Bilaga 1

TYRÉNS

PM

FÖRTYDLIGANDE DUMPNING

SKANDIAPORTEN

SLUTVERSION
2021-05-28

TYRÉNS

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MEDVERKANDE

Beställare:	Projekt Skandiaporten
Kontaktperson:	Kristina Bernstén (GHAB) och Åsa Jansson (Sjöfartsverket)
Konsult:	Tyréns AB
Uppdragsansvarig:	Martin Hörngren
Specialist:	Anna Karlsson

Omslagsfoto:	Pråmen ”Hans” fullastad med muddermassor, på väg ut till dumpningsplats SSV Vinga i projekt Säkrare Farleder. Foto: Thomas Åhsberg.

INNEHÅLLSFÖRTECKNING

1 INLEDNING

I MKB, bilaga E04, sammanfattas hur muddrat material beter sig vid dumpning baserat på det muddrade materialets egenskaper och dumpningsprocesser. Det har från remissinstanserna Länsstyrelsen, Havs- och vattenmyndigheten samt Miljöförvaltningen i Göteborgs stad inkommit frågor som berör följande:

- Beskrivning av sugmuddrade sedimentets egenskaper.
- Hur vatteninblandning påverkar sedimenten
- Skillnader i dumpningsprocesser mellan gräv- och sugmuddrade massor
- Vad ligger till grund för spridningsberäkningarna
- Hur mängden spill bedömts/beräknats.
- Vad som påverkar dumpningsprecisionen.

I detta PM ges en mer detaljerad beskrivning av muddrat sediment och dumpningsprocesser i syfte att förtydliga sammanfattningen i MKB.

2 DET MUDDRADE SEDIMENTET

I projekt Skandiaporten uppkommer ca 14 miljoner tfm^3 muddermassor. Volymen består i huvudsak av leror och en mindre del sprängsten. Den största volymen leror (mer än 13 miljoner tfm^3) består av preindustriellt avsatt post-glacial eller glacial lera och en mindre del (ca 285 000 tfm^3) lera avsatta under antropogena förhållanden. Lerans generella egenskaper såsom plasticitet och densitet har redovisats i TB och sedimentprovtagning med bland annat kornstorleksanalys och föroreningsinnehåll i MKB.

2.1 SUGMUDDRING (HYDRAULISK MUDDRING)

Sugmuddrat sediment är muddrat genom s.k. hydraulisk muddring där jetstrålar lösgör sediment som sugs upp genom ett sughuvud och vidare upp i mudderverket. I trailern består därmed muddermassorna av lera som slagits sönder i lerklumpar av varierande storleksgrad samt lerpartiklar och havsvatten. Andelen havsvatten i trailern uppgår till ca 60 % enligt erfarenheter från projekt Säkrare Farleder.

Det sugmuddrade sedimentet är en blandning av lerklumpar och en högdensitets-slurry. I pråmen flockulerar lerpartiklar till följd av den höga densiteten på en tidsskala av minuter. Flockar och lerklumpar sjunker till botten. Den teoretiska densiteten i en pråm med sugmuddrad lera (ca 1500 kg/m^3 eller 800 kgTS/m^3) och 60 % tillfört vatten (saltvatten 1020 kg/m^3) är drygt 1200 kg/m^3 om allt skulle vara totalt omblandat. Halten lera i pråmen är därmed 300 000 mg/l och motsvarar densiteten i ett normalt bottensediment i sjöar och kustområden.

2.2 GRÄVMUDDRING (MEKANISK MUDDRING)

Grävmuddring eller s.k. mekanisk muddring innebär muddring med grävskopa eller miljöskopa. Grävmuddrad marin lera är kompakt och håller ihop i stora block eller större lerklumpar efter muddring. Dessa lerblock och lerklumpar har samma egenskaper som de hade som omuddrade, dvs en densitet på drygt 1500 kg/m^3 och medelsensitiv. Leran behåller i stort sett sin form av block och klumpar under transport i pråmen ut till dumpningsplatsen.

3 DUMPNINGSPROCESSER

3.1 VETENSKAPLIG BAKGRUND MED BERÄKNINGAR/BEDÖMNINGAR

Det är väl belagt i den vetenskapliga litteraturen hur massor beter sig vid dumpning. En av de viktigaste studierna som genomförts avseende förståelsen av processer i samband med dumpning är en studie från 1978 (Bokuniewicz). Många av de referenser som finns i MKB avseende dumpning har i sin tur denna studie som referens.

