Revue Paralia, Volume 3 (2010) pp 7.13-7.24
Keywords: Dredging, Turbidity, Environmental Monitoring Plan, New Caledonia, Reef Ecosystem, Interoperable Database, Sustainable Development

Monitoring the turbidity associated with the dredging in Vavouto Bay near New Caledonian sites listed by UNESCO

Michel ALLENBACH [1], Morgan MANGEAS [2], TOURAIVANE [1]

1. Université de la Nouvelle-Calédonie, PPME, EA 3325, BPR4, 98851 Nouméa Cedex.
   allenbach@univ-nc.nc ; touraivane@univ-nc.nc
2. IRD Centre de Nouméa, US Espace, BP A5, 98848 Nouméa Cedex.
   morgan.mangeas@ird.noumea.nc

Abstract:
The construction of a world-class nickel foundry necessitates the opening of a large navigation channel (4,500 metres long, producing 7,300,000 cubic metres 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. This paper presents the environmental monitoring plan, which includes a network to monitor the turbidity and physiochemical parameters of water and sediment in real time, as well as a large biological component. It then presents the results of the environmental tests conducted, and the interest of an original method to ensure the communication of the test results to local populations: the creation of the Koniambo Environmental Committee (CEK, "comité environmental du Koniambo"). The last section addresses the interest to be found in using interoperable databases: they facilitate internal and external communication and simplify the verification methods to implement.

Received 30 October 2010, accepted 5 November 2010, available online 20 December 2010.

Translated version not certified, published under the responsibility of the article authors.

How to cite the original paper:
ALLENBACH M., MANGEAS M., TOURAIVANE (2010). *Le suivi de la turbidité associée au dragage de Vavouto à proximité des sites néocalédoniens classés par l'UNESCO*. Revue Paralia, Vol. 3, pp 7.1-7.12.
DOI:10.5150/revue-paralia.2010.007 (disponible en ligne – http://www.paralia.fr – available online)

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 in 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 "Nouméa Agreement", the Koniambo Project, named after the mining site that will be exploited to supply the plant. Building the infrastructures (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 island 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.

2. Rapid description of the dredging

2.1 General information

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 metres deep, 120 metres wide, and 4.5 kilometres 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 cubic metres 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 cubic metres, and a backhoe dredge (BHD) with a dipper bucket of 40 cubic metres, assisted by two self-propelled barges with a capacity of 3,700 cubic metres each were used. The TSHD was assigned to dredge fine, loose sediment, and the BHD was assigned to solid sediment.

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 metres. 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 incidence 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, 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.

