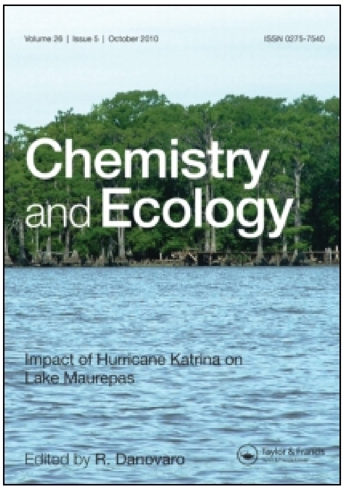

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Physical and sedimentological characterisation of dredged sediments

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Physical and sedimentological characterisation of dredged sediments

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Port dredging operations inevitably create a turbid plume around the dredge and it is necessary to follow the movement of this to impede its diffusion into the surrounding environment and reduce any negative impacts. To characterise the extension and concentration of the plume induced by dredging it is necessary to study the physical properties of the water, the residence time of the sediments in the water column and the diffusion velocity of the water and sediments. It is also essential to characterise the area and determine the specifics of the port environment under so-called normal maritime-traffic conditions. During the initial stage of such a study it is necessary to obtain measurements under diverse wind–wave conditions to characterise the physical features of the water column of the port area, the turbidity, the quantity and dimension of the suspended particulate matter and the current dynamics. In this article we present a series of physico-sedimentological operations to characterise a zone to be dredged based upon our experience during pre-dredging work in the Port of Genoa (Italy).

Keywords: dredging; ADCP; turbidity; dimensional analysis; TPM; Port of Genoa

1. Introduction

Coastal work, such as port dredging, beach and coastline stabilisation, and drain construction, is often carried out near fragile or protected areas; for this reason, the responsible authorities generally try to mitigate the impact of such works through the imposition of environmental tools and obligations [1].

As part of this mitigation process the responsible authorities often request the enactment of a precise control programme to avoid environmental damage that could assume major proportions. Such programmes include all the routine procedures for monitoring the quality of the water (from a biogeochemical point of view) [2], preferring to pre-empt the occurrence of undesired side effects, such as those outlined by Gray and Jensen [3], rather than undertake mitigation work after the event.

Dredging can often induce notable resuspension phenomena with an increase in turbidity and a consequent mobilisation of the contaminants associated with such suspended particles [4]. Therefore, particular attention has to be given to determine the properties of the solid fraction

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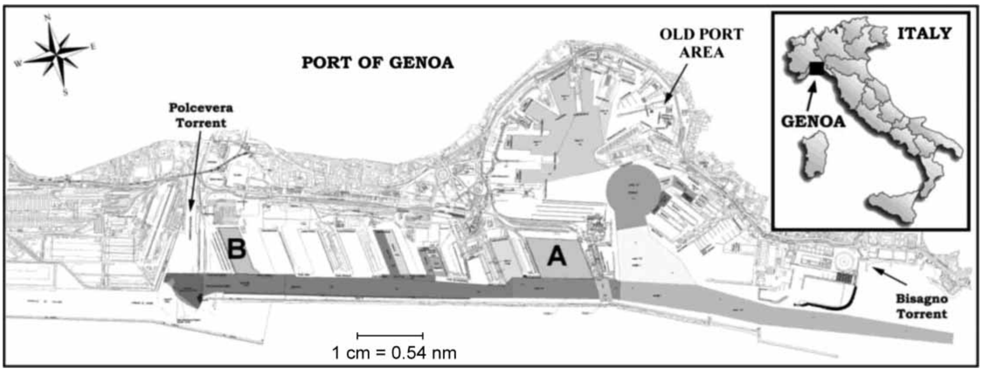

Figure 1. Localisation of the Port of Genoa in the Ligurian Sea. In this scheme the mouths of the two torrents inside and outside the actual port area are shown. The different grey areas indicate the zones where the dredging will be carried out: part of the dredging will be outside the port area proper, in the ship access canal to the east of the entrance. 'A' (Bettolo Quay) and 'B' (Derna Quay) represent the two basins that will be closed and filled with dredged material, with containers of 2.0 and 0.7×10^6 m^3 of sediments respectively. nm = nautical miles.

resuspended in the dredged areas, in both the short- and long-term, in terms of possible damage to the marine habitat of the surrounding area [5–8].

Whereas some nations have the possibility of managing dredged sediments through, for example, offshore capping (Norway [9], Germany [10], USA [11–13]), the relevant legislation in Italy and many other countries specifies that the dredging works must not have any negative effect on marine plants and meadows (e.g. *Posidonia oceanica* [14] and *Zostera marina* [15] meadows). A clear indication of this is evident in the European BEACHMED-E Project which specifies that all proposed dredging work must be studied beforehand, using mathematical models to determine the possible impact and the best mitigation procedures, to avoid damage to phanerogamic meadows [16].