Genom omfattande fältmätningar vid fem dumpningsplatser, två estuarina, en i havet och två i Great Lakes i USA har man definierat processerna genom vilka muddrat sediment faller mot botten efter dumpning från en pråm eller TSHD. Dumpningsplatserna hade varierande djup mellan 15-67 m och strömmarna i omgivande vatten varierade mellan 0-0.7 m/s. Ett brett spektrum av vatten- och väderförhållanden förelåg under studierna. Det muddrade materialet som dumpades varierade från mycket flytande lera till marin silt med hög densitet och de volymer som släpptes ut vid en enda dumpning varierade från 380 till 6120 m^3. Trots dessa varierande förhållanden, konstaterades det att samma grundläggande sekvens av processer ägde rum på varje plats och bestod av: (1) Konvektiv fas då sedimentet faller genom vattenmassan, (2) nedslaget av muddermassor på botten och (3) spridning av en bottenplym som följer av själva nedslaget. I bilaga A finns en detaljerad beskrivning av de tre faserna att läsa som ett urklipp från artikeln.

Sammanfattningsvis drar studien flera viktiga slutsatser från mätningarna:

- **Spill**: Mängden spill vid dumpning är liten, mindre än 1 % i de flesta fall.
- **Djup**: Djupet påverkar inte hur sedimentet faller genom vattenmassan eftersom maximal fallhastighet uppnås efter kort fallsträcka. Lerklumpar större än 0.15 m faller något snabbare än den dynamiska plymen.

  Med större djup ökar medrivningen och inblandningen av omgivande vatten vilket i sin tur minskar densiteten i den dynamiska plymen som därigenom ökar i omkrets. Vatteninblandning i den dynamiska plymen kan uppgå till ca 70 % vid ett djup av ca 50 m. Detta påverkar varken mängden spill eller nedlagskraften i botten eller den efterföljande radiella spridningen utmed botten.
- **Ström**: Den omgivande strömmens påverkan på förskjutningen av nedslagsplatsen från dumpningspositionen kan lätt räknas ut och har mycket liten effekt på dumpningsprecisionen.
- **Bottenförhållanden**: Om bottensedimentet är mjukt kommer rörelseenergin från nedslaget att delvis absorberas genom plastisk deformation av bottensedimentet. Generellt sett minskar därför dispersionen av lerklumpar med mjukar bottensediment.
- **Batymetri och bottenråhet**: Genom att dumpa muddrat material i en håla begränsas utbredningen av den radiella dynamiska plym som bildas vid nedslaget.

  Dumpning ger upphov till oregelbundenheter i sedimenten som dämpar den radiella dynamiska plymens utbredning.

Studien gjordes på uppdrag av US Army Corps of Engineers som har tagit fram en manual för muddring och dumpning. I denna manual, som bl.a. bygger på Bokuniewicz (1978), finns en detaljerad beskrivning av de fysikaliska processerna i samband med dumpning. Ett utdrag som i detalj beskriver processer som är av betydelse för projekt Skandiaporten ges i bilaga B.

Manualen togs ursprungligen fram 1983 och har sedan dess uppdaterats ett antal gånger, senast 2015. Förutom att beskriva de fysikaliska processerna som i Bokuniewicz (1978) anges här anges också ett spann för andel spill, mellan 1-4 %, från ett antal studier. Manualen beskriver också ett verktyg, STFATE, för beräkning av spill i samband med dumpning. Detta verktyg är en empirisk modell för beskrivning av kortvariga processer i samband med dumpning.

I ett examensarbete från 2008 (Svahnström) vid Uppsala universitet presenterades en studie med STFATE av hur olika parametrar som vattendjup, strömhastighet, och materialets egenskaper påverkar faktorer som mängd spill och omfattningen av den radiella spridningen vid botten. Slutsatsen från arbetet är bl.a. att djupet och andelen klumpar jämfört med lerpartiklar är av störst betydelse för mängden spill. Även mängden sediment per dumpning är av betydelse om den blir mindre än 200 m^3 per dumpningstillfälle.

I examensarbetet finns mängden spill beskriven som uppstår vid dumpning av fina sediment. Beräkningarna visar att spillprocenten vid 80 m djup och för ett material som består av en blandning av lerklumpar och lerpartiklar blir runt 4 %, dvs samma spillprocent som använts i projekt Skandiaporten. Beräkningarna visar också att strömhastigheten i vattnet inte påverkar andelen spill och att den radiella spridningen vid botten inte är beroende av dumpningsdjupet.

