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RECOMMENDATIONS ON MEASURING AND DETERMINING TURBIDITY TRIGGER-VALUES

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An Environmetrics Australia Technical Report

Recommended Data Processing and Trigger-Value Methods for the LPC CDP

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Limitations Statement

This report provides recommendations for the processing of monitored turbidity data and their subsequent use in establishing turbidity trigger values. These recommendations are based entirely on the results of desk-top investigations using *indicative* data sets. As such, no claim is made as to the applicability of the approaches to any specific project. The passage of time, manifestation of latent conditions or impact of future events may require further exploration, subsequent data analysis, and re-evaluation of the findings, observations, conclusions, and recommendations expressed in this document. Accordingly, Environmetrics Australia Pty. Ltd. accepts no liability or responsibility whatsoever for or in respect of any use of or reliance upon this document, its recommendations or any other information contained herein by any party.

1. INTRODUCTION

This document provides recommendations for data processing and trigger-value setting as part of Lyttelton Port Company's (LPC) channel deepening project (CDP).

The purpose of this document is to input into proposed consent conditions by setting out proposed methodologies for the following:

1. Development of a statistical profile of background turbidity at all monitoring locations
2. Analysis of the statistical profile of background turbidity
3. Definition of Tier 1, Tier 2 and Tier 3 trigger values based on a modified IFD approach

Inclusion of all the full discussion and technical detail of the proposed methodologies into consent conditions would not be appropriate. Nevertheless, it is vitally important that the mathematical and statistical methodologies as well as the supporting arguments have been documented elsewhere and are readily available for scrutiny by other experts. The wider technical basis underpinning these recommendations is provided in the companion report *"Statistical Considerations Associated with the Establishment of Turbidity Triggers: Candidate Methodologies for Large-Scale Dredging Projects"* (Fox, 2016) hereafter referred to as **The Report**.

Suggested wordings for implementation into the consent conditions and/or the Environmental, Monitoring and Management Plan (EMMP) are provided in the section 2. This text has been provided to provide a clear link between the data collection and processing activities and the establishment and use of trigger-values.

2. SUGGESTED WORDING FOR THE INCLUSION IN THE EMMP AND/OR CONSENT CONDITIONS

I: Data Processing: Quality Assurance

1. Turbidity data will be collected at times, places and sampling frequencies set out in the EMMP;
2. Data integrity and quality will be assured via a two-stage process comprised of *functional QA/QC* methods and procedures and *statistical QA/QC* as described in Section 2 of The Report
3. The *functional QA/QC* component will be undertaken at the time of data acquisition using procedures and processes specified by the responsible Contractor;
4. The *statistical QA/QC* component will be undertaken by an accredited statistician and utilise statistical methods consistent with the activities described in Section 2 of The Report and attached as **Appendix A**;

II: Data Processing: Smoothing

1. The impact of transient, high-frequency oscillations in the time-series of quality-assured turbidity data will be reduced through a process of statistical smoothing;
2. The smoothing technique will be an implementation of the Kolmogorov-Zurbenko (KZ) Filter as described in section 2.1 of The Report with parameters $m=4$ and $k=3$ and attached as **Appendix B**;

III: Data Processing: Treatment of Missing values

1. Treatment of missing individual turbidity readings shall be in accordance with procedures and processes specified by the Contractor responsible for the implementation of the turbidity monitoring program;
2. Treatment of contiguous blocks of missing data for periods in excess of 24 hours and where data from a second instrument is also unavailable shall utilise methods described in Section 2.4 of The Report and attached as **Appendix C**.

IV: Statistical Analysis: Background Turbidity

1. Data used to develop a statistical profile of background turbidity shall have undergone steps I-III above;
2. Statistical procedures used to develop the background turbidity profile shall be consistent with those outlined in Section 3 of The Report, including (but not limited to):
    - Graphical, tabular and numerical summaries organised by site and time;
    - Quantification of spatial and temporal patterns, dependencies and anomalies in the measured turbidity signals;
    - Investigation into the influences of natural forcings such as wind speed, wind direction, rainfall, currents, and tide.
    - Estimation of the parameters in the NTU-TSS relationship and assessment of spatial-temporal dependencies of same;

- Identification of appropriate theoretical distributions to describe overall turbidity properties;
- Assessment of the representativeness of climatic and oceanographic conditions during the background data collection period.

V: Trigger Values

1. Trigger values will utilise monitored data that has undergone steps I-III and augmented with the incremental turbidity due to dredging as predicted by LPC's hydrodynamic modelling. The conversion between modelled TSS and NTU will be achieved using the models identified in IV;
2. The modified IFD approach as detailed in section 4.6 of The Report and attached as **Appendix D** shall be used to establish numerical trigger values;
3. The *intensity* levels associated with the 'Tier 1, 'Tier 2, and 'Tier 3 classifications shall correspond to high order., percentiles of the data in V.1 above (80^{th}., 95^{th}., and 99^{th} are suggested);
4. The permissible number (*frequency*) of 'Tier1, 'Tier2, and 'Tier3 exceedances in a reporting period will be determined in accordance with the method outlined in section 4.6 of The Report and attached as **Appendix D**;
5. The maximum average *duration* of 'Tier 1, 'Tier 2, and 'Tier 3 exceedances in a reporting period will be determined in accordance with the method outlined in section 4.6 of The Report and attached as **Appendix D**;
6. The management response associated each of the 'Tier 1, 'Tier 2, and 'Tier 3 triggers is <u>not</u> required provided both the number and average duration of turbidity exceedances in the reporting period are within the limits identified in V.4 and V.5 above;
7. Contemporaneous control charting of *median* turbidity at sentinel sites and the rolling 80^{th}. percentile of turbidity at a selected reference site(s) as described in section 4 of The Report may be used as an internal LPC back-up monitoring tool.