We have recently been involved in a project to find a method to characterise the physical, dynamic and sedimentological components of the water masses during a dredging and reclamation project in the Port of Genoa. In this case, the goal was to safeguard several nearby *Posidonia oceanica* meadows and the economically important tourist activities to the east of the port [17] from increased turbidity during dredging and reclamation works.

The work, conducted before the dredging, enabled us to define the characteristics of the area to be dredged, and to determine the critical limits of the turbidity and current velocity during the operations that would involve dredging $\sim 2.7 \times 10^6$ m^3 of sediment in the port itself and outside its two entrances, with the sediment to be used for landfill operations [18–21].

The Port of Genoa (Figure 1) is situated in the northernmost part of the Ligurian Sea (northwestern Mediterranean Sea) and extends almost uninterrupted for 15 km from the centre of the city (Old Port of Genoa) to its westernmost sector, with a total port surface area of $\sim 7 \times 10^6$ m^2.

The areas to be dredged lie in the innermost part of the port and along its entire protective sea wall. At the eastern and western ends of the area lie the mouths of the two most important city torrents, which, in the case of heavy rain, can notably increase the turbidity of the port waters. The supply of these two water courses is very variable but significant and, in the case of heavy rain, influences the chemico-physical and sedimentological characteristics of the port area.

2. Methods

In February–March 2008, we collected samples from 24 sites during 5 campaigns, conducted under different wind–wave conditions to evaluate the situation in the port area with the wind coming from the southeast, southwest and north, under calm conditions and after intense rain. In this way we were able to characterise all the variables that influence the port waters.

The current-meter measurements were obtained with an acoustic current doppler profiler (ADCP), RDI 600 kHz Workhorse Sentinel, fixed to the research vessel with the transducers at a depth of 50 cm, and were visualised in real-time using WinADCP software [22,23].

Physical profiles were made for each sampling point with an Idromar IP10 conductivity–temperature–depth (CTD) probe with turbidity and dissolved-oxygen sensors. The hydrological data were then corrected and processed according to international procedures [24]. Standard algorithms [25] were used to compute the potential temperature, salinity and potential density anomaly.

Water samples, collected with a Niskin bottle, were used to calibrate the acoustic backscatter and to convert the ADCP signal into suspended material concentrations in the water [26] using DRL SediView Software and Method [27,28]. The quality of the calibration depends very much on collecting sufficient water samples, which must be representative of the material present in the water column and the concentration gradient found by measuring water with a high particle concentration (potential plume induced by the dredging) and water not influenced by the induced turbidity [29]. To obtain this double characterisation, the sampling depth was established on the basis of the turbid profiles obtained with the CTD sensor (we sampled the turbid plume, when present, the ‘clear waters’ [30] and the bottom waters [31]).

Sedimentary transport data was obtained through turbidity measurements and direct concentration measurements [31,32]. Such measurements are related to the sediment size and particulate matter composition [33,34], and so we also made direct measurements of the particulate matter grain sizes and concentrations.

Turbidity measurements were made with a Seapoint Turbidity Meter and the total particulate matter (TPM) concentration was determined during the cruises using a Seapoint sensor and collecting water samples. The latter were collected during these cruises and filtered to measure the concentration and to calibrate the observed turbidity with the TPM concentration in $mg \cdot L^{-1}$. The depths at which the water samples were collected were chosen to coincide with selected layers with high optical turbidity, following the turbidity profile in real-time. In the laboratory, the TPM concentration was determined as described previously [27,35].

Linear regression of the data (TPM vs. turbidity) yielded a very good correlation with $R^2 = 0.94$ (TPM = 6.92 × turbidity − 27.28. N-pair = 38, $p = 0.038$, alpha = 5%; Pearson’s coefficient = 0.97).

The dimensional analyses were carried out in laboratory using a Coulter Counter® Multisizer™ 3 with a triple sampling cell [36]: a 50 μm capillary was used to define the fine fraction (1–30 μm), and 100 μm (2–60 μm) and 280 μm (6–168 μm) capillaries were used to define the larger fractions; these analyses provided reliable results in the range 1–168 μm [37–39].

Furthermore, to calibrate the response of the instruments to a very turbid plume, such as that generated by dredging operations, we sampled the turbid plume generated by the berthing of a ferry (Grimaldi Lines). This simulation was used to try to understand the behaviour, development and diffusion of a turbid plume and the residence time of the resuspended sediments in the water column.

During sampling inside the port, it was noted how ferry berthing raised a turbid plume that propagated towards the surface. We, therefore, decided to use this event to simulate what might happen during the port-dredging operations and to study the effects of a turbid plume (representative of reality even if at a reduced scale). It was noted that this plume initially propagated towards the surface, increasing in extent but diminishing in concentration, before rapidly resettling.