I ansökan, bilaga E04, finns en referens, Kemps & Masisni (2016) där författarna gör en genomgång av hur sediment uppkommer och frisätts genom hydraulisk muddring (se bilaga C för detaljer). Genomgången av fältmätningar i studien visar att för en bottentömmande pråm/mudderverk blir mängden spill från dumpade massor, med liknande kornstorleksfördelning som i projekt Skandiaporten, ca 1-2 procent vid vattendjupet 30-45 m. Vid 80 m djup kan denna mängd antas vara dubbelt så stor, dvs 2-4 %. Andra studier där sugmuddrade massor med hög andel fina sediment dumpats på djup mellan 14-94 m visar på ett spill mellan 1-6 %. Inte heller här påvisades något samband mellan omgivande ström och andel spill.

3.2 SLUTSATSER SKANDIAPORTEN

Det muddrade sedimentet i projekt Skandiaporten består främst av sugmuddrad glacial eller postglacial lera, som muddras och dumpas i marin miljö. Detta innebär att sedimenten är kohesiva och utgörs av lerklumpar och flockar snarare än finfördelade i partiklar. Detta är viktigt för bedömningen av mängden spill. Den mängd vatten som tillkommer i samband med sugmuddring kan tyckas stor men är av liten betydelse för mängden spill i samband med dumpning till följd av lerans egenskaper.

Det är väl belagt i den vetenskapliga litteraturen hur massor beter sig vid dumpning; att merparten av det dumpade sedimentet faller i princip rakt ner oavsett om det är som en dynamisk plym eller lerblock, att strömhastigheten i vattenmassan har liten betydelse för den fallande plymens nedslagsplats, att plymen faller med en konstant hastighet om ca 1 m/s osv. Mängden spill, dvs den andel fina sediment som genom medrivning bildar en passiv plym, har normalt bedömts genom mätningar och empiriska formler där hänsyn tas till bl.a. sedimentets egenskaper, muddringmetod och pråmstorlek. Som beskrivits i bilaga E04 i ansökan baseras bedömningen av mängden spill på vetenskaplig litteratur då dynamiska plymprocesser inte kan modelleras på ett tillförlitligt sätt med de modellsystem som finns idag (Kemps & Masini 2017).

I bedömningen av mängden spill i projekt Skandiaporten har hänsyn tagits till bottendjup, sedimenttyp, muddringsmetod, och hydrodynamiska förhållanden såsom språngskikt etc. Djupet påverkar hur stor medrivningen och inblandningen av vatten till plymen blir men påverkar inte fallhastigheten genom vatten av partiklar, flockar eller klumpar. Spillet ökar dock med ökat vattendjup.

Den bedömda spillprocenten på 4 % i projekt Skandiaporten är en rimlig bedömning utifrån beräkningar med den empiriska modellen STFATE samt omfattande fältstudier världen över, varav några redovisas i detta PM. Mekaniskt muddrad lera kan förväntas generera mindre spill än 4 % men eftersom merparten av lerorna är sugmuddrade har den bedömda spillprocenten för sugmuddrat sediment använts i beräkningarna i MKB.

4 REFERENSER

Bokuniewicz, H. J., Gebert,J, Gordon, R.B., Higgins, J.L., Kaminsky, P. (1978). *Field Study of the Mechanics of the Placement of Dredged Material at Open-Water Sites*. Prepared by Yale University for the US Army Engineer Waterways Experiment. Technical Report D- 78-79.

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Svahnström, E. (2008). *Dredged material disposal in open water - the physical process and short term modeling*. Examensarbete Mars 2008, Uppsala Universitet.

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BILAGOR

I bilagorna A-C nedan ges korta utdrag av originaltexten som underlag för fördjupning.

A. FRÅN ARTIKELN: ”FIELD STUDY OF THE MECHANISC OF THE PLACEMENT OF DREDGED MATERIAL AT OPEN-WATER DISPOSAL SITES”

Från artikelns sammanfattning om dumpningens tre faser:

1. *Descent* (Konvektiv fas)

Dredged material released into the receiving water as clods acquires terminal speed after fall through a small fraction of the water depth and then descends to the bottom at a nearly constant speed. The displacement of the impact point of the clods due to lateral current in the receiving water can be calculated by the same methods that are used to find the termina l fall speed. Material released in dispersed form falls in a jet of dense fluid. Any distribution of material between jet and clod descent is possible, the proportion of material in the two forms has a major effect on the structure of the resultant deposit at the disposal site. The jet is observed to fall at a nearly constant speed and entrains a large volume of ambient water during transit from the surface to the bottom. In a typical case, the volume of fluid reaching the bottom in the jet may be 70 times the volume released at the surface. Because of the large entrainment, the jet quickly attains the lateral speed of any current flowing in the receiving water. Its impact point can be predicted with good accuracy. If the current Is known. The descent of the jet sets up a circulation pattern in the ambient water inward toward the discharge point on the surface and outwards on the bottom ; the resultant inflow around the hull of the dredge or scow helps contain the dredged material in a narrowly defined zone of descent. (There will be losses of material into the ambient water if the dredge releases additional material after the jet phase of descent is completed.) Much of the initial potential energy of the dredged material is used up in accelerating the entrained water and in setting up the circulation pattern in the ambient water; the kinetic energy of the jet in its impact with the bottom is, therefore, held to a relatively low value.