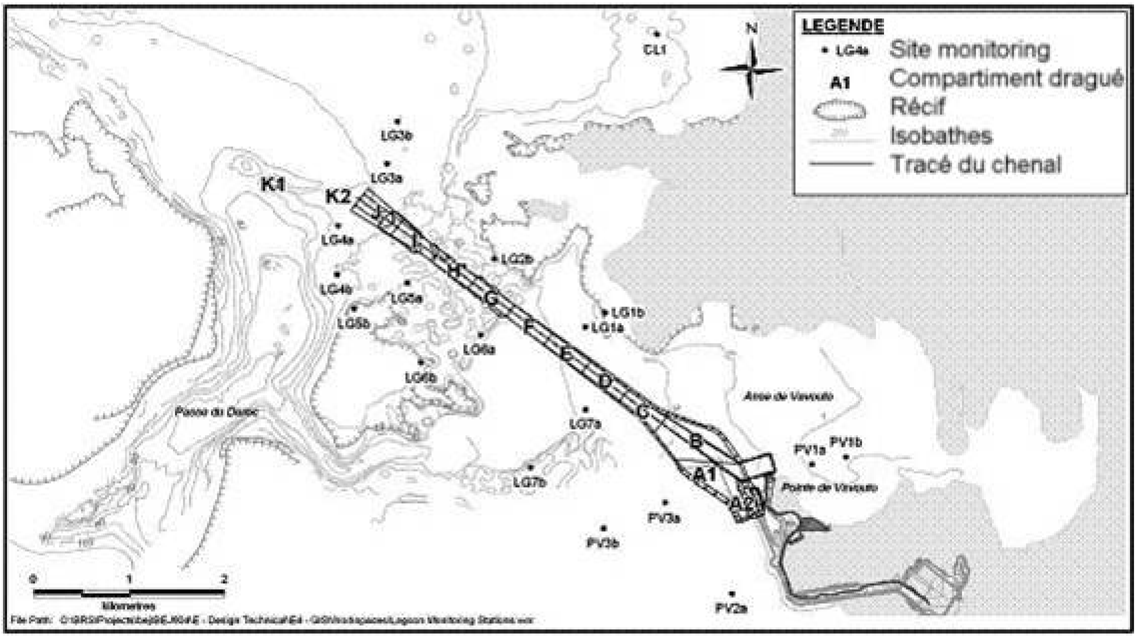


Figure 1. Map of the Channel and the 13 Work Zones (according to KBR-Report BEJ604).

2.2 <u>A fragile environmental context</u>

The work involves a lagoon area located in immediate proximity to zones recently (2008) included on the UNESCO World Heritage List.

Eighty-five percent complete today, the progress in the work makes it possible to conduct a critical analysis of the environmental monitoring program's degree of effectiveness in regard to the expectations expressed. The Koniambo Nickel Society (KNS) industrial project is, in fact, central to a crucial challenge for the country: managing successful sustainable development that respects a fragile environment and the societal practices of the indigenous peoples living in the area affected.

Melanesians' strong cultural attachment to their natural surroundings makes them very attentive to respecting the environment. A large fishing clan (the Oundjo tribe) in the VKP region is, in fact, located in the immediate vicinity of the land footprint of the Vavouto industrial site, and has expressed its concern that the maritime work would

affect its fishing sites. The environmental constraints from the local populations on the industrial project are therefore high.
Strong constraints also come from international environmental associations and organizations. The listing of the New Caledonia’s reef mandates strict control and exemplary practices to safeguard natural sites. The undertaking of a large construction program raised logical questions about the risks for the ecosystem. The few negative echoes heard until present in regard to the dredging project show the success of the approach in terms of information: clear communication policy, attractive partnership with local populations, creation of the Koniambo environment committee.

3. The environmental monitoring plan for the Vavouto dredging operations (turbidity component)

3.1 General remarks on the method adopted

At the end of 2007, the environmental management plan for the dredging of the channel, requested by INERIS in 2005, was produced for KNS by Kellogg Brown Root Ltd. (KBR Inc., 2007) and submitted to the Nord Province. The Province commissioned a third-party expert, the University of New Caledonia (UNC), to validate the plan; after the UNC submitted its conclusions (ALLENBACH, 2008), the work began in August 2008. The plan identifies 6 key issues of variable importance: water quality, air quality, ecology (flora and fauna), noise, waste management, and dangerous substances.

3.2 Measures pertaining to the monitoring of ambient turbidity in the lagoon

Only the component focusing on monitoring ambient turbidity in the lagoon will be discussed in this paper. First, it is the most visible effect, justifiably likely to federate fears about and opposition to the work. Second, it is the most penalizing parameter for the coral ecosystem.
Table 1 (below) compares the initial proposal produced by KBR for KNS with the measures adopted by the Provincial authorities after the third-party expertise by UNC. The system of stationary buoys set up to measure turbidity in real time (radio transmission of the data collected, at the rate of one reading every 3 minutes) and using more classical methods (autonomous buoys with data loggers taking readings every 30 minutes, with the data collected weekly) consists of 2 OMC-045-B-1200 data-buoys (measuring turbidity and swells) and 8 OMC-045-B-250 data buoys (measuring turbidity). The buoys were equipped with multi-parameter probes of the YSI 6920 and HYDROLAB MS5 and DS5 types. The field work is done by two service providers under the supervision of Hatch-Technip (HT) and KBR.

3.3 Monitoring results

The monitoring within the lagoon, around the direct path of the channel, complied with the recommended sampling plan and the sensors were deployed very rapidly. Beyond the reef, on the outer slope, however, the sensors were placed very late (8 months after the start of work), and some of the data was lost. Analysis of the first 18 months of data shows that the authorized thresholds were not significantly exceeded (>70 NTUs over 1 hour or >30 NTUs over 3 days). The only overages noted were due to soiling problems (biofouling) and sensor breakdowns, which were resolved with cleaning by divers and maintenance teams. Dysfunctions (broken signal) were also noted for radio-transmitted data, and were resolved by replacing the relays.

