Indian River Lagoon (IRL) Basin Management Action Plans (BMAPs)
Muck Removal Project Credit Guidance
Florida Department of Environmental Protection (DEP)
Revised Draft October 2019

Overview

Projects that remove muck overlying the natural, sandy substrate of IRL and its tributaries are beneficial to the recovery of seagrasses, a critical habitat within the IRL system. Muck deposits contain nutrients that flux into the water column, increasing the abundance of phytoplankton, drift macroalgae, and epiphytes that attenuate light and constrain seagrass growth and propagation. Even for deep-water areas where seagrass coverage is not expected, muck deposits therein are a major source of nutrients and turbidity that readily spreads affecting the broader, shallower seagrass areas of the IRL. For these reasons, DEP considers the control and removal of muck deposits within the IRL as a beneficial nutrient reduction strategy.

Most IRL muck originates from upland soils and vegetation. For this reason, stringent watershed soil-erosion control and soil/vegetation containment measures are needed. Without such measures in place, muck removal will need to be frequently repeated, which is neither cost-effective nor time efficient. Ideally, muck removal projects should be performed in conjunction with soil and vegetation retention programs, including public awareness activities, which limit the amount of muck material deposited into the IRL.

Muck removal projects are required to meet applicable permitting requirements along with any evaluation and tests of the muck as specified by state and federal regulatory agencies. The data supporting this guidance, and the guidance itself, are specific to and only applicable to the IRL system with respect to determining BMAP credit for muck removal. This guidance is best applied to the IRL proper and to downstream marine or estuarine tributary reaches open to the IRL and canals.

Guidance Items for Muck Removal Project Credit

Muck removal projects must meet the following guidance items or criteria to receive BMAP credit for nutrient reductions:

1. ***Definition of Muck and Minimum Thickness for Credit:***

   Definition of IRL muck: To be considered IRL muck (Trefry and Trocine 2011), the sediment must be dark grey to black in color and contain >75 % water by weight and ≥10 % organic matter (on a dry weight basis) as measured by Loss on Ignition (LOI) at 550°C. Another typical characteristic of IRL muck that can set it apart from other organic sediments is that it contains clay and silt that is ≥50 % of the sample by dry weight. This latter characteristic is provided as an informational item only and does not necessarily need to be quantified for the sediment in question to be considered IRL muck or not.

   Minimum muck thickness relative to conventional dredge methods: Presently, the minimum sediment depth or layer thickness that the common or more conventional methods of dredging sediment (e.g., hydraulic, mechanical bucket) can achieve is about 30 centimeters (cm) (~1 foot). Therefore, if no other technologically or economically feasible method of removing muck capable of shallower and more precise dredge depths is available, then a median muck deposit thickness of 30 cm or greater for a muck-removal project area is allowable for credit. There would be a high risk for significant over-dredge into the natural substrate if a conventional dredge method is planned/accepted for any project area in which the median muck thickness is less than this 30 cm thickness.

Minimum muck thickness relative to non-conventional dredge methods: Non-conventional dredge methods are defined here as more "surgically" precise methods capable of removing sediment at sediment depths or sediment-layer thicknesses that are less than 30 cm. If a non-conventional method is planned/accepted for a project, then a minimum median muck thickness for a project area can be 10 cm (~4 inches). Any deposit or proposed project area that contains muck (as defined above), but is less than 10 cm thick (as a median) is regarded as a less important, long-term nutrient-source threat to the IRL (J. Trefry, personal communication, 7/3/18).

The thickness of the deposit can be manually measured using a graduated pole (pole specifications are found in Appendix A, under the section "Equipment"**)** that is pushed into the sediment to the point of refusal. An estimate of the area of muck material to be removed that meets the above definition of muck is also needed and is required to calculate BMAP credit. Other survey methods (e.g., remote sensing) can be used, but must be approved by DEP; and, for the sake of data quality control, should be statistically validated by the manual pole method.

