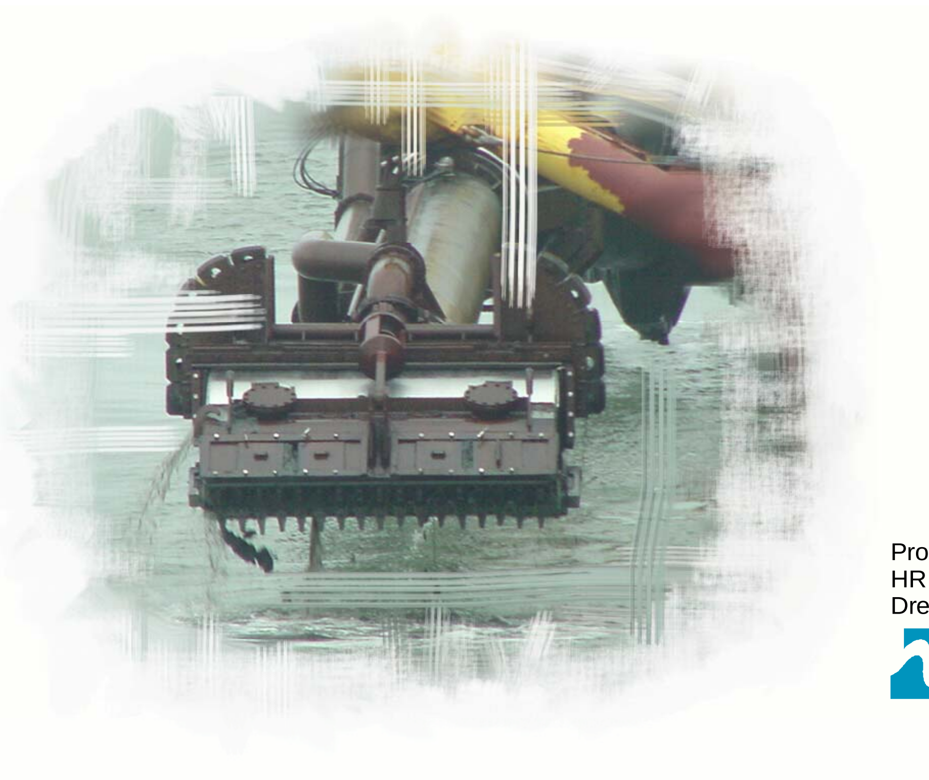
Vereniging van Waterbouwers in Bagger- Kust en Oeverwerken

Protocol for the Field Measurement of Sediment Release from Dredgers

A practical guide to measuring sediment release from dredging plant for calibration and verification of numerical models

Issue 1, August 2003



Produced for VBKO TASS Project by
HR Wallingford Ltd &
Dredging Research Ltd

AUTHORS' NOTE

This protocol is an evolving document that will occasionally be updated as field experience is gained. Some of the techniques described here have not yet been fully evaluated. In particular, the sampling of trailer overflow using the flow-through samplers described in Section 7.2 (as opposed to simple 'bottle' samplers has not yet been clearly demonstrated to be necessary. The results of the Rotterdam experiment during which the flow-through samplers were used are still being analysed but preliminary indications are that such samplers are required.

Users of the protocol are encouraged to provide feedback to HR Wallingford and Dredging Research Ltd concerning their experiences of field measurement of sediment release. All comments will be gratefully received and will be taken into consideration during preparation of future versions of the protocol.

PROTOCOL FOR THE FIELD MEASUREMENT OF SEDIMENT RELEASE FROM DREDGERS

1. INTRODUCTION

1.1 Background

Suspended sediment, when present in concentrations that significantly exceed the normal range of concentration in a particular location, has the potential to cause damage to habitats and ecology. In some cases, excessive sediment concentrations may also adversely impact the operation of shore-based installations with water intakes (eg. desalination plants, power station cooling systems).

The release of sediment from dredging plant has been a prominent environmental issue since the 1970's. Despite the attention that has been focussed on this issue, and the importance attached to it by many, the mechanisms that give rise to sediment release from dredging plant are poorly understood. Accurate prediction of sediment release rates for a given type of dredging operation is not possible. It is also the case that confident prediction of the effects of a given rate of sediment release on, for example, the ecology, is equally difficult except in extreme cases.

Suspended sediment in the wake of an overflowing trailing suction hopper dredger.

Although there are widely acknowledged difficulties in predicting sediment release rates and their potential impacts, many dredging projects are preceded by environmental studies that place considerable reliance on predictions of sediment release rates. These studies may result in the imposition of contract requirements concerning both the manner in which the work should be undertaken and the environmental restrictions that are imposed such as:

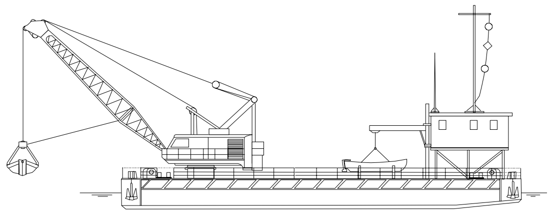
- specification of the types and sizes of dredger that must be used;
- limitations on the speed or manner of operation;
- imposition of maximum permissible suspended sediment concentrations.

Often, these requirements will be unrealistic, sometimes unattainable. They may result in unnecessary costs and contractual disputes. It may also happen that the requirements are insufficient to provide adequate protection to the environment, although the widely applied precautionary approach tends to make this an infrequent occurrence.

In an effort to address one aspect of this wide-ranging and complex problem, VBKO (Vereniging van Waterbouwers in Bagger- Kust en Oeverwerken) of the Netherlands commissioned, in 1998, HR Wallingford Ltd and Dredging Research Ltd of the UK to develop preliminary models to predict the rate of release of sediment from the following types of dredging plant:

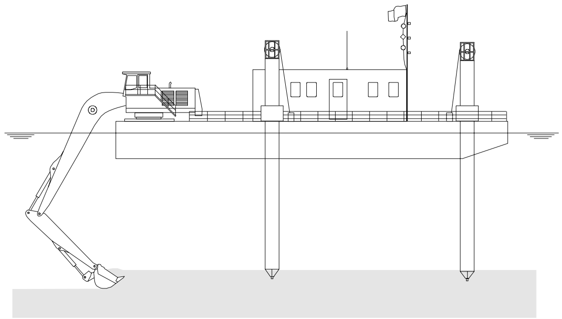
- grab (clamshell) dredgers;
- backhoes;
- bucket (ladder) dredgers;
- cutter suction (cutterhead) dredgers;
- trailing suction hopper dredgers.

It is the intention that, when calibrated by field measurements, the models will be included in a software package (TASS - Turbidity ASsessment Software) that can be used with reasonable confidence by all parties, including regulators and industry alike, to predict sediment release during dredging.



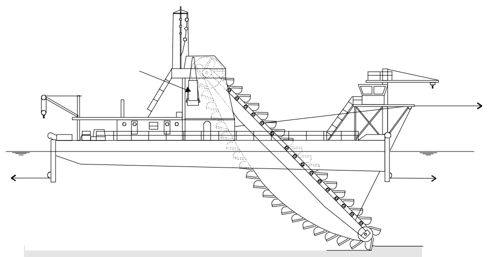
The grab dredger - the traditional workhorse of the dredging industry.

Development of the preliminary models was completed in early 1999. The research sought to identify all the mechanisms by which sediment is released during dredging and to develop models that predict the rates of release. Use was made of previous research efforts, particularly work undertaken by the Corps of Engineers in the USA and by several Netherlands organisations including the Dredging Research Association (CSB).



The backhoe dredger has become more common since the 1970s and is frequently used in stiff materials, confined areas and for work requiring high accuracy, eg. pipeline trenches.

A detailed review of published reports on sediment release from dredging operations revealed that field measurement methods were inconsistent and frequently failed to result in the collection of all the data required to assess releases from different types of plant working in different soil and rock conditions. The inconsistencies prevent direct and meaningful comparison between the measurements and thus reduce their value.



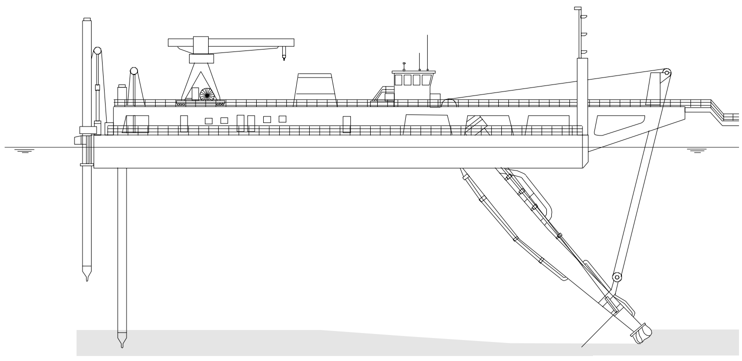
The bucket dredger is still widely used, especially in hard soils and confined areas.

As a result of this work, it was decided that there is an urgent requirement for a set of standard field measurement protocols which can be used to provide calibration data for the models. Phase 2 of the project has therefore focused on the development of these protocols. Draft protocols were developed for each of the five dredgers covered by the project. Two field trials were then undertaken to test most of the procedures described here.

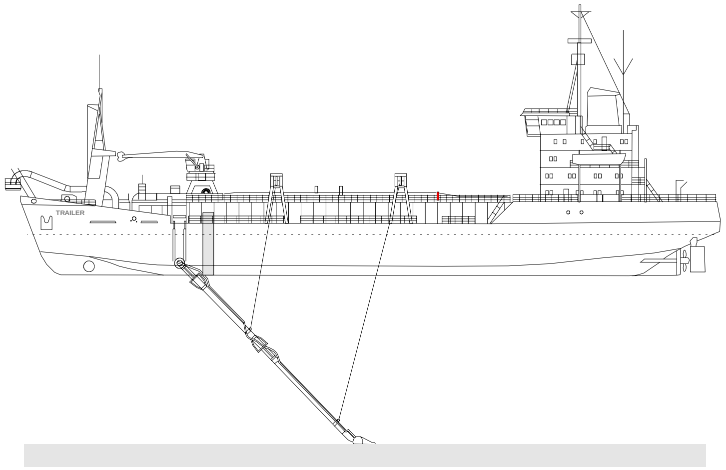
The first trial took place on the River Tees in England in May 2000 around a grab dredger undertaking maintenance work. The second trial, in Rotterdam in June 2003, measured sediment release from a trailing suction hopper dredger working on maintenance dredging (muddy sediments) and sand winning operations.

This document presents a general protocol for all of the dredgers included in this project. Many aspects of the protocols have been tested but it is recognised that some refinements may be necessary as more field experience is gained.

The cutter suction dredger - generally used in stiff soils and rock.



The first draft was circulated for review within the dredging industry in Europe and the USA. A list of those organisations and individuals who reviewed the protocol is provided in Appendix C. The authors are grateful for the opinions of the reviewers and have tried, as far as possible, to take all comments into consideration when preparing this version. However, it is stressed that this document represents the views of the TASS project team and is not necessarily endorsed in whole or in part by the reviewers listed in Appendix C.



The trailing suction hopper dredger is the most widely used type of dredger. Some modern vessels are huge, with hopper capacities in excess of 30,000 m^3. Trailers have played a major role in many of the recent large land reclamation projects in SE Asia and are the preferred tool for maintenance of coastal waterways.

1.2 Purpose of the Protocol

For calibration of sediment release models….

The primary purpose of this protocol is to provide guidance on standard methods of measuring sediment release from dredging plant in order that the measurements can be used to calibrate the TASS models. If measurements are to be of value for model calibration, it is necessary that they are detailed, accurate and complete. They must be supported by a comprehensive description of the materials being dredged, the characteristics of the site and the dredger and the manner in which the dredger is operated during the measurements.

This detailed approach to measurement will not be possible, for financial or practical reasons, in all circumstances. The TASS team recognise that simpler, less costly measurements can be undertaken which, while not providing all of the detail that is required for model calibration, can, if undertaken and reported in a standard manner, provide useful ‘second level’ information. The protocol therefore includes guidance on the manner in which relatively simple methods of measurement can be applied.

….not for environmental monitoring

This protocol is specifically not intended to provide guidance for undertaking environmental impact or compliance monitoring during dredging operations. The objectives and requirements for environmental monitoring are quite different from those for measurement of sediment release from working dredgers. However, some readers may find that that certain aspects of the measurement techniques described here will assist them when designing environmental monitoring campaigns.

….not for calibration of sediment transport models

Similarly, this protocol is not intended to provide guidance on measurements designed to calibrate or validate numerical models of sediment transport. However, as with environmental monitoring, some aspects of the protocol may be of use to those engaged in such activities. It is also the case, perhaps more so than environmental monitoring, that sediment transport model calibration field studies can often be designed in such a manner as to provide information that can be used for calibration of sediment release models.

….however

When designing measurement campaigns around working dredgers, even if the primary objective is not measurement of the sediment release rate, readers are encouraged to take note of this protocol and to consider how, with some adaptation and modification, their measurements can provide useful data that can be used by others.

1.3 Summary of Protocol Structure

Following this *Introduction*, the remainder of this document is set out as follows:

Section 2 presents a review of the mechanisms of sediment release and the nature of sediment plumes arising from dredging operations.

Section 3 describes the measurement philosophy adopted in this protocol.

Section 4 describes the Primary Measurement Method that has been adopted by the TASS team for measuring losses from semi-stationary dredgers (ie. grabs, backhoes, bucket dredgers and cutter suction dredgers) for the purposes of calibrating the TASS models.

Section 5 describes Secondary Methods that can be used to obtain calibration data for semi-stationary dredgers; these methods are acceptable alternatives to the Primary Method but will not usually yield data of the same accuracy and detail.

Section 6 describes Tertiary Methods of measurement. These relatively simple methods will not provide data of sufficient accuracy or detail to be used directly to calibrate models but might be used indirectly to validate or support the models.

Section 7 describes methods of measurement that can be used for trailing suction hopper dredgers.

Section 8 reviews the characteristics of ‘ideal’ dredging sites which would be suitable for undertaking detailed measurements for the purpose of obtaining calibration data.

Section 9 describes the equipment required to undertake the measurements in accordance with this protocol, the calibration of the equipment and its layout on the survey boat.

Measurements of sediment loss have little value if the losses cannot be related directly and in detail to the site conditions, the type of dredger used and the manner in which it is operated. A considerable amount of supporting data is required and this is described in *Section 10*.

Section 11 summarises the procedures used to compute sediment flux.

Section 12 sets out reporting requirements.

2. SEDIMENT RELEASE MECHANISMS AND THE NATURE OF SEDIMENT PLUMES

2.1 Introduction

Sediment can be released from dredgers by a wide range of mechanisms and at different levels in the water column. The mechanisms that give rise to the release are often complex. The models being developed for the TASS project attempt to predict the magnitude of each of the major sources of sediment release and, for each model, there may be several components that require separate calibration.

This section presents a review of the manner in which sediment is released by each of the five types of dredger included in the project in order to provide the reader with an understanding of what needs to be measured when collecting calibration data. It is assumed that the reader has a working knowledge of the dredgers that are reviewed here.

The Key Points:

- in all types of dredging operation, sediment release occurs at several locations, at different stages of the dredging cycle and at varying depths in the water column;
- sediment plumes are therefore complex in terms of spatial distribution in the water column;
- most dredging processes are discontinuous - the resulting plumes are also discontinuous - a 'steady state' is rarely, if ever, attained;
- a large number of measurements are therefore required in order to establish a 'characteristic' rate of sediment release and the overall range of release rate for a particular type of operation.

2.2 Grab (clamshell) Dredgers

2.2.1 Release mechanisms

The main causes of sediment release from grab dredgers are:

- impact of the grab on the bed;
- disturbance of the bed during closing and initial removal from the bed;
- spillage from the grab and erosion of exposed soil during hoisting (especially with open, non-watertight grabs);
- material washed from the outer surface of the grab during hoisting;
- leakage during slewing to the barge;
- washing of residual adhering material during lowering.

All these mechanisms are incorporated in the TASS model. The model does not yet incorporate the following additional resuspension mechanisms:

- aerosol formation during re-entry;
- biogenic gas escaping from the disturbed dredged bed;
- erosion of the freshly-dredged, disturbed bed by water currents;
- 'sweeping' - levelling of the final dredged surface by dragging the grab across it at the specified dredging level in order to minimise overdredging volumes;
- by splashing and leakage from the transport barge.

Release by aerosol formation is likely to be very difficult to quantify. Release by the other mechanisms listed above, while not yet included in the current TASS models, could be investigated using some of the methods described in this protocol. As data becomes available, these mechanisms will be introduced, in modular form, to the models.

The relative magnitudes of the main releases will depend on many factors including soil type, water depth, the type of grab being used, speed of working and the degree of skill and care employed by the grab operator.

2.2.2 The nature of the sediment plumes

From consideration of the primary mechanisms of release, it may be expected that the plume formed by a grab dredger will display the following features:

- a near-bed cloud of sediment put into suspension by grab impact and excavation;
- a columnar plume extending from the bed to the surface comprising sediment that has washed from the grab and the exposed soil (including any leakage through the grab jaws);
- a near-surface plume representing material escaping from the grab as it is pulled from the water and slewed towards the transport barge.

It is becoming apparent during the TASS research (and work in the USA) that one of the largest sources of release (when using a conventional grab) occurs as the loaded grab is removed from the water and when it is slewed over the surface towards the barge.

Thus, while much of the released sediment will form a relatively narrow plume in the main body of the water column where the grab was hoisted to the surface, there may also be a wide, near-surface plume that extends over a much wider area (depending of the length of the crane boom and the location of the barge relative to the location of dredging).

The magnitude of the near-surface release will be greatly increased by a poorly maintained grab that does not close tightly and by the presence of debris that prevents full closure.

The grab appears to have fully closed but there is still significant release of material due to spillage from the top of the grab.

If a cross section is made through the plume immediately downstream of the dredger, it is unlikely that all three of the main components would be seen at the same time. It is clear from the above that grab dredging is a discontinuous process and that:

- each stage of each grabbing cycle will be characterised by different rates of sediment release;
- the releases will occur sequentially.

The sediment plumes that result from grab dredging will therefore be discontinuous and, at a given point downstream of the dredger, the released sediment that is observed will vary continuously in both location in the water column and concentration.

2.3 Backhoes

2.3.1 Release mechanisms

The release mechanisms from backhoe dredgers are broadly similar to those from grab dredgers and the plumes will comprise the same three main components, ie. impact and excavation, hoisting and slewing to the barge.

As these dredgers are usually fitted with spuds, additional releases may occur as the dredger is moved from one location to another. This mechanism is not yet incorporated in the TASS model.

Operator expertise is considered to be an important factor with backhoes. The degree to which the bucket is maintained in a horizontal position, thus minimising spillage, as it is brought to the surface and slewed to the barge is very largely dependent on the skill of the operator. Substantial spillage might result from careless or inexperienced operation.

2.3.2 The nature of the sediment plumes

As the release mechanisms are broadly similar to those for grab dredgers, it is expected that the resulting plumes will also be similar, ie. comprising three main components representing the excavation, raising the bucket and slewing to the barge. However, as the backhoe bucket is solid, release of material when the bucket is above water will occur only from the top of the bucket - there will be no leakage resulting from non-closure. It is therefore possible (but as yet unproven) that, close to the dredger, the near-surface plume may be less prominent than is the case with grabs.

2.4 Bucket Ladder Dredgers

2.4.1 Release mechanisms

In the case of bucket dredgers, sediment release occurs due to:

- disturbance around the buckets as they are digging;
- sediment spilling and being eroded from the buckets as they ascend, sometimes aggravated by shaking of the bucket chain (eg. when working in hard or inhomogeneous materials);
- leakage from the discharge chutes;
- residual adhering sediment being washed from the empty buckets as they descend;
- release of air trapped in the descending buckets, especially when they turn at the bottom tumbler;
- dragging the bucket chain over the bed (and/or turbulence around the moving ladder) when working in shallow water.

Additional complicating factors may include the effects of biogenic gas release, the erosion of disturbed sediment from the freshly-dredged bed, and splashing and leakage from barges.

By comparison with grabs and backhoes, the bucket dredging process is relatively continuous and, when working in uniform soil conditions, the sediment release rate will be comparatively uniform except at the end of each swing when the dredger slows the swing speed prior to changing direction.

2.4.2 The nature of the sediment plumes

Plumes from bucket ladder dredgers have yet to be examined in detail in the field. However, it is expected that, because the dredging process is relatively continuous, sediment release from all sources will usually be visible together in an instantaneous cross section made down-current of the dredger. It is likely that the sediment will be distributed throughout the water column but the relative magnitudes of the near-bed, main water column and near-surface plumes have yet to be established.

2.5 Cutter Suction Dredgers

2.5.1 Release mechanisms

Cutter suction dredgers are relatively simple in terms of sediment release mechanisms. In most cases, almost all of the sediment is put into suspension by the action of the cutterhead. However, additional sediment will be put into suspension when working in shallow water if the ladder is dragging over the bed. Even if the ladder is not in contact with the bed, the induced large-scale turbulence around the ladder may put weak, erodible sediments into suspension.

Sediment may also be suspended due to sidewires eroding the bed and by the spuds when moving the dredger.

The transport of the dredged material to the surface is, theoretically, fully enclosed and unless there is leakage of pipelines, there should be no sediment release. If the dredger is loading into barges, significant releases can occur from the barge due to splashing, overflow and, possibly, leakage from the barge.

2.5.2 The nature of the sediment plumes

When working with pipeline transport, the sediment plume from a cutter dredger is initially relatively small and confined to the area around the cutterhead. Compared with all other types of dredger considered here, the rate of release is expected to be relatively constant (when working in homogeneous materials) during the main part of the swing. As the dredger approaches the end of the swing, it slows down and the sediment release rate may be reduced.

The plume created by turbulence around the ladder when working in shallow water may be larger than that created by the cutterhead and become rapidly mixed through the water column.