Table 1. Comparison of recommend and selected measures

Measures proposed by KNS	***Measures set up***
Daily visual surveillance of sediment plumes; *Measuring water turbidity every 30 minutes and weekly downloading of the data recorded by specific buoys.*	*Set up of a system to measure and transmit water turbidity values in real time (3-minute increments);* *Simultaneous measurement of water turbidity every 30 minutes with weekly downloading of the data;* *Manual measurements near the dredging zone;* *Establishment of a warning system triggered when values exceed the critical thresholds defined by the project.*

3.4 Environment-related communication

The provincial authorities and the industrialist agreed to create a unit to interface between the population and the Koniambo project, the CEK. Composed of elected members, scientists and representatives of the associative and customary worlds, and directly integrated in the project that subsidizes it, it is run by salaried environmental technicians hired by it. It intervenes effectively to ensure that promises are kept and to obtain environmental compensation in the case of dysfunctions. It runs the monitoring result communication sessions, and creates the desired arenas for discussion. This approach is an uncontested success: after 18 months of work and less than 3 months from completion, the program has received no significant criticism.

4. Data organization

In the framework of the dredging EMP, a huge amount of data is available. There is approximately 5 Go 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 an interoperable 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, useable database. This tedious, time and human resource consuming intensive task consisted of what could be called "reverse engineering" using the available data and submitted reports to try to understand the methods used by the various actors and these actors' constraints:

- What was measured?
- Who measured it?
- When was it measured?
- Where was it measured?
- How was it measured?
- Under what conditions was it measured (wind direction/speed, wave direction/height, tidal cycles)?
- What was the measured value?

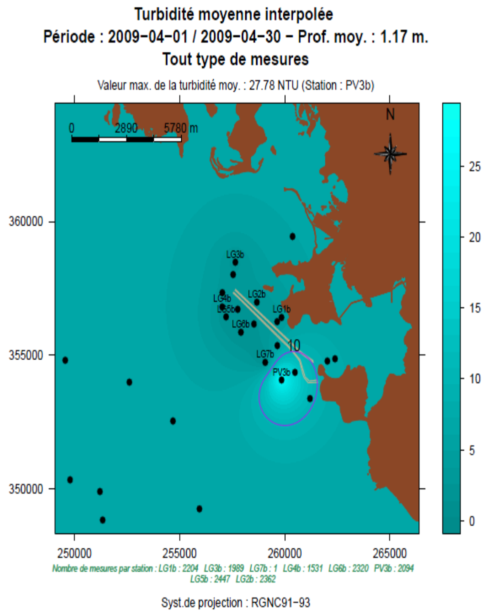
Organizing this "retro database" and the associated meta-data naturally required the definition of a conceptual model to clearly define the relationships between the various data sets. For analytical purposes, in addition to the available data on turbidity, supplementary data were included in the database (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, it was possible to extract from this information the measurements taken during a given period of time, at a

specific station or over a larger area, obtain access to the calibration parameters of the probes used, output the results in map form, etc.
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 (CDMs). The data were entered into a POSTGRES database using this structure.

5. Elaboration of a tool to analyze turbidity data series

Once access to the data had 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 resiliency.
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.
A prototype was produced to answer the expert's questions. It queries the database, conducts the statistical analysis of the data, and makes it possible to present the results of the analysis. 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 overage (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 was the geostatistical method of kriging, which makes it possible to grasp the spatial structure of the phenomenon examined.
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 (Marcotte) to make the interpolation

process automatic. A set color scale was chosen to facilitate map comparisons and obtain a better visualization of the evolution of turbidity throughout the work.
An example of the temporal curve is shown in Figure 3. This curve was automatically generated to show a spike in turbidity observed on April 7, 2009, at a depth of between 1 and 2 metres. 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 overages were 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.



(The blue outline indicates a zone where the turbidity value rose above the authorized threshold.)

Figure 2. Example of the spatial distribution of turbidity.

