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Hydrolink

REDUCING ENVIRONMENTAL IMPACTS OF DREDGING THROUGH ADAPTIVE MONITORING – EXPERIENCE FROM MALAYSIA

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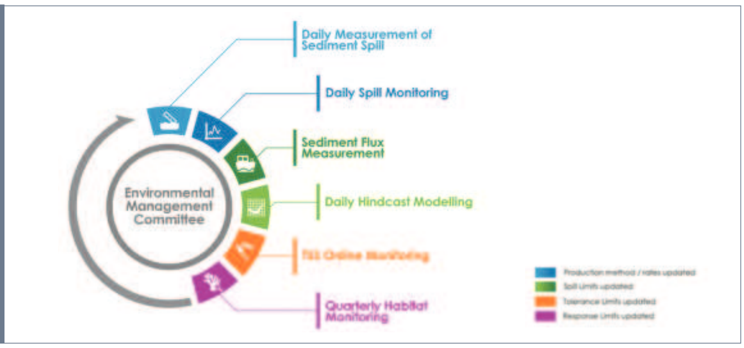


Figure 1. Key components of a feedback EMMP

Dredging and Its Impacts

The increasing requirement for economic growth has led to the need to modify the natural environment to accommodate developments that can contribute to this growth. An area where development has focused is the coastal zones which constitute a small percentage of the total global land mass, but has significant development potential. Rapid development in this area has meant increased construction of coastal infrastructure, such as urban development, ports, marinas, airports, oil and gas pipelines and support facilities, power plants, tourist facilities, etc.

Dredging works are often required for these types of projects to increase the nearshore water depth in order to enable larger vessels to navigate and berth at a port or jetty serving the area. Dredging without proper management can have irreversible impacts in highly sensitive environments, especially near coral reef areas and other similarly vulnerable systems. Properly designed and managed dredging works can:

- Eliminate or minimize any irreversible impacts on sensitive receptors;
- Have only minimal temporary impacts (transient impacts to fishing grounds, aquaculture, coral reefs and/or tourist areas)
- Minimize risks of real or perceived impacts that could lead to interruption of the dredging works; and
- Enable better documentation of dredging and monitoring activities.

Environmental Impact Assessment

Before dredging works are carried out, it is a common practice to undertake an environmental impact assessment (EIA) to determine the baseline conditions, assess potential impacts and define the necessary mitigation measures. This usually includes extensive field data collection and detailed hydraulic modelling. Key potential impacts addressed in an EIA can be categorized into two groups:

- **Permanent Impacts** are induced by the proposed structures and works on currents, water levels, waves, sediment transport, water quality, shoreline evolution in and near the area, etc. These impacts last as long as the structures and works are in place;
- **Temporary Impacts** occur during construction (dredging) work and are usually related to sediment spill during dredging. The extent and potential impacts of sediment plumes generated during the dredging depend on the type of dredger, dredging methodology, type of sediments and flow conditions. These impacts are usually limited to the duration of dredging. However, if not managed properly they could become permanent.

The assessment of temporary impacts is usually based on a number of assumptions which are based on best available information, but which are often uncertain at the EIA stage. Some key uncertainties at this stage include:

- Exact dredging methodology and production rates (the exact equipment is known when the contractor is appointed and has planned the work in detail);
- Timing of the works, both in terms of starting time and duration;
- Sediment properties in dredging spill – the settling properties of the sediment suspended in a passive plume in the water column as a result of dredging becomes exactly known only after commencement of dredging;
- Current flows and climatic conditions are variable and usually there are no data on their variability and seasonality;
- The spill rates depend on production rates, geotechnical and climatic conditions;
- Use of overflow environmental device (enviro valve), or other equipment in the dredger.