2.6 Trailing Suction Hopper Dredgers

2.6.1 Release mechanisms

There are five main mechanisms by which sediment may be released into the water column by a trailing suction hopper dredger:

- overflow from the hopper;
- use of Lean Mixture OverBoard (LMOB) systems;
- disturbance around the draghead;
- scour of the bed caused by the main propellers and bow thrusters.
- operation of de-gassing systems.

The THSD Cornelia (Baggermaatschappij Bos Kalis) working near Rotterdam, The Netherlands

The lean mixture overboard (LMOB) system is used mainly when dredging in soft soils and is designed to prevent low density mixtures entering the hopper and occupying space which could be used for the storage of higher density mixtures. The system operates by diverting the flow from the discharge side of the pump to a discharge point in the vessel's hull. LMOB is used intermittently, mainly at the commencement of a dredging run and when the ship is turning.

The relative importance of these release mechanisms varies according to the nature of the soil being dredged and, in some cases, on operating restrictions imposed to minimise environmental effects. In addition, sediment may be put into suspension by the release of biogenic gas from disturbed, recently-dredged areas. This mechanism is not yet incorporated in the TASS models.

In broad terms, there are two main operating modes which determine the general magnitude of sediment release:

- working in non-cohesive, relatively coarse materials with overflow;
- working in cohesive or very fine materials without overflow.

Occasionally, a combination of the two modes occurs, but this is relatively uncommon. Overflow is usually used when dredging sands, stiff clays and gravels. It is characterised as follows:

- major discharge of sediment from the overflow, when the hopper has been filled with mixture, including during turning between trailing runs;
- relatively minor re-suspension of sediment at the draghead;
- propeller scour (depending on water depth relative to the draft, and on the nature of the bed material);
- no use of Light Mixture OverBoard (LMOB) systems.

In this mode, the release of sediment through the overflow may be orders of magnitude greater than the release caused by other mechanisms.

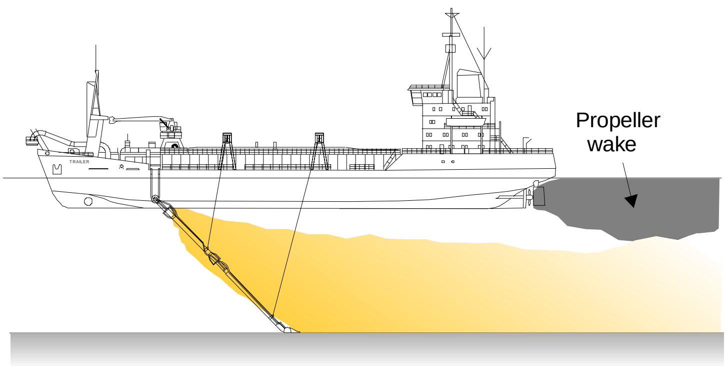
Dredging without overflow usually occurs when dredging silts and soft clays. It is characterised as follows:

- use of the LMOB system;
- propeller scour (depending on water depth relative to the draft, and on the nature of the bed material);
- re-suspension of sediment at the draghead when at or near the seabed.

The release mechanisms fall into two groups, releases from within the vessel and releases due to the disturbance of the bed. The releases from within the vessel (ie. overflow and LMOB discharge) will in most cases be the greatest and are characterised by severe entrainment of air bubbles, preventing meaningful measurements close to the ship. The release of sediment by these mechanisms must, therefore, be measured directly on board the trailer.

2.6.2 The nature of the sediment plumes

When working with overflow, the sediment released by the overflow will be dominant and will probably completely obscure the sediment released by other mechanisms. If the density of the overflow is sufficiently high and the speed of the vessel through the water is sufficiently low, the plume will initially be very dynamic and will descend rapidly towards the bed (Figure 2.1) resulting, in a very short space of time, in a well developed depth-related concentration gradient. The plume may be significantly wider near the bed than at the surface.



As the dredger passes over the plume, some material may be entrained from the top of the plume by the propeller wake and redistributed back towards the surface but the bulk of the released sediment will remain in the lower part of the water column.

Figure 2.1 A dynamic overflow plume

If the overflow density is low and the vessel speed is high, the plume descent speed will be relatively slow. The plume will tend to mix rapidly with the surrounding water and will be diffused (Figure 2.2).

A large proportion of the released sediment will be further disturbed by the propeller wake of the ship. The concentration gradient within the plume will initially be weak. The shape of the plume (in cross-section) will be more columnar than that resulting from dynamic, high-density overflows.

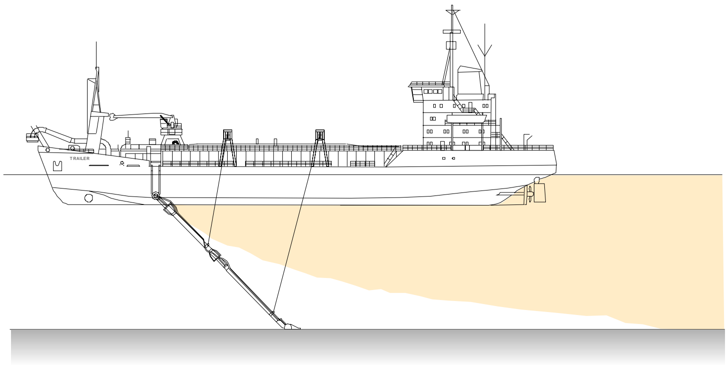


Figure 2.2 A weakly-dynamic overflow plume

When working without overflow, the draghead plumes will stream behind the dredger, rising a little way into the water column due to turbulence. Near-surface patches of sediment may result from intermittent LMOB releases. In shallow water, the draghead plumes may become entrained into the main part of the water column by the propeller wake. Propeller scour of a weak, erodible bed will form wide (somewhat wider than the dredger), initially very turbulent plumes in the lower part of the water column.

2.7 Phases of Plume Development and Decay

2.7.1 Plume Development

In an ideal world it would be possible to measure the rate of release of sediment at exactly the location(s) where it is released. However, with the single exception of the overflow from trailer dredgers, it is not possible to do this for both practical and safety reasons. In addition, both conventional turbidity meters and acoustic measurements of suspended sediment, on which this protocol is largely based, are subject to measurement errors when air bubbles are entrained in the water column, as is almost invariably the case close to dredging equipment.

Even if it were possible to undertake such measurements, they may be of little practical use when estimating the potential impacts of dredging. In most cases, these impacts are assessed on the basis of the results of numerical modelling of sediment transport away from the dredging site. With most types of dredger, the release of material at the source(s) includes relatively large lumps of material that descend almost immediately to the bed. These certainly do not impact on the sediment regime beyond the immediate area of the dredging. However, it is noted that such material (having being weakened during the dredging process) may contribute by other processes to the overall sediment transport from the dredging area and may also be important in the context of assessing the impacts of contaminated materials.

An additional complicating factor arises from the very turbulent zone in the immediate vicinity of the dredging equipment. Movement of cutterheads and cutter ladders, grabs, buckets and trailer dragheads creates significant artificial turbulence that initially hinders the settling of all but the largest particles. The size of this zone is in most cases likely to be small, perhaps of the order of a few metres around the moving equipment. The duration of this phase of plume development is short and is measured in seconds.

As the released sediment is moved out of this turbulent zone by water currents (or the dredging equipment moves away), the behaviour of the remaining sediment in suspension (ie. excluding the large lumps) becomes more predictable and easier to model. For these reasons, two ‘sources’ of sediment release have been defined: the True Source and the Practical Source.

The True Source is the actual location where sediment becomes detached from the dredging equipment. It is in an area of high turbulence where the processes of plume development are dominated by 'fall out' of large lumps and by the severely hindered settlement of all other particles. This area is defined, for the purposes of this protocol as the Dredging Zone.

The Practical Source lies at the edge of the dredging zone. This point may, in some cases, be approximately coincident with the closest point to the dredger at which meaningful measurements can be made. More importantly, it is the point at which subsequent plume behaviour becomes reasonably predictable and quantifiable.

The stages of plume development are schematically illustrated in Figure 2.3. Over a timescale of seconds, and a distance of a few metres, the plume passes from the Dredging Zone into the Near Field. The material remaining in suspension is advected away from the dredger by the ambient current and it becomes possible to describe the elongating cloud of suspended material as a plume.

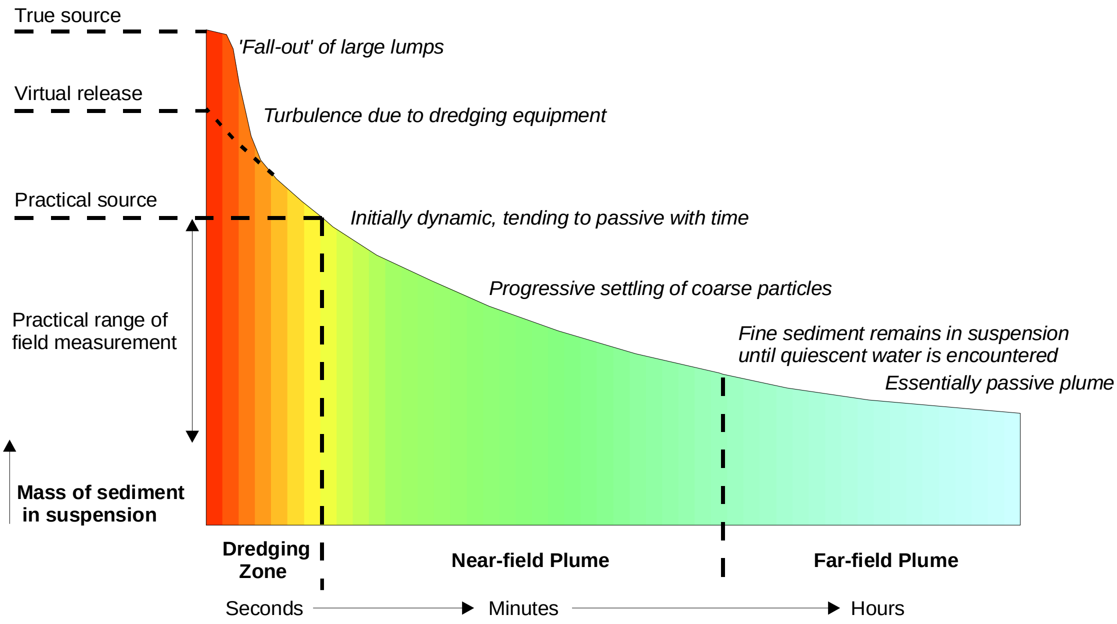


Figure 2.3 Stages and processes of plume development

In almost all cases, the material that passes from the dredging zone into the near field will comprise a continuum of particle sizes ranging from lumps that were too small to settle to the bed through the turbulence within the dredging zone, to sands, silts and clays. Three processes will then act, in combination, on the suspension:

- the plume will initially behave in a dynamic manner, and will settle as a whole towards the bed as a dense liquid at a speed that is determined by its size and density contrast with the ambient water; this initial descent speed may be orders of magnitude faster than the theoretical settling speed of the individual finer particles contained in the suspension;
- differential settling will take place within the suspension, with the coarser particles settling faster than the finer particles;
- water currents, if present, will advect the suspension away from the dredging site.

Dynamic plumes are most commonly associated with high-volume, high-concentration overflow release from trailers but it is the case that most plumes are initially characterised by some degree of dynamic behaviour. The TASS models incorporate a dynamic plume module to simulate the early stages of plume development in the near-field.

Even when the plume behaves dynamically, differential settlement will be an important mechanism of development. Coarse sand with a diameter of 2mm will settle at about 300mm/s. At the other end of the sand size spectrum the finest sand (0.063mm) will settle at about 3mm/s. In 15 m of water moving at 0.5m/s very fine sand introduced at the water surface will take about 1.5 hours to settle and will travel about 2.5km before reaching the bed. Very coarse sand will take 50s to settle and will travel only 25m. Disaggregated mud in suspension (at any concentration) in the same circumstances will not settle to the bed. The water velocity has to be below about 0.1m/s in the near bed zone for any settlement to take place.

The near-field phase of plume development can therefore be summarised as the period in which an initially dynamic plume loses its momentum as differential settlement, assisted by turbulent diffusion, acts to reduce its excess density. The coarse particles will progressively settle out of suspension, leaving only the fine particles to form a passive plume that moves into the Far-Field. The duration of this near-field stage of plume development will vary considerably depending mainly on the initial concentration and size distribution of the particles in the suspension, the volume of the suspensions, water depth and magnitude of the normal hydraulic turbulence that takes place in moving water. In most cases, it is likely to be complete within a period of tens of minutes, perhaps as much as 1 - 1.5 hours.

The Far-Field plume is essentially passive and comprises a dilute suspension of fine sediments. The term “far field” is most commonly used in the context of the fate of the fine fraction of the material and the limits of potential environmental effects. The path taken by the plume and the solids suspended in it are determined by the site-specific hydrodynamics. These may be unidirectional as in the case of canals or variable and oscillatory in the case of coastal waters or estuaries. It is beyond the scope of this document to describe these. Many computer models exist that are capable of providing the necessary hydrodynamic background to plume evolution.

There is no clear boundary between near-field and far-field. The one that is implied here is that for far-field applications only the finest material remains, which settles at a rate proportional to the concentration, whereas in the near-field there may be sediment settling out from the flowing water at different rates.

2.7.2 Towards a definition of sediment release

It is clear from the above that the various processes affecting the movement of sediment from the original (true) source do not occur in discrete packages and that the particle size distribution of the released material varies significantly over time. The entire process may be described as a continuum. Thus, any definition of sediment release rate will be somewhat arbitrary.

One alternative is to devise a definition that is appropriate for input to plume models. For near-field models, or when near-field modelling is an integral part of far field modelling, the description of the “source” must include:

- the location of the source;
- the flux of sediment at that point;
- the particle size distribution (or more directly the settling velocity distribution) of suspended sediment at that point.

From the particle size distribution (or settling velocity distribution) it may be theoretically possible to continuously calculate the settling rates and to derive the type of curve shown in Figure 2.1. However, the first few seconds, when large lumps are falling out of suspension, would be difficult to simulate because the particle size distribution of all the material released at the true source is almost impossible to establish by measurement.

An alternative approach is to fit a curve to the measured decay of the flux in the near-field and to extrapolate back to the theoretical location of the True Source (zero on the x axis of Figure 2.3). This computed release rate can then be defined as the Virtual Release Rate. Whilst this would have mathematical relevance as input to a plume model it would not necessarily represent what was happening at this location. However, it should only be used if the plume model properly represents sediment settling rates across the particle size spectrum otherwise it would lead to an overestimate of advection into the far field.

2.7.3 Summary of terminology

The above discussion leads to the following definitions that have been adopted by the TASS project:

True Source	Location(s) of the active part(s) of the dredging unit from which sediment is released.
True Release Rate	The rate at which sediment is released at the **True Source** (not directly measurable).
Dredging Zone	The zone immediately below and adjacent to the active dredging unit where the material is subjected to mechanically induced turbulence. Large lumps and coarse material settle to bed through clouds of finer suspended material.
Practical Source	The boundary between the **Dredging Zone** and the **Near-Field Plume**. In practice this is likely to be the nearest point to the active unit where it is possible to obtain meaningful and relevant measurements. Its location relative to the true source must be known.
Practical Release Rate	The rate at which sediment passes out of the **Dredging Zone**.
Near-field Plume	The stage of plume development in which the coarser fraction of suspended sediment settles to the bed whilst being advected by the ambient currents; the initial stages may be dynamic but the plume becomes more passive with time.
Virtual Release Rate	The estimated **Release Rate** that is back-calculated from the decay curve of the Near-Field Plume.
Far-field Plume	The stage of plume development in which only the fine fraction remains in suspension and is capable of being advected over long distances by the ambient currents as long as the velocity of that current remains above a critical threshold.
Age of Plume	The time that has passed since the sediment first entered the water column at the true source.

It is recommended that this terminology be used in any reports on field measurements of sediment release undertaken using this protocol.

3. MEASUREMENT PHILOSOPHY - THE BASIC PRINCIPLES

The Basics

- ❑ Measure as much as possible as close as possible to the Practical Source and at varying distances away from it.
- ❑ Measurements must be supported by full details of the dredging operation - otherwise they are worthless.
- ❑ Measurements will be more reliable if made at open, unobstructed locations with uniform soil conditions and low background sediment concentrations.

3.1 What Should We Measure, What Can We Measure?

The primary objective of the calibration measurements is to establish the Practical Rate of Release as defined in Section 2. In many cases, it may not be possible to measure this rate of release at the Practical Source for three reasons:

- the practical source may be inaccessible (eg. under the dredger) or too close to the dredger for measurements to made safely;
- almost all methods of dredging generate air bubbles that will corrupt suspended solids data obtained very close to dredgers using the techniques adopted in the protocol;
- the ambient current regime may be too disturbed close to the dredger (because of the movement of the dredger) to obtain meaningful data.

It is therefore inevitable that most releases must be measured at locations that are remote from the dredger. From the discussion in Section 2, it is clear that the best chance of establishing the Practical Source is to measure at several points on the decay curve in the near-field plume while ensuring that a proportion of the measurements are made as close as possible to the Practical Source. Figure 3.1 illustrates three measurement zones that define measurement possibilities..

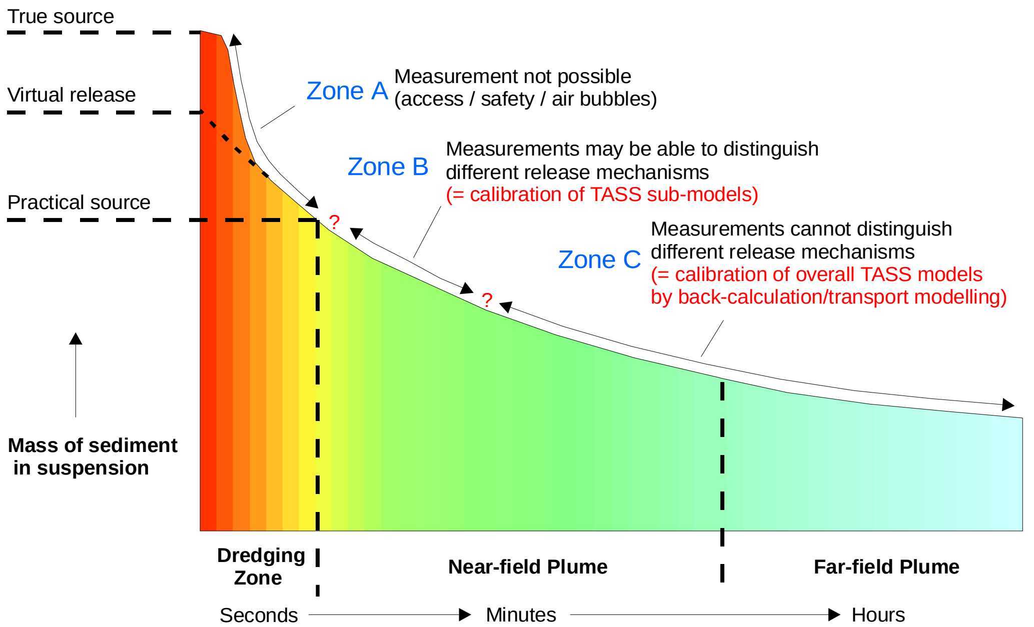


Figure 3.1 Measurement zones illustrated in terms of location on the plume decay curve.

With the one exception of the overflow releases from trailers (which can be measured on-board the dredger - see Section 7), it will be found that the shortest distance from the dredger where reliable measurement can be made will be defined by the length of time taken for entrained air bubbles to dissipate. Unless the current is very slow, the distance over which bubble dissipation occurs will normally exceed the distance required for safety (air bubble entrainment and establishing appropriate measurement locations are discussed in Section 9.3). The combined considerations of access, safety and data quality thus define Zone A in Figure 3.1 where measurements cannot be undertaken.

Measurements in slack water or in very weak currents are, in fact, unlikely to provide the data required for model calibration because much of the sediment will settle to the bed under the dredger. It is therefore necessary to conduct measurements in water currents that carry a significant proportion of the released material to a point where is can be measured.

It is also important, for most of the TASS models, to calibrate individual components of the models. For example, the grab model predicts release near the bed due to grab impact and excavation, in the main body of the water column due to erosion and leakage during hoisting, and at the surface as the grab leaves the water and is slewed to the barge. In order to calibrate the sub-models, the measurements must be undertaken close to the points of release before the plumes have had time to diffuse and merge with each other. This therefore defines a second zone (B) in which these objectives might be achieved. There is as yet insufficient experience to define the timescale of Zone B but it is likely to be less than 5 minutes from the time of release.

Zone C extends over the later part of the near-field phase of plume development and into the far-field. In this zone, the processes affecting plume development will have resulted in a diffuse plume from which a significant proportion of the sediment that initially passed out of the dredging zone may have settled to the bed. Data obtained in this Zone can be used to calibrate only the total release predicted by a TASS model. This would need to be done indirectly by comparing the observational data with far-field conditions predicted by the TASS release and dynamic plume models in combination with an appropriate passive plume model.

3.2 Classes of Measurement (Semi-stationary Dredgers)

From the discussion in Section 3.1, in combination with consideration of available measurement technologies, it is possible to identify three classes of measurement that can be used to calibrate the TASS models of the semi-stationary dredgers (ie. grabs, backhoes, bucket ladder dredgers and cutter suction dredgers). These are introduced below and described in detail in Sections 4, 5 and 6. Measurements for the calibration of the trailer model are a special case and are described separately in Section 7.

3.2.1 Primary (Preferred) Method

The Primary Method is designed to obtain detailed calibration data that can be used directly to calibrate both the overall release models and the sub-models of release from different stages of the dredging process. Because the sediment release is measured in terms of the mass of sediment release per unit of time, it is necessary to measure the current speed at the measurement location. Therefore, the method must be able to quantify throughout the cross-sectional area of the plume both current speed and solids concentration in Zone B where the plume may be of very limited extent.