During the berthing of a ferry we took a series of five CTD profiles, eight water samples, and current and particulate measurements with an ADCP. During this test we recalibrated the turbidimeter to transform the $mg \cdot L^{-1}$ into FTU because the resuspended sediments were different from those normally found in port waters, being largely composed of heavy particles. This experiment (called the *Grimaldi* experiment, which lasted ~30 min) is described below (see Section 3.4).

3. Results and discussion

3.1. *Physical characteristics of the water masses*

The characteristics of the water masses inside the port were always strongly influenced by the wind–wave conditions, the supply of the two main water courses (the Polcevera and Bisagno Torrents) and run-off in the port area.

The horizontal temperature distribution highlighted how the lowest values were concentrated in the internal zone of the Old Port and the easternmost part of the port (12.28 and 11.73 °C, respectively), whereas the westernmost area of the port channel had higher values (max. 15.41 °C). These differences were less evident in the bottom water layer, where there was greater homogeneity.

Near the mouths of the two torrents, which empty near the port and inside the protective sea wall, a thick surface layer of relatively fresh water was often noted: this layer tended to drift into the port from the Polcevera Torrent when the wind blew from the north or north-west and from the Bisagno Torrent when the wind blew from the south-east.

The possibility of fresh water entering the port area adds a new variable to our scenario. In fact, the TPM values obtained at a depth of 1 m at the mouth of the Bisagno were $7\,\mathrm{mg \cdot L^{-1}}$ and the turbidity values were 17 FTU. If we compare these values with those from inside the port we note that a turbidity value of 17 FTU corresponds to a TPM value $>70\,\mathrm{mg \cdot L^{-1}}$. This apparent contradiction in the measurements can be explained by the difference in the composition and grain size of the particles of continental and port origin.

3.2. *Hydrodynamics of the water masses*

The dynamics of the port area are very complex and the existence of structures jutting into the water interfere with the normal circulation, and the relative shallowness of the port area further accentuates the influence of the wind on the entire water column.

Our measurements revealed that the winds from the southern quadrants tended to confine the water masses to the port area, whereas winds from the northern quadrants tended to induce currents in the western area of the port, which flowed towards the south–south-west with a maximum velocity of $50\,\mathrm{cm \cdot s^{-1}}$. Instead, in the eastern area of the port the waters tended to flow towards the inner part of the protective sea wall from where they flowed out of the port area through the eastern port entrance with maximum velocities of $20–25\,\mathrm{cm \cdot s^{-1}}$ (Figure 2).

During the last cruise of March, we noted how, in the internal part of the port, independent of sea and weather conditions, the direction and intensity of the currents were substantially influenced by the complicated geometry of the area, characterised by the presence of piers of different shape, size and orientation. The results obtained were a series of current vectors going in all directions with different intensities (Figure 3).

Our measurements revealed that the currents of greater intensity tended to move outwards from the port, whereas there were practically no flows towards the innermost area. This situation induces slow, limited changes in this circulation cell, creating a confined area with low oxygen content.

3.3. *Sedimentological characteristics of the water masses*

The turbidity values of the water column were relatively constant, varying between 2 and 6 FTU and in general, the majority of the suspended particulate matter had small dimensions ($Ø < 20\,\mu\mathrm{m}$).

Figure 2. Surface current vectors obtained from the ADCP measurements (beginning of March campaign, characterised by a strong wind swinging from north-east to north): vectors, magnified only for graphic reasons, are proportional to the intensity (with the highest values of $50\,\mathrm{cm \cdot s^{-1}}$) and direction of the current (from Google Earth, 5.0.11337.1968 (beta ver.)).

Figure 3. The dock: vectors of the surface current obtained from the ADCP measurements (end of March campaign, with strong wind from south-east): the dimensions are proportional to the intensity (with higher values of $25\,\mathrm{cm \cdot s^{-1}}$ for the largest vector) and direction of the current (from Google Earth, 5.0.11337.1968 (beta ver.)).

Starting from the equation of the regression line (Section 2), hypothesising TPM $= 0$ then the turbidity (with value $\neq 0$) had an important component related to the presence of very small particles, bacteria, chlorophyll, pico-phytoplankton, air bubbles and so on [40–42], characterised by a load practically $= 0$.

As a consequence, the characteristics of the waters inside the port have turbidity values, corresponding to TPM in $mg \cdot L^{-1}$, higher than those found at sea, probably because of the greater presence of vegetable and decomposed organic matter. Instead, if we examine the turbidity and TPM values found during a ferry berthing experiment, to be discussed below, we can see that high FTU values correspond to very high TPM values because the ferry berthing induced a major resuspension of sediments characterised by a large number of particles of small–medium size but great weight (iron oxides, deriving from port activities). This difference shows how the concentration values of the material in the water (in $mg \cdot L^{-1}$) can rapidly change from low to very high. Under normal conditions, only the port waters near the mouth of the Bisagno Torrent have relatively high FTU values in the surface layer (max. value ~24 FTU).

