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Monitoring the turbidity associated with the dredging in Vavouto Bay in New Caledonia

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Abstract : The construction of a world-class nickel foundry necessitates the opening of a large navigation channel (4,500 m long, producing 7,300,000 m^3 of dredging spoils) in New Caledonia's northwestern lagoon in immediate proximity to coral reefs listed on the World Heritage List because of their exceptional biodiversity. The challenge is crucial: contribute to the economic re-balancing required by law while respecting a fragile environment and the societal practices of local populations. In order to minimize the effects of the Vavouto fairway dredging works, an Environmental management Plan (EMP) was set up. The Northern Province has commissioned the University of New Caledonia to keep track of this EMP in various domains and to develop a tool for data analysis based on the network of sensors, which monitors turbidity and physiochemical parameters of water and sediment in real time. This paper explains how such an environmental monitoring tool was developed to ensure that the management plan has been followed, using turbidity measures collected during the dredging works. This tool produces interpolated turbidity maps, over a time period chosen by the user. Data is treated so that turbidity measurements can be interpolated over the whole dredging area. Maps constitute a back-up to analyse and to detect threshold overruns. The user can choose their own threshold values or work with the ones defined in the management plan. In case of overruns, some time series are drawn to allow a more accurate analysis of the turbidity peaks.

Keywords : *Dredging, Turbidity, Environmental Monitoring Plan – New Caledonia*

1 INTRODUCTION: OVERVIEW OF THE "KONIAMBO PROJECT"

On the northwest coast of New Caledonia's main island, Grande Terre, in the Southwestern Pacific, the construction of a nickel ore processing plant is underway and should be completed by 2013. The construction site, of global scale, impacts the "VKP" zone, named after the three communes (Voh, Koné and Poimbout) where most of the direct and indirect infrastructures are located for a key industrial program under the "Noumea Agreement", the Koniambo Project, named after the mining site that will be exploited to supply the plant. Building the infrastructure (plant, site facilities, thermal power plant, mining site) requires a significant amount of imported raw materials (coal, hydrocarbons, prefabricated modules for the plant); this in turn makes it necessary to export the finished product (ferro-nickel). In the Oceania islands context, sea transport was the obvious choice, and the decision was made to build a port. The site chosen for the port facility (Vavouto Bay) required the opening of a navigation channel to allow safe access to the site for ships of up to 50,000 DWT (Deadweight tonnage).

This paper describes a part of the control of the EMP (Environmental Management Plan) established by KNS (Koniambo Nickel Society) and is associated with the dredging of an access channel to the port of Vavouto. The Northern Province has commissioned the University of New Caledonia to keep track of this EMP in various domains (Allenbach, 2008). This paper describes a part of this work and is focused on the potential impact of dredging on sea water quality (turbidity and chemical constituents in sediments). The tool described, to track changes in turbidity, is designed to evolve to take into account other indicators for monitoring, for example coral communities, seagrass and microalgae, or turtles and marine mammals.

2 RAPID DESCRIPTION OF THE DREDGING

Entrusted to the Jan de Nul company, one of the world leaders in dredging, work began in August 2008, and was scheduled to end in April 2010. The aim was to dig a navigation channel (12 m deep, 120 m wide, and 4.5 km long) between the industrial port facilities associated with the plant and the Duroc Passage that allows access to the high seas beyond the barrier reef. The preliminary studies estimated a volume of 7,300,000 m^3 of spoils to be extracted in the form of variable materials ranging from silt, mud and sand to hard corallogenic concretions depending on the zone.

These characteristics necessitated the on-site use of two types of dredging in the 13 zones identified during the reconnaissance work (Figure 1). A trailing suction hopper dredge (TSHD) with a capacity of 3,700 m^3, and a backhoe dredge (BHD) with a dipper bucket of 40 m^3, assisted by two self-propelled barges with a capacity of 3,700 m^3 each were used. The TSHD was assigned to dredge fine, loose sediment, and the BHD was assigned to solid sediment.

Given the sensitivity of the environmental context of the New Caledonian lagoon, a number of measures have been taken to preserve the environment. These measures are part of an environmental management plan (EMP). The EMP begins with identifying and describing the environmental features, both inside and around the site, which are likely to be affected by dredging and dumping of spoil.