The only manner in which these objectives can presently be satisfied is to use Acoustic Doppler Profilers (ADPs). These can be deployed from a moving survey boat and measure the water current in discrete cells throughout most of the water column. In addition, most are able to measure the intensity of the acoustic backscatter from particles in the water column and this measurement can be processed to derive solids concentration. The Primary Method is described in Section 4.

ADP terminology

The term Acoustic Doppler Profiler is used here in its generic sense to describe all of those instruments that measure water currents using the Doppler effect including:

- ADCP (RD Instruments Inc)
- ADP (Sontek Inc)
- NDP and AquaDopp (Nortek A/S)
- DCM (Aanderaa Instruments)

3.2.2 Secondary Methods

Alternative methods can be used in Zone B to measure total sediment flux but these are unlikely to provide the detail that is required to calibrate the individual components of the various TASS models. In addition, because they do not measure continuously throughout the water column, it is likely that the number of measurements required to obtain a reliable characteristic rate of release will be greater than the number needed using the primary method.

These methods are based on the use of profiling turbidity meters or towed arrays of turbidity meters, in conjunction with current data obtained using ADP's or conventional current meters, and are termed Secondary Methods. Secondary Methods are described in Section 5.

3.2.3 Tertiary Methods

Tertiary Methods are those which provide data that can only be used in an indirect manner to calibrate TASS. These include the techniques used for the primary and secondary methods when they are applied in Zone C. Tertiary Methods are described in Section 6.

3.3 Measurements in Context

It is a fundamental principle of the approach adopted by the TASS project team that any measurement of sediment release from a dredger (however the measurement is made) is of no value for the purposes of model calibration unless it is accompanied by a detailed description of the dredger, its manner of operation, the materials being dredged and the nature of the site where the dredging was undertaken. It is, in fact, precisely because so many previous attempts at measurement were not supported by these data that this protocol was deemed to be necessary.

All of these factors have a significant effect on the rate at which sediment is released. Release rates in uniform soil conditions may vary by an order of magnitude depending on the manner of dredger operation. For a given type of dredger, the release rates will vary over a much wider range depending on the nature of the material being dredged. The protocol therefore requires that detailed supporting data are provided with each release measurement. These requirements are set out in Section 8.

3.4 Making Life Easy

In order to simplify the collection and interpretation of release measurement data and to generally increase the reliance than can be placed on them, it is important to undertake measurements in situations where complicating factors can either be eliminated or quantified.

For example, if a certain type of dredging operation resulted in the formation of a narrow plume with concentrations above background of, say, 100-200 mg/L, it would be very difficult to quantify the release rate if the measurements were undertaken at a location where the natural sediment concentrations were several 100's of mg/L and varied by 50% or more over short distances and timescales. Under such conditions, distinguishing the dredging-induced plume from the natural sediment population would be almost impossible. It would also be very difficult to interpret the results of measurements made while working in very variable soil conditions

The general principle adopted in this protocol is that measurements will be more reliable if made at open, unobstructed locations with uniform soil conditions and low background sediment concentrations. Section 9 discusses the characteristics of 'favourable' sites where calibration data can be obtained (and interpreted) with relative ease.

4 THE PRIMARY METHOD

4.1 Summary Description

The recommended approach for obtaining data that can be used for detailed calibration of the TASS models is based on the use of Acoustic Doppler Profilers (ADPs) that have the ability to measure acoustic backscatter intensity from particles suspended in the water, in addition to current speed and direction. The backscatter intensity can, with appropriate calibration and data processing, be used to derive suspended solids concentrations.

Equipment Checklist

- ❑ Survey boat
- ❑ Acoustic Doppler Profiler [ADP] mounted on side or bow of boat
- ❑ GPS interfaced with ADP
- ❑ Profiling turbidity meter (hand- or winch-operated) with data logging facility
- ❑ Water sampler
- ❑ Temperature & Salinity sensors

When deployed from a moving boat, these instruments are able to measure the sediment flux (mass of sediment per unit time) through survey lines located immediately down-current of the dredger.

The main advantage of this approach is that ADP's measure both currents and concentrations with a high degree of spatial resolution throughout most of the water column. It is therefore possible to 'map', in considerable detail, the variation of sediment flux within plumes, even the narrow plumes that, for example, are found close to grab dredgers. The resolution of the measurements depends on the specification and settings of the particular instrument that is used and the sailing speed of the boat through the plume. However, measurements at vertical intervals of 0.25m and horizontal intervals of 1-2 metres are typical of what can be achieved.

The following main items of equipment are required, in addition to the ADP:

- a profiling turbidity meter to obtain data from the near-surface and near-bed zones;
- water sampling equipment to provide calibration data for the ADP;
- temperature and salinity profiling sensors to provide input data for the computation of suspended solids using the ADP backscatter data.

Although this is the preferred method, it is acknowledged to be difficult and should be undertaken only by experienced personnel familiar with the technique and its limitations. In particular, the accurate calibration and processing of the ADP data are complex issues requiring specialist analytical procedures and software. These aspects are reviewed in Section 9. Readers who wish to use this technique and who are not familiar with it are strongly advised to retain the services of a specialist organisation.

Figure 4.1. A 600 kHz Broadband ADP mounted on the side of a survey boat ready for profiling.

There are three ways in which this type of measurement can be undertaken, depending on the type of dredger and site conditions:

1) sailing simple transects downstream of the dredger;
2) from an anchored boat as the dredger passes the boat (cutter suction and bucket ladder dredgers only);
3) sailing box transects around the dredger.

4.1.1 Simple transects

This approach is best suited to sites with the following characteristics:

- where the flow of water away from the dredger is in approximately the same direction throughout the full depth of the water column;
- reasonably uniform background sediment concentrations (in terms of both location and time).

The method is to sail repeated transects through the plume down-current of the dredger (Figure 4.2). Each measurement transect must extend across the full width of the plume into waters that are not affected by the sediment released from the dredger. The measurement lines may be at varying distances from the dredger as long as the distance is known for each line.

Most of the measurements should be made as close as possible to the dredger in order that most of the released sediment is quantified but they should not be so close to the dredger as to be affected by air bubbles generated by the dredger (Section 9).

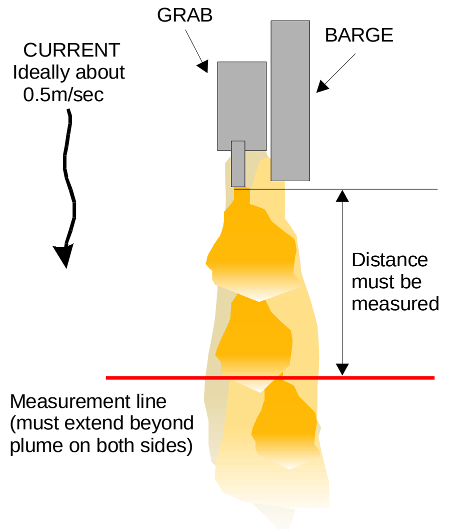


Figure 4.2 Measurement of sediment flux down-current of dredger

At intervals during the measurements, the survey boat should be stopped in order to collect calibration data (water samples) both within and adjacent to the dredging plume (Section 4.4). The profiling turbidity meter should also be deployed occasionally in order to investigate conditions in the near-bed and near-surface zones where the ADP cannot obtain data (Section 4.3). Temperature and salinity data are required for the ADP data processing are these are best obtained using sensors mounted on the profiler, although these data can be obtained separately if necessary.

The sediment flux through though each ADP measurement ‘cell’ (typically about 1.5 m wide x 0.25m high) is derived by multiplying the solids concentration by the measured discharge (volume of water per unit of time) in that cell. The total flux through the survey line is obtained by summing the flux measured in all of the cells.

The natural, or background flux is derived by multiplying the total measured discharge through the line by the average suspended solids concentration observed on each side of the dredging plume. The sediment flux attributable to the dredging operation is then given by the total flux less the inferred background flux. The method of data analysis is described in more detail in Section 11.

4.1.2 Stationary boat / moving dredger

A second approach, that can only be used for cutter suction and bucket ladder dredgers, is to anchor the survey boat immediately down-current of the arc through which the dredger will swing (Figure 4.3). This approach is effectively the reverse of the moving-boat approach - the plume passes the survey boat rather than the boat passing through the plume. Each single measurement should commence before the dredger reaches the measurement location and stop when the sediment released by the dredger can no longer be detected.

This approach has not yet been tested but is expected to yield results that are as accurate as the simple transect approach.

It is important to measure at several locations along the arc defined by the cutterhead (or bucket ladder) in order to account for the reduced swing speed near the ends of the arc.

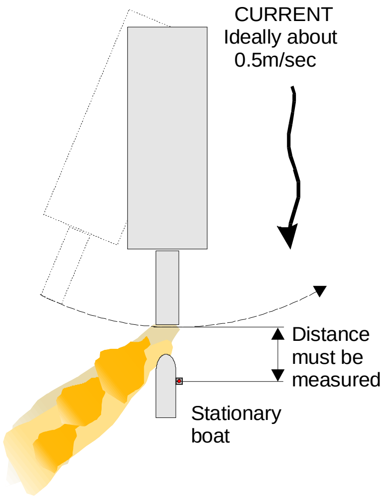


Figure 4.3 Stationary boat method that can be used with dredgers that swing while working.

4.2 Location and Number of Measurements

The measurement transects should be made over a range of distances from the dredger and should be biased towards transects close to the dredger. Some measurements must be made as close as possible to the dredger and this distance will depend partly on practical and safety considerations and partly on the extent to which the dredging process introduces air bubbles to the water column.

Air bubbles will severely corrupt the ADP backscatter data. In the experience of the TASS team, air bubbles created by the semi-stationary plant (to which the Primary Method applies) will be dissipated within 100-200 seconds. If the water current is, for example, 0.5 m/sec, this means that the closest measurement transects will be between 50 and 100 metres from the dredger. The actual length of time required for bubble dissipation will depend on water depths, the type of dredger and its manner of operation. Field trials must be carried out at the start of measurements in order to investigate the extent of air bubble contamination and to determine how close the transects can be made without risk of corrupting the measurement data. The procedures for these trials are described in Section 9.

The number of measurement transects that are required in order to derive a characteristic rate of release has yet to be established. However, it is expected that it will vary depending on the type of dredger being used. Those dredgers which work in the least continuous manner (ie. grabs and backhoes) will require a greater number of transects than those which work a relatively continuous, semi-automated manner (ie. bucket and cutter suction dredgers).

During the first trial of this protocol, a total of 21 measurements were obtained while working with a grab dredger. It had been intended to make more measurements but technical difficulties and the limited amount of time available prevented this. It was evident from the results that, although there was a definite trend to the data, the 21 measurements were not sufficient to determine the characteristic rate of release.

On this basis, it has been estimated by the TASS team that about 50 separate measurement transects may be necessary to establish a characteristic release rate for a grab dredger with a reasonable degree of confidence. It is expected that a similar number would be required for backhoes. Fewer transects may suffice for bucket and cutter suction dredgers because the dredging process is more continuous than that of grabs and backhoes but, until further field data have been obtained, it is not possible to provide firm guidance. It should be noted that the indicative numbers given here apply to a single combination of site characteristics, soil type and dredger operating parameters.

About 30% of the transects should be made as close as possible to the dredger. The remainder should be located at varying distances down-current of the dredger up to the point where the plume is about 10-15 minutes old. It should be noted however that as the distance from the dredger increases so too do the difficulties of accurately distinguishing the plume from the background sediment. The frequency of transects should therefore generally decrease with increasing distance from the dredger.

4.3 Near-bed and Near-surface Data

4.3.1 ADP limitations

ADPs are unable to collect data in the near-bed and the near-surface zones (Figure 4.4). The near-surface zone cannot be measured because the transducers must be immersed at a depth sufficient to avoid near-surface air bubbles. Normally, an immersion depth of 1 metre is sufficient but this may be reduced when working in calm water. In addition to the immersion depth, there is a short distance immediately in front of the transducers where data cannot be obtained. This varies according to the type of ADP being used but is of the order of 0.5 to 1.0m. Subject to these limitations, the transducers should be mounted as shallow as possible in order to maximise the proportion of the water column from which data can be obtained.

In the near-bed zone, the signal is corrupted by sidelobe echoes from the bed and cannot be used to derive solids concentrations. The height of the near-bed area is (expressed as a percentage of the distance between the transducers and the bed) is calculated as $100 \times Cos\alpha$ where α is the ADP beam angle from the vertical.

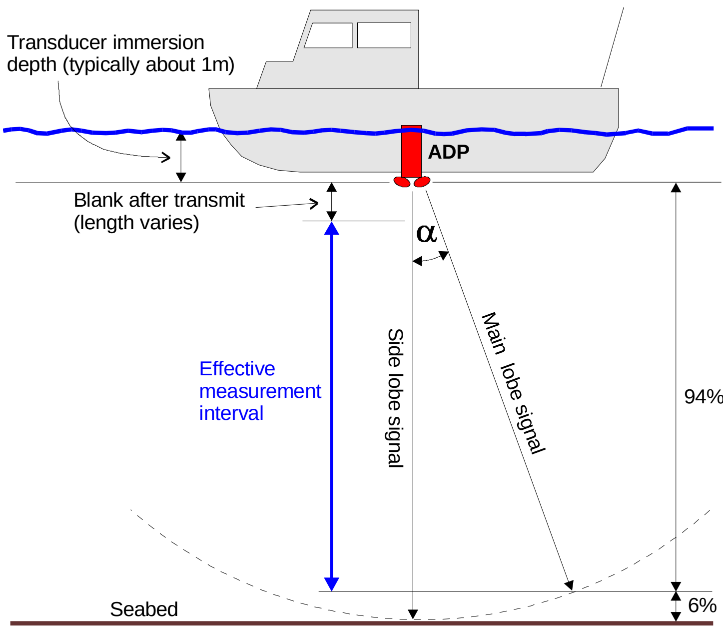


Figure 4.4. Effective measurement interval of the ADP (assuming a 20° beam angle)

In the case of instruments with a 20° beam angle, the distance over which backscatter data are corrupted is 6% of the distance between the transducers and the bed. This rises to 15% in the case of instruments with a 30° beam angle. The use of instruments with a 20° beam spread is therefore preferred.

4.3.2 Near-bed and near-surface data solutions

There are two approaches that can be used to obtain data in the near-bed and near-surface zones:

- by extrapolation of the ADP data during processing;
- by direct measurement with a profiling turbidity meter.

The former is achieved by fitting curves through both the ADP current and concentration data in order to extrapolate the measured data into the 'blind' zones. This is a generally reliable approach in the near-surface zone but may not be adequate to deal with the near-bed zone where concentration gradients may occasionally be so steep that they are not possible to predict by curve-fitting through the data in the main water column. It is also the case that, very close to working dredgers, the distribution of sediment in the water column may be very irregular. In most cases, curve fitting is unlikely to be appropriate. It is therefore recommended that a profiling turbidity meter be used to investigate concentration gradients in the near-bed zone.

It is recognised that such instruments can be deployed only intermittently and that, at best, they will only provide some general guidance on the near-bed concentrations. However, two other factors need to be considered:

- it is necessary to collect both water samples and temperature/salinity profile data for ADP data processing; the equipment required to do this can be mounted on the profiler, thus saving time during data collection;
- in the near-bed zone, the current velocity tends towards zero; errors in the estimation of solids concentration may not, therefore, translate into very large error in the computation of total sediment flux through the measurement line.

Figure 4.5 shows the profiling turbidity meter used during the first test of this protocol on the River Tees in England.

The central white housing contains the turbidity meter. Three black water sample tubes are attached to the housing, these are triggered remotely from the surface. Temperature, salinity and depth sensors are mounted within the protective framework near the bottom of the profiler. The profiler can be deployed using a high-speed winch, or, if sufficient deck space is available and the profiler is sufficiently light, by hand.

The turbidity meter must be calibrated against water samples obtained during the measurements.

Figure 4.5. A profiling turbidity meter with attached water samplers

4.4 Field Calibration of the ADP

4.4.1 Requirement for calibration

The relationship between acoustic backscatter intensity and solids concentration is complex and is specific to both the instrument and the site. It is therefore necessary to collect calibration data during the measurements. The calibration data are used to establish:

- the backscatter response (ie, the acoustic backscatter intensity arising from a solids concentration of 1 mg/L, after fully correcting for acoustic attenuation due to beam spreading, water absorption, and scattering and absorption by the sediment through which the signal passes), and
- the sediment attenuation coefficient (ie. the attenuation of the signal; caused by scattering and absorption of the signal by the sediment in suspension).

Both of these vary in response to changes of the characteristics of the sediment in suspension. These parameters, in addition to others defining the performance characteristics of the ADP, are required in order to process the ADP data. (refer to Section 9).

4.4.2 Method of Calibration

The preferred method of field calibration is to obtain water samples at known depths and times while also recording ADP data, both within the plume and in ‘clear’ water adjacent to the plume. The water samples are later analysed to determine the suspended solids concentration. An alternative approach is to calibrate using a turbidity meter data but this is not recommended for two reasons:

- turbidity meters also require calibration using water samples;
- turbidity metres and ADPs respond to variations of particle size in opposite manners, ADPs generally become more sensitive as particle size increases while turbidity meters become less sensitive; this can give rise to very significant calibration errors.

The procedure for obtaining calibration data is to position the boat facing into the current and to deploy the water sampler over the same side of the boat as the ADP so that they are in the same ‘streamline’ Figure 4.6).

The water samples should be obtained at several depths throughout the water column while the ADP is recording. The ADP operator should note the exact time and depth of each water sample so that the concentration can later be matched to the ADP backscatter data. Good communication between the ADP and water sampler operators is essential.

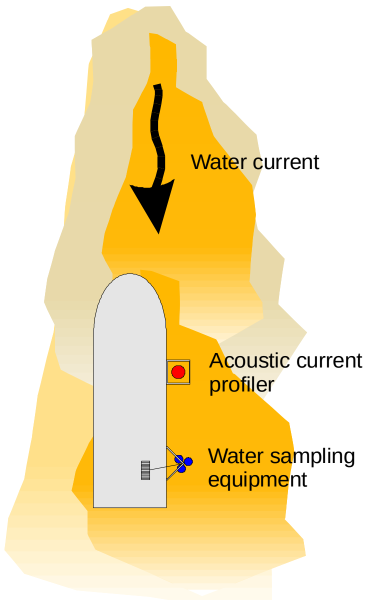


Figure 4.6. Procedure for obtaining ADP calibration water samples.

It is also necessary to obtain calibration samples within the plume at varying distances from the dredger because the calibration can be expected to vary as the coarser sediment settles out of the plume first. It is therefore necessary to record the distance from the dredger at the time the samples are obtained.

Ideally, the water samples should be obtained using a multi-bottle 'rosette'-type sampler which enables samples to be obtained very quickly. Using such equipment, it may be possible to obtain up to 12 samples at various depths in the water column in about 1 minute. Single-bottle samplers are acceptable but the time required to obtain calibration data must be extended. Pump samplers may also be used but are not recommended because they can take up to 60 seconds to obtain a sample during which time sediment concentration will vary over a wide range and calibration of the ADP will be more difficult as a result. If pump samplers are used, care must be taken to measure the length of time taken for water to travel through the hose as allowance will need to be made for this when matching the water sample data to the ADP data.

4.4.3 Amount of calibration data required

Many samples may be required in order to establish a reliable calibration. One reason for this is that it is not possible to obtain samples at exactly the same location and time as the ADP data. Thus, different volumes of water will be 'sampled' by the two techniques at slightly different times and will, inevitably, yield different solids concentrations. A large number of samples are therefore required in order that statistical methods can be applied to identify the relationships that are needed for data processing.

It is recommended that the equivalent of three samples are obtained for each measurement transect. Thus, if 50 measurement transects are made, about 150 samples should be obtained. Of these, approximately 80% should be obtained within the sediment plume created by the dredger and the remainder should be obtained in water unaffected by the plume.

4.5 More Detailed Information and Specifications

The information provided above gives only a simple overview of the general approach to measurement. More details about all aspects of the Primary Method are provided in the following Sections:

Topic	Location
Equipment	
Acoustic Doppler Profilers: - types, mounting requirements, and use	Section 9.3.1
Positioning systems	Section 9.2
Turbidity meters	Section 9.5.1
Temperature and salinity sensors	Section 9.4
ADP calibration and data processing	Section 9.3.6
Calculating the sediment flux	Section 11
Supporting data requirements	Section 8

5 SECONDARY METHODS

5.1 General Description

Secondary methods provide sediment flux data but these are not as detailed as those which can be obtained using the primary methods. It is therefore likely that a greater number of measurements will be required in order to determine characteristic rates of sediment release.

The secondary methods use towed arrays of turbidity meters or profiling turbidity meters.

- Towed arrays (Section 5.1.1) comprise a series of sensors spaced along a cable that is towed behind the survey boat so that data are collected, as far as possible, throughout the full depth of the water column.
- Profiling turbidity meters (Section 5.1.2) are alternately raised and lowered through the full water column as the survey boat passes through the plume.

In order to comply with the requirements of this protocol, current data must also be obtained. These data are preferably obtained by means of an ADP mounted on the survey boat. A less satisfactory approach is to measure the current profile separately using a conventional current meter lowered from the survey boat at a location near the centre of the plume (Section 5.1.3).

5.1.1 Towed arrays

Two instruments are required at each measurement depth, a turbidity meter and a depth sensor. A depressor should be fitted to the end of the array so that the lowest sensor is as close to the bed as possible. If it is not possible to include a depth sensor with each turbidity sensor, a single sensor can be fitted to the depressor. However, this approach may result in errors of turbidity sensor depth measurement as it assumes that the sensor array forms a straight line between the tow-point and the depressor. The errors will be small if the array is short and is deployed in shallow water but will increase as the length of array increases.

The number of sensors in the array should obviously be as great as possible but costs and handling difficulties increase rapidly as sensors are added. Sensible data require at least five sensors. A data logger interfaced with the DGPS system on board the survey boat is required to continuously record the data for later analysis.