Dimensional analysis of the samples revealed a relatively low number of particles in February, between 3.4 and 13.0×10^6 parts $\cdot L^{-1}$, and a decidedly low number in March, between 0.2 and 1.6×10^6 parts $\cdot L^{-1}$. The water sample taken from the station near the mouth of the Bisagno at the end of February had 32.5×10^6 parts $\cdot L^{-1}$. This value was even higher than the those found in the turbid plume raised by the ferry berthing (max. 20.2×10^6 parts $\cdot L^{-1}$). This demonstrates that conditions similar to those induced inside the port by ships of major dimensions often occur near the mouth of the Bisagno Torrent, but with decisively lower TPM values.

To emphasise the presence and dynamics of particulate matter in the port, a series of samples was taken from along the inside of the protective sea wall to establish the vertical TPM distribution. This distribution (Figure 4) highlighted how, for example, at the end of February, with the wind swinging from the south-east to the south-west, the TPM was confined to the port. Winds from the southern quadrants tend to drive the suspended particulate matter from the Bisagno Torrent (station 16 with a TPM of 10–12 $mg \cdot L^{-1}$) into the port as far as the eastern entrance: this particulate matter tends to enter the surface layers. All the other sampling stations had relatively low TPM values (between 2.4 and 5 $mg \cdot L^{-1}$) and even stations 8 and 9, near the mouth of the Polcevera Torrent, did not reveal the presence of such matter.

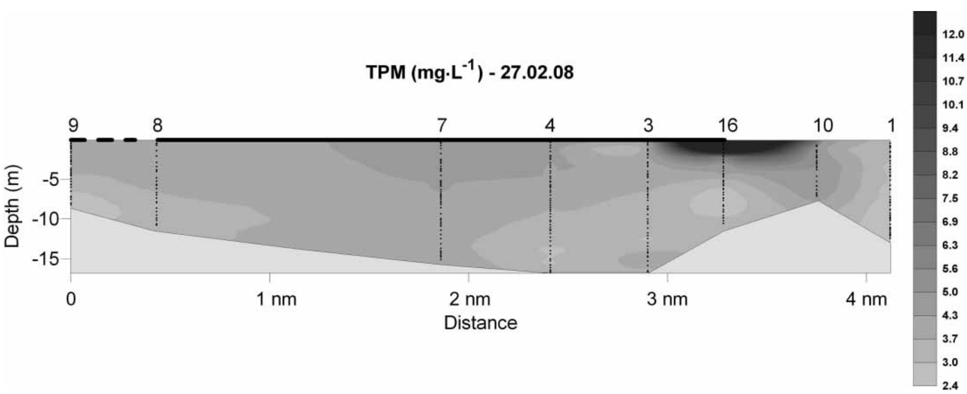

Figure 4. Vertical TPM distribution found during the campaign at the end of February, with the wind swinging from south-east to south-west; TPM values are in $mg \cdot L^{-1}$. The unbroken line represents the outer protective sea wall while the broken line represents the western entrance to the port. nm = nautical miles.

3.4. *Grimaldi experiments*

Measurements taken around the ferry revealed that the turbid plume did not disperse beyond the waters directly influenced by the ferry manoeuvre. In fact, at a distance of 20–30 m from the ferry the turbidity profile did not demonstrate any change from the 'normal' conditions found before the creation of the plume.

The time required for conditions to return to normal was relatively short, ∼20 min. The graph of the five turbidity measurements obtained near the ferry during the manoeuvre (10.30–10.55 a.m.) reveals that the temporal trend of the plume that initially involved the bottom 10 m (with concentrations around 50–60 FTU) reaches the surface waters after only a few minutes. After 15 min the surface layer begins to lose its turbid load and return to normal. After ∼20 min the underlying waters also tend to return to normal with a constant drop in turbid values (Figure 5).

The development of the plume was studied contemporaneously with a different method, taking ADCP measurements and subsequently elaborating them with SediView software to obtain the TPM concentration in $mg \cdot L^{-1}$. The results are reported in Figure 6 which shows how the turbid plume resettles almost completely in this period; after an initial increase in TPM, reaching and even surpassing 200 $mg \cdot L^{-1}$, there is a rapid decrease in values, which remain high for a longer time only near the bottom.