Scientific evidence indicates that very thin deposits of 10 cm or less can flux nutrients (if there is a fairly constant carbon input and a concentration gradient of nutrients in the sediment) and that layers of muck ≤5 cm may even cease to have a net flux of nutrients within 5–10 years (J. Trefry, FIT, personal communication, 7/3/18). However, it has also been observed to date that ~90 % of the sediment samples taken Lagoon-wide at or below 30-cm thickness of probe-penetrable sediment actually fall below the minimum technical criteria that constitute the definition of IRL muck (>75 % water by weight and ≥10 % organic matter dry weight). In other words, probe-penetrable deposits that are ≤30 cm are more than likely NOT to be IRL muck, as technically defined in this guidance document. This may be due to the fact that such thin layers are readily mixed with natural substrate sands and incoming sands and clays that decrease the overall organic content. Thicker organic-rich deposits (>30 cm) are more likely to be IRL muck as defined and as supported by the data (A. Fox, FIT, personal communication, 8/6/2019; Trefry et al. 2019). Finally, the cost of removing shallow (≤30 cm) deposits and the higher risk of over-dredging to do so may be prohibitive unless performed in conjunction with the removal of thicker deposits adjacent or nearby.

2. Removal to the Natural Substrate: Regardless of thickness, BMAP credit will be considered for removal of muck deposits if the permitted dredge-depth target is to or within the background or natural substrate (e.g., sandy, muddy sand, or sand-shell sediment). Muck must be completely removed down to the natural substrate throughout the proposed project area to the maximum *areal* extent possible, with consideration to safety and engineering limitations, in order to maximize the nutrient reduction benefits of the project.

The intent of this guidance is to encourage environmental dredging that maximizes muck removal by area as well as by depth. It may not be possible to remove sediment close to docks, stream banks, and canal walls for environmental (riparian) or structural liability reasons. The effect of structures and banks on dredging credits will vary by situation, but in general, the portions of the project area not dredged are not included in the muck removal area requested for credit. The muck that cannot be removed within or adjacent the project area increases the likelihood that the dredged bottom will be re-covered by the muck left behind, reducing or negating the benefit of the dredge project, eventually losing some or all of the BMAP credit that was initially considered (if muck thickness is >30 cm).

3. Upstream Limit for Tributaries and Canals: A salinity ≥1 part per thousand will be used to delineate potential, BMAP-credited muck removal projects within any given reach or segment of a tributary or canal waterway that is hydrologically open to the IRL. The presence of a dam or other water control structure that bisects an IRL tributary or canal waterway will also be considered as a reasonable upstream limit or boundary for muck removal projects that can receive BMAP credits.

The minimum salinity limit is imposed because fine-grain material and organic matter suspended in the water column and transported from a freshwater reach of the waterway to its estuarine reach will start to flocculate and settle to the bottom as salt concentration increases to about ≥1 part per thousand salinity. As these flocs settle out of the water column, they form fresh deposits of sediment including muck.

If a hydrologic barrier (e.g., dam, weir, or some structure that impedes tidal flow) is present in the waterway, then it is likely that freshwater exists upstream of the barrier. Moreover, and in most cases, the waterway upstream of the barrier and its maintenance (including debris removal and sediment dredging) is the responsibility of a local or regional agency that has the budgetary and regulatory or permitted authority to clean out accumulated debris and sediments upstream of the barrier and should do so periodically as a watershed muck and nutrient source control measure. Therefore, the award of BMAP credit will be limited to muck removal projects downstream of hydrologic barriers and where salinity is ≥1 part per thousand.

4. Sediment Nutrient Flux Rates and BMAP Credit Determination: Nutrient flux rates from both muck and its proximal natural substrate will be used to determine BMAP credit for muck removal projects. Flux rates are estimated from the muck organic matter content measurement described in Appendix A. Sediments, organic enriched or not, have a potential to release nutrients. However, organic-enriched sediments such as muck, have the greater potential to release considerably more nitrogen (N) and phosphorus (P) than the less-organic, sandier sediments that make up the natural bottom or substrate of the IRL. Compared to sandy or sand-shell sediments, muck has higher nutrient (carbon [C], N, and P) content and larger microbial populations that degrade or break down (mineralization) organic matter, readily diffusing dissolved N (mostly as ammonia) and P (mostly as phosphate) to the overlying water column. Muck susceptibility to re-suspension can exacerbate nutrient release to the water column due to its greater exposure to dissolved oxygen (oxidation mineralization).