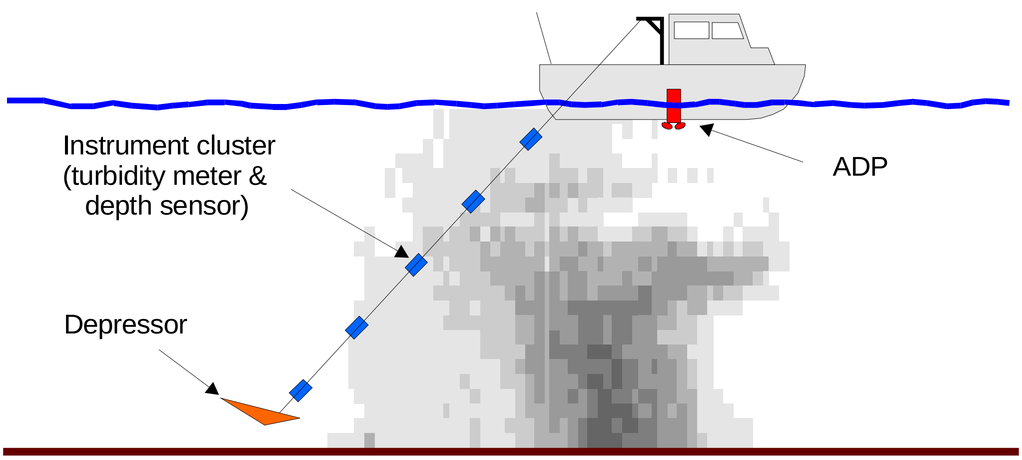


Figure 5.1 General arrangement of a towed array.

5.1.2 Profiling Turbidity Meters

The general approach to measurement using profiling turbidity meters is illustrated in Figure 5.2. The survey boat is sailed as slowly as possible through the plume as the sensor is raised and lowered through the water column. It is important to start profiling from a point well outside the plume in order to ensure that the whole plume is profiled.

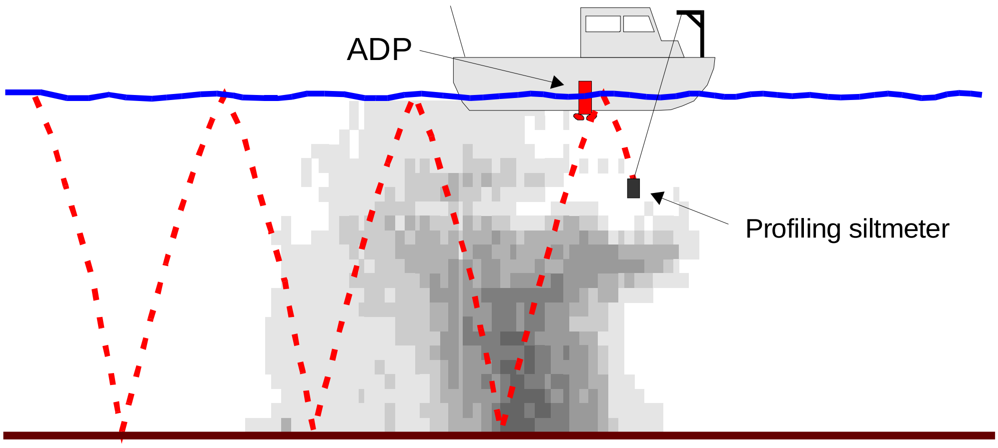


Figure 5.2 Profiling turbidity meter with attached water samplers

The main difficulty with this approach arises from the limited width of the sediment plume close to the working dredger. It may be difficult, or even impossible, to obtain profiling siltmeter data sufficiently fast to fully characterise the plume if it is less than about 50 metres wide. This was found to be the case during the first trial of this protocol with a grab dredger. The plumes were typically 10-30 metres wide and, although the profiling turbidity was raised and lowered at about 1 metre per second, careful examination of the data suggested that this was insufficient to characterise the plume.

5.1.3 Current data

The water currents can be measured either using an ADP or a conventional current meter. The use of an ADP is preferred because the current data can be obtained simultaneously with the suspended solids data during each transect and because detailed data will be obtained over the full length of each transect.

If a conventional current meter must be used, it will be necessary first to undertake a measurement transect using the sensor array and then to immediately move to the centre of the plume and measure a profile of current data. This single profile will then have to be applied to the entire width of the measurement profile, a process that will introduce errors in the estimation of sediment flux unless the currents are very uniform across the width of the plume.

Measuring the current profile using conventional current meters may take 10 minutes or more. If done using the main survey boat, this will significantly reduce the frequency with which transects can be undertaken. Consideration should be given to using a second boat for the current measurements.

5.2 Calibration of the Turbidity Meter

Calibration of the turbidity meter should be undertaken separately from the measurements. At intervals during the measurements, the boat should be aligned with the current flow. If the water sampler is separate from the turbidity profiler, the two instruments should be deployed from the same side of the boat so that they are in the same streamline. A set of water samples should be taken throughout the water column, accurately synchronised with the turbidity meter.

Calibration data should be obtained both within the plume and in the natural sediment population on either side of the plume. When working in the plume, data should be obtained at different distances from the dredger in order to identify variations of the calibration due to changes in sediment particle size distribution that may occur as material settles out of the plume to the bed.

At the end of each working day, the turbidity meter sensor should be 'dipped' into each of the water samples in a light-proof box and the reading noted. This will eliminate problems arising from temporal synchronisation and spatial co-location.

5.3 Application

These methods are only applicable to the 'simple transect' or 'stationary boat' approaches described in Section 4.

5.3.1 Simple transects

Because the current data and the suspended solids data are obtained separately and at different locations, the computation of sediment flux will inevitably involve approximations. For a single straight line down-current of the dredger, this may be acceptable.

5.3.2 Stationary boat

If the measurements are made using the stationary boat approach described in Section 4, problems arising from separate measurement of current and concentration are likely to be as spatial separation of the measurements will be small. The stationary boat application is therefore the most suitable approach for measurements using the secondary methods.

5.4 More Detailed Information and Specifications

The information provided above gives only a simple overview of the general approach to measurement. More detail about all aspects of the Secondary Methods are provided in the following sections:

Topic	Location
Equipment	
Turbidity meters	Section 9.5
Positioning systems	Section 9.2
Temperature and salinity measurement	Section 9.4
Computing the sediment flux	Sections 11.3 and 11.4
Supporting data requirements	Section 10

6 TERTIARY METHODS

6.1 Types of Measurement

Tertiary methods do not provide data that can be used directly to calibrate the TASS models. They comprise:

- far-field profiling in which wide plumes are measured in detail using ADPs, towed arrays or profiling turbidity meters;
- near- or far-field single-point measurements using water samplers and/or turbidity meters.

Far-field profiling measurements, if correctly made and reported may be valuable as an indirect means of calibrating the TASS models because they can be compared with the combined outputs of dynamic and passive plume models which use the TASS model data as their input. Far-field measurements that confirm, or otherwise, the conditions predicted by the models may provide a valuable indication of the accuracy of the predicted overall rate of release. These methods are not able to provide data for the calibration of the separate components of the model, eg. the release of sediment that occurs during the different stages of the grab dredging cycle.

The single-point measurements, in the near-field or far-field, will be of limited value for TASS calibration.

6.2 Far-Field Profiling Methods

6.2.1 General Approach

The far-field profiling methods are essentially the same as those used for Primary and Secondary level measurements using ADPs, towed arrays or profiling turbidity meters. However, the measurements are less difficult for the following reasons:

- in the far-field, the sediment plumes will tend to be larger, more diffuse and better mixed than they are close to the dredger, this means that towed arrays and profiling systems will be better able to accurately quantify the sediment in suspension;
- because the plumes will comprise predominantly fine particles, the size distribution of which will change only very slowly, it will be easier to calibrate acoustic data and turbidity meters.

It is worth noting that these methods can also be used for calibration or validation of passive plume models.

Sites where such measurements are undertaken should preferably be in open water as the plumes expand laterally over time and, especially in the cases of overflow plumes from trailers, may be hundreds of metres wide after only a few tens of minutes. The water current must be approximately unidirectional or, if the site is in a tidal area where current directions reverse, the measurements must commence at an early stage of each tide in order to permit sufficient time for the measurements to be carried out before the tide turns.

A simple way of ‘tracking’ released sediment of approximately the same age is to release a drogue (Figure 6.1) from the dredger and to sail repeated transects past the drogue, approximately perpendicular to the current direction, as it drifts away from the dredger. In most cases, it is found that much of the released sediment will descend to the lower part of the water column very soon after release. It is therefore recommended to set the 'sail' of the drogue to a depth of about 70-80% of the water depth.

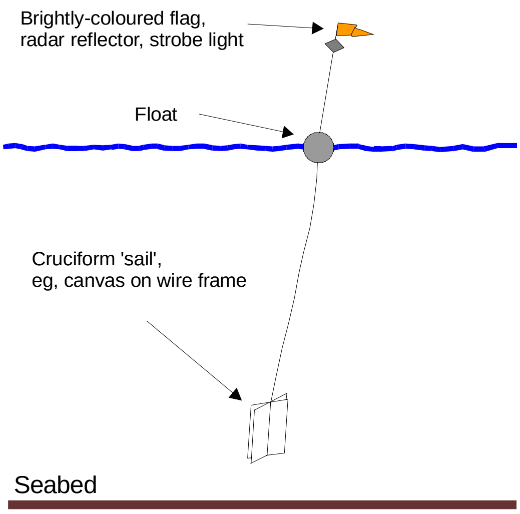
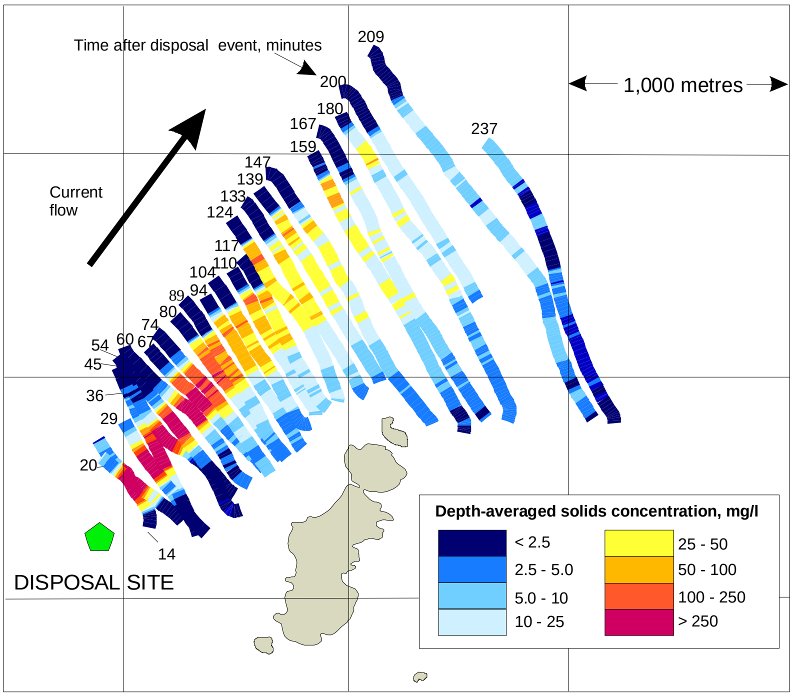


Figure 6.1a. General arrangement of a drogue for plume tracking

Figure 6.1b. A drogue being deployed from the stern of a trailer dredger.

6.2.2 An Example

An example of far-field ADP profiling data is shown in Figure 6.2. These data were obtained during an investigation of disposal operations but the principles apply equally to dredging operations. The water depth at the disposal site was approximately 30 metres. A drogue was deployed from the trailing suction hopper dredger as she discharged.



The survey boat sailed a total of 21 transects past the drogue, perpendicular to the current direction, over a period of about three hours.

The plume was carried northeast by the weak current (approx 0.15 m/sec), spreading rapidly as it settled into the lower part of the water column. In this case, the plume was very easy to detect as background suspended solids concentrations were very low.

Figure 6.2. Far-field plume tracking data obtained using an ADP.

The data were analysed to derive the depth-averaged solids concentration in the lower half of the water column, averaged over a horizontal distance of 50 metres at the centre of the plume.

These data are plotted against time after disposal in Figure 6.3, together with similar data from 5 other events that were monitored.

The decays of the plumes formed by a 9,000 m^3 vessel fitted with bottom-valves (blue) and by a 2,800 m^3 split-hull trailer (red) are very different.

Although occasional irregularities are evident in the data, the form of the decay curves is clear and makes an interesting comparison with Figure 3.1.

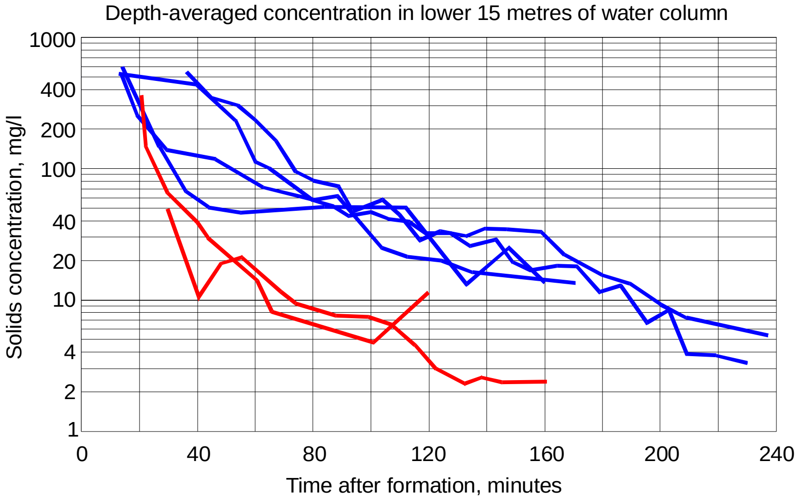


Figure 6.3 Decay of plumes formed by disposal operations from two trailing suction hopper dredgers

6.2.3 Calibration data

Far-field plume tracking may extend over considerable distances and last for several hours. Although the material in suspension is likely to comprise only fine particles, differential settlement will occur and the calibration of both ADPs and turbidity meters will change in response. It is therefore essential to occasionally stop the survey boat and to collect water sample calibration data. As is the case with measurements in the near-field, calibration data should be obtained within the plume and in the unaffected waters on either side of the plume.

6.3 Single-point Measurements

In some cases, for example, during routine monitoring of dredging operations, observations will be limited to single point measurements at pre-determined locations around the dredger. Inevitably, these provide limited data but they are still useful in the context of the TASS project. The single point measurements may comprise:

- vertical turbidity meter profiles;
- water samples taken at selected depths;
- turbidity meter observations at selected depths.

If the usefulness of such measurements is to be maximised, it is important that they are related to the age of the sediment plume and that the individual measurements can be located within the plume. The first requirement implies that the position of the dredger be known at the time that the measurements are made and that they be supplemented with observations of current speed. These can be made using direct-reading current metres suspended from the survey vessel or, if available, ADPs.

The second requirement implies that sufficient locations are monitored to permit, at least, the approximate extent of the plume to be defined. A single straight line of measurement points down-current of the dredger will provide little useful information because it will not be possible to tell whether the data have been obtained at the core of the plume (where the highest concentrations can be expected) or at the plume margins. *Figure 6.4* shows a simple approach to such measurements, based on a rectangular grid, which enables the plume footprint and the sample locations relative to the plume to be established.

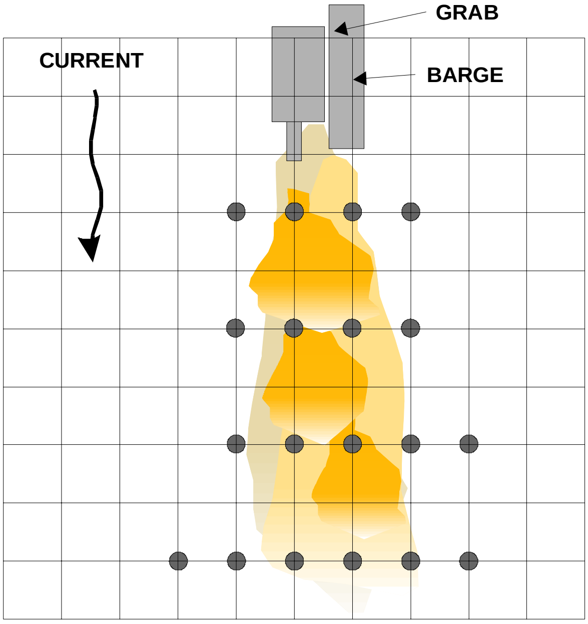


Figure 6.5. Single-point measurements on a rectangular grid down-current of the dredger.

As the distance from the dredger increases, it should be possible to widen the grid spacing in order to reduce the overall number of observations which need to be made.

This approach is best suited to profiling turbidity meters because full profiles of data can quickly be obtained at each location. It is evident that this method, when based only on water sample data, would require a very large number of water samples in order to provide sufficient data and would be time-consuming.

7. MEASUREMENT METHODS FOR TRAILING SUCTION HOPPER DREDGERS

7.1 Introduction

Trailing suction hopper dredgers differ from the semi-stationary dredgers in several respects that are important to the method of measurement:

- they move relatively fast over large areas;
- the propellers generate huge amounts of air bubbles; any measurements obtained in propeller wakes using turbidity meters or acoustic methods will not be valid;
- the overflow from trailers also generates air bubbles.

For these reasons, a completely different approach must be used when working with trailers. Guidance is provided here on the measurement of:

- release through the overflow;
- release by Lean Mixture OverBoard (LMOB) systems;
- resuspension by the draghead;
- far-field plume decay.

7.2 Measurement of Overflow Releases

There are two components to the measurement of overflow release:

1) measuring the flow rate;
2) measuring the solids concentration in the flow.

Measurement of the solids concentration in the flow requires access to the overflow and is not possible in vessels with a closed hopper.

The flow rate and concentration will vary with time. It is therefore important that a near-continuous measurement of both flow and concentration is achieved throughout the overflow period.

7.2.1 Measuring flow rate

Measurement of the flow rate through the overflow must be done indirectly. Trailer dredgers have two main types of overflow arrangement, a bellmouth weir that is usually located near the front of the hopper, or weirs located along each side of the hopper. The extreme turbulence in the overflow, the length of the weir(s) and the frequent presence of foam on the surface prevents any direct measurement at the weir.

The overflow rate is the same as the flow rate into the hopper. In most modern dredgers, instrumentation is fitted that continuously registers this flow rate (and solids concentration) in order to assist the control of the dredging process. Where appropriate instrumentation is not available, in may be necessary to fit temporary systems. It is important that the flow rate sensors are accurately calibrated.

An alternative approach, which may provide fair but not very accurate data, is to make a continuous video recording of a depth gauge mounted on the rim of the overflow.

7.2.2 Measuring solids concentration

Concentrations of suspended sediment may vary over the depth of water flowing over the weir and the mixture will be highly aerated (Figure 7.1). The use of siltmeters, acoustic devices or density sensors to establish concentrations in the overflow will therefore yield unreliable data and is not recommended.

Figure 7.1 View of the overflow of a trailer. Extreme turbulence, aeration and the almost invariable presence of froth makes this a difficult environment in which to obtain reliable measurements of solids concentration. The width of the view in the photograph is about 2m and the flow rate is approximately 5 m^3/sec.

Water sampling is presently the only reliable method of obtaining useable data. Pumped water samples are not considered to be a viable approach due to potentially significant errors arising from momentum effects. A more reliable approach is to use a purpose-built water sampler in which sample containers (open at both ends) are submerged in the flow over the weir. It is important that the sampler is dimensioned so that it samples the full depth of the flow (which may be up to about 0.3m) and is located parallel to the direction of flow.

Figure 7.2 shows the type of sampler that was used during the Rotterdam trial of this protocol. It comprises an open box section with spring-loaded doors at both ends. The sampler is mounted, using quick-release clamps, on a ‘carrier’ that travels along two polypropylene ropes that extend from the hopper coaming to the rim of the overflow. The ropes pass through two short tubular sections at the front of the carrier (visible at the front of the sampler in Figure 7.2 and under an open framework at the back of the sampler. The framework guides the sampler and is shaped so that the sampler rides easily over the rim of the overflow during placement and recovery.

The sampler slides down the ropes to the overflow under gravity. When it is in place, the doors are triggered using a lightweight chain. The sampler is then hauled back to the coaming of the hopper with a rope.

Figure 7.2. Overflow sampler (capacity 4 litres) used during the Rotterdam TASS protocol trial.

The contents of the sampler should then be carefully poured into a container that can be tightly sealed. Exactly one litre of water is placed in the sampler (with one door closed) to rinse out any adhering soil. This is then emptied into the sample container. A correction needs to be made to the laboratory determination of the solids content in order to compensate for the water added to clean the sampler.

It is preferable to have three samplers located at approximately equal distances around the rim of the overflow. This is because the hopper may load unevenly and, even if the overflow is level, because the flow of solids into the overflow may not be uniform.

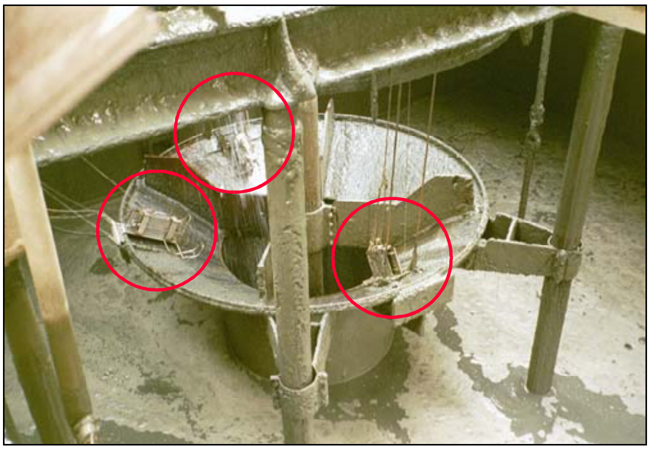


Figure 7.3. Three samplers (circled) on the rim of the overflow awaiting the start of overflow.