To account for these uncertainties, a level of "conservatism" is usually applied in the modelling in support of the EIA. However, because of these uncertainties it is not possible to assure that there will be no negative impacts on any sensitive receptors. Recognizing the uncertainties, not least among them the variable conditions at the site, it is good practice to manage dredging works based on actual observations during dredging operations to ensure that that no unforeseen impacts are realized, that the given Environmental Quality Objectives (EQO) are met, and that dredging works are carried out with minimal disruptions and within specified cost constraints. To meet these multiple objectives, DHI has developed a pro-adaptive Environmental Feedback Monitoring and Management process for dredging works which for the past two decades has been successfully applied in Europe, Malaysia, Singapore and elsewhere.

Environmental Feedback Monitoring and Management of Dredging Works

Pro-adaptive Environmental Monitoring and Management Plans (EMMP) based upon feedback monitoring principles are typically required for marine related construction activities notably those that lie within close proximity to sensitive environmental receptors, such as, coral reefs and seagrasses. This approach was initiated and developed by DHI in Denmark in the 1990's for the Øresund road-rail link between Denmark and Sweden (Doorn-Groen, 2007). Since then, the successful technique has been refined and implemented in Singapore (Pasir Panjang Terminal Expansion), Indonesia (Turtle Island, Bali), Brunei (Pulau Muara Besar) and Malaysia (Sapangar Port, Teluk Rubiah, and Pengerang Terminal). Some of these projects are described in the Central Dredging Association (CEDA)'s position paper (2015) on adaptive monitoring.

Proactive EMMP is implemented during the dredging works, so that potential impacts can be more readily and accurately identified and mitigated as the project progresses. The principles upon which this approach is based are:
- Working-with-nature approach;
- Operational forecast and online monitoring of key environmental parameters;
- Predicting and preventing potential impacts by an adaptive management program.

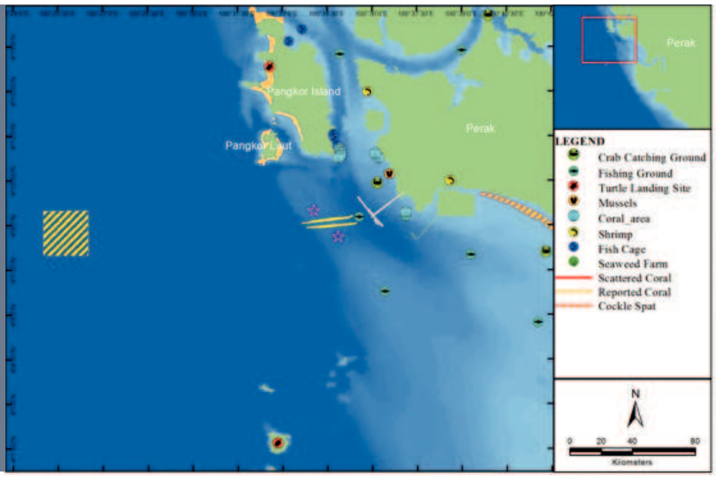
While traditional non-feedback EMMPs are reactive and dependent on coarse spatial and temporal field data monitoring, feedback EMMP utilizes the combination of detailed numerical hindcast and forecast sediment plume models and intensive field data monitoring. The main components of the feedback EMMP include the following:
- Environmental baseline data collection;
- Determination of environmental tolerance limits for the key environmental receptors;
- Assessment and update of work plans specifying the distribution of dredging works;
- Specification of sediment spill budget for the associated dredging works;
- Compliance monitoring (daily basis) against the pre-determined sediment spill budget limit;
- Control monitoring of real time measurements and comparison to response limits, such as online turbidity data or weekly sedimentation data;
- Sediment spill hindcast modelling (daily basis) which assesses the impacts arising from the actual dredging works and hydraulic conditions;
- Habitat monitoring (quarterly basis) of key sensitive biological receptors such as coral reefs, seagrasses, etc.

As such, feedback EMMP provides the level of responsiveness and documentation necessary to assure both authorities and other stakeholders that the works meet the EQOs throughout the construction period.