Literature-derived nutrient flux rates: Published or reported estimations of nutrient flux rates from sandy (natural) sediments and from muck sediments are presented in **Table 1**.

Reported ammonia-N flux rates from natural substrate sediments range from 220 kilograms per square kilometer per year (kg/km^2/yr) (Montgomery et al. 1979) to 4,700 kg/km^2/yr (Reddy et al. 2001). In strong contrast, ammonia-N flux rates from muck ranged from 9,800 kg/km^2/yr (Trefry et al. 1992) up to 40,000 kg/km^2/yr (Fox and Trefry 2018).

Reported P flux rates for natural substrate sediments range from 40 kg/km^2/yr (Reddy et al. 2001) to 400 kg/km^2/yr (Trefry et al. 1992); and for muck, the range is 1,000 kg/km^2/yr (Trefry et al. 2016) up to 10,000 kg/km^2/yr (Fox and Trefry 2018).

Table 1. IRL Sediment Flux Rates From the Literature

(Updated literature values may become available as new research is performed.)

1 South Central IRL
2 Throughout IRL system
3 North IRL
4 Turkey Creek
N/A: Not applicable

Source	Muck Ammonia Flux (kg/km2/yr)	Natural Substrate Ammonia Flux (kg/km2/yr)	Muck Phosphorus Flux (kg/km2/yr)	Natural Substrate Phosphorus Flux (kg/km2/yr)
Montgomery et al., 1979[1]	N/A	220	N/A	N/A
Trefry et al., 1992[2]	9,800	1,230	2,170	400
Reddy et al., 2001[2]	N/A	4,730	N/A	40
Trefry et al., 2016[3]	10,000 – 30,000	N/A	1,000 – 5,000	N/A
Fox and Trefry, 2018[4]	20,000 – 40,000	N/A	5,000 – 10,000	N/A
Average for Natural Substrate		**2,100**		**200**

BMAP Credit Determinations for Current or New Projects: Nutrient flux rates from both muck and from natural substrate sediments will be applied in the determination of a *net* flux rate and, conversely, potential nutrient reduction or net flux reduction. As such, this determination of potential nutrient reduction is considered the BMAP credit that can be awarded to a muck removal project. The *net* flux rate is determined from the flux rate from the muck minus the flux rate from the natural, sandy substrate. Site-specific sediment measurements and calculated flux rates per project area are requirements to determine BMAP credits. Muck sediment sampling and other requisite measurements are specified in Appendix A.

The calculations to be conducted are based on the strong relationship between benthic fluxes of N and P and the organic matter content or the %LOI of the sediment (Fox and Trefry 2018). The primary permittee or stakeholder of the project shall follow the method prescribed in Appendix A to conduct the necessary field and laboratory measurements and calculate N and P fluxes from the project area.

This method relies on site-specific data, collected from the project area pursuant to methods described or cited in Appendix A, which will serve as the data input to the method equation for calculating a flux rate. For the sake of convenience without having to run the equation calculation, one can instead refer to the "look up" table of flux-rate values (Table 2) that has been developed based on the expected % LOI ranges for IRL muck. The values in Table 2 were developed by Dr. A. Fox and Dr. J. Trefry based on an equation that embodies the strong correlation of LOI with IRL muck N flux and P flux and builds upon the previous work of Fox and Trefry (2018).

Table 2. Fluxes of Nitrogen and Phosphorus from Sediments as a Function of Sediment LOI @ 550°C

% LOI @ 550°C	Muck Ammonia Flux (kg/km^2/yr)	Muck Phosphorus Flux (kg/km^2/yr)
10.0 – 10.9	8,000	400
11.0 – 11.9	9,000	500
12.0 – 12.9	10,000	700
13.0 – 13.9	11,000	800
14.0 – 14.9	13,000	1,000
15.0 – 15.9	15,000	1,200
16.0 – 16.9	17,000	1,500
17.0 – 17.9	20,000	1,800
18.0 – 18.9	25,000	2,300
19.0 – 19.9	31,000	3,000
≥20	41,000	3,900

The flux rate determinations and calculation of BMAP credits, using the average of the natural substrate values from Table 1 and the muck flux values from Table 2, are best described by example as shown below.