7.2.3 Frequency of Sampling

The general rule to be applied to sampling frequency is 'as often as possible'. However, using the system employed during the Rotterdam Trial, it was found that the each sample took approximately 3-4 minutes to obtain, including decanting the sample into the container and cleaning the sampler before re-deployment. With three sampling crews in action, the overall sampling rate was therefore about 1 per minute, yielding typically 30-50 samples per 40-minute overflow period. The minimum number of samples required to characterise each period of overflow is unlikely to be less than 10.

7.2.4 Safety

Sampling the overflow of a trailer is an inherently dangerous operation. Several people will be required to do this effectively and they will be working in a confined area over an open hopper with many obstructions. During the Rotterdam trial, a crew of 10 was needed to sample the overflow (Figure 7.4).

It is essential that the most stringent safety precautions be implemented for this work, including:

- erecting temporary safety rails;
- use of life vests, high visibility clothing and safety lines;
- provision of adequate lighting;
- detailed staff instruction; allocation of clearly-defined tasks.

Figure 7.4. Overflow sampling crew during the Rotterdam trial.

7.2.5 Supporting Data

During loading, the height of the overflow may be varied by the operator. This will influence the flow rate and solids concentration of the overflow and may result in intermittent overflow. It is therefore necessary to maintain records of the overflow level and any periods where overflow was interrupted (eg. by raising the overflow above the water level in the hopper or when the LMOB system is working).

7.2.6 Testing of Overflow Samples

The most important requirement is the suspended solids concentration and this should be determined for all samples. In order to fully analyse the release rate during overflow, it also necessary to know how particle size, particle specific gravity and organic content vary during the loading cycle. The following is the recommended minimum amount of testing that is required:

- Solids concentration 100%
- Particle size distribution 20%
- Particle specific gravity 10%
- Organic content 10%

The samples selected for analysis of particle size, particle specific gravity and organic content should be distributed evenly throughout the duration of overflow.

7.3 Measurement of Sediment Release from LMOB Systems

To determine the total solids discharged during operation of the LMOB system, it is necessary to determine the rate of discharge and the density of mixture. The rate of discharge will be the same as the flow in the suction pipe(s). This is usually known and recorded in the data logging system on board the dredger. The density of the incoming mixture is also usually known.

It is important to ensure that it will be possible to determine the density of the mixture being discharged and the time when the LMOB system is operating. If the density meter is not in a suitable position, it will be necessary to either:

- have a temporary meter installed at a location which gives a representative reading of the material being discharged, or
- to compute the time taken for mixture to travel from the density meter to the LMOB outlet so that time offsets can be applied to the observations.

Although the flow and density of the mixture can be continuously recorded, most LMOB systems are manually operated. It will therefore be necessary to manually record the times at which the operator(s) activate the system.

7.4 Measurement of Sediment Resuspension by the Draghead

7.4.1 Method of Measurement

The sediment plumes created by disturbance around the draghead are initially very small and located close to the bed. Very quickly after formation, the propellers of the dredger pass over them. The propeller wakes will, if the water is not very deep, disturb the plumes and mix air bubbles into them. At that stage, it will be impossible to make meaningful measurements. Even if, in very deep water, the plumes are not quickly disturbed by the wakes it will be impossible to undertake any measurements (such as acoustic measurements) while the boat is in the wakes.

The measurements must be made during the early stages of the loading cycle before any overflow starts in order not to contaminate the draghead plume with sediment released through the overflow. For the same reason, the LMOB system must not be operating during these measurements.

As with all plumes, solids concentrations will vary significantly and it is therefore necessary to use acoustic methods to map them. The measurements must be made using an ADP towed under the propeller wake and as close as possible to the stern (Figure 7.5). No alternative procedure has been identified by the TASS team.

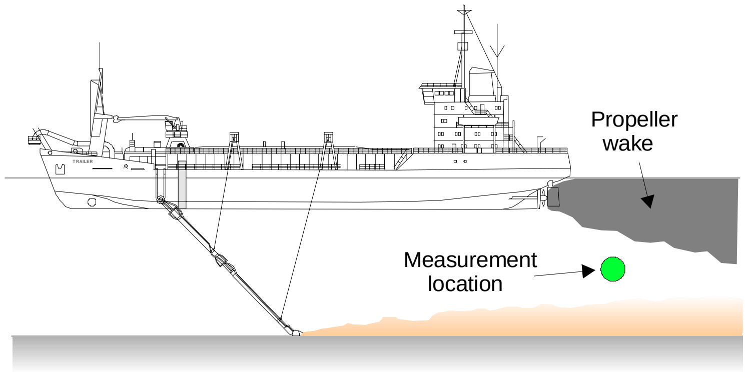


Figure 7.5 A deep-towed ADP must pass under the propeller wakes and close to the stern of the trailer in order to measure draghead plumes.

The tow fish can be simple and relatively cheap to construct such as one shown in Figure 7.6, which was provided by the Corps of Engineers for the 2002 Rotterdam trial.

Some trial and error is required to balance the system so that it swims horizontally when being towed. The attitude of the ADP can be determined using the pitch and roll sensors that are fitted to some ADPs.

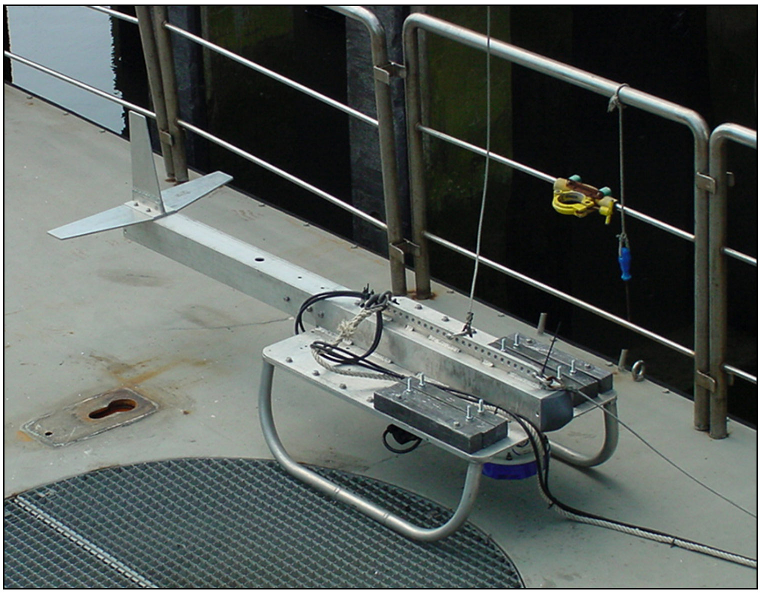


Figure 7.6. ADP tow fish used during the Rotterdam Trial.

More complex (and costly) tow fish are available that are fitted with steerable ‘control surfaces’ that can be operated from the survey boat.

As it is important to measure the distance between the draghead(s) and the point at which the draghead plume is measured, the ADP should (as far as is possible) be towed immediately below the davit from which it is deployed. A significant amount of weight will be required to achieve this. The positioning system used on the survey boat should provide (with the application of suitable offsets, if necessary) the position of the davit.

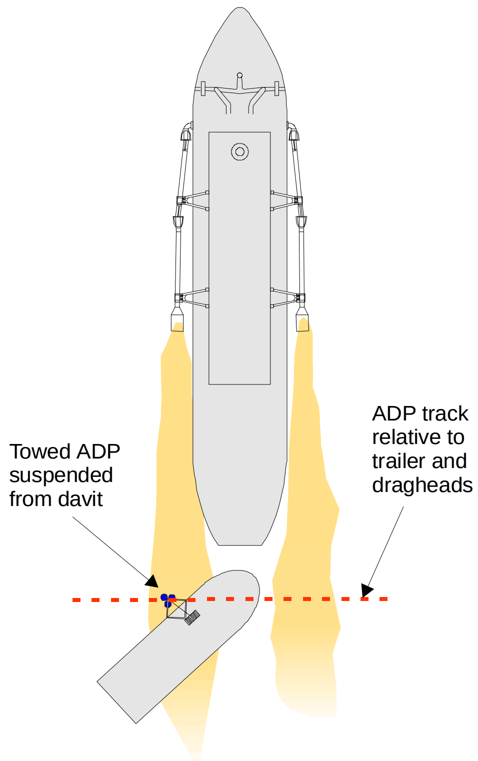


Figure 7.7 Towfish course behind dredger.

The survey boat should be aligned diagonally to the course of the dredger and sailed so that it maintains its position close the dredger as it passes over the draghead plumes (Figure 7.7). On some occasions during the Rotterdam trial, the ADP passed less than 5m behind the trailer (Figure 7.8).

Figure 7.8. Getting close and serious.

7.4.2 Calibration of the ADP

It is clearly impossible to calibrate the ADP by taking simultaneous water samples from within the plume. Some indication of the range of concentrations that are present might be obtained by towing a second fish, equipped with a turbidity meter, through the plume just above the bed. However, this would not yield a direct calibration (because the turbidity meter must also be calibrated) and independently controlling two tow fish at the same time would be very difficult.

After careful consideration, the TASS team concluded that calibrating in a decayed overflow plume is probably the best that can be achieved. The reason for this is that the relatively fine particles that form the bulk of the draghead plume are likely to be broadly similar to the sediment particles released through the overflow when working in the same materials. On the basis of previous experience, the air bubbles in the overflow plume should dissipate within about 15 minutes, after which it is safe to commence calibrations.

7.4.3 Computation of release rate

The method of computing the release rate is described in Section 11.5.

7.5 Far-field Plume Decay Measurements

Because the (overflow) plumes from trailer dredgers are relatively large and may persist for several hours, they are ideally suited to the application of the far-field methods of observation described in Section 6, using ADPs, towed arrays or profiling turbidity meters.

The size of the dredging area, and the frequency with which the trailer must turn during loading, will affect the ease with which the measurements can be interpreted. Ideally, sites where such measurements are undertaken will be large enough to permit long straight trailing runs. If the dredger has to turn, it may result in the superposition of the plume on a decayed plume created earlier in the loading cycle. This will give rise to ‘confused’ data that are difficult to interpret.

8. CHARACTERITSICS OF APPROPRIATE MEASUREMENT SITES

The ideal site:

- ❑ has a unidirectional current flow, speed between 0.5 and 1.0 m/sec;
- ❑ is not located where saline wedges may give rise to equipment calibration difficulties;
- ❑ is open and unobstructed;
- ❑ has low background sediment concentrations with small variation;
- ❑ has no other shipping;
- ❑ has uniform soil conditions.

8.1 Introduction

If detailed measurements are to be undertaken specifically to calibrate the TASS predictive models, they should preferably be undertaken at sites where conditions are such that accurate identification and quantification of the sediment plume are as easy as possible. The following should be taken into account when selecting sites for such measurements:

- the current regime;
- saline wedges;
- water depth;
- the presence of structures (eg. quay walls) in measurement area;
- background sediment concentrations and the effects of other shipping movements;
- soil conditions.

In addition, the opportunity to vary the dredger configuration should also be considered.

8.2 Current Regime

The loss measurements are based on the measurement of sediment flux away from the dredging site and it is therefore necessary to undertake the measurements where there is a water current. Ideally the current will have the following characteristics:

- it will be relatively uniform in direction throughout the water column;
- the average speed will lie in the range 0.25 to 0.5 m/sec.

When working in tidal waters, it will be necessary to avoid making measurements during the periods around slack water.

Uniformity of flow direction reduces the length of the transects across the sediment plume. If the current is sheared (ie. the current direction varies with depth), the length of the transects will increase and the rate of data collection will decrease. If the current shear is more than about 45^{o}, the measurements will be difficult to make.

If the current is very weak, a large proportion of the released sediment may settle to the bed before it reaches a location where it can be measured.
If the current is very strong:

- it may be difficult for the survey boat to sail slowly across the plume;
- air bubbles may be introduced into the water column by the rapid flow of water along the hulls of semi-stationary dredgers such as grabs and backhoes;
- it will aggravate the difficulties of spatial co-location of different types of equipment suspended from the survey boat, especially during calibration data collection.

8.3 Saline Wedges

Areas characterised by well-developed saline wedges may give rise to difficulties of accurate measurement due to flocculation of fine sediment at the interface between fresh and saline water. It will also make the calibration of measurement instruments more difficult. In some cases, the direction of current flow will be in opposite directions at different depths as the saline wedge passes through the site.

Although saline wedges frequently occur in areas where dredging is undertaken and may be difficult to avoid completely, the measurement campaign should, if possible, be planned so that at least some measurements are undertaken during periods when the wedge lies well upstream or well downstream of the measurement site.

8.4 Water Depth

The water depth is not critical but there is some advantage in making measurements at a site where dredging can be undertaken in different water depths in order to investigate the effects of depth on the release rate, particularly with grabs, backhoes and bucket ladder dredgers. In tidal areas, varying tide levels may provide sufficient variation to investigate this parameter. However, as far as possible, each set of measurements (ie. the measurements required to establish a single characteristic release rate for a given set of conditions) should be undertaken in uniform water depths.

Subject to possible limitations arising from the specification of the ADP (if used), there is no upper limit to water depth. However, if profiling turbidity meters are being used, the time required to obtain turbidity profiles will increase as the water depth increases, thus reducing the rate at which siltmeter transects can be sailed. Deep water will also increase the size of the near-bed zone where reliable ADP backscatter and current measurements can be obtained (Refer to *Section 4.3 and Figure 4.4*).

In shallow water, it may be difficult to distinguish between sediment losses due to different stages of the dredging cycle, eg. those due to the grab excavation process and those due to raising and lowering the grab. If profiling turbidity meters are being used, the rate of data collection in shallow water will be relatively high. If ADPs are being used, the proportion of the water column which cannot be profiled by the ADP due to the immersion depth of the transducers will increase (*Figure 4.4*). The possibility of sediment resuspension by the survey boat should also be considered when working in very shallow water.

8.5 Structures (eg. quay walls) in Measurement Area

Ideally, the site should not be located close to structures as these may interfere with the measurements. As it is necessary to collect data across the entire width of the plume and into clear water on either side, the site should not be located where the plume will impinge against, for example, a seawall, riverbank or quay. Note that ADP sidelobe echoes from structures some distance away from the sediment plume can result in data corruption. It is recommended that if ADPs are being used the dredging site should be located so that the measurement boat should not need to approach within 20 metres of any structure.

These requirements may be more severe if a towed array of turbidity sensors is being used due to the length of the array behind the survey boat.

8.6 Background Sediment Concentrations

Ideally, the background sediment regime should be characterised by relatively low concentrations and small natural variation. Low concentrations will make the plume resulting from the dredging work more 'visible' and it can be tracked over greater distances before merging with the background. Small variation of background concentration will make data analysis and interpretation easier and less prone to error. Areas close to outfalls should be avoided because these may be discharging particulate matter.

Dredging is frequently undertaken in ports and channels where the movement of other vessels may put sediment into suspension (Figure 8.1). It is preferable that calibration measurements are carried out at sites where there is little or no other marine traffic. If this is not possible, efforts should be made to make the measurements at times when there is little traffic.

In all cases, it is essential to record the movements of other vessels and to identify sediment plumes (and air bubbles entrained in wakes) which may be caused by such traffic and which may 'contaminate' the plumes generated by the dredging activity.

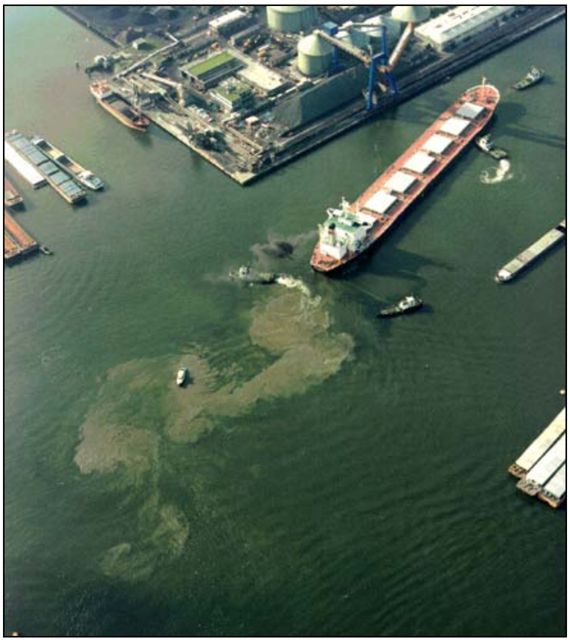


Figure 8.1 A bulk carrier manoeuvring in the Port of Rotterdam.

8.7 Soil conditions

The nature of the soil or rock is a primary factor in determining the rate of sediment release during dredging and it is essential that the material which is dredged during loss measurements is fully characterised if the loss measurements are to have any value.

Measurements undertaken for the purposes of calibration should ideally involve dredging in uniform soil conditions so that the release measurements can confidently be associated with a defined set of soil parameters. On large sites where several different types of soil or rock are present, it may be possible to undertake a number of separate measurements in the different soil types and thus increase the calibration database. However, as far as is possible, each set of measurements should be undertaken in uniform conditions.

8.8 Opportunity to vary the dredger configuration and operation

In the case of loss measurements undertaken for the purpose of providing calibration data, it is desirable that there is some opportunity to vary certain aspects of dredger configuration and operation in order to investigate their effects on losses. *Table 8.1* lists some of the parameters that might be varied during calibration measurements.

Table 8.1. Dredging parameters which could be varied during loss measurements.

Dredger	***Operating parameters***
Grab	• using open and closed grabs; • using different sizes of grab; • varying the grab hoisting speed; • vary the slewing speed..
Backhoe	• using open and closed buckets; • using different sizes of bucket; • varying the cycle time; • varying the slewing speed.
Bucket	• varying the cut height and step length; • varying the swing speed; • varying the bucket speed.
Cutter suction	• varying the cut height and step length; • using different cutterhead rotation speeds; • using different swing speeds; • varying the suction velocity.
Trailing suction hopper	• changing the suction pipe velocity • varying the trailing speed • loading with one suction pipe instead of two.

If such variations can be introduced during field measurements they will provide a greater calibration database.

9. SELECTION, CALIBRATION AND USE OF EQUIPMENT

9.1 Survey Boat

The type of survey boat that is required will depend on the type of equipment to be deployed and on the sea conditions in the survey area. In some cases local regulations and licensing conditions may require certain sizes of vessel to be used and, more frequently, the choice of vessel may be limited by availability and cost. It is likely that the boat that is used will represent a compromise solution but some guidance is presented below.

9.1.1 Size

Subject to considerations of safety and the space required for deployment and recovery of equipment, the boat should generally be as small as possible, particularly if ADPs are being used to collect data. The reasons for this are:

- small, shallow-draught boats usually produce small wakes and the potential for air bubble contamination is therefore minimised; this is particularly important when sailing repeated transects along the same line in weak currents;
- small boats are less likely to disturb the currents;
- speed of measurement is important; the ability of small boats to turn quickly after each measurement transect will result in more measurements per working hour;
- being more manoeuvrable, small boats are better suited to working close to dredgers, they can get closer to nearby structures and can follow sediment plumes into shallow water.

9.1.2 Sailing Speed

If the measurements are to include the use of profiling turbidity meters to measure sediment flux away from the dredger, the boat should have the capacity to sail very slowly (ie. at 1 knot or less) without loss of steerage in order to permit the collection of as many profiles as possible across narrow plumes. Boats that require use of bow thrusters or forward-mounted Schottel drives in order to maintain steerage are not favoured if ADPs are to be used unless it is possible to mount the ADP over the bow of the vessel. This is because of the potential for contamination of ADP data by air bubbles.

9.1.3 On-board Communications

All personnel involved in data collection must be able to communicate easily with each other. Decisions will often need to be made quickly and operators of different types of equipment will need to coordinate their activities. The operators of the primary data collection equipment (eg. ADPs, towed arrays etc) should be located in the wheelhouse where they have a clear view of the dredger and surrounding area and are able to talk to the helmsman. The principle operators should also have a clear view of the deck area from which other equipment is being deployed (eg. water samplers) so that different data collection activities can be accurately coordinated.

9.1.4 Safety

The safety of survey personnel is vital. All survey boats should carry appropriate safety equipment including lifeboats/life rafts, personal buoyancy aids, distress flares, radios, and first aid equipment. Personnel working on the boat should be familiar with emergency procedures and wear appropriate protective clothing. Deck crew should at all times wear safety boots, a life vest and (if equipment is being deployed by cranes or davits) hard hats.

9.2 Positioning Equipment

9.2.1 Survey boat

Accurate electronic positioning systems are required. Differential global positioning systems (DGPS) are necessary. If ADPs, towed arrays or profiling turbidity meters are being used, the positioning system should be interfaced directly with the data recorders. Wherever possible, the DGPS antennae should be located directly above the measurement equipment. If this is not possible, the offsets between the antennae and the equipment should be known so that, if necessary, corrections can be applied during data post-processing.

The depths of all measurements must also be known. Calibrated depth sensors should be attached to water samplers, turbidity meters and to temperature and salinity sensors. The immersion depths of ADP transducers should be recorded.

9.2.2 Dredger

Accurate knowledge of the location at which sediment is being released is essential and the requirement for accuracy increases as the distance between the dredger and the survey boat decreases. The location of the main DGPS antenna on the dredger may be many metres away from the source of the sediment release and it is the position of the latter that is required to be known. There are two solutions to this problem:

- locate additional DGPS antennae directly above the sediment release point(s); this can be done relatively easily with, for example, the overflow of a trailer or the end of the crane boom of a grab dredger, or
- use a system that measures the ship's heading and compute the location of the sediment release point using the measured offsets between the DGPS antenna and the release point; this approach is necessary, for example, for the cutterhead of a cutter suction dredger.

Whichever system is used, it is essential that all position data are time-tagged using satellite time.