2. *Impact* (Nedslag)

If the kinetic energy of the descending clods is sufficiently low when they arrive at the bottom, they will lodge in the impact area and form a central, cone-shaped deposit. This results in the most effective containment of the dredged material on the disposal site both during placement and, because of the high erosion resistance of the deposit, subsequently as the deposit is exposed to currents or other disturbances. If the kinetic energy of the clods at the time of impact is high, they will disintegrate as they strike the bottom. The dredged material carried down as clods will then enter the bottom surge generated by the Impact of the jet. The descending jet, as it reaches the bottom, is deflected laterally and starts to spread across the bottom. Sediment in the impact area--either dredged material or natural bottom material--may be eroded during the impact of the jet and join the dredged material in motion in the bottom surge. It will be seen from this discussion that the mechanical properties of the dredged material and the bottom sediments under conditions of impact loading are the principal factors controlling the form of the resultant deposit on the disposal site and Its susceptibility to subsequent dispersion.

3. *Surge* (svallvåg)

The bottom surge generated by the impact of the descending jet with the bottom is a form of density current. It spreads radially outward from the impact area and continues to run until its initial kinetic and potential energy is dissipated. As the surge moves out of the Impact area, there Is entrainment of ambient water and erosion *of the bottom follows, as the surge loses energy by deposition. The greatest thickness of the surge is found to be about 15 percent of the water depth; it is a relatively thin layer as it spreads across the bottom. The upper surface of the surge Is sharply defined and, as It spreads, it leaves behind a wake of turbid water from which sediment settles. The range of the surge at typical disposal operations is about 150 to 300 m and deposition start about 100 m out from the impact area. The friction law that determines the rate of dissipation of energy in the surge has not yet been determined; this Is an Important area for further research.*

Artikeln fortsätter med att beskriva variabler som påverkar kvantitativa aspekter av dumpningen:

A large number of variables determine the quantitative aspects of the placement process at any given site. The present research shows that the most important of these are the mechanical properties of the dredged material, the speed at which the dredged material Is inserted into the receiving water from the hoppers, the water depth, and the current in the receiving water at the disposal site. The effect of each may be summarized as shown below.

<u>Mechanical properties</u>
If the dredged material in the hoppers Is cohesive, it will be released for the most part in the form of clods. If the impact strength of the dredged material is sufficiently great, the clods will survive impact with the bottom and a compact deposit of dredged material on the bottom will be formed, a deposit resistant to subsequent erosion and dispersion.

<u>Depth</u>
The deeper the water at the disposal site, the longer the descent path and the greater the amount of ambient water entrained by the descending jet. Thus, there is more dilution of the dredged material during placement on a deep-water site. The resultant bottom surge Is then thicker and probably has a longer range. The deposit of dredged material carried in the jet phase of descent will, therefore, be spread over a greater area when the water at the disposal site is deeper.

<u>Current</u>
Current over the disposal site causes displacement of the descending dredged material, whether the descent Is by the fall of clods or by a fluid jet. However, the amount of the displacement can be predicted for both cases. Strong currents do not result in dispersion of dredged material during placement nor are they necessarily a cause of inaccurate placement on a designated disposal area if the placement operation is properly designed and executed.

<u>Application</u>
Several immediate applications of this research could be made. One, for example, is the design of containment disposal sites, I.e., sites designed to minimize the dispersal of dredged material. In such a site the run of the bottom surge would be minimized by Increasing the rate at which its energy is dissipated. Several alternative methods are available.
…
Alternatively, a pit could be designed that would confine the run of the surge to any desired limit.

B. US ARMY CORPS OF ENGINEERS : ” DREDGING AND DREDGED MATERIAL MANAGEMENT”

Från handboken, om dumpning i öppet vatten:

3.3 Physical Fate of Dredged Material Placed in Open Water.

3.3.1 Introduction.

3.3.1.1 Efficient management of open-water placement sites requires the ability to predict and track the movement, or fate, of dredged material upon release. This ability is essential to meet the environmental requirements for site selection and use (that is, water quality standards and site size and capacity) and determination of operational constraints related to placement methods. The short-term fate of dredged material includes its effects as it descends through the water column and settles on the bottom in the near field (the vicinity of the placement area) within the minutes and hours following its release. Its long-term fate involves dredged material mound erosion and resuspension over longer time frames, such as years, and the redeposition of this material. Long-term management of aquatic disposal sites also requires an understanding of how much area the dredged material mound encompasses, when the mound encroaches on the site boundaries, how much material leaves the site, and where the material ultimately goes.