Example data and calculations:

Average LOI @ 550°C of muck samples = 14.6 %
Area of muck deposit with median thickness >30 cm = 0.21 km^2 (assumes conventional dredging will be applied to project area)

Obtain N and P fluxes by using **Table 2** and the average LOI value as follows:

Muck flux of N = 13,000 $kg/km^2/yr$ from Table 2 at LOI = 14.6 %
Muck flux of P = 1,000 $kg/km^2/yr$ from Table 2 at LOI = 14.6 %

Then, the total nitrogen (TN) and total phosphorus (TP) credits for muck removal will be calculated as follows:

For TN:

Eq.1. $\mathbf{Flux_{muck} – Flux_{natural} = Flux_{net}}$

= 13,000 kg $N/km^2/yr$ – 2,100 kg $N/km^2/yr$ = 10,900 kg $N/km^2/yr$

Where $Flux_{muck}$ (13,000 kg $N/km^2/yr$) was taken from Table 2 and $Flux_{natural}$ (2,100 kg $N/km^2/yr$) is the average of the observed values, rounded to the nearest 100, for natural sediment presented in Table 1. [1]

For TP:

Eq. 1. $\mathbf{Flux_{muck} – Flux_{natural} = Flux_{net}}$

= 1,000 kg $P/km^2/yr$ – 200 kg $P/km^2/yr$ = 800 kg $P/km^2/yr$

Where $Flux_{muck}$ (1,000 kg $P/km^2/yr$) was taken from Table 2 and $Flux_{natural}$ (200kg $P/km^2/yr$) is the average of the observed values, rounded to the nearest 100, for natural sediment presented in Table 1.

Equation 1 represents net flux, but conversely, it also represents the *net reduction* in the amount or mass of TN or TP potentially fluxed to the IRL system upon completion of muck removal. The result is expressed in mass/area/year (e.g., $kg/km^2/yr$). Sediments of the natural substrate have the potential to flux nutrients to overlying waters, but that rate of flux should be much lower than that of muck. Therefore, the difference between the fluxes of muck and natural substrate should represent a net reduction in flux when the muck is removed from the system.

The net flux (or reduction) that is calculated to establish the completed project's BMAP credit can be termed as $\mathbf{Flux^0_{net}}$; and subsequent net-flux determinations for the same project area can be termed $\mathbf{Flux'_{net}}$ (and tagged with the date of sample; e.g., $\mathbf{Flux'_{net}}$ **08-07-2019**).

[1] The chosen flux values for natural sediment are not only the averages of reported fluxes for natural, sandier sediment of the IRL system, but also closely agree with the IRL sediment data more recently obtained by Drs. Trefry and Fox, FIT (A. Fox, personal communication, 8/12/2019).

The average of the reported values for the natural substrate (Table 1) in the example calculations were chosen as an environmental safety factor.

The next calculation uses Equation 2 below and the project area of 0.21 km^2 (as stated in the project example above) to calculate the entire or Total project's BMAP credit in units of lb/yr :

Eq. 2. TN BMAP Credit (lbs/yr) = $Flux_{net}$ (kg/km^2/yr) * total area dredged to natural substrate (km^2) * 2.2 (lbs/kg)

= 10,900 kg N/km^2/yr * 0.21 km^2 * 2.2 lbs/kg = 5,000 lbs/yr (result is rounded to nearest 100 lbs).

TP BMAP Credit (lbs/yr) = $Flux_{net}$ (kg/km^2/yr) * total area dredged to natural substrate (km^2) * 2.2 (lbs/kg)

= 800 kg P/km^2/yr * 0.21 km^2 * 2.2 lbs/kg) = 400 lbs/yr (result is rounded to nearest 100 lbs).

BMAP credit is equivalent to the net reduction in flux or nutrient loading, expressed as pounds per year (lbs/yr), from the project area's sediments following completion of the muck removal project. For planning purposes only, equations 1 and 2 can be used to calculate a *preliminary* or *provisional* BMAP credit before the project is completed or before the post-project dredge assessment is completed. However, it is the *final* BMAP credit (also using Eqs.1 and 2) determined upon completion of the project's final post-dredge assessment that will be awarded as the project's BMAP credit.