9.3 Acoustic Doppler Profilers

9.3.1 ADP Selection

The specification, performance and accuracy of ADPs varies widely. ADPs that are used for measurement of sediment release must have the following characteristics:

- they must be capable of measuring and recording the backscatter intensity from particles suspended in the water column;
- if they are being used to measure solids flux (as opposed to the simple concentration measurements described in Section 6) they must have a 'bottom track' facility, ie. they should be able track their course over the seabed without the need for a separate DGPS positioning system (although DGPS positioning is still required in order to determine the distance between the dredger and the measurements and may also be necessary if the bed is mobile, giving rise to bottom tracking errors);
- they must have a nominal profiling range that exceeds the water depth at the measurement site by at least 50% (in order to compensate for the attenuation of the signal due to the sediment in suspension).

There are two principle types of ADPs; narrowband and broadband. Manufacturers of broadband instrument claim a higher accuracy of current measurement. This will undoubtedly benefit the measurement of sediment flux. However, narrow band instruments will be adequate for most purposes, particularly when working in wide and diffuse plumes where the flux estimate will be based on numerous measurements.

Of greater importance is the distinction between these two types of instrument in terms of their accuracy when measuring suspended sediment concentrations. Narrowband instruments are subject to 'random phase' errors in the measurement of backscatter intensity. These errors mean that a single 'ping' will have a measurement uncertainty of about 50%. In order to reduce the uncertainty to 10%, a total 25 measurements are required. This seriously compromises the ability of the technique to provide the degree of spatial and temporal resolution that is required when working in narrow plumes with significant variations of concentration. In contrast, the nature of the signal from a broadband instrument is such that random phase errors can effectively be ignored. Their accuracy of measurement (assuming that all other components of the calibration are perfect) is about ±5% for a single ping.

Overall, broadband instruments are best suited to the types of measurement described here and their advantages are most clear when working in very narrow plumes. For far-field measurements, in wide and diffuse plumes, the distinction becomes less important.

9.3.2 ADP Mounting Arrangements

The ADP transducers must be immersed at a depth sufficient to avoid air bubbles in the near-surface zone. The extent to which air bubbles will be encountered depends in part on the characteristics of the bow wake of the survey boat and in part on the wave conditions at the measurement site. Normally, an immersion depth of 1 metre is sufficient but this may be reduced when working in calm water. In general, the transducers should be mounted as shallow as possible in order to maximise the proportion of the water column from which data can be recovered (refer to *Figure 6.1*).

There are three main mounting options:

- *over the bow* - this is the best location for the avoidance of air bubbles but bow mountings are relatively complex;
- *over the side* - this is usually the easiest arrangement, requiring only simple brackets; the ADP should be deployed as far away from the hull as possible in order to avoid air bubbles, at least 0.75m is recommended
- *hull-mounted in a moon-pool or sea chest* - these types of mounting are usually used for semi-permanent installations, their main disadvantage is that the transducers will probably be at a depth that is greater than the optimum for this type of measurement; air bubbles can also be a problem.

In most situations, a side-mounting is preferred. The ADP should be located approximately midships where the effects of the bow wake are usually minimal.

9.3.3 Sailing Speed and Noise Effects (ADPs)

Before measurements commence, it is important to test the effects of noise resulting from air bubbles (from the bow wake of the survey boat) impacting the ADP transducers and by the water passing over the transducers. The purpose of the tests is to establish that the ADP is correctly mounted and is not affected by air bubbles from the survey boat and to establish the maximum 'safe' sailing speed (ie. the speed below which noise effects are not detectable).

Noise levels will depend on the speed at which the boat is sailed. With a 1200 kHz instrument, it may be possible to sail at up to 3 m/sec without causing excessive noise. With a 300 kHz instrument, the maximum 'safe' sailing speed may reduce to 2 m/sec or less.

However, in most situations, a much slower sailing speed will be used in order to maximise the resolution of the measurements in the sediment plumes.

9.3.4 ADP Power supply

It is essential that the power supply to the ADP transducers remains constant during the survey. While experience has shown that the power management systems in modern instruments generally maintain a constant supply voltage, it is recommended that the power supply to the deck box be controlled using an uninterruptible power supply (UPS) which ensures a constant voltage. An alternative approach is to run the ADP from fully-charged truck batteries that are constantly trickle-charged during use.

9.3.5 External Compass

Accurate measurement of discharge and solids flux requires accurate data on instrument position and heading. If the ADP has a bottom tracking facility, this should be used for computation of both currents and measurement cell widths because the errors that arise in both measurements cancel each other. If there is no bottom track facility (or when working in areas with a mobile bed), it will be necessary to rely on the GPS system for positioning data and on a compass for heading data. The internal compasses of most ADPs are either insufficiently accurate for this purposes or are affected by external magnetic sources. It is therefore essential to use a properly calibrated external compass in order to obtain the accurate heading data required to derive accurate current measurements. A gyro-compass is the preferred type but a frequently-calibrated external fluxgate compass may also be used.

9.3.6 Calibration and Data Processing

The derivation of solids concentration values is complex and requires specialised software. Readers are advised to consult a specialist firm, experienced in these matters, if this technique is to be used. The following description is provided only to indicate the general nature of the required data processing.

The following operations are necessary in order to convert backscatter intensity observations to values of solids concentration:

- each of the three or four transducers of the ADP must be separately calibrated to provide the relationship between instrument counts and decibels; in some instruments, this relationship may vary with the temperature of the equipment;
- the signal should be corrected to compensate for beam-spreading; the compensation should take into consideration the different form of spreading in the near-field and the far-field of the transducers;
- the signal is then corrected to account for attenuation due to absorption by the water; at many sites this will vary with depth as the water temperature and salinity vary.

Having made these corrections to the backscatter measurements, the calibration data can then be used to establish:

- the site-specific relationship between acoustic backscatter intensity and solids concentration;
- the site-specific coefficient of attenuation that is caused by absorption and scattering of the signal by the sediment.

These must be derived using an iterative procedure involving comparison of concentration estimates derived from the acoustic data and the water sample concentrations. Noting that a perfect correlation between individual water sample concentrations and concentration estimates derived from the acoustic data is almost impossible to obtain due to the inevitable impossibility of perfect temporal and spatial sampling correlation, a satisfactory calibration can be defined as follows:

1) apparent errors of concentration are random and there is no indication of any relationship between the magnitude of the errors and:
   - solids concentration;
   - range (ie. depth) to the water samples; or
   - time;
2) at least 80% of the ADP concentration estimates are within ± 20% of the water sample concentrations.

It is likely that the calibration will vary during the measurement period (mainly depending on the distance from the plume source) and that more than one calibration will need to be used during data analysis.

9.4 Temperature and Salinity Measurement

In order to process the ADP backscatter data accurately, detailed data on temperature and salinity must be obtained at appropriate time intervals through the entire depth of the water column. Temperature and salinity sensors should be calibrated before and after each survey. It should be noted that, even if ADPs are not used for measurements, temperature and salinity data should be obtained as background data to support the observations.

9.5 Turbidity Meters

9.5.1 Selection

There are two main requirements with respect to the selection of turbidity meters:

- they must be capable of measuring in the full range of expected sediment concentrations, and
- they must not be affected by ambient light.

The peak concentrations in plumes generated by semi-stationary plant such as grabs and bucket ladder dredgers are usually in the range of a few hundred mg/L. The manufacturers performance data should be consulted for information about the range of concentrations that can be measured by individual instruments.

Insensitivity to ambient light is provided by instruments that work within the infra red part of the light spectrum or with visible light instruments that apply a compensation for ambient light by measuring over more than one distance (path length).

Profiling turbidity meters should be capable of very fast deployment and recovery in order that sufficient data can be obtained while the survey boat sails across a relatively narrow sediment plume. The winch used to deploy the siltmeter should therefore be capable of operation at a wire speed of at least 1 metre per second. The siltmeter must be equipped with a calibrated depth sensor interfaced with the recording device in order that the depth of observation can be logged accurately.
Conventional turbidity meters used for obtaining single-point data may be deployed by hand using a marked rope or wire to establish the observation depth. However, if the water currents are sufficiently fast to cause the siltmeter to hang at an angle, the use of depth sensors is preferred.

9.5.2 Calibration

The response of most turbidity meters reduces as sediment particle size increases, typically in inverse proportion to the diameter of the sediment. Thus, if the average particle diameter increases by 100%, the turbidity meter response decreases by 50%. The particle size distribution of the sediment in suspension will change as the plume moves away from the dredger due to differential settlement. It is therefore essential to calibrate turbidity meters in such a manner that variations with the age of the plume can be established.

The calibration of turbidity meters must be established using the water sample concentration data obtained during the fieldwork. It is not acceptable to apply a global conversion from millivolts or FTU in order to derive solids concentrations. The calibration should be obtained by dipping, the turbidity meter sensor into the water samples (thus eliminating the temporal and spatial co-location errors that arise from field calibration) at the end of each working period. This should be done in a light-proof box. The samples must not been filtered to remove particles of any size, irrespective of the capability of the siltmeter to detect such particles.

The calibration of the siltmeter must also be checked for ‘zero drift’ during the deployment. Zero drift errors should be identified using the pre- and post-survey formazin calibrations.

9.6 Water Sampling Equipment

If profiling turbidity meters are being used, bottle-type samplers with the capacity to obtain near-instantaneous samples should be mounted on the siltmeter so that samples can be taken during siltmeter deployment, thus saving time. This also ensure a high degree of spatial correlation between siltmeter data and the water samples which must be used to calibrate the siltmeter.

If water samples are to be obtained independently from turbidity meter data, the sampler should be fitted with a depth sensor. Rosette-type samplers, capable of taking several samples during a single ‘cast’ are preferred in order to save time.

Pump water samplers may also be used and may in fact be required in order to obtain large samples for sediment particle size analysis. However, pump samplers can give rise to substantial sampling errors due to kinetic effects, especially when working in suspensions containing coarse sediment. In such situations, care must be taken to orientate the intake nozzle with the water current and to match the intake velocity to the current velocity while ensuring that the velocity is sufficient to prevent sediment settling in the hosepipe. The time taken for the water to pass from the intake nozzle to the sample container (the ‘residence’ time) should be taken into account when matching data collection times.

9.7 Dredger Instrumentation

In addition to knowing the position of the sources of sediment release, it is essential to be able to relate loss measurements to the manner of operation of the dredger. The dredger should be fitted with instrumentation which, at least, permits the accurate observation and manual recording of its position, the dredging depth and the main operating parameters.
Ideally, the instrumentation will be capable of recording these (time-stamped) data for later analysis. Refer to *Section 7.6* and *Appendix B* for details of the data that should be recorded.

9.8 Time Synchronisation

It is essential that all measurements are accurately time-synchronised. For very simple measurements (eg. single-point measurements of solids concentration), this may require only the synchronisation of the watches used by the observer on board the dredger and the crew on board the survey boat. For more complex measurements, such as measurement of sediment flux using a combination of acoustic and conventional methods it will be necessary to apply a more complex approach to synchronisation.

When undertaking surveys using ADPs, it will generally be found to be most convenient to use the clock in the computer that is used to operate the ADP as the main ‘survey clock’. This should be set up at the beginning of each survey period using the GPS time signal. All other survey activities should be timed according to this clock. The dredging observer on-board the dredger will be equipped with an accurate digital watch which should also be synchronised with GPS time signal.

All measurement activities on-board the survey boat will be related to the actual time indicated by the ADP computer clock. In the case of the ADP data, this will be automatic. In the case of water samples and siltmeter data, it will be the responsibility of the ADP operator to record the exact time at which the samples or data are obtained. A simple way of doing this is to note the ADP data ensemble number at the time of sampling. The siltmeter and water sample operators should also keep a separate record of the time of their activities using their wristwatches. These records will only be used as a crude back-up check on the timing of general activities.

9.9 Measurement Cycles

Measurements should generally be undertaken on a continuous basis throughout the measurement period. However, when analysing and reporting the observations, they should be divided into data sets which represent, as near as is possible, periods during which ground conditions, water depths and the manner of operation of the dredger were consistent.

9.10 Air Bubbles

Both ADPs and turbidity meters are affected by the presence of air bubbles entrained in the water column. It is essential, especially when working close to dredging plant, that every effort is made to establish whether the data are corrupted by air bubbles and to modify the measurement methods to avoid such contamination. Aeration of the water column close to semi-stationary dredgers can affect turbidity meters to the extent that measured concentrations may be about twice the actual concentrations. A similar amount of air contamination would affect ADP backscatter observations more severely, giving rise to apparent solids concentrations which may be an order of magnitude higher than the true concentrations. Aeration of the water in overflow plumes from trailers (and in propeller wakes) may be intense and will have a dramatic effect on siltmeter and ADP observations.

In the case of cutter suction dredgers, it is unlikely that air bubbles will be a problem, but grabs, backhoes and bucket dredgers all tend to entrain some air in the water column. If ADPs are being used, it is possible to determine whether or not air bubbles are present by undertaking tests as follows (using a grab as an example):

- run ADP lines down-current of the dredger while it is anchored but not working (this will reveal any air bubbles formed by flow around the hull of the dredger or by discharges from the dredger, eg. cooling water discharge);
- run ADP lines down-current of the dredger while it is simulating dredging activity but not actually disturbing the sea- or riverbed (this will reveal air bubbles formed as the

grab descends through the water column or formed by spillage of water from the grab as it slews to the barge).

Turbidity meters can be used in the same manner but it will generally not be so easy to identify minor air bubble contamination.

In the case of trailer dredgers, it is difficult to positively identify the point at which air bubbles due to overflow, LMOB release and propeller wakes have dissipated. However, experience suggests that observations made in plumes less than about 15 minutes after formation should be treated with extreme caution.

9.11 Gas Bubbles

It is frequently the case that soft muddy sediments contain organic material that, through decay, results in the generation of biogenic gas. When disturbed by dredging activity, the gas may be released into the water column. Gas release may also occur, in tidal areas, due to reduced hydrostatic pressure when the tide is low.

Gas bubbles will ‘contaminate’ concentration measurements in exactly the same manner as air bubbles. Tests such as those described in Section 9.10 cannot be undertaken to investigate the effects of gas but, at an order of magnitude level, the gas bubbles are likely to dissipate (rise to the surface) at a similar rate to air bubbles generated by the dredger. In some cases the dissipation rate may be slower because the gas bubbles have to rise from the bed to the surface whereas the air bubbles generated by the dredger may not initially extend down to the bed.

Little guidance can be given for dealing with gas bubbles except to advise extreme caution and to carefully observe the water surface during the measurements in order to detect any bubbles that may be present.

9.12 Video Cameras

Time-stamped video records of the dredging operation can be invaluable. This is particularly the case when working with backhoes and grabs where the on-board observer has to record a lot of data about the timing of each cycle. A video camera provides a useful back-up to these observations. The video camera clock should be synchronised with GPS time before each set of observations.

10. SUPPORTING DATA REQUIREMENTS

10.1 General

Measurements of sediment release have little value unless they can be related directly to the type and size of dredger, its manner of operation and the site and soil conditions. The accurate recording of these data is therefore as important as the accurate measurement of the losses. Supporting data requirements include:

- site morphology and bathymetry;
- hydrodynamic and water quality conditions;
- ground conditions;
- dredging equipment characteristics;
- dredging activity;
- dredged volumes.

10.2 Site Morphology and Bathymetry

A plan showing the general layout of the site and its environs should be provided. The plan should show features, such as outfalls or shipping lanes, that may influence the background sediment regime. The location of the site at which the measurements were made should be clearly shown.

A plan showing the site bathymetry should be shown. It is preferred that bed levels be indicated in metres and they must be related to a known datum. Pre-dredging and post dredging bathymetry should be provided.

10.3 Hydrodynamic and Water Quality Conditions

A summary should be provided of the site hydrodynamic and water quality conditions. This should include the following data:

- tides;
- currents;
- background sediment concentration and its variation during the measurements;
- water temperature and salinity;
- wind and wave conditions;
- features of the site that may affect water quality and movement, eg. outfalls, locks and sluices, barrages etc (although sites with these features should be avoided in possible).

10.4 Ground Conditions

At most sites where dredging is to be undertaken (with the possible exception of some maintenance dredging operations), a ground investigation will have been undertaken. This will usually have included boreholes or vibrocores, in situ testing and laboratory testing on recovered samples. If the intensity of the investigation was sufficient, it is possible that these data can be used to support the loss measurements. If the data are not sufficient to fully characterise the soils at the exact site where the loss measurements are undertaken, it will be necessary to collect additional data. For some soil properties, data can be obtained using samples of the material obtained during the dredging (eg. from grabs) or immediately after dredging.

The number of tests that are required to define soil and rock properties will vary from one site to another and a degree of judgement will be required. Tables 10.1, 10.2 and 10.3 list the data that are required to characterise soils and rocks. These are considered to be the minimum requirement for adequate characterisation.

Table 10.1 Geotechnical data requirements - Cohesive Soils

Data	***Comments***
General soil description	
Particle size by sieving	
Particle size by sedimentation…………….	Also known as 'hydrometry'
Unconfined compressive strength………...	Firm - stiff soils
Laboratory or field shear vane…………….	Soft and very soft soils only
Atterberg limits	
Water content	
Natural bulk density	
Particle specific gravity	

In very soft soils, viscosity tests provide useful data. The gas content can also be tested in soft soils. However, both are specialist tests which may be difficult to arrange.

When determining the particle size distribution of fine soils using the method of sedimentation, the test should be carried out twice. The first test should be undertaken in distilled water in the normal manner following sample treatment with dispersants. The test should undertaken a second time in water taken from the measurement site and without treating the sample with dispersants.

Table 10.2 Geotechnical data requirements - Non-Cohesive Soils

Data	***Comments***
General soil description	
Particle size by sieving	
Particle size by sedimentation………………	Not required if no fines present
Relative density……………………………	eg. Standard penetration test or cone penetration test
Particle specific gravity	
Natural bulk density	
Organic content	

The natural bulk density should also be reported if possible but it is a difficult parameter to measure accurately in non-cohesive soils due to sample disturbance.

Table 10.3 Geotechnical data requirements - Rocks

Data	***Data***
General rock description	Mineralogical analysis
Unconfined compressive strength	Young's modulus
Wet bulk density	Brazilian tensile strength
Specific gravity	Point load strength
Porosity	Rock mass description eg. RQD, fracture spacing etc

All soil and rock tests must be undertaken in accordance with recognised standards. Most standard test procedures are based on British (BS) or USA (ASTM) standards and are very similar. It is essential that the standards which are used are noted in the report. More detailed accounts about the characterisation of material to be dredged are provided in PIANC (1984 and 2000).

10.5 Dredging Equipment Characteristics

In all cases, a detailed description of the dredger and of the excavating equipment must be provided. Details of the required data are summarised in Appendix A for each of the five types of dredger covered by this project.

10.6 Dredging Activity

10.6.1 The Dredging Cycle

It is essential to maintain for the full duration of the measurements a very detailed record of the dredging cycles. This is a full-time job for a staff member who should be stationed next to the dredger operator. Details of the information which is required for each of the five types of dredger included in the TASS project are provided in Appendix B.

10.6.2 Debris

Many dredging sites in harbours are characterised by the presence of debris (Figure 10.1). This will influence the amount of sediment put into suspension by all types of dredger. It is recognised that this is difficult to describe in quantitative terms but a general description of the type, size and frequency of debris should be provided.

Figure 10.1 Debris, typical of that found in harbours, includes timbers, ropes and wires, tyres and scrap metal.

If possible, eg. with grab dredgers, a note should be made of any failure to close the grab completely due to debris (or for any other reason). A simple approach to quantitative description of non-closure is to record the estimated distance, in centimetres, between the bottom lips of the grabs (refer to Figure 10.2) when the bucket is raised above the water. It should also be noted if material is visibly escaping from the grab.

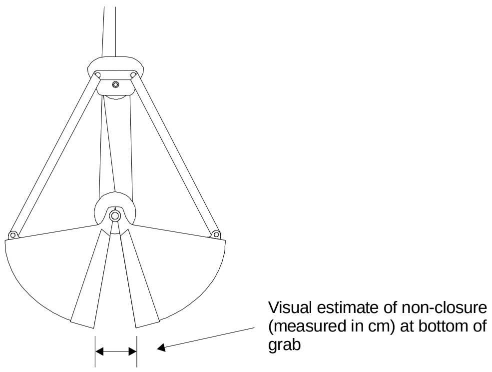


Figure 10.2 Estimating the degree of non-closure of grab

10.6.3 Other Activities

All other activities concerning the dredging activity should be recorded including:

1) moving the dredger
2) barge changes
3) delays

10.7 Dredged Volumes

If accurate and detailed records are maintained of the dredging in progress during the measurements, it should be possible to derive a reasonable estimate of the dredged volume. In the case of grab dredgers and backhoes, for example, an indicative volume can be obtained from the hopper volume of the dredged material adjusted to allow for an appropriate bulking factor. Indicative volumes for bucket and cutter suction dredgers may be obtained directly from the dredging records (ie. cut depth, swing width etc) making due allowance for spillage. Indicative volumes for trailer dredgers might be obtained from the TDS (**T**onnes **D**ry **S**olids) system, if fitted, in combination with knowledge of the *in situ* soil characteristics.

Reliable estimates of the *in situ* dredged volume can only be obtained by comparison of pre- and post-dredging bathymetric surveys. It is therefore desirable that such surveys be included as a part of the measurements. Note that if the measurements involve only a small volume of dredging (as is likely to be the case with a grab working for one or two days) it is preferable to undertake the survey using swath or multi-beam systems. Single beam surveys will need to be run at a very close line spacing (2-3 metres) in order to obtain acceptable accuracy.

11. SEDIMENT FLUX CALCULATION PROCEDURES

11.1 General

Sediment Flux is…

…the rate at which suspended sediment passes through a defined cross-sectional area of the water column. The preferred units of measurement are kg/sec. The total sediment flux immediately downstream of a working dredger comprises the combination of the background flux (ie. the sediment that is transported naturally) and the flux due to the additional sediment put into suspension by the dredger.