The material removed from the littoral zone, to attain the depth desired by the project, is transported to the dredging spoils disposal area, located beyond the barrier reef where the depth exceeds 1,000 m. The disposal area for the dredging spoils (concentrated suspension from the TSHD, and semi-solid sediment saturated with water from the barges assisting the BHD) is a 1 km by 1 km square located 5 km from the external slope of the barrier reef to the southwest of Duroc Passage. Its location, reputed to have no effect on reef biodiversity, was the subject of many models validated by INERIS, the third-party expert in the overall environmental impact assessment produced by the Koniambo Project. The third-party expert's conclusions (Allenbach, 2008), submitted in 2005, enabled Order No. 180/2005 of 31/12/2005 providing government authorization to undertake the dredging, containment and dumping of dredging spoils on the public maritime property of the Nord Province, to be issued.

In its recommendations, INERIS requested an Environmental Management Plan (EMP) covering the impacts of the work. Given the vast scope of the aspects covered by the EMP, this paper cites the general characteristics of this environmental monitoring very briefly, and then focuses on only one issue: ambient turbidity.

Turbidity is caused by the presence in the water of suspended particles of clay, silt, organic matter, plankton and other microscopic organisms, organic acids. This is one of the indicators used to assess water quality (USGS - U.S. Geological Survey Office of Water Quality, 2010).

High concentrations of particles can change the light penetration and lead to the suffocation of aquatic organisms. If light penetration is reduced significantly, it will also decrease photosynthesis and thus cause a depletion of oxygen in the water (Water On The Web, 2008).

The turbidity unit prescribed by the Environmental Protection Agency (EPA - USA) is the NTU (Nephelometric Turbidity Unit), a unit that refers to the type of instrument (turbidimeter or nephelometer) used to evaluate the distribution of light in a solution with suspended particles :

- 0 - 5NTU: clear water,
- 5 - 30 NTU: Water slightly turbid,
- Beyond 50 NTU: cloudy water.

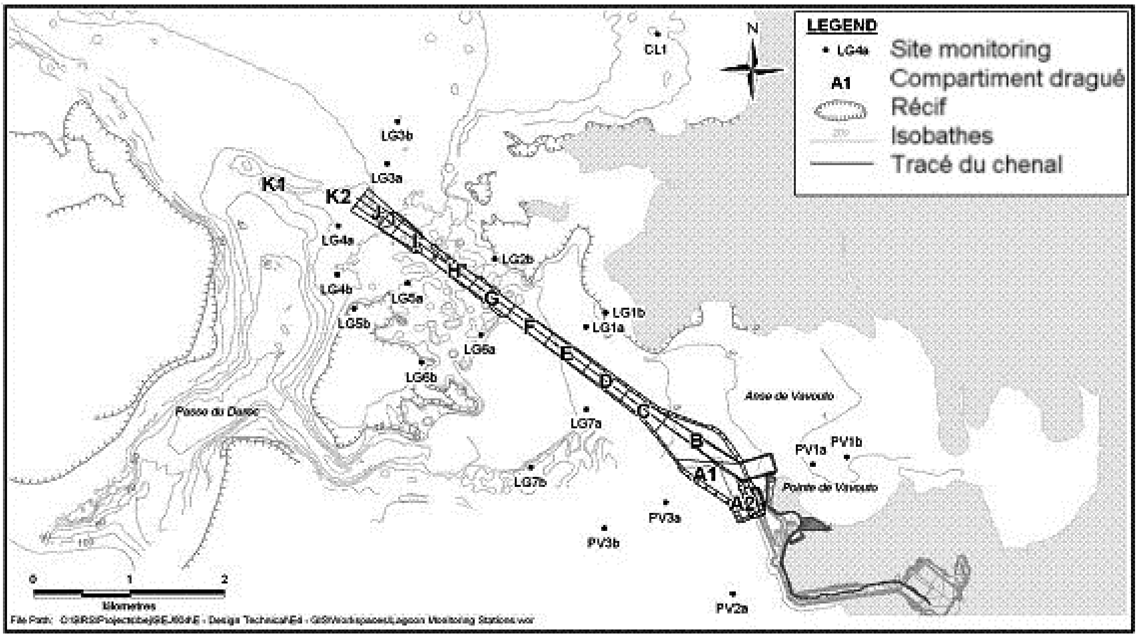

Figure 1. Map of the Channel and the 13 Work Zones (according to KBR-Report BEJ604, 2007).

3 DATA ORGANIZATION

In the framework of the dredging EMP, a huge amount of data is available. There is approximately 5 GB of data for the turbidity component alone, usually in the form of spreadsheets and text files: turbidity measurements, satellite images of the affected zone, investigation reports on the depth profiles and plumes according to type of ship, visual plume surveillance reports, monthly ship activity reports, probe maintenance reports, ship audit reports, dumping locations, etc.