Determination of a Reduction in the Final BMAP Credit: The *final* BMAP credit that is awarded to any new muck removal project may be reduced if the post-project median muck thickness is >30 cm AND the associated, post-project net flux (**$Flux'_{net}$**) exceeds the initial net flux (**$Flux^0_{net}$**). The amount of exceedance, or the positive difference between **$Flux'_{net}$** and **$Flux^0_{net}$**, will be the amount of the reduction in credit. Following a project's completion, any accrual of probe-penetrable sediment (which may or may not be IRL muck, as defined on p. 1) with a total thickness up to, but not exceeding, 30 cm will NOT be subject to reduction in BMAP credit. These guidance criteria apply to any project utilizing conventional dredging methods or non-conventional, thin-layer muck removal methods. Once a reduction in credit has been applied the *final* BMAP credit is now the *revised final* BMAP credit.

5. Reporting of Post-Project Muck Thickness or Nutrient Flux Rates: Post-project muck deposition thicknesses and nutrient flux rates, both reported as medians over the project area, should be determined by180 days following the project's completion date as part of the project's final dredge assessment. These determinations will establish the *final* or *revised* *final* BMAP credit to be awarded the project for the first 10 years following the project's final post-dredge assessment.

Preventing sediment from entering waterways is preferable to repeated removal of muck deposits. At the time a request is made for credit, the requesting entity shall provide a plan for how they will reduce the amount of sedimentary material entering waterways. A list of sedimentation prevention efforts either proposed or completed must be submitted with the request for credit.

A check of muck depth is required at the 5-year mark from completion of the project, preferably at locations that contained the deepest deposits, as well as compliance with all permit conditions at that time. A minimum of 5 measurements of muck depth is recommended, but the sampling sizes specified in Table A.1 should be used as guidance. It is conceivable that deposition rates are low enough that remeasurement yields no notable deposition. Though credits will not be reduced based on the results of the 5-year recheck, the recheck is important to gage the success of the dredging project, estimate rate of redeposition, and provide an estimate of what to expect at the 9-year mark. A high rate of deposition warrants a review of the causes for the high rate. The recheck may also provide time to plan for replacement activities if BMAP credit is likely to be reduced at the 9-year assessment.

Additionally, 9 years following a project's completion date, the primary permittee or stakeholder for the muck removal project is responsible for repeating the measurements and flux determinations specified above (in accordance with methods in Appendix A and guidance item #4 above), and reporting those results to DEP. Observations of land use changes around the dredged area or climatic events that could affect deposition depth and rate should be noted. DEP shall use the report to evaluate whether project credit should be reduced at the end of 10 years following the project's completion date. The amount of credit may be reduced based on a median thickness of muck >30 cm within the project area (which triggers a new net flux determination) AND on the associated (post-project) muck nutrient flux rate, $\mathbf{Flux'_{net}}$ @ >30 cm (see guidance item #4, *Determination of a Reduction in the Final BMAP Credit*).

6. Time Limitations and Time Extensions on Awarded Credits:

a. Muck deposition in the IRL system is a nearly continuous process due to upland runoff; therefore, credits assigned to a muck removal project are initially time-limited to a minimum of 10 years. One year prior to that 10-year time limit, the project area shall be surveyed for sediment re-deposition or accrual. The data collected from the survey will be used to assess whether project BMAP credits will be reduced or be sustained per guidance item #4.
b. The initial time limit of 10 years can be extended by an additional 10 years if the primary permittee or stakeholder can meet the following two requirements. (1) They can demonstrate that effective watershed source controls are in place or in progress (plan) and, (2) the median muck thickness over the project area is ≤30 cm, for which full BMAP

credit will be sustained. Otherwise, flux rates are determined and used as specified in guidance item #4 above to determine reduced BMAP credit. If the credit is reduced to 0 (per guidance item #4), then 6c below applies.

c. At the end of the *total* time limit of 10 years, which would be assigned to a project that does not meet the conditions in 6b (i.e., one or both requirements are not met: $\leq$30 cm median muck thickness and demonstrable watershed controls are in place), BMAP credits applied to that project will cease, but can be re-awarded to the project area upon completion of the re-dredging of muck in accordance with the requirements in this guidance document.

d. At the end of the *total* time limit of 20 years assigned to a project (by virtue of meeting conditions in 6b and per guidance item #4), its BMAP credits will cease, because the BMAPs are written to be implemented in a 20-year time frame.