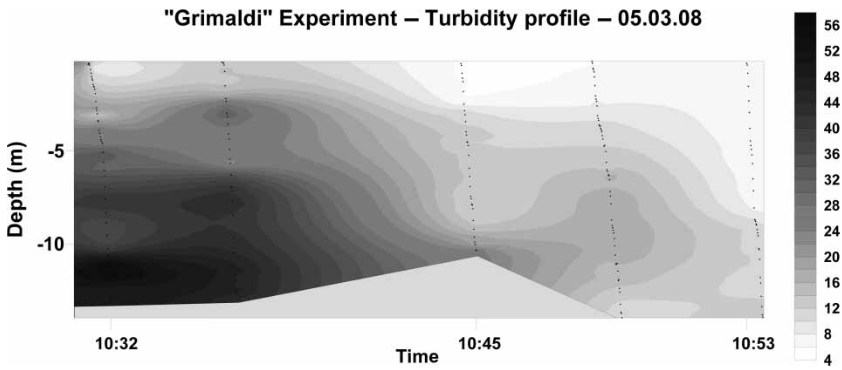

Figure 5. Turbidity time profile during the Grimaldi experiment carried out at the beginning of March (the variation in the bottom profile is due to a slight movement of the boat because of the leeway, which did not, however, affect the data). Values in FTU.

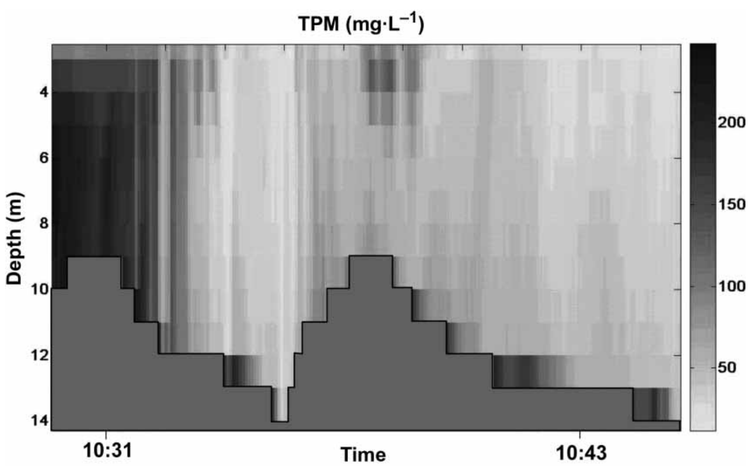

Figure 6. Vertical profile of the TPM time distribution processed with SediView, starting from current values measured with the ADCP, and calibrated with the turbidity data. Values in $mg \cdot L^{-1}$.

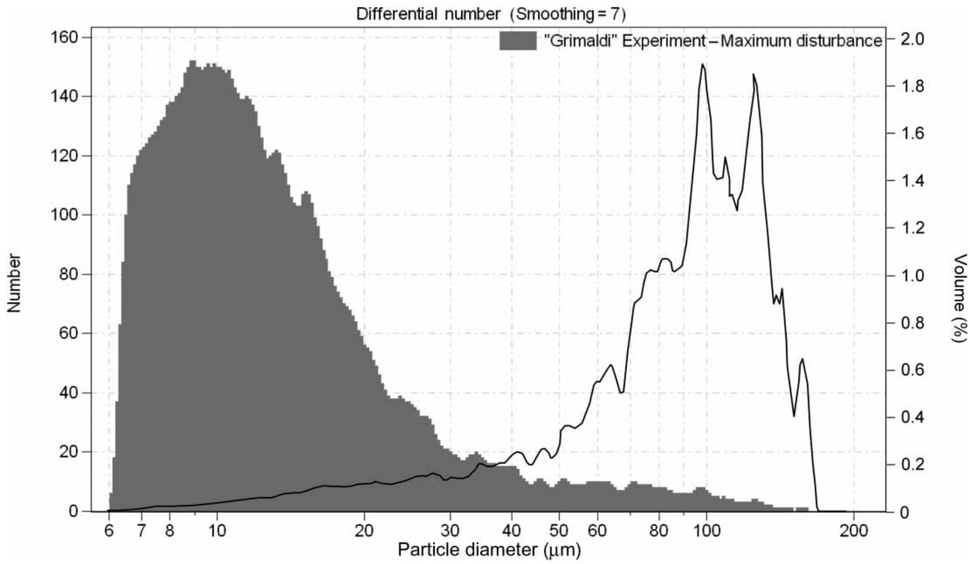

Figure 7. Dimensional spectra diagram (in number, on the left, and in vol. %, on the right) of the same sample relative to the 'maximum disturbance' phase of the Grimaldi experiment.

This experiment gave similar results for all the campaigns: the turbid plume generated by the ferry manoeuvre resettled within 30 min, re-establishing 'normal' conditions.