Faced with the quantity of data produced, one could legitimately hope that the data would be structured in a clear manner, as the third-party expertise that led to the dredging permit had requested. On close examination, it turned out that it was a mass of basically unorganized data. The measurements were taken by different companies and appear to be disparate. They were done using different protocols, depending on the companies involved and the sensors used. They were communicated in heterogeneous formats, and not structured in a database. The lack of organization of such heterogeneous data, in terms of both structure and substance, is a major hindrance to obtaining an overall view of the phenomena monitored. Furthermore, it made both the task of the expert in charge of supervising the work and the communication with decision makers and populations more difficult.

In terms of monitoring, this lack of an overall vision at the start of the project has made a complete reorganization of the data acquired necessary. This required the identification of common parameters for each type of measurement and the specificities of these parameters so they could be integrated into a coherent, usable database. This tedious, time consuming, and human resource intensive task, consisted of what could be called "reverse engineering" using the available data and submission of reports to try to understand the methods used by the various actors and the actors' constraints.

Organizing this “retro-database” and the associated metadata naturally required the definition of a conceptual model to clearly define the relationships between the various data sets. For analytical purposes, in addition to the available data on turbidity, supplementary data were included in the database (e.g. the turbidity threshold values set in the EMP, the passage of dredges in the vicinity of monitoring stations) to answer the expert’s questions (professional uses). Among these questions, was it possible i) to extract from this information the measurements taken during a given period of time, at a specific station or over a larger area, ii) to obtain access to the calibration parameters of the probes used, iii) to output the results in map form, etc.

3.1 The physical data model

The first step in the homogenisation of the data was to identify common parameters for each type of measure and for each company. In a second time, their characteristics were also identified and included in the standard database.

The structure of the database was developed using PowerDesigner which is a modeling software package. It allows the generation of a conceptual data model that provides a formal representation of data. This model is then transformed into a physical data model, the latter specifying the modalities of implementation of a physical database.

The database structure was created using open-source standards to ensure interoperability with the help of PowerAMC, which makes it possible to produce conceptual data models. The data was stored in a POSTGRES database using this structure.

The aim of this approach was to design an environmental monitoring tool for various purposes: spatial analysis, assessment of the impact of dredging, automatic updating of the database and monitoring turbidity.

3.2 Elaboration of a Tool to Analyze Turbidity Data Series

Once access to the data has been facilitated by the creation of a database, the goal was to develop tools suited to the environmental data tracking expertise needs.

The first expressed need was to efficiently analyze turbidity data from the various sensors over a given period of time so as to compare them with other parameters such as dredging work or the passage of a barge or ship, a high intensity weather incident, or simply the detection of a sensor problem. The aim was therefore to produce a spatial and temporal summary of the turbidity data in the form of interpolated maps for daily, weekly, monthly and annual periods. In particular, doing this makes it easy to compare the initial state of a zone before, during and after the dredging work, and study the area’s resilience (the ability of an ecosystem to return to its original state after being disturbed).

Another expressed need was to be able to automatically detect the zones and periods in which the threshold values had been exceeded and visualize them in map form.

Several tests have been undertaken before defining the tool, which needs to be efficient, and to limit complex user manipulation to produce all the interpolated maps. In this approach, the user (the expert) chooses their period of interest and the tool automatically performs data selection and extraction, statistical analysis and presents the results. Practically speaking, several maps are produced and show the turbidity values based on whether the measurements were taken individually on site or constantly via sensors with radio or manual transmission of the data. An additional map shows all the measurements. It is possible to discriminate between types of measurements and compare them, as the expert wishes. Four maps can be produced for a chosen period and for each depth at which interpolation is possible.

A curve showing the evolution of turbidity over time (at the chosen stations and depths) can also be produced in order to study the nature of the coverage (a temporary spike, for example). It was shown that the turbidity variable has all the statistical characteristics of a “regionalized variable” (DROESBEKE et al., 2006) and that the interpolation of the turbidity values for the entire dredging zone using a number of points (a minimum of 6 stations) is representative of the zone under observation.

The interpolation method chosen is the geostatistical method of kriging which allows the understanding of the spatial structure of the examined phenomenon. Kriging also has the characteristic of being an exact interpolator. The spatial structure was analyzed by calculating an experimental variogram measuring the degree of dissimilarity between the points based on their distance (variance). It described the spatial continuity and regularity of the phenomenon. A model variogram was adjusted to the experimental variogram to make the interpolation process automatic.