EMMP Case Study – Teluk Rubiah, Malaysia

A feedback EMMP was successfully applied in Malaysia for the dredging works at the proposed iron ore terminal developed by Vale Malaysia Minerals Sdn Bhd at Teluk Rubiah, Perak, Malaysia. The USD 1.4 billion project includes the development of an iron ore distribution

Figure 2. Site location for Vale iron ore terminal at Teluk Rubiah, Malaysia. The yellow lines refer to the dredged channel; grey lines refer to the jetty; yellow box refers to the disposal site



centre, a 1.8 km deep water jetty receiving shipments of iron ore from Brazil and exporting blended iron ore as well as pellets, and a dredged channel for access to the jetty. Standard dredging mitigation measures were inadequate due to complex site conditions in the area, including sensitive environmental habitats, fishing grounds, aquaculture farms, and tourist resorts. The client needed a comprehensive and reactive EMMP to keep the dredging impacts to a minimum while ensuring that the targeted construction schedule and budget were achieved.

A combined monitoring approach was applied at the project site to carefully manage the expected sediment spills during dredging to ensure that set tolerances for environmental receptors were not exceeded. This was achieved through a spill control and feedback monitoring with the following processes:
1. Application of a daily spill budget approach;
2. Modelling based on DHI's MIKE 21 MT (mud transport model) throughout the dredge period to ensure that the spill budget is adhered to and the EQOs are met. The sediment transport model describes the transport of the sediment spill to evaluate the location of the sediment plume both in space and time. The model was revalidated against measured data to ensure that the predictions are as accurate as possible;
3. Continuous real time measurements and monitoring works;
4. Adoption of mitigation measures if required to achieve the environmental objectives.

Dredging Spill Limit

The spill limit developed during the EIA was re-assessed before the start of dredging works. This was done based on more detailed information provided by the dredging contractor and a value was defined as a starting spill limit for the dredging period during the Northeast monsoon. Adjustments to this spill limit value were re-assessed during the dredging period as part of the adaptive management programme.

Plume Monitoring & Management

A comprehensive monitoring campaign was implemented that included:
- Monitoring of overflow to calculate the spill;
- Hindcast modelling of all dredging operations based on actual dredging records. This

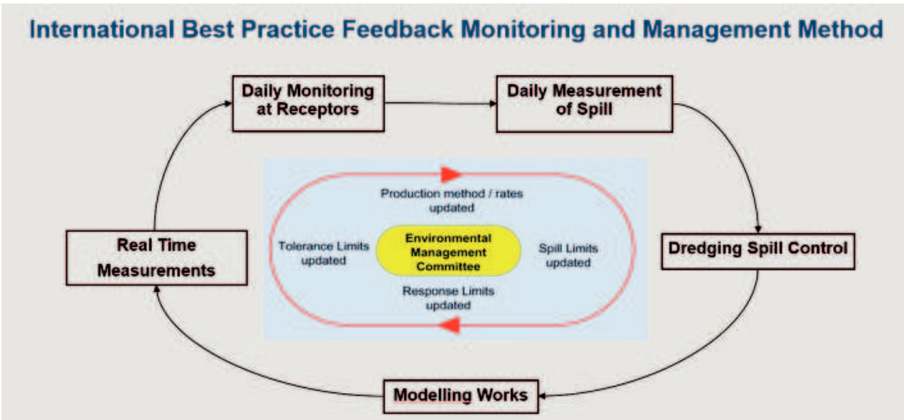


Figure 3. Feedback monitoring approach applied for the Teluk Rubiah project

provided a detailed image of the sediment plume both in space and time;
- Daily water sampling at fixed stations;
- Online Acoustic Doppler Current Profiler (ADCP) measurements at two locations to derive Total Suspended Solids (TSS) levels and current flow conditions; and
- Current and TSS transects at three stages of the project to produce details of the spatial extent of the sediment plume for model calibration;

Trigger Levels

Three trigger levels based on TSS concentrations were defined for the project:
- Level 1 based on a daily "spike" exceedance occurs;
- Level 2 based on the analysis of 3-day running average values;
- Level 3 based on 7 or 14-day running average values.