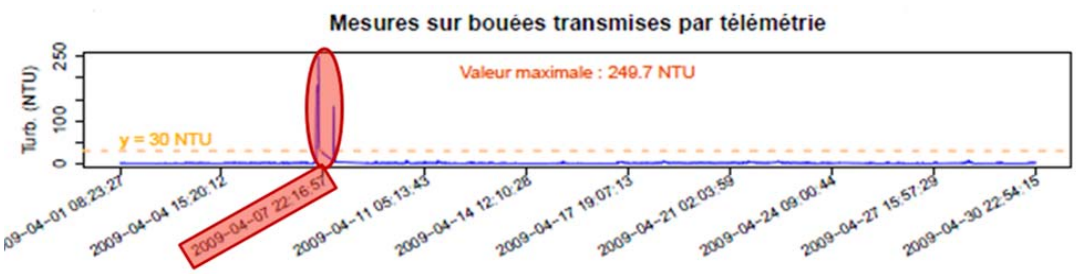


Figure 3. Evolution over time of turbidity at LG3b station, at a depth of 1 to 2 metres, in April 2009.

6. 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.

6.1 The Interest of creating an interoperable database

Various initiatives in Europe (INSPIRE) and internationally (GMES, GEOSS) aim to federate activities in regard to information systems so as to optimize the use of existing and future infrastructures. The aim is to develop methods to collect and distribute data and enable their integration in environmental monitoring projects. The evolution of Environmental Information Systems (EISs) relies on distributed and interoperable architectures. The interest of such approaches is found in the ease of sharing and disseminating information to different communities of actors (decision makers, technical offices, the private sector, and the general public). Simultaneously, standardization initiatives have emerged to encourage: (a) the use of open source applications to process the data from sensors, and (b) cooperation between sensor system suppliers and managers, and data "consumers."

Several organizations provide data acquisition systems, but few provide interfaces and none offer generic standardized tools. For instance, the Open Geospatial Consortium, Inc. (OGC) aims to publish specifications on structuring the dissemination of data from sensors of all types hosted on and controllable by Internet. The purpose of these standards is to allow networks of sensors that can be consulted from a distance using public protocols to be set up. The standards in the "Sensor Web Enablement" (SWE) suite offered by OGC form a fertile framework to standardize data acquisition, storage and dissemination—data on both the description of sensors themselves as well as the data produced by these sensors. For instance, the following specifications are part of this suite:

- the Sensor Model Language Encoding Standard (SensorML) provides a common format in which to describe the characteristics of sensor systems (geolocation, measurement processing, programming, automatic alerts, etc).
- the Observations and Measurements Encoding Standard (O&M) defines a conceptual data model to organize databases (in relation to temporally situated sampling events) and the measurements taken (value corresponding to an observed phenomenon). Beyond these two values, O&M also makes it possible to describe other properties

such as the process used to obtain these values, the spatial position (crucial with mobile sensors), and sampling quality.

It is interesting to note that, even for sensors that cannot transmit measurements and be piloted from a distance according to the recommended standards, it is possible to input data into a "buffer" database that can stimulate some of the behavior of a standardized sensor. Compliance with these standards also facilitates the comparison of data from real or simulated sensors with other widespread OGC standards devoted to geographic information such as the Web Map Service (WMS) and the Web Coverage Service (WCS).

Elaborating and using information systems are both greatly simplified by avoiding the difficulties due to the disparity of sensors and by relying on acknowledged data models. It should be emphasized that this stage is crucial and often skipped or habitually under-estimated, which leads to a higher workload afterward, data quantity or quality unsuited to needs, and ultimately sometimes insurmountable difficulties analyzing the data. The information system serves generically as the foundation on which one can develop dissemination/visualization tools; it can also be used to provide thematic condensed scoreboards for the purposes of alerts, consultation and decision making.

6.2 The interest of optimized processing of heterogeneous naturalistic data

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 different natures (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' advance knowledge (through a graph structure) and the information contained in the data.

7. References

ALLENBACH M. (2008). *Projet Koniambo (travaux de dragage) - Analyse critique du plan de suivi environnemental*. Rapport, Université de la Nouvelle-Calédonie, 69 p.

BORGELT C., KRUSE R. (2002). *Graphical Models: Methods for Data Analysis and Mining*. Chichester, UK: Wiley. ISBN 0-470-84337-3.

DROESBEKE J.-J., LEJEUNE M., SAPORTA G. (2006). *Analyse statistique des données spatiales.* Paris: Technip.

DRAY S., DUFOUR A.B. (2007). *The ade4 package: implementing the duality diagram for ecologists*. Journal of Statistical Software 22(4), pp 1-20.

KBR -Kellog Brown Root Ltd- (2007). *Plan de suivi environnemental des travaux de dragage*, Rapport BEJ604-G-REP-001, 47 p.