3.3.1.2 Factors influencing dredged material behavior at open-water placement sites include the following:

a. The physical characteristics of the dredged material, such as its particle size distribution and mineralogical composition.

b. The nature of the placement operation, such as the type of discharge vessel, discharge rate, and solids concentration of the slurry.

c. The physical environment in the vicinity of the placement site, including currents, waves, tide, and storms.

d. Bottom sediment characteristics and topography (Johanson, Bowen, and Henry 1976; Barnard 1978).

e. Water depth.

The great variability of these factors from site to site, as well as potential seasonal fluctuations, increases the difficulty of predicting open-water dredged material behavior.

3.3.1.3 Hopper dredge or barge and pipeline are the typical placement methods of dredged material in open water. Release to the receiving water is the only aspect of dredged material placement over which direct control can be exercised by conventional dredge operations. Once the material is released from the dredge, the mechanics of the transport phases is beyond manipulation by operators.

3.3.1.4 Hopper dredging results in a dredged material mixture of water and solids stored in the hopper or bin for transport to the placement site. At the placement site, hopper doors in the bottom of the hull of the ship are opened, the entire hopper contents are emptied in the open water in a matter of minutes, and then the dredge *returns to the dredging site to reload. This procedure produces a series of discrete discharges at intervals of perhaps one to several hours.*

3.3.1.5 Bucket or clamshell dredges remove the sediment being dredged at nearly its in situ density and place it on a barge or scow for transportation to the placement area. Although several barges may be used so that the dredging is essentially continuous, placement occurs as a series of discrete discharges. The mechanically dredged material may be a slurry similar to that in a hopper dredge, but often sediments dredged by clamshell remain in fairly large consolidated clumps and reach the bottom in this form. Similar to hopper dredge placement operations, barges are designed with bottom doors or with a split hull, and the contents may be emptied within seconds, essentially as an instantaneous discharge.

3.3.1.7 The physical forces affecting both the short- and long-term fate of dredged material placed in open water include gravity and forcing due to waves and currents. Water column currents are the dominating environmental force acting on dredged material placed in open water. Currents generally result from the combined actions of several components: large-scale ocean/coastal current regimes due to tidal circulation and/or storm-surge propagation, locally generated wind-stress-generated currents, inertial currents, and estuarine/riverine plume effects.

3.3.2 Short-term fate.

3.3.2.1 The short-term behavior of dredged material, once it has been released into open water from a hopper dredge and barge and from pipeline discharges, has been studied. The following section focuses on dredged material behavior during discrete placement events, such as placement from a hopper dredge.

3.3.2.2 Field evaluations from data obtained at five sites by Bokuniewicz et al. (1978) and physical model tests by Johnson and Schroeder (1993) have shown that open-water placement of dredged material from a hopper dredge or barge generally follows a three-step process:

a. Convective descent, during which the material falls under the influence of gravity.

b. Dynamic collapse, occurring when the descending cloud or jet either impacts the bottom or arrives at a level of neutral buoyancy, in which case the descent is retarded and horizontal spreading dominates (this spreading material is also referred to as an underflow).

c. Passive transport-dispersion, commencing when the material transport and spreading are determined more by ambient currents and turbulence than by the dynamics of the placement operation (Moritz, Johnson, and Scheffner 2000).

3.3.2.3 Convective descent.
a. During the convective descent phase, in almost every case for both bottom release and pipeline placement, the bulk of the dredged materials falls in a dense jet directly to the bottom with minor losses to the water column. Released dredged material possesses an initial downward momentum and a density greater than that of the surrounding water. These conditions result in forces that cause the material to settle in the form of a cloud, or density current, rather than as individual particles. As the cloud settles, shear stresses develop at the interface between the moving cloud and the ambient water, resulting in dissipation of the initial momentum and the creation of turbulent eddies that entrain ambient fluid. In the case of clouds possessing an initial

momentum, vortex rings form at the time of release and tend to cause deeper penetration of the ambient water. The material that falls as clods acquires terminal speed after falling through a small fraction of the water depth and then descends to the bottom at a nearly constant speed. Any distribution of material between jet and clod descent is possible; the proportion of material in the two forms has a major effect on the structure of the resultant deposit at the placement site.