Level 1 was unlikely to cause any impacts and no immediate action was required. These events were, however, analysed to avoid any further issues and close attention was paid to sediment spill rates on subsequent days. For Level 2 cases, the exceedance had to be investigated based on results from the monitoring and modelling works and mitigation measures had to be implemented to ensure that levels were brought back under the limit. Lastly, Level 3 indicated a long term violation of the trigger values and immediate actions were required. The trigger levels were defined at the start of the feedback monitoring programme based on collected data and published information for:
- Sediment spill – The three levels were defined based on duration as a daily spike, 3-day running average exceeds the spill limit and 14-day running average exceeds the spill limit;
- Modelling – Three levels were also defined based on duration e.g. excess of TSS > 5 mg/l for more than 10% of the time for daily, 3-day and 14-day running periods;
- Monitored data – Measured data do not distinguish between background and dredged derived concentrations, but they are important to verify the models and effects that are not resolved by the model. The trigger levels defined based on the type of receptor and the conditions at the site "clear" and "turbid water" were based on baseline data with different trigger values. These values are assessed on a daily, 3-day and 7 day running period.

Analysis

The dredging works were monitored continuously based on daily records. This information was provided by the dredging contractor and included the location of the dredger in time and its operational status (dredging, travel time, disposal, etc.). This information together with overflow sampling was used to carry out modelling and in conjunction with the daily spill records, daily monitoring data at sensitive receptors. The online TSS measurements provided a detailed picture, both in space and time, of the on-site conditions. Based on this information the environmental team evaluated the conditions on daily basis to determine if any violation occurred and, if necessary, define mitigation measures.

Close interaction between the dredging contractor and the environmental team allowed having discussions on the best approaches that would minimize impacts, especially in the northern area, where the most sensitive receptors were located. One of the mitigation actions implemented was that of only allowing turbid water from the dredger's hopper to be "overflowed" into the sea when currents were southward. This way the generated sediment plume was directed southward, away from the most sensitive receptors. A comparison of dredging with controlled and not controlled spill is shown in Figure 4. As can be observed in Figure 4, in controlled operations the TSS levels in the sensitive areas are reduced.

Another implemented mitigation measure was to concentrate the overflow from the hopper along the outer offshore dredging areas so that the plume moves away from the sensitive receptors This was only practical at the initial stages of the project when the dredging area included the overall channel. However, in later stages, when the dredging had to focus on particular sectors of the channel, this option was not viable.

During the dredging the communication between the dredging contractor and the environmental team was extremely important as mitigation measures had to take into consideration operational conditions. In particular conditions an increase in dredging rates was required for a short period for operational reasons. When this occurred the sediment spill impact was closely followed, particularly at the identified sensitive receptors based both on monitoring data and modelling results.
Modelling was extremely important in the analysis as it provided a link between the dredging and the monitoring data. In one case, an exceedance was observed at one particular station and the hindcast modelling confirmed that this was caused by the dredging due to a combination of high spill rates and overflowing from one of the trips at the eastern end of the

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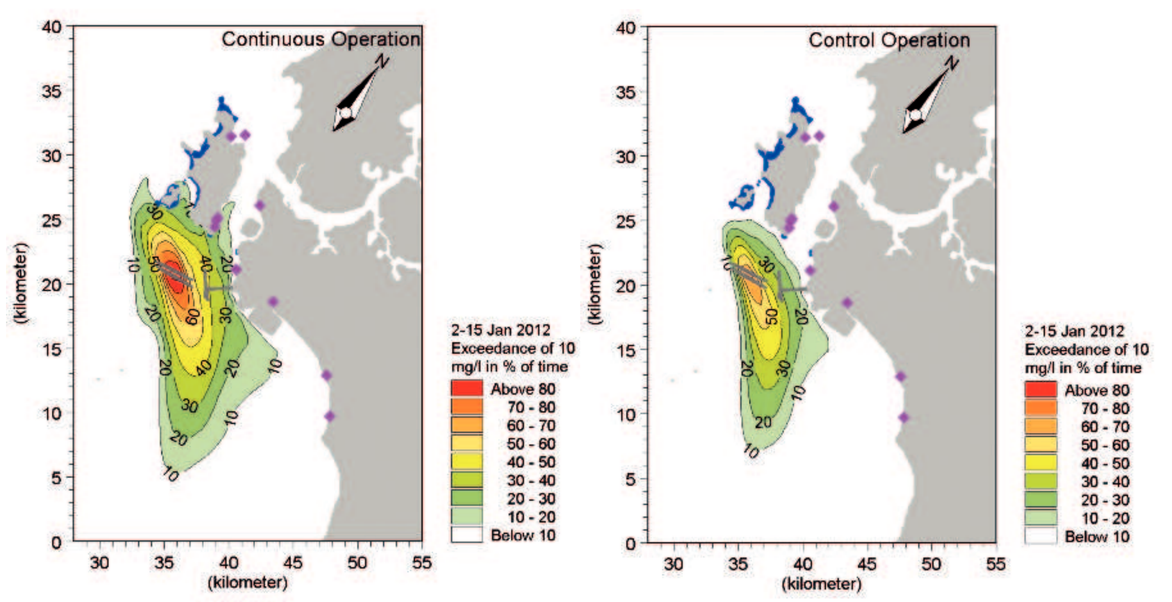