During this study of the development of a turbid plume, water samples were taken to calibrate the instruments and conduct the dimensional analyses of the particles. The resuspended matter

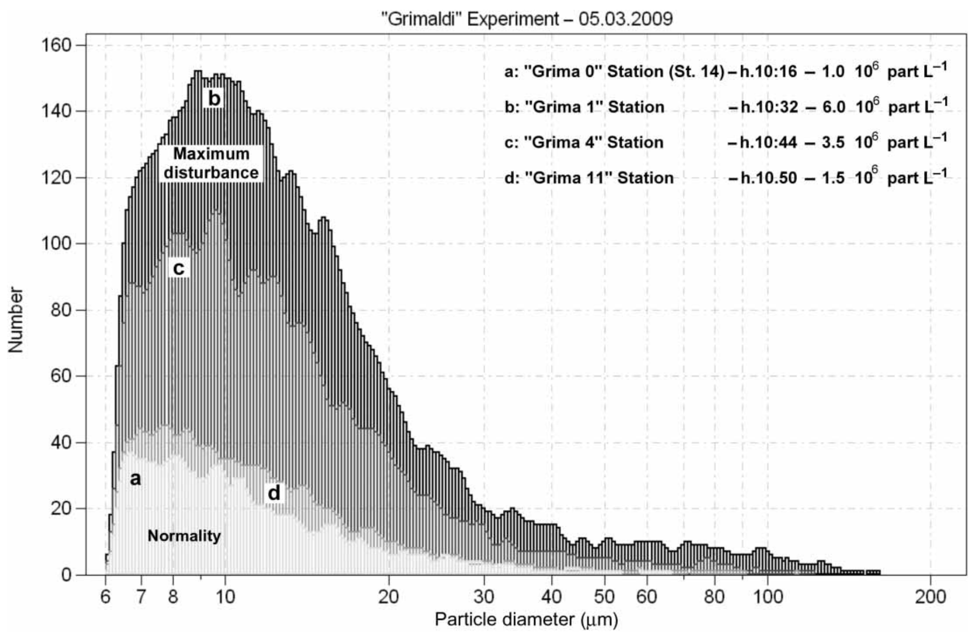

Figure 8. In this diagram the four phases of the experiment are shown: we report the dimensional spectra of the samples taken and analysed with a Coulter® Counter Multisizer™ 3, using a 280 μm capillary; the spectra represent the distribution of the particle number versus their dimensions (values in μm). Following the experiment we could easily determine how the particulate matter was resuspended during the berthing of the ferry and the particle grain sizes.

contained a high percentage of particles with diameters between 6 and 20 μm (Figure 7), but there was also a good percentage of particles of larger grain sizes, Ø > 50 μm (4%), which strongly influenced the calculations of the volume of resuspended matter (these larger particles represented 84% of the total sample volume) and, resettled rapidly, obscuring the particles of small grain size. The number of particles counted in these water samples, varying between 1.4 and 20.2×10^6 parts $\cdot$ L^{-1}, was notably greater than that of 'normal' port conditions.

The third phase of the study took the residence time of the particles in the turbid plume into consideration using the grain sizes of the particles themselves. Various water samples taken at different times were analysed to better understand how the particles resettle.

In Figure 8 we have reported the dimensional spectra of the samples collected at different times: *Grimaldi 0*, taken before the beginning of the berthing manoeuvre, had 1×10^6 parts $\cdot$ L^{-1} of small grain sizes. The successive samples showed a dramatic increase in the number and grain size of the particles (maximum disturbance, *Grimaldi 1*) with $> 6 \times 10^6$ parts $\cdot$ L^{-1}. The number of particles then diminished over time until initial conditions were re-established (*Grimaldi 11*) in ∼60 min. It should be noted here that during the berthing, particles of very large dimension (>100 μm) were resuspended, whereas under normal conditions the dimension never reaches 70 μm.

4. Conclusions

In this article, we have presented a straightforward method for determining the dynamics and sedimentological characteristics of an area to be dredged; this method was applied to the pre-dredging operations of the Port of Genoa during five oceanographic campaigns.

The programme enabled us to establish the basis for monitoring to be carried out during the dredging operations in a zone near areas that need to be protected from the negative effects of sediment mobilisation (*Posidonia oceanica* meadows, swimming beaches, marine parks, etc.), and also allowed us to establish which physical characteristics of the zone would be determinant in selecting the monitoring programme and managing the turbid plume.

The sampling and analyses carried out following this method demonstrated that there is extreme variability in the current direction in the port, due to the morphological complexity of the basin and the existence of port structures jutting out in all directions, and this induces a series of fluxes and vortexes without any specific direction around the wharves. Furthermore, during ferry and tug manoeuvres the turbidity increases notably, reaching a maximum corresponding to a maximum concentration and quantity of TPM and particles per litre. It seems that the turbid plume generated by ferries and tugs, and probably that of a dredge, does not disperse outside the port proper, reaching only a diameter of about a few hundred metres around the point of maximum disturbance which tends to settle rapidly with the water column returning to its 'normal' conditions within 1 h.

On the basis of these results, we were able to determine where to install fixed stations at the two port entrances to continuously monitor the inward and outward water movement during the dredging and, in the case of the development of a turbid plume, to provide sufficient warning in time to stop the dredging until more favourable conditions prevail.

Finally, this method, although site specific, could be adapted to other sites requiring specific monitoring but where the complex morphology of the area makes the use of predictive mathematical models difficult.