The maps produced show the user (the expert) the spatial distribution of turbidity values. A fixed colour scale was chosen to facilitate map comparisons. The colour scale is a gradient representing values of turbidity from 0 to 100 NTU. When turbidity values are greater than 100 NTU (although this is rare in the monitoring), the white colour is assigned to them. It would have been possible to use a sliding scale ranging from minimum to maximum value of the map to be produced but the comparison of these maps would have been more difficult. The disadvantage of a fixed scale is that if, for a given card, turbidity varies only on a very limited range, colour variations are not very visible. In addition, each map is accompanied by the map of variance, to assist the user in their analysis. The number of measurements used to calculate the average for these stations, as well as the maximum value that the turbidity reached and in what station are indicated on the map.

4 RESULTS

An example of the temporal curve is shown in Figure 2. This curve was automatically generated to show a spike in turbidity observed on April 7, 2009, at a depth of between 1 and 2 m. It is interesting to note that the spike detected at the LG3b station can also be seen in the records of the neighboring LG4b, LG5b and PV3b stations during the same timeframe. In light of the results, the expert could conclude that these threshold coverages could be the result of the same event, which spread through the zone, and can decide to conduct further research to discover the cause of the anomaly.

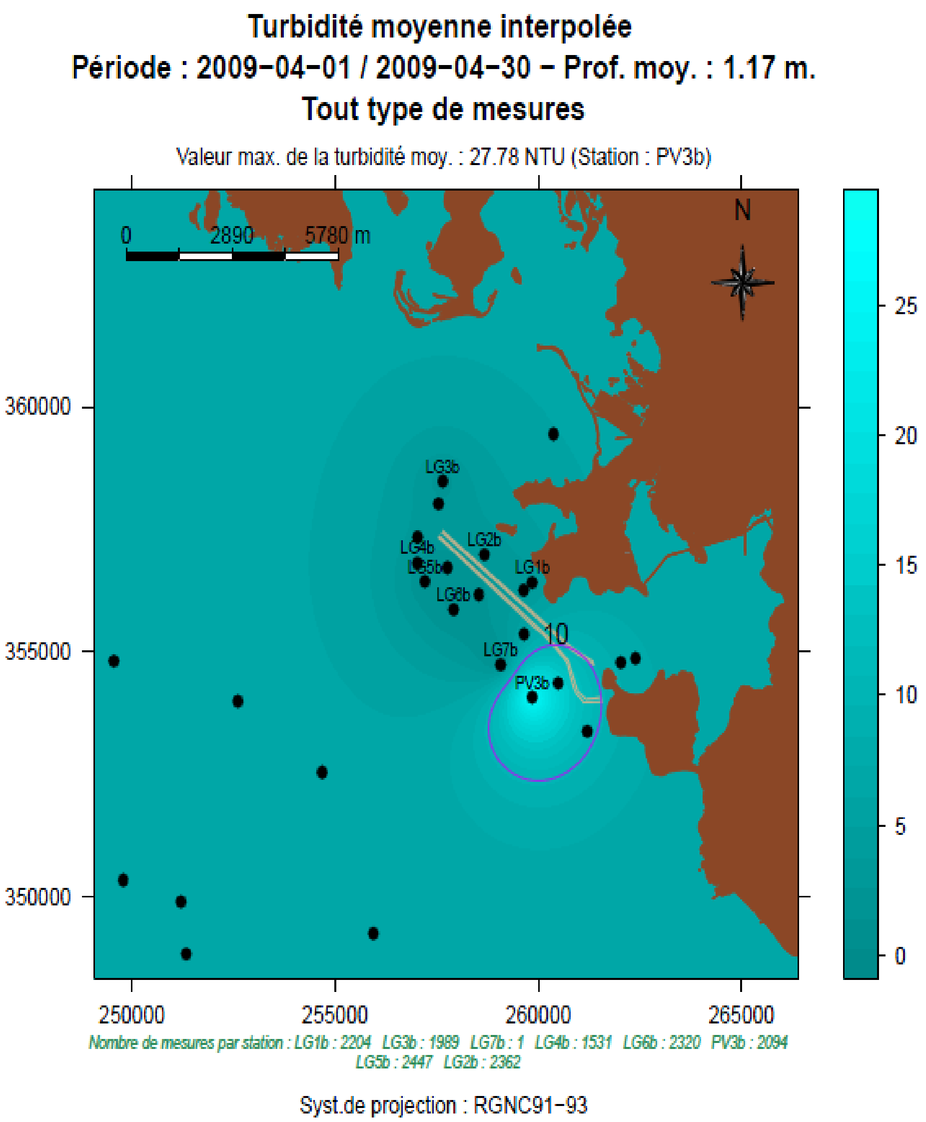

Figure 2. Example of the Spatial Distribution of Turbidity.
(The blue outline indicates a zone where the turbidity value rose above the authorized threshold.)