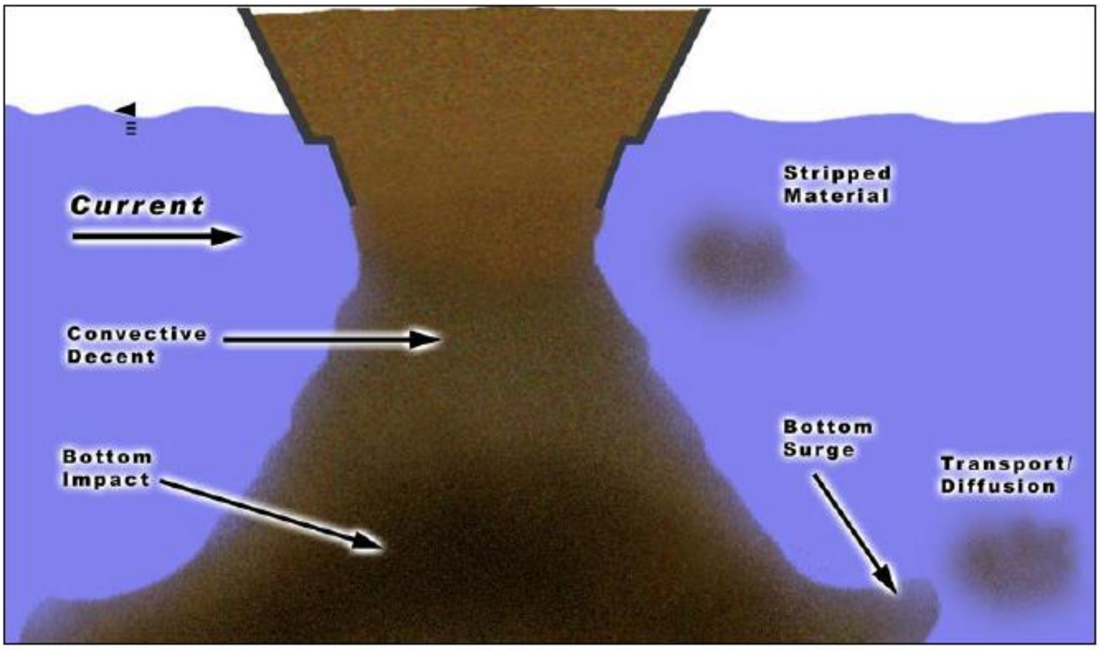

Figure 3-2. Schematic of the Behavior of Dredged Material Released in Open Water

b. Bokuniewicz et al. (1978) observed that the jet falls at an early constant speed and to entrain a large volume of ambient water during transit from the surface to the bottom. For exam-ple, the volume of fluid reaching the bottom in the jet may be 70 times the volume released at the surface. Because of the large entrainment and the corresponding reduction in jet density, the jet quickly attains the lateral speed of any current flowing in the receiving water. Its impact point can be predicted with good accuracy if the current is known. The descent of the jet sets up circulation patterns in the ambient water inward toward the discharge point on the surface and outward on the bottom. The resultant inflow around the hull of the dredge or scow helps contain the dredged material in a narrowly defined zone of descent. The speed of this convective descent was measured by Bokuniewicz et al. (1978) and was consistently found to be about 1 m/sec (3.3 ft/sec).

c. Instantaneous placement of dredged material in relatively shallow water produces a rapid convective descent of the material with a vertical velocity on the order of 1 m/sec (3.3 ft/sec). Settling velocities calculated for individual particles do not apply during this form of transport. Since the time during which the cloud is in contact with the upper portions of the water column is a minute or less, ambient water currents (except near the bottom) are of little consequence except as they affect the transport of any turbidity cloud that may be generated during the descent. If near-bottom currents are low, precision placement may proceed under almost any current condition occurring in the upper portions of the water column, except for turbidity cloud considerations (Johanson, Bowen, and Henry 1976).

3.3.2.4 Dynamic collapse.

a. Dynamic collapse occurs when the cloud encounters a boundary, either a density layer (pycnocline) or the bottom and is characterized by horizontal spreading. Collapse is driven primarily by a pressure force and is resisted by inertial and frictional forces. In the case of precision placement of dredged material into a specific site, it is important that the cloud penetrate through any density layer and reach the bottom. In general, sudden releases of fairly large quantities of dredged material in shallow water penetrate a density layer and impact on the bottom. The cloud flattens out and appears somewhat like a disk as it assumes a horizontal circular shape (assuming a flat bottom and no obstructions) with a small vertical dimension. Under these conditions, flow continues in the form of a density or turbidity current.

b. If a clod of dredged material impacts the bottom at high speed, it disintegrates, and the contained material is dispersed. If the impact speed is low, the clod remains intact upon deposition. Clod disintegration can be avoided if the kinetic energy of the clod is dissipated by plastic deformation before material failure occurs or the clod arrives at the bottom. Since the kinetic energy per unit mass of a falling clod increases as the clod size increases, it is expected that there is an upper bound to the size of clods that can be deposited on the bottom intact.