7. Dredged Material Stored Away from Surface Waters: This item will be addressed through the regulatory permit process, but it is worth mentioning here as well. Dredged material from a muck removal project, whether contained at a temporary or permanent disposal management site, must be completely removed from contact with the surface waters of the IRL system, including any waterway conveyances that drain to the IRL or its tributaries. The distance from surface waters that the dredged materials are stored for *temporary* containment and handling will be determined on a case-by-case basis through the permitting process. Brevard County recommends a distance of at least 200 meters between a *permanent* containment site and surface waters of the IRL system. Again, permit requirements may dictate the manner and location of storage and handling of dredged muck and other associated sediment material.

8. Source Control Requirements: An important consideration in the awarding of BMAP credit for muck removal projects is the implementation of actions that limit the deposition of upland soils and vegetation in the IRL and its tributaries. Many of the activities required by municipal separate storm sewer system (MS4) permitting also address control of upland erosion and are appropriate source control measures. Source control actions that can be considered as a minimum for credit include:

- Erosion and Sediment Control Ordinance;
- Landscaping Ordinance;
- Street Sweeping;
- Maintaining a Vegetative Cover on Banks of Drainage Features (canals, ditches, streams); and
- Outreach Program Informing Residential and Commercial Property Owners about sediment control.

The implementation of additional best management practices, including educational and training programs, which address erosion of upland soils and stabilization of shorelines is encouraged. Some examples of other actions include construction of riparian buffers along public waterways, citizen outreach programs that encourage construction and protection of riparian areas located on private property or provides training for property owners on how to manage their property that fronts a waterway, and construction of rain gardens or swales. Vegetated buffers immediately upland of the waterway and aquatic emergent vegetation along upland/waterway margins are effective in controlling suspended solids and reducing nutrients both as surface and subsurface discharges (Mayer et al., 2006). Living shorelines where vegetation is mixed with structural material (living and nonliving) can be an enhancement of a vegetated buffer or riparian buffer (http://floridalivingshorelines.com/).

9. Report Documentation Needed for Project Evaluation and Award of BMAP Credit: This guidance information will be developed by DEP as a checklist or data entry form once other parts of the guidance are confirmed.

10. Contact Information: To submit muck removal projects for the IRL BMAP(s) or if you have questions, please contact the appropriate IRL Basin BMAP Coordinator at DEP, Division of Environmental and Restoration, Watershed Planning and Coordination Section, Tallahassee, Florida; phone # 850-245-7508.

11. References:

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Appendix A. Muck Sediment Survey and Sampling Strategy for Determining BMAP Nutrient Credit for Muck Removal

Sampling Strategy Objectives

The strategy prescribed for muck sediment sampling in the IRL system is intended to cover only the essential, minimum steps to (1) identify or verify within the boundaries of a proposed muck-removal project area that it is, indeed, muck as defined on p. 1 of this guidance document; and that muck covers the entirety of the project area; and (2) collect and interpret certain field measurements and sediment data for the purpose of delineating the project area boundaries, determining the areal extent (km^2) of the project area containing muck, the median muck thickness, and the median annual muck flux rates of nitrogen and phosphorus (based on % LOI of the sediment samples) from which potential BMAP credit for the project is determined.

Sampling Plan

The project lead (e.g. primary stakeholder or permit applicant) shall provide to DEP via BMAP Coordinator a plan that provides (with the aid of a map or maps as needed) introductory or background information on the project, the sampling approach (sampling design, number of sampling stations, the field measurements to be taken and at what stations), and the quality assurance/quality control (QA/QC) protocol. This sampling plan guidance addresses only the sampling objectives stated above; it does not include additional samplings and analyses that may be required for regulatory permits.

Introduction/Background – Minimum Information Required

- Project area's waterbody name(s) and Project Name if different from waterbody name,
- Location of water body and delineation of project area therein,
- Any information on physical dimensions of the waterbody and of the muck deposit (area, thicknesses) within the waterbody or project area therein,
- Any information on physical and/or chemical characteristics of the project area's muck, and
- Any information on habitat resources near or within the project area.