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References

[1] T.P. Puckette, *Evaluation of dredge material plumes – Physical monitoring techniques*, TN DOER-E5, US Army Engineer Research and Development Centre, Vicksburg, MS, 1998. Available at http://www.wes.army.mil/el/dots/doer.
[2] K.K. Ruffin, *The persistence of anthropogenic turbidity plumes in a shallow waste estuary*, Estuar. Coast. Shelf Sci. 47(5) (1998), pp. 579–592.
[3] J.S. Gray and K. Jensen, *Feedback monitoring: A new way of protecting the environment*, Trends Ecol. Evol. 8 (1993), pp. 267–305.
[4] C. Je, D.F. Hayes, and K. Kim, *Simulation of resuspended sediments resulting from dredging operations by a numerical flocculent transport model*, Chemosphere 70 (2007), pp.187–195.
[5] P.M. Chapman, *Presentation and interpretation of Sediment Quality Triad data*, Ecotoxicology 5 (1996), pp. 327–339.
[6] J.J. Vegter, J. Lowe, and H. Kasamas, *Sustainable management of contaminated land: An overview. A report from the Contaminated Land Rehabilitation Network for Environmental Technologies*, Austrian Federal Environment Agency, 2002 on behalf of CLARINET, Version August 2002.
[7] R.M. Darbra, N. Pittam, K.A. Royston, J.P. Darbra, and H. Journee, *Survey on environmental monitoring requirements of European ports*, J. Environ. Manage. 90 (2009), pp. 1396–1403.
[8] T.J. Fredette and G.T. French, *Understanding the physical and environmental consequences of dredged material disposal: History in New England and current perspectives*, Mar. Pollut. Bull. 49 (2004), pp. 93–102.
[9] Norwegian Geotechnical Institute (NGI), *Confined aquatic disposal facility in a deep fjord basin: The Oslo Harbour Remediation Project*, NGI 2007. Available at www.renoslofjord.no/sfiles/3/21/1/file/Oslo_Fjord_Clean_Up.pdf.
[10] U. Förstner, S. Heise, and P. Heiningen, *From monitoring to measures: Historical contaminated sediments in the Elbe river basin*, SedNet 2008 presentation, Oslo, Norway, 2008. Available at http://www.sednet.org/library/library-sednetconference5.htm.
[11] A. Sumeri, *Dredged material is not spoil – A status on the use of dredged material in Puget Sound to isolate contaminated sediment*, 14th World Dredging Congress, Amsterdam, The Netherlands, 1995.
[12] Assessment and Remediation of Contaminated Sediments (ARCS) Program, In-situ *capping guidance*, EPA 905-B96-004, 1996. Available at http://www.epa.gov/glnpo/arcs/EPA-905-B94-003/EPA-905-B94-003-toc.html.
[13] US Army Corps of Engineers (USACE), *Guidance for subaqueous dredged material capping*, 1998. Available at http://www.wes.army.mil/el/dots/doer/pdf/doer-1.pdf.
[14] J. Terrados and J. Borum, *Why are seagrasses important? Goods and services provided by seagrass meadows*, in *European Seagrasses: An Introduction to Monitoring and Management*, J. Borum, C.M. Duarte, D. Krause-Jensen, & T.M. Greve, eds., The M&MS Project Publication, Denmark, 2004, pp. 8–10. Available at http://www.seagrasses.org.
[15] P.M. Harris, A.D. Neff, S.W. Johnson, and J.D. Thedinga, *Eelgrass habitat and faunal assemblages in the city and borough of Juneau, Alaska*, US Dept of Commerce, NOAA Tech. Memo., NMFS-AFSC-182, 2008.
[16] BEACHMED-E, *La gestion stratégique de la défense des littoraux pour un développement soutenable des zones côtières de la Méditerranée (code 3S0155R), Programme Opérationnel INTERREG III C – Zone Sud. Composante 2. Mesure 2.4: Partage, perfectionnement et application du protocole ENV1 aux activités de dragage et de rechargement avec des sables fossiles, et applications spécifiques pour l'étude de la turbidité*. Phase A, Rapport finale, 2006. Available at: http://www.beachmed.it/Beachmede/SousProjets/EUDREP/tabid/95/Default.aspx.
[17] Directive 92/43/EEC, *Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (Habitats Directive)*, Official Journal of the EC, 1992, L0043.
[18] Directive 99/31/EC, *Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste (European Landfill Directive)*, Official Journal of the EC, 1999, L182.
[19] L. Gerrits and J. Edelenbos, *Management of sediments through stakeholder involvement. The risks and value of engaging stakeholders when looking for solutions for sediment-related problems*, J. Soils Sed. 4(4) (2004), pp. 239–246.
[20] H. Köthe, *Existing sediment management guidelines: An overview. What will happen with the sediment/dredged material?* J. Soils Sed. 3(3) (2003), pp. 139–143.
[21] A. Netzband, A.L. Hakstege, and K. Hamer, *Treatment and confined disposal of dredged material*. Report, Part Two, of Dutch–German exchange on dredged material (DGE), Bonn, Den Haag, 2002.
[22] RD Instruments, *ADCP, Principles of operation: A practical primer*, 2nd ed., RD Instruments, San Diego, 1996.
[23] G.R. Wall, E.A. Nystrom, and S. Litten, *Use of an ADCP to compute suspended-sediment discharge in the tidal Hudson River, New York*, Scientific Investigations Report 2006-5055, US Geological Survey, Reston, VA, 2006.
[24] UNESCO, *Algorithms for computation of fundamental properties of seawater*, Tech. Papers Mar. Sci. 44 (1988), p. 53.
[25] UNESCO, *The acquisition, calibration and analysis of CTD data. A report of SCOR WG 51*, Tech. Papers Mar. Sci. 54 (1983), p. 96.
[26] J.W. Gartner, *Estimating suspended solids concentrations from backscatter intensity measured by acoustic Doppler current profiler in San Francisco Bay, California*, Mar. Geol. 211 (2004), pp. 169–187.
[27] J.M. Land and R.N. Bray, *Acoustic measurement of suspended solids for monitoring of dredging and dredged material disposal*, J. Dredging Eng. 2(3) (2000), pp. 1–17.