c. At Ashtabula and Rochester, NY (Bokuniewicz et al. 1978), the base surge spread radially outward in the shape of a thin expanding toroid of turbid water. Both its thickness and speed decreased as its radius increased. As the surge proceeded outward, it shed behind a thin, slowly moving cloud of suspended dredged material that settled to the lake floor. The entrainment of ambient water and friction eventually caused the velocity of the surge to decrease to the point where all its contained sediment was deposited. The initial energy of the surge and the rate of energy dissipation determine the range of the base surge, the area of the bottom that is covered by dredged material, and the form and thickness of this deposit. Ideally, the deposition of dredged material is expected to occur in a ring around the impact point.

d. To describe a bottom surge adequately, it is necessary to know its velocity as a function of distance from the impact point, its thickness, and the concentration of solids contained therein. If sufficient data are available, it is possible to determine whether erosion or deposition occurs at a given radial distance, whether additional ambient water is entrained, and how rapidly kinetic energy is lost. These data may then be used to estimate the size of the deposit that will be formed on any given aquatic disposal site.

e. The thickness of the base surge was found to depend on water depth: the greater the depth, the thicker the surge. Bokuniewicz et al. (1978) obtained base surge data at sites in the Great Lakes. As the water depth at the placement site increased from 20 to 50 m (65 to 164 ft), the greatest thickness of the surge increased from 4 to 7 m (13 to 23 ft). This result was expected since, at the greater depth, the volume of water entrained during descent was greater, but the speed of the surge over the bottom was not changed appreciably. The surge thickness was also observed to be relatively large at the New York Bight site (Bokuniewicz et al. 1978). While the water depth was greater there, the quantity of dredged material released was also much greater, and the surge spreading speed was higher. Data were insufficient to separate the effects of all of these variables in determining surge thickness. Figure 3-4 is a contour diagram defining the thickness of the base surge for the Ashtabula, Rochester, and New York Bight data after adjusting to the Ashtabula travel-time curve. The concentration of solids suspended in the base surge was determined from pumped water samples and *from transmissometers. At the Great Lakes sites, concentrations were as high as 11 g/L within about 50 m (164 ft) of the impact point. Three minutes after the head of the surge had passed, the concentrations were down to about 1 g/L, and returned to background values in less than 15 minutes.*

3.3.2.5 Transport-diffusion. At most placement sites, the convective descent and dynamic collapse phases last on the order of only a few minutes. When the rate of spreading of the collapsing cloud becomes less than an estimated rate of spreading due to turbulent diffusion, the collapse phase is terminated and the "longer" term transport-diffusion phase is initiated. In this phase, material in suspension is transported and diffused by the ambient current while under-going settling. Any non-sediment constituents are also transported and diffused. During the passive transport-diffusion phase, material transport and spreading are determined by ambient currents and turbulence rather than by the dynamics of placement operation. The clouds are transported by the velocity at the centroid of the cloud while experiencing both vertical and horizontal turbulent diffusion. Suspended sediment concentrations in the clouds are assumed to have a Gaussian distribution. Solids settle by discrete settling or flocculant settling.

3.3.2.6 Stripping of fine sediments.
a. The fate of fine-grained dredged sediments stripped from the descending jet during open-water placement can be an issue in some situations, such as concern over the impact of the water column plume and, especially, during the placement of contaminated sediments.

b. As noted earlier, during open-water placement of dredged sediments from a barge or hopper dredge, the vast majority of released dredged sediments descend rapidly to the bottom as a coherent, well-defined jet of material. However, some small fraction of fine-grained material can remain in upper and middle levels of the water column and, depending on ambient currents, may be transported from the site. This fine-grained material may be released to the water column in different ways. As the descending cloud or jet moves downward, a circulation is set up such that ambient fluid is entrained into the backside of the cloud or jet. This entrained fluid decreases the overall density of the cloud and the turbulent mixing created in the cloud or jet separates some of the fine-grained material from the denser core of sediments. These fine-grained particles are then left behind at different levels in the water column as the cloud or jet continues its descent to the bottom. They then settle at their particle-settling rate, but they can become trapped in the water column if stratification exists (typically seen only in deep water). This is one form of what is commonly called stripping.

c. Truitt (1986) provides a good summary of approximately nine major field studies where measurements were made to estimate the volume of sediments that are stripped from the main jet and remain suspended in the water column a considerable length of time. For the five studies that dealt with mechanically dredged sediment placed in barges, three studies had suspended sediment masses of 1%, and two studies had suspended sediment masses of 2%-4%. A study of dredged material placement in Hong Kong showed that loss of sediments due to stripping during barge placement of fine sediments into pits ranged from 1% to 3% (Land and Bray 1998).