Figure 4. Predicted TSS 10 mg/l level exceedence for continuous (left) and control (right) dredging operations

channel just during flow reversal. This was discussed with the dredging contractor and corrective measures were taken to reduce TSS levels at the sensitive receptor area.
As part of the EMMP there was also close communication between the environmental team and the regulatory authorities. Fortnightly environmental reports were issued and visits to the dredger were organized to brief the authorities on the status of the dredging and the procedures that were in place. A very positive feedback was obtained from these discussions.

Conclusions

The implementation of a feedback EMMP programme can be very beneficial during dredging operations as it provides a detailed assessment of the dredging works and their possible impact on sensitive receptors. This allows for optimization of the dredging operations – both in terms of cost and time – while minimizing impacts on the receptors. In addition, it ensures the authorities that the works are in compliance with what was proposed during the EIA.

The application of this methodology in the Teluk Rubiah, Malaysia has proven to be highly successful as it allowed to handle the uncertainties of the assumptions made in the early stages of the project and produced accurate predictions that enabled the environmental team and the dredging contractor to manage the dredging works with minimal impacts. Through the understanding of the hydraulic and environmental conditions of the dredging area, the critical components from nature that could potentially impact the environment were identified, which allowed for a more efficient approach than the standard mitigation measures that would have added 50% to the cost of the project. Critical to the client, apart from completing the dredging without any environmental breach, was also the fact that the project was completed ahead of schedule at much lower cost than initially calculated. The dialogue between the environmental team, dredging contractor, and the authorities was vital in achieving this successful outcome.

Acknowledgement

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References

S. M. Doorn-Groen, 2007. Environmental Monitoring and Management of Reclamation Works Close to Sensitive Habitats. Terra et Aqua 108, September 2007, pp. 3–18.
CEDA Position Paper, 2015. Integrating Adaptive Environmental Management Into Dredging Projects. Central Dredging Association, March 2015, pp. 1-20.

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Typically, automatic hourly simulations are carried out to forecast water levels and flows in the river channels, and to map the flood inundation process within the flood plains. Hydrological rainfall-runoff models represent the upper catchments, running in continuous simulation mode in order to keep their internal states updated and representative of current conditions. These feed the boundaries of 1D and 2D hydrodynamic models, which model the flows in the river channels, and simulate the movement of water in the flood plains. The results are used to inform and warn DID staff, so they can take immediate action to provide an effective and proactive warning and dissemination response. Results are also passed to DID flood warning web pages, and to dedicated smartphone applications, enabling forecasts to be disseminated more widely. A parallel analytical modelling network, based upon simple but reliable methods such as regression techniques, can take over the forecasting role should the primary systems fail, forecasting water levels at a number of key forecast points around the catchment.

Ongoing structural measures for flood mitigation are captured through a flexible modelling approach that can incorporate model updates to reflect real changes in the catchments, complementing the structural measures being implemented by DID and ensuring a sustainable flood warning solution with long term benefits. ■