Sampling Approach

Systematic design of sampling network: A systematic design is one in which the sampling sites are placed regularly or at equidistance from each other, generally within measurement grid cells or along measurement transects oriented in a manner that provides full coverage of the proposed project area from its perimeter boundaries to its center axis. This type of sampling network design is intended for a project area in which the entire area is subject to a common condition (Environment Canada 2002); and in this case, that common condition is surficial muck sediment.

If the morphometry of the subject waterbody/project area is highly irregular (e.g., embayments, tributaries, or braided channels, etc.) it may be necessary to create sub-area sampling grids or transects. Each sub-area would have its own distinctive grid or transect network and/or spacing between sampling sites.

Number of sediment samples: The number and location of sampling stations necessarily conforms to the entirety of the sampling grid or transect network to ensure full or representative coverage. Toward that end, it is important to locate a sufficient number of the sampling stations along the expected perimeter boundaries of the project area (e.g., at the terminal ends of transects), as well as within the interior of the project area, in order to verify that the proposed dredge area is entirely covered with muck and that the samplings are representative of the entire muck dredge area.

The number of sediment samplings can be derived from an equation (Eq. A1) or a table of values (Table A1; the number of stations are calculated using the equation) known as the Balduck Method (In: Keillor 1993). The Balduck Method estimates the minimum number of samples required to represent a dredge project area based on its areal coverage (km^2). Originally, the method, its equation (Eq. A1) and table of values (Table A1), was set up to provide 3 different sample numbers depending upon its assigned Dredge Factor (Df), a unitless multiplier of 1, 2 or 3 applied to the equation that accounts for the project area's dredge history, the presence or absence of data on sediment contamination, and environmental issues related to pollution (e.g., fish advisory). However, given the fact that the sediment sampling described in this guidance is exclusively focused on the survey of muck presence, thickness, and the collection of muck grab samples (for color, odor, and LOI analyses), and not on metal or organic contaminants or whether or not the area had been dredged before, the Balduck's Method equation and table of values adapted for use here assumes a Df = 1; thus, Df as a multiplier is inconsequential and deleted from the equation.

Eq A1: $\mathbf{N = \cancel{(Df)}(30) \times ((W)(L))^{0.33}}$, where

N = number of sediment sampling stations;
W = width of a single dredge area or the widest dredge sub-area among the multiple sub-areas to be dredged; and
L = length of a single dredge area or the sum of the lengths of the sub-areas of a dredge (project) area.

Table A1. Minimum Number of Sediment Sampling Stations Based on Dredge Area (Adaptation of the Balduck Method and Its Equation)

Dredge Area (km^2)	Minimum Number of Samples
0.004 – 0.008	5- 6
0.008 – 0.017	6 – 7
0.017 – 0.025	8 – 9
0.025 – 0.042	9 – 10
0.042 – 0.054	11
0.054 – 0.071	12
0.071 – 0.083	13
0.083 – 0.108	14
0.108 – 0.133	15
0.133 – 0.167	16
0.167 – 0.192	17
0.192 – 0.233	18
0.233 – 0.275	19
0.275 – 0.317	20
0.317 – 0.367	21
0.367 – 0.417	22
0.417 – 0.483	23
0.483 – 0.542	24
0.542 – 0.625	25
0.625 – 0.692	26
0.692 – 0.775	27
0.775 – 0.858	28
0.858 – 0.938	29
0.938 – 1.000	30

Number and Type of Field Measurements

Field measurements of location (latitude/longitude), water depth and muck depth or thickness should be taken at each of the sediment sampling stations.

Salinity measurements should be taken at 10 % of the sampling stations, at minimum, within a single project area or within each of its sub-areas. If the project area is within a tributary and the total number of sampling stations is determined to be <10, then take at least 2 salinity measurements; one near or at the center of the project area or each of its sub-areas and the other measurement at project area's upper reach boundary (i.e., toward the freshwater reach).

QA/QC Protocol

At a minimum, field replicates and duplicates should be taken at 10 % of the total number of sampling stations. Of course, these are additional samples to the minimum number of sediment samples as determined by the Balduck Method.