Data analysis requirements will depend largely on the type and amount of data collected in the field. Sediment flux analyses are complex and are described here. Four types of calculation are described:

1) measurements in which both current and suspended solids data have been obtained using ADPs (described in Section 4);
2) solids measurement using towed arrays in combination with current measurement using ADPs or conventional current meters (described in Section 5.1.1);
3) solids measurement using profiling turbidity meters in combination with current measurement using ADPs or conventional current meters(described in Section 5.1.2);
4) ADP measurements of solids in draghead plumes (as described in Section 7.4).

11.2 Sediment Flux Calculation Using Only ADP Data

The precise details of the flux computation will depend on the software available to the user. The procedure described below assumes that the software can work with both processed concentration data and current data. The first stage is to establish a reliable calibration (refer to *Section 6.3*) after which the acoustic backscatter data are processed to derive suspended solids concentrations in each measurement cell.

Bottom-track or DGPS referencing?

When computing discharge it is preferable to reference the current data to the ADP bottom track data, rather than data derived by the DGPS. This is because errors of current measurement and position (ie. the horizontal distance represented by each data ensemble) exactly cancel each other with this approach. Bottom track cannot be used if the bed is mobile.

11.2.1 Step 1 – Check for corrupt data

The data files must first be checked carefully to ensure that:

- there is no corruption by air bubbles;
- there are no default values for ‘bad’ data included in the files;
- there are no concentration values which have been corrupted by fish or debris in the water column.

All bad concentration data should be removed from the data file and replaced with good data from an immediately adjacent cell. Similarly, the current data should be checked to remove bad data and replace it with good data from adjacent cells.

11.2.2 Step 2 - Compute measured solids flux

The solids flux is the product of discharge (ie. the flow of water per unit time through each measurement cell) and suspended sediment concentration. It can be computed in two ways:

1) either perpendicular to the line described by the actual course of the survey boat (Flux 1 in Figure 11.1), or
2) perpendicular to a nominal straight line approximately perpendicular to the average current direction (Flux 2 in Figure 11.1).

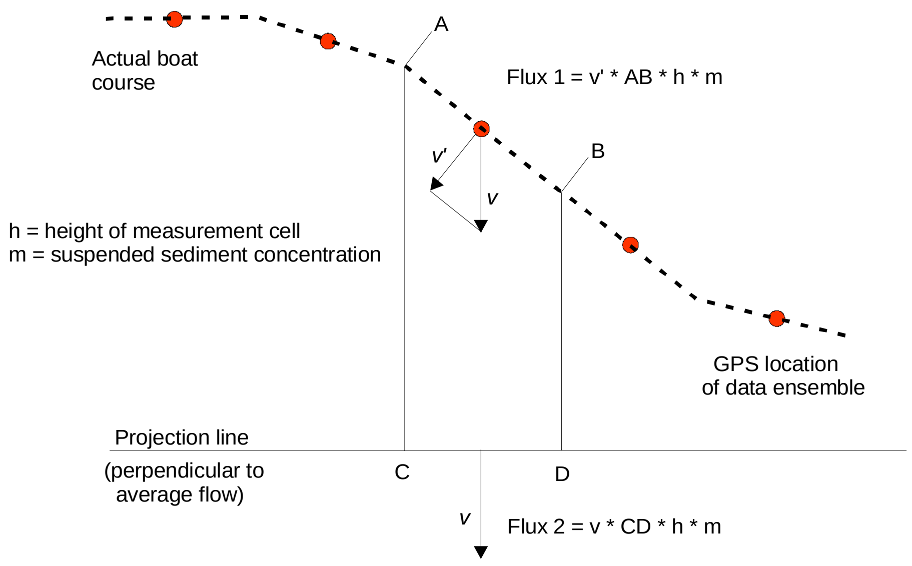


Figure 11.1 Calculation of sediment flux.

Both methods will yield exactly the same value for flux through the survey line. However, if the data are to be presented graphically (eg. as colour-contoured plots of solids concentration or solids flux) it will be necessary to project the data onto the nominal line in order to remove scale distortions due to the slightly irregular course and speed of the survey boat. This is purely a matter of presentation and does not affect the estimates of flux.

Perpendicular to vessel course

The size of each cell is computed by multiplying the height (fixed by the ADP settings) by the length (AB in Figure 11.1). The length of the cell will vary with boat speed and can be computed from the known positions of the boat when each data ensemble was obtained. The discharge in each cell is obtained by multiplying the area of the cell by the current speed perpendicular to the course of the boat (v' in figure 11.1). The flux is the product of concentration and discharge.

Projected

If the data are projected onto a nominal line, it is necessary to compute the following

- the projected area of each measurement cell (h * CD in Figure 11.1);
- the component of current speed perpendicular to the nominal line in each measurement cell (v in Figure 11.1);
- the flux in each measurement cell (= current speed * cell area * concentration).

Whichever of the two methods is used, the total solids flux through the measured part of the transect is obtained by summing the flux through all of the individual cells.

11.2.3 Step 3 – Estimate solids flux in near-surface and near-bed zones

The ADP is unable to obtain data from the complete water column (refer to *Figure 6.1*). The near-surface zone is not measured due to the immersion depth of the ADP transducers and the 'blank-after-transmit' setting. The data from the near-bed zone are corrupted by sidelobe echoes. Two methods can be used to estimate solids flux in these areas.

1) use a profiling turbidity meter data to establish a general relationship between the concentration in:
   - the uppermost ADP data bin and the concentration in the water column above that bin; and
   - the measured concentration in the lowest valid ADP data bin and the concentration in the water column below that bin.
2) estimate the solids concentrations in the upper and lower 'blind' zones by fitting curves through the measured concentration data.

In both cases, the estimated solids concentrations are combined with estimated discharges derived by curve fitting. When working in very young plumes close to the dredger, the distribution of sediment in the water column may be very irregular. In such cases, it may not be possible to derive sensible data by means of curve fitting and a more reliable result might be obtained by using the measured concentrations in the highest and lowest valid bins, adjusted by a factor based on examination of profiling turbidity meter data.

The estimates of near-surface and near-bed sediment flux should then be added to the total measured flux in order to derive the total sediment flux through the measurement line.

11.2.4 Step 4 – Estimate background flux through survey line

The ADP data at each end of the survey line, beyond the area affected by the sediment plume from the dredging operation (refer to *Figure 11.2*), should then be analysed to determine the average background solids concentration at each ADP measurement level.

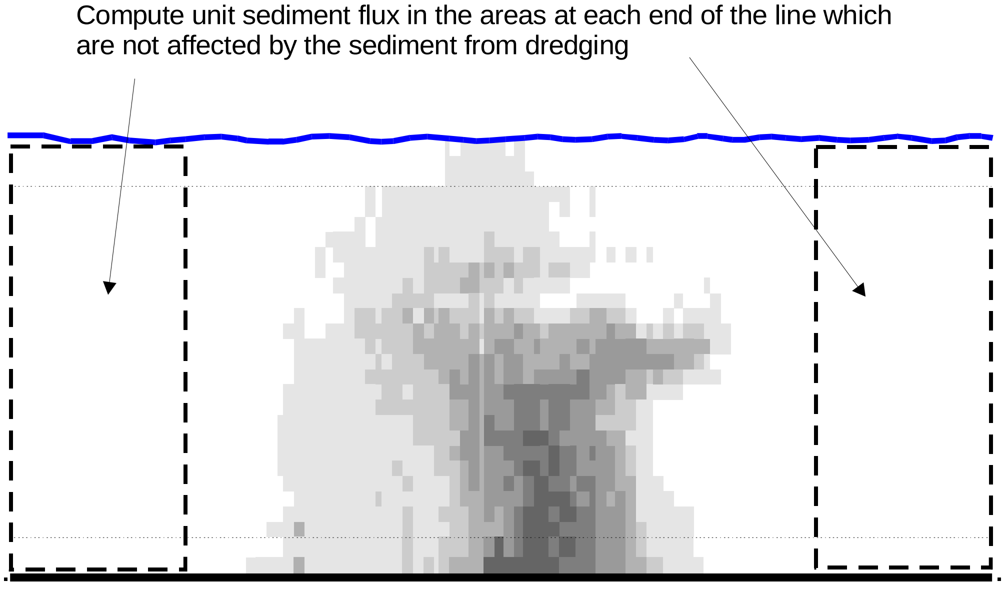


Figure 11.2 Background sediment flux data

The average concentrations at each end of the line should then be compared with each other, separately for each ADP measurement level. If the 'end' averages differ by less than 5-10%, the average of the two concentrations should be calculated. This concentration should then be applied to the discharge data in each ADP data cell at the appropriate level in the area of the transect affected by the plume. The estimated background flux is then computed for each ADP measurement depth along the full width of the nominal line. These are summed to derive the estimated total background flux through the full cross section of the nominal line.

If the end estimates differ by more than 5-10%, the difference must be spread evenly through the data cells within the plume-affected length of the nominal line.

11.2.5 Step 5 – Compute flux due to dredging operation

The sediment flux due to the plume formed by the dredging operation is then obtained by subtracting the estimated total background sediment flux from the estimated total sediment flux. When presenting results, it is important to state what proportion of the flux has been based on estimated discharges and solids concentrations in the near-bed and near-surface zones.

11.3 Sediment Flux Calculation Using Towed Array Data

11.3.1 Turbidity Meter Data with ADP Current Data

The water column is divided into a number of layers, each represented by one of the towed turbidity sensors (Figure 11.3). The solids concentration throughout the full depth of each layer is assumed to be equal to the concentration measured by the corresponding sensor.

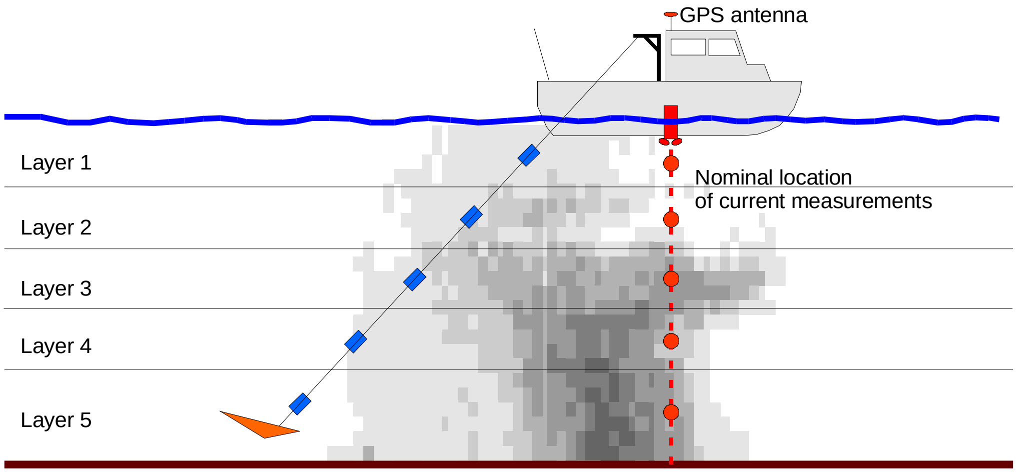


Figure 11.3 Concentration and current data offsets

It is not possible to simultaneously measure the current and the solids concentration at a given point because the towed turbidity sensors are located at varying distances behind the ADP. Calculations of solids flux will therefore inevitably involve some degree of approximation and error. The magnitude of the error will vary from negligible, if the current profile is almost uniform along the transect, to significant, if there is great variation of the current profile along the transect. Errors may also arise if the current varies significantly with time, ie. if the current speed at a given point changes between the time when the ADP measures the current at a point and the time the turbidity meter passes the same point.

The most rigorous approach to computation involves computing the flux at a given point using the current data and solids concentration measured at that same point. In order to do this, the 'lay-back' of each turbidity sensor must be computed so that the position of each solids observation can be derived and matched to the current data obtained at the same point. The position of each solids observation is computed using the DGPS data (ie. the known position of the ADP) in combination with the measured depth of each solids observation and the known distance along the string of each sensor. Figure 11.4 illustrates the method of computation. This calculation is strictly only correct if the sensor array is straight which, in most cases will be an acceptable approximation. If the array forms a marked catenary, more complex calculations may be required.

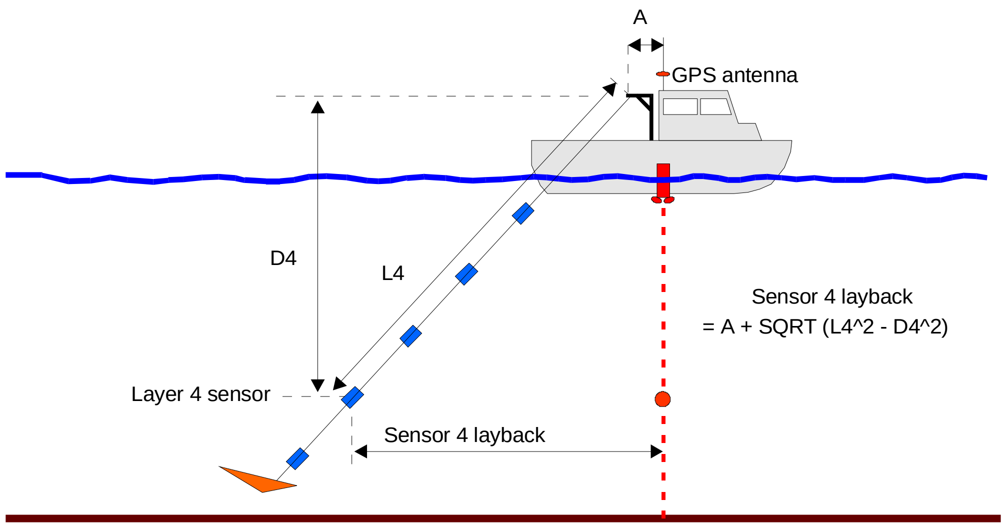


Figure 11.4 Calculation of sensor layback.

An alternative approach is to assume that the current profile is consistent along the full length of the transect. The total measured discharge in each layer is then multiplied by the average solids concentration in that layer in order to derive the total solids flux. While being relatively simple in terms of computational effort, this approach should only be used in open water areas with a uniform water depth where the assumption of a consistent current profile along the length of the transect can be demonstrated.

Whichever method is used, it is necessary to project all data onto a nominal straight line and to base the flux computation on the component of current speed perpendicular to the line. Computation of the background sediment flux and derivation of the sediment flux due to the dredging operation is undertaken in a similar manner to that described in Section 11.2.

11.3.2 Turbidity Meter Data with Conventional Current Meter Data

If a conventional current meter is used to obtain current profile data, it is likely (due to time constraints) that only one profile of data will be available for each measurement transect. This will have to be applied to the whole of the transect. The current meter data are used to obtain an average current speed and direction for each of the depth increments represented by the turbidity sensors.

The total mass of solids in suspension in each measurement layer is derived by calculating the average solids concentration measured by the sensor along the full length of the transect. In order to remove the effects of varying boat speed and course, the concentration data should first be projected onto a nominal straight line across the plume. Each concentration measurement is then weighted by the projected length of the course on the line. The flux is given by the product of the current speed and the concentration of sediment in suspension. Computation of the background sediment flux and derivation of the sediment flux due to the dredging operation is undertaken in a similar manner to that described in Section 11.2.

11.4 Sediment Flux Calculation Using Profiling Turbidity Meter Data

11.4.1 Profiling Turbidity Meter Data with ADP Current Data

Calculation of flux using the data obtained from the profiling turbidity meter, in conjunction with the ADP current data, is relatively crude. However, as long as sufficient turbidity meter profiles have been obtained in each transect, it should yield reasonably reliable data.

Step 1 – Compute discharge

The times at which the profiling turbidity meter was at the bed and at the surface should have been recorded during the survey. The ADP data can be divided into sections, each of which represents a single ‘upward’ or ‘downward’ turbidity profile (Figure 11.5). For each of these sections, calculate the discharge (perpendicular to the nominal line) for each ADP depth increment. The discharge in the ‘blind’ zones at the top and bottom of the water column should be estimated using an appropriate curve fitting function.

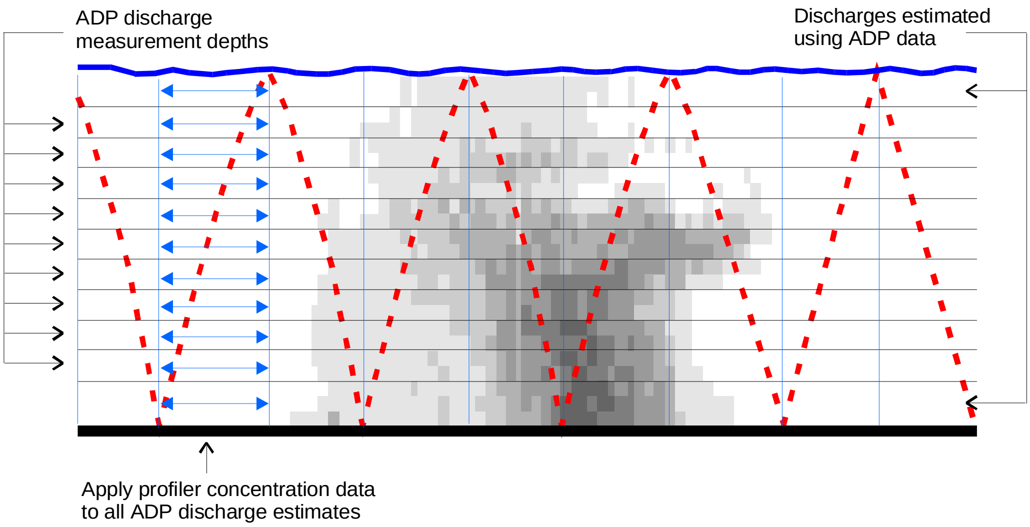


Figure 11.5 Subdivision of ADP current measurements to match turbidity meter profile data.

Step 2 – Compute sediment concentration and flux

The average solids concentration within each ADP measurement depth increment should be computed separately for each siltmeter profile. These data should then be factored by the corresponding ADP discharge measurement in order to derive the sediment fluxes. The sum of all the flux estimates will yield the total flux through the measurement line.

Step 3 - Compute background flux and flux due to dredging

The background flux is obtained in a manner similar to that described in Section 11.2, using turbidity meter profiles obtained on both sides of the plume. The flux due to the dredging is the total flux less the background flux. When presenting results, it is important to state what proportion of the flux has been based on estimated discharges in the near-bed and near-surface zones.

11.4.2 Profiling Turbidity Meter Data with Conventional Current Data

If a conventional current meter is used to obtain current profile data, it is likely (due to time constraints) that only one profile of data will be available for each measurement transect. This will have to be applied to the whole of the transect.

The transect should be divided into sections, each representing a single profile. The positions of the profiler when it was at the surface and at the bed should be determined from the DGPS data record in order to compute the lengths of transect represented by each profile. These should then be projected onto a nominal line perpendicular the main current flow direction in order to eliminate errors arising from an irregular course across the plume

The water column should then be divided into discrete depth increments (0.25-0.5m is appropriate) and, for each depth increment, the average solids concentration and average current speed (perpendicular to the projection line) should be computed. The sediment flux in each increment is the product of concentration and current speed. The total flux through the transect is the sum of all the individual estimates of flux. The background flux and flux due to dredging are computed in a similar manner to that described for the other methods.

11.5 Calculation in Draghead Plumes

In the case of draghead plumes, the ADP data must first be projected onto a straight line perpendicular to the track of the dredger (Figure 11.6). The mass of sediment is suspension in a 1-metre slice through the plume is then computed and adjusted for the background concentration, by averaging the observed background concentration on either side of the plume at each measurement level, to derive the mass of sediment due to resuspension.

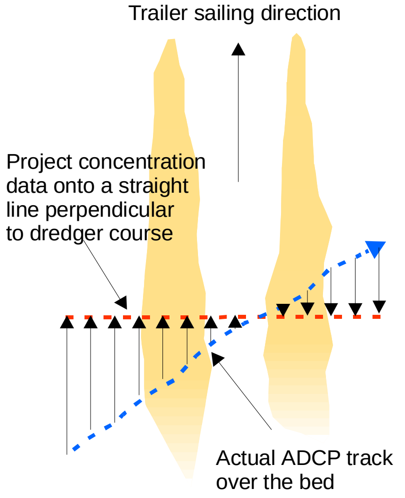


Figure 11.6. Data projection for calculation of draghead resuspension rate.

In this case, it is not necessary to estimate the concentrations in the 'blind zone' near the ADP transducers because the ADP should have been towed above the sediment plume. However, it will be necessary to estimate the solids in the near-bed zone.

Because it is not possible to obtain profiling siltmeter data in draghead plumes, it will be necessary to derive this by curve-fitting through the measurement data.

The rate of release is given by the mass of sediment in suspension per metre multiplied by the trailing speed (m/sec) minus the component of current velocity in the direction of trailing.

For example, if there is 5kg of sediment in suspension in the 1-metre slice through the plume (adjusted for background sediment), the trailing speed is 1 m/sec and the component of current speed <u>in the same direction as the dredger's course</u> is 0.5 m/sec, the rate of release is 2.5 kg/sec. As with other types of computation, the proportion of the release rate that is based on estimated data in the near-bed zone should be reported.

12. REPORTING REQUIREMENTS

It is often the case that the value of measurement data is reduced because it is reported inadequately. All data that are relevant to understanding the manner in which the data were obtained, the nature of the dredging operation to which they relate and uncertainties in the accuracy of the basic observations and the flux estimates, must be presented in the report. The recommended general format of the report is described below.

12.1 Executive Summary

The Executive Summary should be approximately one page in length and summarise:

- the objective of the measurements;
- the type of dredger and the methods of measurement that were used, and
- the main findings of the work.

12.2 Introduction

The *Introduction* should describe the purpose of the measurements, the general circumstances in which they were undertaken and the nature of the dredging operation to which they relate. Location plans should be included which shows clearly where the measurements were made. If necessary these should be at both small and large scales. Other relevant supporting data should be included, such as:

- the name of the organisation which commissioned the work;
- details of the dredging contractor;
- details of the organisations responsible for the measurements.

