watershed Sq Miles]$^{1.1615}$)

To determine the 50th and 95th percentile confidence intervals, the natural log of the watershed area (square miles) was regressed against the natural log of the annual sediment load (tons/year) and multiplied by +/-0.67 and +/- 1.96 times the standard error of the regression (Figure VII-1).

FigureVII-1. Measured and Predicted Annual Sediment Loads in Log space.



CONSIDERATION OF IMPOUNDMENT SITE BULK DENSITY

While the annual load of sediment passing a given site may dictate an acceptable *de minimis* threshold of sediment in terms of mass, it is necessary to evaluate the bulk density of the sediment stored behind a given dam to understand the volume of that sediment. In general, tightly packed, mineral based sediment will have the highest bulk density. As the packing of that sediment decreases, so too will the bulk density. As organic matter is buried with mineral sediments, the overall bulk density will decrease further.

Ideally, the volume weighted bulk density of the site would be determined. In the absence of site level measurements, a default bulk density would be useful. A brief literature review identified a collection of studies that reported the bulk density of sediments that had accumulated behind man-made structures (Table VII-2). The median bulk density from the data set is 1.1 gm/cm^3 or 68 lbs/ft^3. While it would be tempting to use the median as the default bulk density, additional factors should be considered when selecting a default value. To date, most of the dams that have been removed in New Hampshire have been impoundments that might be characterized as riverine with high turnover rates rather than 'lake-like' impoundments with slower turnover rates. Riverine type impoundments would be expected to yield sediments with more minerals and a higher bulk density. The riverine Merrimack Village Dam that was in Merrimack New Hampshire was removed in 2008 and a sediment survey in the planning phase found a bulk density of 1.28 gm/cm^3 (80 lbs/ft^3). That survey provides some confidence that New Hampshire sites are not radically different than other sites around the country.

Given that, unless measured, the bulk density at a site is unknown, a margin of safety should be applied. Where unmeasured, a default bulk density of 1.60 gm/cm^3 or 100 lbs/ft^3 will be used to calculate the volume of sediment that can be released from behind a given dam under the proposed *de minimis* threshold. Where measured, the bulk density of the site will be used to calculate the volume of sediment that can be released from behind a given dam under the proposed *de minimis* threshold.

Table VII-2: Man-made waterbody sites with measured sediment bulk density (dry).

Location	Sediment Bulk Density(gm/cm^3)	Sediment Bulk Density (lbs/ft^3)
MS - Grenada Lake	1.35	84
KS - Pomona Reservoir	0.715	45
KS - Cheney Reservoir (In buried river channel)	0.66	41
KS - Cheney Reservoir (Outside buried river channel)	1.40	87
WI - Wolf River	0.16	10
MS - Denmark Lake	1.45	91
MS - Drewery Lake	1.2	75
MS - Lt 14A-4	1	62
NH - Merrimack Village Dam	1.28	80
CA - Englebright Lake	1.35	84
TX - Martinez Creek 1 Flood Control Reservoir	0.56	35
TX - Martinez Creek 2 Flood Control Reservoir	0.58	36
TX - Martinez Creek 3 Flood Control Reservoir	0.67	42
TX - Calaveras 10 Flood Control Reservoir	1.19	74

DERIVATION OF A DE MINIMIS THRESHOLD FOR ADDITIONAL SEDIMENT LOADS

A small deviation in the natural sediment yield that is limited in duration is a recoverable event for downstream habitat and biota. That deviation should be within the range of natural variability. While the range of natural variability is approximated by using the 50th and 95th percentile confidence intervals of the regression between watershed area and measured sediment loads, it is recognized that none of the sites in the dataset are within New Hampshire. Further, the confidence intervals of the predicted median for a given watershed size are large. Differences in the geology and gradient of the sites in the measured dataset as compared to New Hampshire sites warrant setting a conservative *de minimis* threshold. The proposed 50 percent of annual sediment load as a *de minimis* threshold is considered acceptable since this is a one time event and falls well within the predicted range of variability based upon the dataset included in this analysis (Figure VII-2). This *de minimis* threshold assumes that all due diligence reviews have been performed for toxic substances and suggest no potential biological and habitat issues in the downstream reaches.