d. Some portion of this 1%-4% mass of suspended sediments stripped from the main jet of material likely deposits in the immediate vicinity of the placement and thus remains inside most placement sites although the size of this portion will vary considerably with site and sediment characteristics. In cases where the remaining portion of the stripped *material is an issue of concern, either it can be tracked as it moves in the water column or the area of concern adjacent to the placement area can be monitored to determine if measurable amounts deposit there. Tracking fine material in the water column is a very expensive undertaking with considerable uncertainly involved in measuring small amounts of suspended sediment over a wide area. Similarly, monitoring an adjacent sensitive resource for minute amounts of fines and/or their associated contaminants is also very expensive, time-consuming, and subject to some uncertainty. Therefore, such monitoring requirements are usually imposed in extraordinary situations, and only then to confirm numerical movement predictions through a limited number of monitoring events. To date, there has been no evidence that the amounts of "untracked" sediments stripped during the placement of contaminated have caused unacceptable environmental impacts. Thus, for the vast majority of dredging projects, no attempt is made to collect quantitative data on the fate of the stripped fraction because it is not considered to be cost-effective.*

C. EN GENOMGÅNG AV UPPKOMST OCH FRISÄTTNING AV SEDIMENT GENOM HYDRAULISK MUDDRING (MILLS & KEMPS 2016)

Kort utdrag från sammanfattningen och litteratursammanställning av spill vid fältmätningar:

Executive summary
This report presents a literature review on particle generation when soil or rock material is subjected to dredging processes, the introduction of the particles into the water column (dredge-induced resuspension) and the early stages of dredge plume development. Knowledge in these areas is required to specify suspended sediment source terms for input to dredge plume prediction models that are used in environmental impact assessment of dredging proposals. The report focuses on the two types of hydraulic dredgers that are most commonly employed in major dredging projects in Australia, namely the trailing suction hopper dredger (TSHD) and the cutter suction dredger (CSD). The report responds to Task 2.1 of the WAMSI Dredging Science Node Science Plan (Masini et al. 2011).

7.1.2 Field measurements
Short- term resuspension losses
Gensheimer (2010) described eight field investigations (Gordon 1974, Sustar & Wakeman 1977, Bokuniewicz et al. 1978, Tavolaro 1982, Science Applications International Corporation 1984, Tavolaro 1984, Truitt 1986, Science Applications International Corporation 1988, Truitt 1988) which sought to estimate the quantity of material (expressed as a percentage of the dredged material load released) that is entrained into the water column and remains in suspension following the disposal event. These estimates were made either by direct measurements of turbidity, suspended sediment concentration and current velocity in the water column, or by adopting a mass balance approach based on dry masses and bathymetric data, taken before and after disposal. Reported fines contents of the material loads were high, dumped volumes were in the range 840 to 2780 m3, water depths at various disposal sites ranged from 14 to 94 m and currents were 0.3 m s-1 or less. Estimates of resuspension losses from dredged material disposal events monitored during these investigations ranged from about one to six per cent of the sediment released.

Land and Bray (2000) reported resuspension losses from six dredge spoil disposal events: two from a split hull dredger and four from a twin hopper dredger with bottom valves. The discharged material was a mixture of clay (30%), silt (55%) and fine sand (15%). Water depths ranged from 30 to 45 m. Plume transect measurements were *conducted at about 300 m downstream of the disposal location using ADPs to quantify the net amount of suspended sediment leaving the disposal area. Resuspension losses for the split hull dredger disposal events ranged from 0.86 to 2.09 per cent, whereas losses from the twin hopper disposal events were generally larger, ranging from 5.33 to 8.74 per cent. The capabilities of the split hull dredger to dredge mud at high density and to rapidly discharge its hopper load were invoked by Land and Bray (2000) as reasons for the relatively low resuspension losses associated with disposal from this dredger. They noted that the twin hopper dredger discharged its load of low density material relatively slowly and had to flush its hoppers to fully empty them of soil, giving rise to much larger resuspension losses.*

Land and Bray (2000) also reported percentage loss rate estimates for six barge disposal events. The mixture volumes in the hoppers ranged from 400 to 1000 m3 and the dry densities of the mixtures ranged from 0.75 to 1.23 T m-3. Ambient current speeds during the disposal events were in the range 0.07 – 0.4 m s-1. Estimated loss rates to resuspension were found to range from 1.1 to 3.1 percent and were greatest for fine material loads of low mixture density. Dump events involving large volumes had smaller measured percentage losses than dump events involving small volumes. No clear relationship was found between measured percentage loss and current speed.