12.3 The Dredging Operation

This section of the report should contain all details of the dredging operations

Site characteristics

A general description of the morphology of the site and its environs. A plan should be included showing the exact location and extent of the area dredged during the measurements. Pre- and post-dredging bathymetric surveys should also be included.

The dredger and its method of operation

The type of dredger, including the size and type(s) of grabs (or buckets, cutterhead etc) which were used, and the ancillary vessels (eg. tugs and barges), should be described. Drawings or photographs of the dredger and the grabs should be included. Typical cycle times should be presented.

Soil conditions

The materials that were dredged during the measurements should be described. The detailed results of all laboratory tests should be presented as an appendix to the report. Typical soil properties, based on a statistical analysis of the test data should be summarised in tabular form in the main text.

Hydrodynamic conditions

A description, with supporting figures and tables, of the current regime, water temperature and salinity, wind and waves and the background suspended sediment.

12.4 Methods of Measurement and Data Analysis

The methods and equipment used during the loss measurements should be described. A few sketches and photographs showing the equipment installed on the survey vessel will assist the reader. Plans showing the locations of data collection points and survey lines, relative to the position of the dredger, should be included.

Where the surveys permit the computation of sediment flux, the method of calculating the losses should be described.

12.5 Equipment Calibration and Test Procedures

All calibration data should be included in the report. These must include:

Turbidity Meter

- Plots showing the pre-survey and post-survey formazin calibrations of the turbidity meter.
- Details of each calibration which has been applied to the data, ie. the formula(e) relating millivolts to solids concentration.
- Scattergrams showing the comparison(s) between the water sample concentrations (mg/L) and the original turbidity meter observations (in mV).
- Scattergrams showing the comparison(s) between the water sample concentrations (mg/L) and the derived turbidity meter concentration (mg/L).

Calibration difficulties should be described. All calibration data must be presented. If any calibration data is excluded from the final presentation, the reasons why it has been excluded should be explained.

ADP

- Scattergram(s) showing the relationship between water sample concentrations and concentration estimates derived from the ADP data.
- Scattergram(s) showing the percentage differences between water sample concentrations and concentration estimates derived from the ADP data plotted against the range from the ADP.
- Time-series plot(s) showing the percentage differences between water sample concentrations and concentration estimates derived from the ADP data plotted against time.
- Scattergram(s) showing the percentage differences between water sample concentrations and concentration estimates derived from the ADP data plotted against water sample concentrations.

Calibration difficulties should be described. All calibration data must be presented. If any calibration data is excluded from the final presentation, the reasons why it has been excluded should be explained.

Other Equipment

The pre- and post-survey calibration of the depth, temperature and salinity sensors should be described and the calibration graphs provided. The calibration data for the dredger instrumentation (eg. TDS system, dredging depth sensors etc) should also be provided.

Test Procedures

The national or international standard procedures that were used for the soil and rock tests, the determination of solids content of water samples and the determination of the particle size of the suspended sediment should be noted. If any tests were undertaken for which no recognised standard was available, the full test procedure should be described in an appendix to the report.

12.6 Presentation of Results

Each reported flux measurement should be supported with the following data:

- age of sediment plume at time of flux measurement
- dredger operating parameters relevant to the loss/flux measurement (e.g. grab size and type, analysis of the dredging cycle etc);
- plots of:
    - the background concentration plotted against time during the measurement used to derive the flux estimate;
    - the sediment flux due to dredging plotted against time during the measurements used to derive the flux estimate;
- data on the particle size of the suspended sediment.

Flux measurements should be grouped according to the dredger operating parameters and site conditions so that the measurements in each group represent data obtained under broadly similar conditions. The flux estimates should be presented in graphic form, plotted against the estimated ages of the plume at the measurement locations. If more than one group of data have been obtained, the reasons for the differences (if any) between the flux data should be discussed.

If far-field plume-tracking measurements have been undertaken, the data should be presented in graphic form showing the survey boat tracks (or locations in the case of single-point data) and the measured concentrations (eg. as Figures 6.3 and 6.4).

Estimates of the accuracy of the measurements should also be provided. Where possible, these should include the accuracy of positioning and timekeeping and the accuracy of current and suspended sediment concentration measurements. Estimation of the accuracy of current measurement will generally need to be based on the equipment manufacturers' data while estimates of the accuracy of sediment concentrations will need to be determined by statistical analysis of calibration data.

12.7 Data Files

The measurement techniques described in this protocol may generate substantial amounts of data and it may not be practical to present all of these data in a hard copy report. However, consideration might be given to providing to interested parties, on request, a CD-ROM containing a full set of all the measurement data.

REFERENCES

PIANC, 1984. Classification of Soils to be Dredged. Report of a working group of the Permanent Technical Committee II. Supplement to Bulletin No. 47, Permanent International Association of Navigation Congresses, Brussels

PIANC, 2000. *Site Investigation Requirements for Dredging Works*. Report of Working Group No. 23 of the Permanent Technical Committee II. Supplement to Bulletin No. 103, ISBN 2-87223-113-7, International Navigation Association, Brussels.

APPENDIX A
REQUIREMENTS FOR RECORDING OF DREDGING EQUIPMENT CHARACTERISTICS

A1. Grab Dredgers

A1.1 General arrangement

A general description of the grab dredger should be provided, including:

- photographs and dimensioned drawings showing the general layout;
- the dimensions of the hull, including the actual draft at the time of the measurements;
- details of the anchors and anchoring arrangement;
- general descriptions and dimensions of the transport barges and supporting vessels;
- the general condition (relevant to sediment release) of all plant and equipment;
- if a silt screen is used, this should be described and a drawing showing the arrangement should be provided.

A1.2 The Grab

The grab should be characterised in detail and supporting drawings and photographs provided. The type ands weight of the grab should be specified, particularly the types and arrangement of seals in the case of closed or 'watertight' grabs. The following dimensional data should be recorded for each grab used during the measurements (refer to Figure A.1):

1) nominal bucket capacity (m^3);
2) the external surface area of the grab (m^2) – 'A' in Figure A1 below;
3) the surface of the exposed soil in the grab – 'B' in Figure A1 below (this should be measured for different filling factors), (m^2);
4) plan area of grab when fully open (m^2) – 'C' in Figure A1 below;

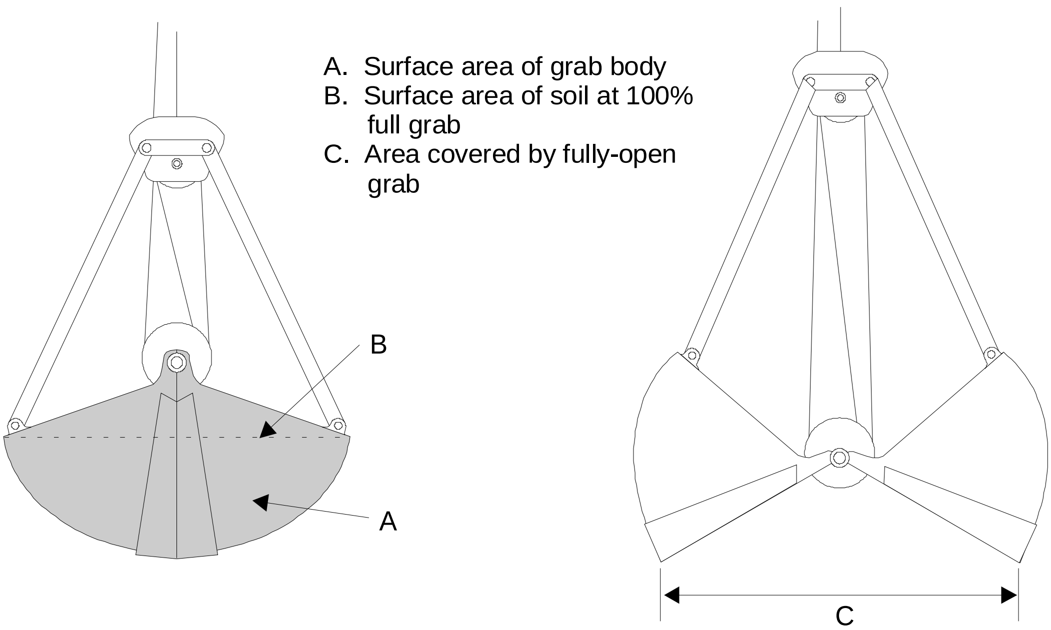


Figure A.1 Required dimensions of grab (in addition to volume)

These measurements may be obtained using several methods:

1) measurement of scaled drawings using a CAD package;
2) careful field measurements of the grab followed by area calculations;
3) if the design of the grab is particularly complex and detailed CAD drawings are not available, surface areas may be determined by 'wallpapering' the surface to be measured with sheets of damp tissue (eg. kitchen roll) of known area.

A2. Backhoes

A2.1 General arrangement

A general description of the backhoe should be provided, including:

- photographs and dimensioned drawings showing the general layout;
- the dimensions of the hull, including the actual draft at the time of the measurements;
- details of the anchors or spuds;
- general descriptions and dimensions of the transport barges and supporting vessels:
- a drawing should be provided that shows the reach of the boom and bucket at various depths;
- the general condition (relevant to sediment release) of all plant and equipment;
- if a silt screen is used, this should be described and a drawing showing the arrangement should be provided.

A2.2 The Bucket

The bucket should be characterised in detail and supporting drawings and photographs provided. The type of bucket should be specified, particularly the types and arrangement of seals in the case of closed or 'watertight' buckets. The following dimensional data should be recorded for each bucket which is used during the measurements (refer to Figure A.2):

1) nominal bucket capacity (m^3);
2) the external surface area of the bucket (m^2);
3) the surface of the exposed soil in the bucket (this should be measured for different filling factors), (m^2);

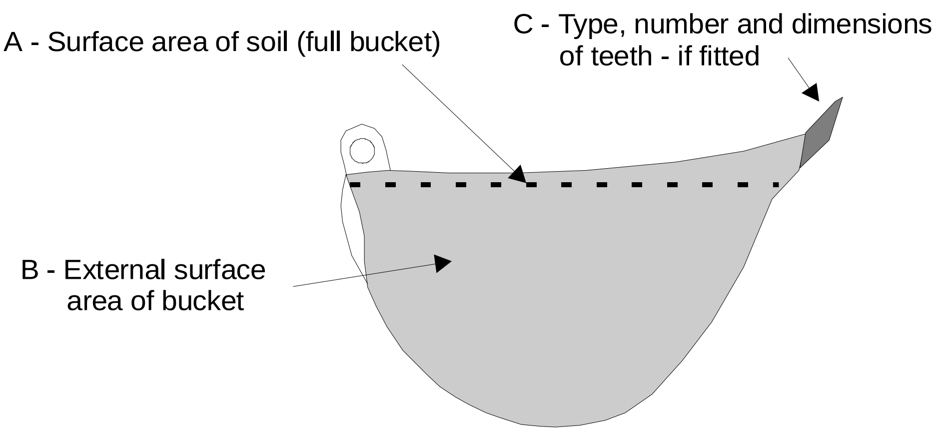


Figure A.2 Required dimensions of bucket (in addition to volume)

These measurements may be obtained using several methods:

1) measurement of scaled drawings using a CAD package;
2) careful field measurements of the bucket followed by area calculations;

3) if the design of the bucket is particularly complex and detailed CAD drawings are not available, surface areas may be determined by 'wallpapering' the surface to be measured with sheets of damp tissue (eg. kitchen roll) of known area.

A3. Bucket Dredgers

A3.1 General Arrangement

A general description of the dredger should be provided, including:

- photographs and dimensioned drawings showing the general layout;
- the dimensions of the hull, including the actual draft at the time of the measurements;
- details of the anchors and anchoring arrangement;
- general descriptions and dimensions of the transport barges and supporting vessels;
- the normal dredging depth of the dredger, ie. the dredging depth at which the top edges of the buckets are horizontal;
- the condition of the (barge-loading) chutes and the extent to which they leak material into the water;
- the general condition (relevant to sediment release) of all plant and equipment;
- any design features or measures that have been implemented to reduce release of sediment (eg. enclosed ladder, buckets with air valves).

A3.2 The Buckets

The buckets must be characterised in detail and supporting drawings and photographs provided. The following dimensional data should be recorded (refer to Figure A.3):

1) nominal bucket capacity (m^3);
2) the surface of the exposed soil in the grab (this should be measured for different filling factors), (m^2);
3) the distance between the buckets <u>measured parallel to the bucket ladder</u> (m);
4) the external surface area of the bucket (m^2).

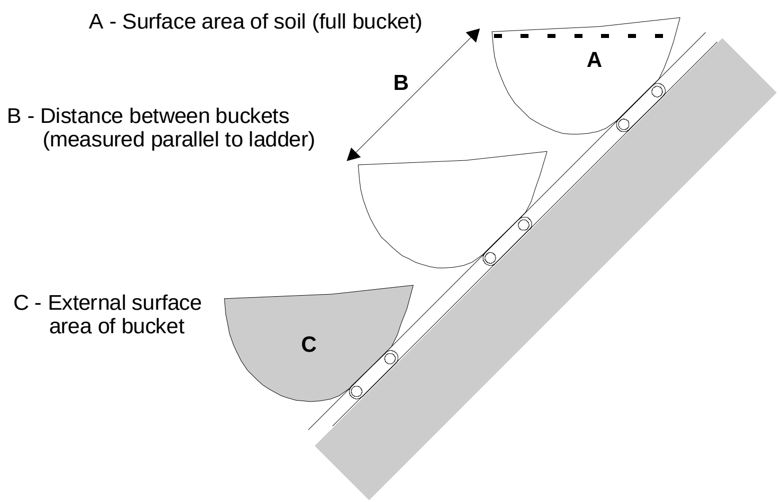


Figure A.3 Required bucket dimensions (in addition to volume)

The surface area of the buckets can be established using the following methods:

1) measurement of scaled drawings using a CAD package;
2) careful field measurements of the bucket followed by area calculations;

3) if the design of the bucket is particularly complex and detailed CAD drawings are not available, surface areas may be determined by 'wallpapering' the surface to be measured with sheets of damp tissue (eg. kitchen roll) of known area.

A4. Cutter Suction Dredgers

A general description of the dredger should be provided, including:

- photographs and dimensioned drawings showing the general layout;
- the anchors and anchoring arrangement, including spuds,
- general descriptions and dimensions of the transport barges (if used) and supporting vessels;
- the type and dimensions of the cutterhead(s), including picks and blades;
- the general condition (relevant to sediment release) of all plant and equipment;
- the general arrangement of floating pipelines and anchors should be shown on a drawing.

A5. Trailing Suction Hopper Dredgers

A general description of the trailer dredger should be provided. This should be supported by photographs and dimensioned drawings showing the general layout.

The following dimensional and other data should be reported:

1) hopper capacity, m^3;
2) hopper length, m;
3) hopper width, m;
4) notional hopper depth, m;
5) maximum load carrying capacity, tonnes;
6) light draft, m;
7) deadweight of vessel, t;
8) buoyancy factor (metres additional draft per tonne of load), m/t;
9) main propeller diameter, mm;
10) power on main propellers, kW;
11) bow thrust propeller diameter, mm;
12) power on bow thrust, kW;
13) length and width of draghead, m;
14) weight of draghead, t;
15) a description of the jetting system (if fitted) including the location of the jets, the water pressure and the rate of delivery;
16) details of the swell compensation system and settings;
17) speed of raising and lowering draghead, m/s;
18) diameter of suction pipe(s), m;
19) locations, type and power of pumps,
20) indicative trailing speeds (average, maximum and minimum).

In addition, the general condition (relevant to sediment release) of all plant and equipment should be reported.

APPENDIX B
REQUIREMENTS FOR RECORDING DREDGING ACTIVITY

B1. Grab Dredgers

Data that must be recorded for every dredging sub-cycle include:

1) dredging depth (m), obtained from the operator's gauges;
2) time of entry of empty grab into the water;
3) time of exit of loaded grab from the water;
4) the grab filling factor.

Every 5th sub-cycle should be recorded in detail as follows:

1) time of entry of empty grab into the water;
2) time of contact with bed;
3) dredging depth;
4) time of start of recovery;
5) time of exit of loaded grab from the water;
6) the grab factor;
7) time when slewing grab reaches barge;
8) time when slewing grab passes from the barge on the return to the dredging location;
9) the approximate maximum hoisting height above water (to clear the barge coamings).

In addition, the following general information must be recorded (with times):

1) the position of the barge relative to the dredger and the times at which it is moved to ensure an even load distribution;
2) barge changes;
3) pauses in the dredging operation;
4) any deck washing activity that results in water flowing over the side;
5) the location of the barge being loaded (ie. port or starboard side);
6) other vessel movements in and close to the measurement location (including the tugs used to change the barges).

B2. Backhoes

Data that must be recorded for every dredging sub-cycle include:

1) dredging depth (m), obtained from the operator's gauges;
2) time of entry of empty bucket into the water;
3) time of exit of loaded bucket from the water;
4) the bucket filling factor.

Every 5th sub-cycle should be recorded in detail as follows:

1) time of entry of empty bucket into the water;
2) time of contact with bed;
3) dredging depth;
4) time of start of recovery;
5) time of exit of loaded bucket from the water;
6) the bucket filling factor;
7) time when slewing bucket reaches barge;
8) time when slewing bucket passes from the barge on the return to the dredging location;
9) the approximate maximum hoisting height above water (to clear the barge coamings).

In addition, records should be kept of the following:

1) spillage from the bucket during slewing;
2) splashing during loading of the barge;
3) signs of biogenic gas release during dredging;
4) the position of the barge relative to the dredger and the times at which it is moved to ensure an even load distribution;
5) barge changes;
6) pauses in the dredging operation;
7) any deck washing activity that results in water flowing over the side;
8) other vessel movements in and close to the measurement location (including the tugs used to change the barges).

B3. Bucket Dredgers

Data that must be recorded for every cut (swing) include:

1) dredging depth (m), obtained from the operator's gauges;
2) time and direction of start of swing;
3) time of end of swing;
4) bucket speed;
5) the bucket filling factor.

In addition, records should be made of the following:

1) gas release from the soil during dredging;
2) splashing or overflow during barge loading leading to sediment release from barges;
3) leakages from the loading chutes;
4) bucket chain 'rattle' (leading to release of sediment from buckets);
5) the position of the barge relative to the dredger and the times at which it is moved to ensure an even load distribution;
6) barge changes
7) pauses in the dredging operation;
8) any deck washing activity that results in water flowing over the side;
9) other vessel movements in and close to the measurement location (including the tugs used to change the barges).

B4. Cutter Suction Dredgers

Data that must be recorded for each dredging cut (swing):

1) dredging depth (m), obtained from the operator's gauges;
2) time of start of swing;
3) time of end of swing;
4) cutterhead rotation speed;
5) suction velocity;
6) cut height and step;
7) overcutting or undercutting.

In addition, records should be made of the following:

1) gas release from the soil during dredging;
2) splashing or overflow during barge loading (if used) leading to sediment release from barges;
3) the position of the barge (if used) relative to the dredger and the times at which it is moved to ensure an even load distribution;
4) barge changes (if used);
5) movement/relocation of the pipeline;
6) pauses in the dredging operation (including spud movements);
7) other vessel movements in and close to the measurement location (including tugs used to change the barges, move pipelines etc).

B5. Trailing Suction Hopper Dredgers

Data that must be recorded for <u>every</u> dredging cycle includes:

1) dredging depth, m;
2) length of trail run, m;
3) trailing speed, knots;
4) pre-load volume of water in hopper, if any, m^3;
5) number of suction pipes in use;
6) mixture density, Mg/m^3;
7) velocity in suction pipe, m/s;
8) density of material settled in hopper, Mg/m^3;
9) turning time, min;
10) time to sail to disposal, dispose and return to dredging site, min;
11) depth of draghead immersion, m;
12) LMOB density setting, if used, Mg/m^3.

APPENDIX C
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Belgium

ir. Hugo De Vlieger
DEC NV,
Zwijndrecht.

ir. Koenraad Mergaert
Ministry of the Flemish Community Administration of Waterways and Maritime Affairs,
Maritime Access Division, Antwerp.

Stijn Claeys
General and Business Development Manager
Medida Hydrographic Services NV,
Zebrugge.

Denmark

Mr Anders Jensen
DHI Water & Environment
Horsholm.

Mr Bo Mogensen
DHI Water & Environment
Horsholm.

Poul E Neilsen
Senior Geologist, Ministry of the Environment
The Danish Forest and Nature Agency
Copenhagen.

France

Dr Roland Boutin
Service Technique des Traveaux Immobiliers et Maritimes
Armees.

Mr Jacques Paul
GIE Dragages-Ports
Rouen Cedex.

Germany

Mr Harald Koethe
Federal Institute of Hydrology (BfG)

Mr. Matthias Adler
Dept of water levels, water quantities, runoff models
Federal Institute of Hydrology, Koblenz.

Mr. Gölz
Federal Institute of Hydrology

Mr. Rahlf
BAW-Hamburg
Federal Institute of Hydraulic Engineering.

Mr. Heinz Glindemann
Port Authority of Hamburg.

Mr Axel Netzband
Port Authority of Hamburg.

Mr Georg Werner
Prozess Wassertiefen, Port Authority of Hamburg.

The Netherlands

ir. Gerard H. van Raalte
Hydronamic BV
Papendrecht.

United Kingdom

Dr Lindsay A Murray
CEFAS, Burnham Laboratory
Burnham-on-Crouch, Essex.

United States of America

Jim Clausner
Research Hydraulic Engineer,
US Army Engineer Research and Development Center,
Coastal and Hydraulics Laboratory, Vicksburg, Mississippi.

Tim Welp
ERDC,
Vicksburg Mississippi

Bill Tubman
ERDC,
Vicksburg Mississippi

Don Hayes
Associate Professor, Civil & Environmental Engineering,
University of Utah, Salt Lake City