The volume of sediment that can be released from behind a given dam under the proposed *de minimis* threshold is a function of the bulk density of the sediment that will be mobilized by the dam removal. As previously discussed, in the absence of site specific density measurements, a density of 1.60 gm/cm^3 or 100 lbs/ft^3 will be assumed. Figure VII-3 illustrates the upper threshold volume of sediment per square mile of drainage area that can be released under the *de minimis* threshold at a bulk density of 100 lbs/ft^3. In the case of a dam with a 100 square mile watershed, 1,694 cubic yards (100 sq mi * 16.94 cu yd/sq mi/year) of sediment could be released under the *de minimis* threshold.

Figure VII-3 displays the shift in the per square mile *de minimis* threshold as a function of watershed area. To apply the *de minimis* curve in Figure VII-3 and calculate the *de minimis* threshold at a given dam site, the volume in cubic yards is calculated as;

$$\underline{\left[21.741\times(\text{Watershed Area(sq mi.)})^{1.1615}\right]\times\left[(2000\text{ lbs/ton})/(100\text{ lbs/cu ft})/(27\text{ cu ft/cu yd})\right]}\times 0.5$$

Figure VII-2. *De minimis* addition to the predicted annual sediment loads by square mile.

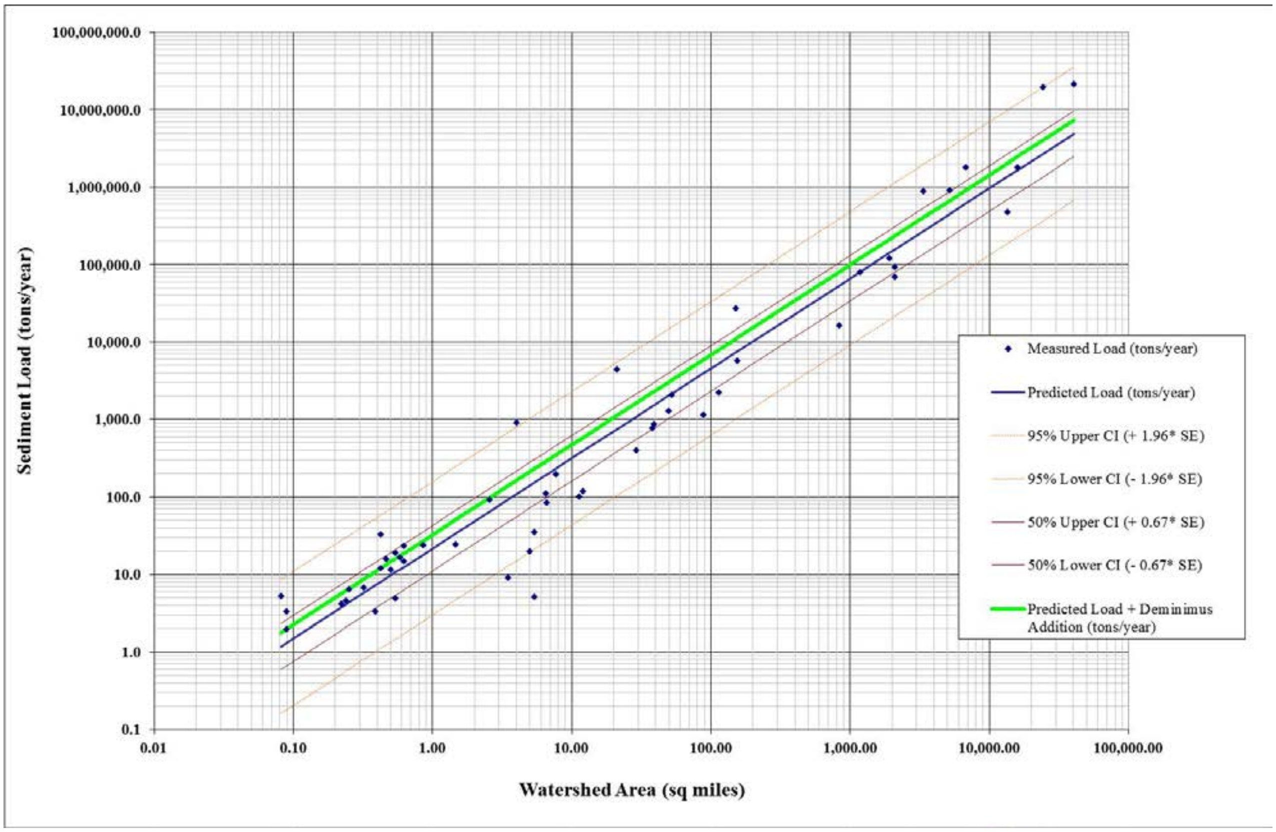
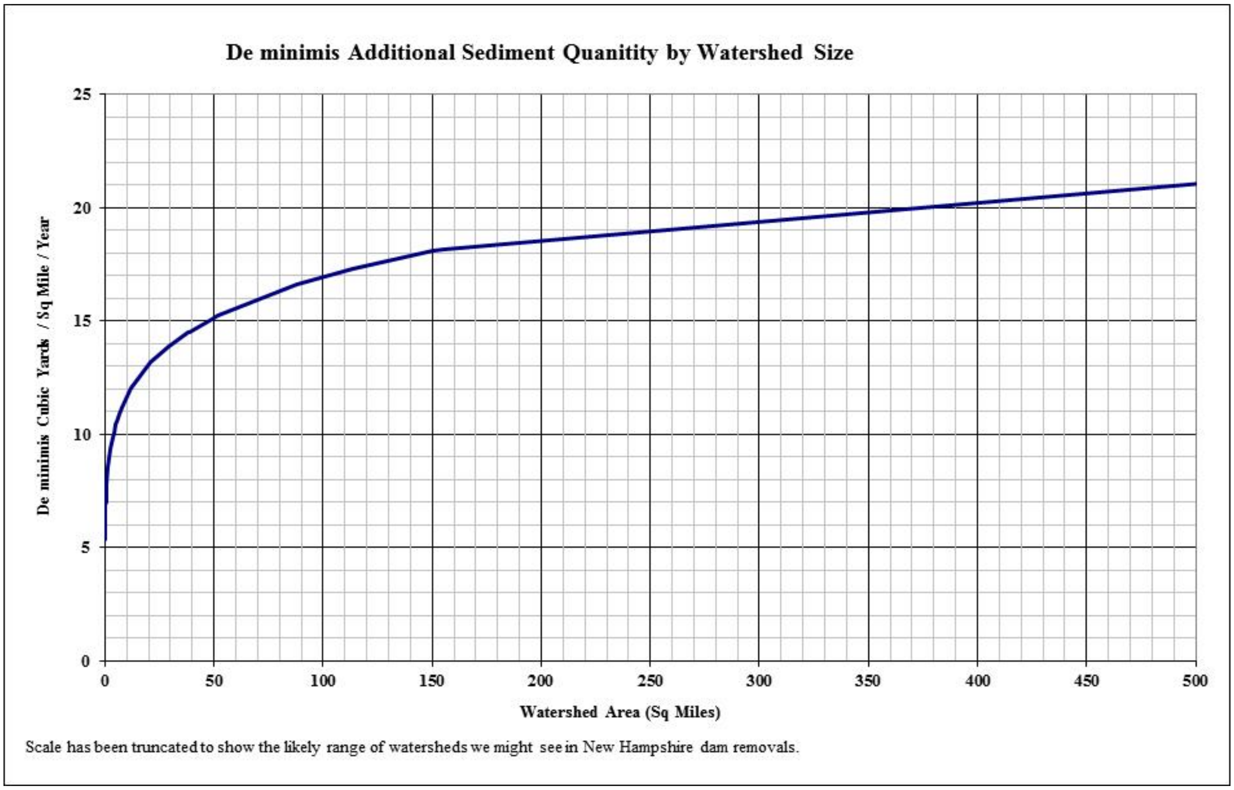