[28] K.J. Reine, D.G. Clarke, and C. Dickerson, *Acoustic characterization of suspended sediment plumes resulting from barge overflow*, Dredging Operations and Environmental Research Program, Technical Notes Collection (ERDC TN-DOER-E15) (2002), U.S. Army Engineer Research and Development Center, Vicksburg, MS. Available at www.wes.army.mil/el/dots/doer.
[29] D. Clarke, A. Martin, C. Dickerson, and D. Moore, *Characterization of suspended sediment plumes associated with knowdown operations at Redwood City, California*, US Army Corps of Engineers, San Francisco (2005).
[30] J.D.H. Strickland and T.R. Parsons, *A practical handbook of seawater analysis*, Bull. Fish. Res. Bd Canada (1968), pp. 167–311.
[31] J.R. Valeur and A. Jensen, *Sedimentological research as a basis for environmental management: The Øresund fixed link*, Sci. Total Environ. 266 (2001), pp. 281–289.
[32] C.J. Gippel, *The use of turbidity instruments to measure stream water suspended sediments concentration*, Department of Geography and Oceanography, University College, Australian Defence Force Academy Monograph Series No. 4, 1989.
[33] E.T. Baker and J.W. Lavelle, *The effect of particle size on the light attenuation coefficient of natural suspensions*, J. Geoph. Res. 89 (1984), pp. 8197–8203.
[34] P. Puig and A. Palanques, *Nepheloid structure and hydrographic control on the Barcelona continental margin, northwestern Mediterranean*, Mar. Geol. 149(1–4) (1998), pp. 39–54.
[35] M. Capello, G. Budillon, L. Cutroneo, and S. Tucci, *The nepheloid bottom layer and water masses at the shelf break of the Western Ross Sea,* Deep-Sea Res. II Top. Stud. 56 (Special Issue) (2009), pp. 843–858.
[36] Coulter® Electronics Ltd, *Fine Particle Application for Coulter Multisizer II. Reference Manual for Coulter® Counter Instruments*, Issue, Luton, UK, 1998.
[37] K. Krank, *Variability of particulate matter in a small coastal inlet*, Can. J. Fish. Aquat. Sci. 37 (1980), pp. 1209–1215.
[38] K. Krank and T.G. Milligan, *The use of the Coulter Counter in studies of particle size distribution*, Aquatic Environment, Bedford Institute of Oceanography, Report Series, BI-R-79-7, Dartmouth, Canada, 1978.
[39] T.G. Milligan and K. Krank, *Electroresistance particle size analyzers*, in *Principles, Methods, and Application of Particle Size Analysis*, J.P.M. Syvitski, ed., Cambridge University Press, Cambridge (1991), pp. 109–118.
[40] J.J. Packman, K. J. Comings, and D. B. Booth, *Using turbidity to determine total suspended solids in urbanizing streams in the Puget Lowlands*, in *Confronting Uncertainty: Managing Change in Water Resources and the Environment*, Canadian Water Resources Association Annual Meeting, Vancouver, British Columbia (1999), pp. 158–165.
[41] D. Stramski, E. Boss, D. Bogucki, and K.J. Voss, *The role of seawater constituents in light backscattering in the ocean*, Progr. Oceanogr. 61 (2004), pp. 27–65.
[42] A. Hommersom, S. Peters, M.R. Wernand, and J. de Boer, *Spatial and temporal variability in bio-optical properties of the Wadden Sea*, Estuar. Coast. Shelf Sci. (2009), doi:10.1016/j.ecss.2009.03.042.