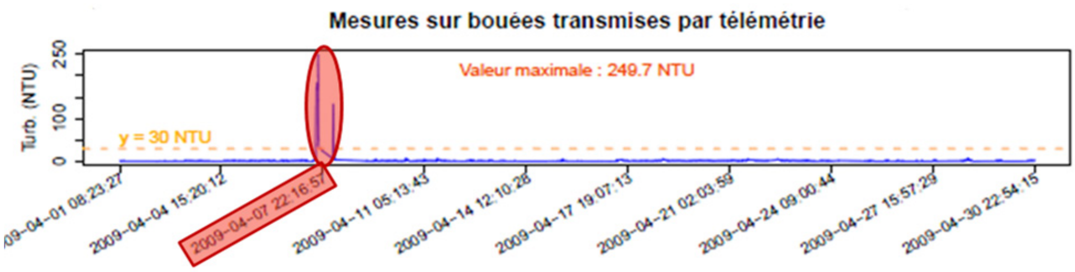

Figure 3. Evolution over Time of Turbidity at LG3b Station, at a depth of 1 to 2 m, in April 2009.

5 POTENTIAL IMPROVEMENTS TO THE METHOD AND CONCLUSION

The analysis and transmission of results would have been facilitated if the collection, organization, storage and distribution of the data had been better organized. Reflection involving all the actors (consultancy firm, mining company, experts and local governments), conducted prior to the work, would have produced a more coherent process, from acquisition to analysis. Here, it is not a matter of trying to standardize the output of each actor, given that each has its tools and operating methods, but rather to provide recommendations so that this output can be integrated into an immediately usable information system for the purposes of analysis and index visualization, or even as decision-making tools.

In the Vavouto study, the turbidity data were provided in the form of tables, which enabled basic statistical operations to estimate the quality, reliability and accuracy of the data (identification of instances of a factor of 1 or higher, frequency, trends and seasonality, noise assessment, and the detection of outliers and/or missing data). Data cleanup and data verification were, however, necessary. It was difficult to make the process automatic because the data were contained in several separate files and formats, on different media.

Organizing the data collected in a structured database, backed by a set protocol and supplemented by sufficiently detailed associated metadata to determine the collection source and conditions would have greatly simplified this necessary phase of exploratory analysis. This is crucial when conducting environmental studies integrating data of a different nature (quantity ongoing or single-measurement, ordinate quality or not, etc.) and variable quality.

Beyond describing the data, one of the goals was to determine the turbidity values exceeding a set threshold and compare these events with other factors (e.g. sensor cleaning). The possibility of using a structured database allowing queries that use temporal and spatial criteria simultaneously would have been of particular interest here, and would have saved considerable time if it had been set up at the start rather than after-the-fact and for verification purposes. It should be noted that most modern statistics software such as R (Dray & Dufour, 2007) can query the most common databases.

The experience with the Vavouto “turbidity” database allows us to formulate a few general recommendations for the Koniambo Project and other projects.

It is recommended that the industrialist and the policy makers implement the database/analysis tools/information system trio for the overall environmental monitoring of the Koniambo Project, which shall continue beyond the dredging operations. In this type of approach, the aim is to evaluate the correlation between variables so as to calculate the interpolations and model spatio-temporal dynamics. Indicators can be elaborated based on the modeling. These indicators must be elaborated by experts, and the associated confidence intervals, biases and precisions must be provided. The data dynamic can be studied, either in univariate mode (the dynamic of one specific variable, e.g. turbidity in our case) or in multivariate mode (i.e. estimate the spatial and temporal distribution of sediment based on currents, weather and other data). This step requires the use of mathematical models whose implementation can be complex (definition of the model’s structure and calibration of the parameters). Based on indicators and model results, automatic recommendations can be proposed to help decision makers determine what measures should be taken.

These tools can rely on methods ranging from a simple linear combination of decisive parameters to a complex process using the concepts of artificial intelligence such as Bayesian networks (Borgelt & Kruse, 2002). These probability graphs notably have qualities that allow the simultaneous consideration of experts' advanced knowledge (through a graph structure) and the information contained in the data.

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