Figure VII-3. ***De minimis*** **volume of sediment per watershed square mile.**



EXAMPLES FROM RECENT DAM REMOVALS

Four examples are provided below to illustrate how the proposed *de minimis* threshold may have been applied to several recent dam removals within New Hampshire. In the each case:

A) the area of material that looks to have been mobilized was estimated by examining before and after aerial photography;
B) the watershed area was used to calculate the *de minimis* cubic yards of sediment;
C) an average depth in inches of 'acceptable' mobilized sediment within the mobilized area was calculated by dividing B) by A); and
D) where a pre-removal or post-removal estimate of potentially mobilized material was available, the sediment average depth within the mobilized area was calculated.

Where D) exceeds C) above, the data suggests that the *de minimis* sediment volume threshold was exceeded. Where C) exceeds D) above, the data suggests that the *de minimis* sediment volume threshold was not exceeded. Where no pre-removal or post removal estimate of mobilized material is available, the general knowledge of the site pre and post removal can be used to speculate whether the *de minimis* sediment volume threshold was or was not exceeded

It appears that in two of the four cases the project could have moved forward under the *de minimis* sediment volume threshold proposed.

Black Brook Maxwell Pond Dam – Likely not *de minimis* – Special consideration given due to proximity to the Merrimack River

Site	Watershed Area (mi^2)	Predicted Load in CY/year & [ton/year]	Original Area of Impoundment (acres)	A) Estimated area that became mobile out of the previously impounded area (acres)	B) *De minimis* CY	C) Maximum Effective Average inches of sediment depth in the mobile area that would be considered *de minimis*	Estimated mobile sediment (CY)	D) Estimated Depth over mobilized area (inches)
Black Brook	22.25	591 [798]	7.7	1.16	**296**	**2**	**9,500**	**61**

Souhegan River – Likely not *de minimis* – Special consideration given due to proximity to the Merrimack River

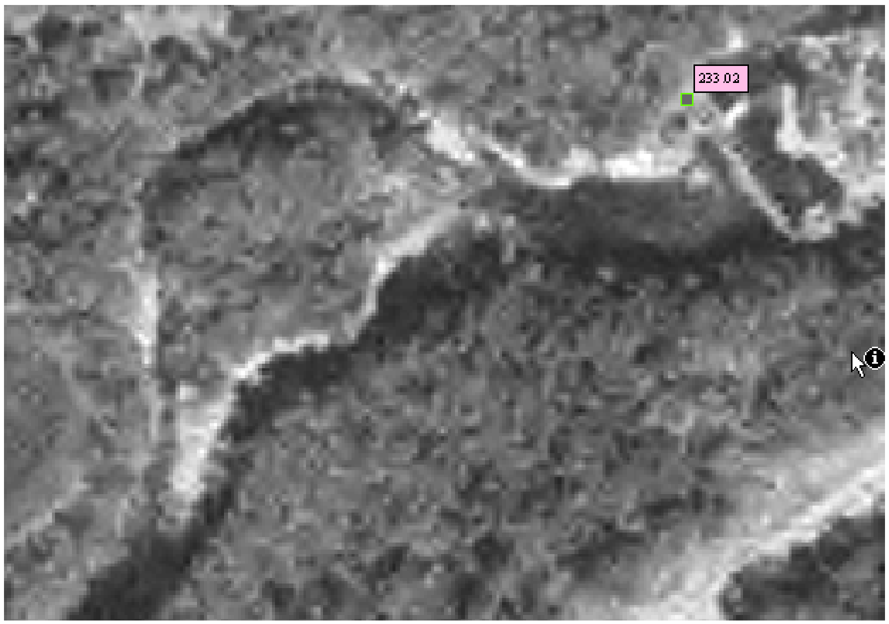
Site	Watershed Area (mi^2)	Predicted Load in CY/year & [ton/year]	Original Area of Impoundment (acres)	A) Estimated area that became mobile out of the previously impounded area (acres)	B) *De minimis* CY	C) Maximum Effective Average inches of sediment depth in the mobile area that would be considered *de minimis*	Estimated mobile sediment (CY)	D) Estimated Depth over mobilized area (inches)
Souhegan (Merrimack Village Dam)	171	6,318 [8,529]	12	6.70	**3,159**	**4**	**75,000**	**83**