A field replicate is a complete and separate collection of a sediment sample at a sampling station (perhaps taken off the side of the boat opposite the side where the first sample was taken so as not to take the replicate at a previously disturbed site). The purpose of replication is to assess intra-site variability and/or field sampling techniques.

A lab duplicate is collected by splitting a sample that has already been collected into two samples for analysis to help assess laboratory analytical variability.

If there is any transfer of samples to another entity (e.g., sampling entity passes samples on to a separate laboratory entity), a chain-of-custody protocol should be followed including the necessary forms for inclusion in a QA/QC section of a report.

[Note: DEP may require additional QA/QC measures but replicates and duplicates are the minimum QA/QC requirements recommended].

Equipment

- Global Positioning System (GPS) for recording station location latitude/longitude.
- Graduated line with weighted 20-cm disc at the end for measuring water depth (cm).
- The simplest method uses a graduated polyvinyl chloride (PVC) pole for manually measuring muck thickness or depth. For the sake of consistency across projects in the IRL system, muck thickness surveys will be carried out using a 1¼ inches outside diameter (OD), capped PVC with 4-millimeter (mm) diameter holes at half-meter intervals along its length to maintain neutral buoyancy. The pole, marked in centimeter graduations, is lowered into the water column until the surface layer of sediment is encountered; this depth is recorded as the water depth. The pole is then pushed into the sediment until a firm bottom is struck and the total depth minus the water depth is recorded as the thickness of the muck layer. Water depths are validated at ~5 % of the sites by lowering a 20-cm diameter weighted disk (typically a 3 lb weight) attached to a calibrated rope until it settles onto bottom sediments. Other survey methods (e.g., remote sensing) can be used, but must be approved by DEP before credit is awarded; and for the sake of data quality control, shall be statistically validated by the manual pole method.
- Salinometer (hand-held optical salinometer, or some electronic instrument meter with a salinity probe). Pre-trip and post-trip calibrations should be performed and recorded.
- Eckman dredge sediment sampler or Petite Ponar sediment sampler are recommended. However, samples of muck can be collected using several different pieces of equipment including corers, scoops, as well as the dredge/grab samplers. DEP standard operating procedure (SOP)-001/01 FS 4000 Sediment Sampling describes the different sampling

devices and collection methodologies. The DEP protocols are available at: http://publicfiles.dep.state.fl.us/dear/sas/sopdoc/2008sops/fs4000.pdf.

- Munsell color chart. The hues to look for are grays and blacks. The lower the numbers are for chroma and value the more likely the sample is in the gray to black color range.
- Remove sample from sampling device with a clean non-reactive utensil and transfer to sample container. DEP-SOP-001/01 FS 4000 describes different sampling methods. If needed, a large bowl, tray, or bucket to receive the sediment sampler contents for subsequent transfer to sample containers could be used.
- A clean scoop, spoon or similar device to transfer sediment from the sampling device, bowl, tray, or bucket to sample container.
- A jug of distilled water for second and final rinsing of sediment sampler, bowl or tray or bucket, scoop or spoon following the first rinsing using project area's ambient water.
- Clean glass or plastic jars with screw-on lids to be used as the sediment sample containers for delivery to the laboratory.
- Field notebook and/or data sheets.
- Sample container labels and markers (labels note the station name, date and time of collection).

All jars, samplers, and other equipment that are to come into contact with a sediment sample needs to be cleaned prior to the sampling trip by first washing with phosphate-free Liquinox soap, then a tap water rinse followed by a distilled water rinse and allowed to air dry.

Laboratory Analysis – LOI %

LOI % @ 550°C on the sediment samples shall be determined using either the ASTM (American Society for Testing and Material 1996) or the method described by Heiri et al. 2001.

References for Appendix A

Environment Canada. 2002. Sediment Sampling Guide for Dredging and Marine Engineering Projects in the St. Lawrence River. Vol. 1. Planning Guidelines. Environment Canada, Environmental Protection Branch, Quebec Region. Montreal, Quebec. Report 104 pages.

Heiri, O., Lotter, A.F., Lemcke, G. 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. Journal of Paleolimnology 25:101-110.

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