Contoocook River – West Henniker Dam – Likely *de minimis.* The removed dam was a fairly low head dam. The linear morphology of the impoundment produced a velocity regime in this impoundment that did not to lend itself to the accumulation of large amounts of sediment. Potentially mobilized material was not determined before removal.

Site	**Watershed Area (mi^2)**	**Predicted Load in CY/year & [ton/year]**	**Original Area of Impoundment (acres)**	**A) Estimated area that became mobile out of the previously impounded area (acres)**	**B) *De minimis* CY**	**C) Maximum Effective Average inches of sediment depth in the mobile area that would be considered *de minimis***	**Estimated mobile sediment (CY)**	**D) Estimated Depth over mobilized area (inches)**
West Henniker Dam (Contoocook River)	374	15,680 [21,168]	10	7.37	**7,840**	**8**	Not estimated	Could not be calculated

Bearcamp – Likely *de minimis.* The removed dam was a in a state of partial breach. The morphology of the remaining impoundment and the velocity regime of this impoundment did not to lend itself to the accumulation of large amounts of sediment. Potentially mobilized material was not determined before removal.

Site	Watershed Area (mi^2)	Predicted Load in CY/year & [ton/year]	Original Area of Impoundment (acres)	A) Estimated area that became mobile out of the previously impounded area (acres)	B) *De minimis* CY	C) Maximum Effective Average inches of sediment depth in the mobile area that would be considered *de minimis*	Estimated mobile sediment (CY)	D) Estimated Depth over mobilized area (inches)
Bearcamp River	65.25	2,063 [2,786]	1	0.32	**1,032**	**24**	Not estimated	Could not be calculated



Section VII - DeMinimus Sediment Calculator

Potential Dam Removal Project	**EXAMPLE: SOME DAM**		**<---Enter the name of your dam**
Watershed Area (sq mi)	156	0	**<---Enter your watershed area**
Bulk Density lbs/cf **(1 gm/cm^3 = 62.42769 lbs/cf)** ***Use 100 lbs/cf if unknown.***	9	100	**<---Enter your bulk density or use the default of 100 lbs/cf**
Predicted Load (ton/year)	7,666	0	<---Calculated for you
Predicted Load (CY/year)	63,098	0	<---Calculated for you
Predicted *De minimus* CY	**31,549**	**0**	<---Calculated for you

This spreadsheet calculates the predicted de minimus sediment volume in cubic yards. It is based on the following equation from Section VII - White Paper - Evaluation of Sediment Quantity From Dam Removals

De minimus in CY = $\left[21.741 \times (\text{Watershed Area (sq mi)})^{1.1615}\right] \times \left[(2000\ \text{lbs/ton})/(\text{B.D. lbs/cf}) / (27\ \text{cf/CY})\right] \times 0.5$

lbs = pounds
cf = cubic feet
CY = cubic yard
sq mi = square mile
B.D. = bulk density (100 lbs/cf is assumed in the absence of site specific data)

Disclaimer: The NHDES is not responsible for the use or interpretation of this information, nor for any inaccuracies. If errors are discovered

For access to Excel Spreadsheet, see:
http://des.nh.gov/organization/divisions/water/dam/damremoval/documents/nhdes-sediment-protocol-sectionvii-deminimus-calculator.xlsx