V1: Cause and Effect

1. In the event turbidity conditions resulting in a 'Tier 3' exceedence a detailed analysis of all turbidity data obtained from steps I-III up to and including the time of exceedance will be undertaken using methods described in sections 2.2 and 2.3 of The Report;
2. The findings associated with the analyses undertaken in V1.1 will be used by LPC to assist in the assessment of the relative contributions of 'natural' and dredge-related turbidity to the measured turbidity signal.

References

ANZECC and ARMCANZ (2000). National Water Quality Management Strategy, Paper No. 7a Australian Guidelines for Water Quality Monitoring and Reporting, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Fox, DR. (2016). Statistical Considerations Associated with the Establishment of Turbidity Triggers Candidate Methodologies for Large-Scale Dredging Projects. Environmetrics Australia Technical Report, Beaumaris, Victoria, September 16 2016.

McArthur, C., Ferry, R., Proni, J. (2002) Development of guidelines for dredged material disposal based on abiotic determinants of coral reef community structure. *Proc. Third Specialty Conference on dredging and dredged material disposal*, Coasts, Oceans, Ports and Rivers Institute (COPRI) of ASCE, May 5, 2002, Orlando, FL USA.

Appendix A : QA/QC methods

The Report makes a distinction between **functional QA/QC and statistical QA/QC.** The former relates to the preliminary data processing activities undertaken at or close to the time of data acquisition and utilise agreed procedures to ensure that no gross errors of recording have occurred. These activities include, but are not limited to:

- Flagging and if necessary, removing readings obtained when equipment was known to be faulty, unreliable, or unserviceable;
- Flagging, but not removing readings obtained during adverse weather or oceanographic conditions;
- In the case of dual-instrument deployments, aggregating readings in accordance with agreed protocols;
- Implementing agreed protocols in the case of instrument failure for a dual-instrument deployment.

Functionally-assured data are to undergo further, more detailed analysis by a qualified statistician to identify anomalous readings and, were appropriate to take remedial action. The focus of this statistical QA/QC process is to:

- Identify extreme and unusual data in terms of their *statistical* properties;
- Use statistical data imputation techniques in accordance with agreed protocols to overcome problems created by blocks of missing data;
- Use statistical smoothing techniques in accordance with agreed protocols to attenuate the influence of aberrant observations; and
- In accordance with agreed protocols, apply low-pass statistical filters to characterise the nature of the underlying response-generating process and of the stochastic error component.

Appendix B : Kolmogorov-Zurbenko (KZ) Filter method

Quality-assured data (*see Appendix A*) will be smoothed using a version of the Kolmogorov-Zurbenko (KZ) Filter in order to:

- reduce the influence of extremely high and transient individual turbidity readings that are not indicative of the overall turbidity time-series;
- obtain an estimate of the underlying time-varying turbidity signal in a way that preserves the key features of the turbidity trace with minimal loss of fidelity;
- assist in the identification of patterns and trends in the turbidity signal.

In the following, $X(t), t = 0, \pm 1, \pm 2, \ldots,$ denotes a 'raw' turbidity reading taken the t^{th} time increment (assumed to be 15 minutes) relative to the present time. The KZ filter computed by taking *k* time iterations of a moving average (MA) filter of *m* points is given by Equation B.1.

$$KZ_{m,k}\left[X(t)\right] = \sum_{s=-k(m-1)/2}^{k(m-1)/2} \frac{a_s^{m,k}}{m^k} X(t+s) \qquad \text{(B.1)}$$

where the $a_s^{m,k}$ terms are given by the polynomial coefficients of $\left(1+z+\cdots+z^{m-1}\right)^k$:

$$\sum_{s=-k(m-1)/2}^{k(m-1)/2} z^{s+k(m-1)/2} a_s^{m,k} = \left(1+z+\cdots+z^{m-1}\right)^k \qquad \text{(B.2)}$$

For the LPC project, the values for *m* and *k* will be set at 3 (the rationale for this choice is provided in Section 2 of The Report). With these values of *m* and *k*, the current KZ-smoothed value is computed by applying the weights $\left\{\frac{6}{27}, \frac{3}{27}, \frac{1}{27}\right\}$ to the raw turbidity readings obtained 15, 30, and 45 minutes both *prior* to and *subsequent* to the present time and summing. To this result is added $\left\{\frac{7}{27}\right\}$ of the current raw turbidity reading to obtained the current smoothed value. This scheme implies that the smoothing at each 15-minute time increment is based on a window of width 1.5 hours centred on the current reading.

Computational details are also outlined under the heading 'Implementation' in Section 2 of The Report.

Appendix C : Treatment of missing blocks of data

An advantage of the KZ Filter (*see Appendix B*) is that it is robust to the presence of small amounts of missing data. With a 15-minute time-increment and *m=3* and *k=3*, the KZ-filter will be a weighted average of the current turbidity reading and the three adjacent readings. Although a smoothed turbidity reading will be produced at the same frequency as the sampling (ie. one every 15 minutes) it will lag the raw data by 45 minutes. As discussed in The Report, missing data pose various challenges for the subsequent statistical analysis and treatment of the turbidity series. Under the scheme outlined in this document, the KZ filtering of data can continue provided there is no more than six (6) contiguous missing values of the recorded turbidity. Where more than 6 contiguous readings are reported as 'missing', advanced statistical modelling techniques as discussed in section 2.4 of The Report shall be used to statistically 'impute' the likely values of the missing data. This data imputation will be done in such a way that the resulting sequence:

(i) is consistent with the autocorrelation of the actual data recorded prior to the period of 'missingness';

(ii) utilises actual data recorded at nearby locations using spatial covariance modelling techniques;

(iii) has statistical properties that are consistent with actual data recorded immediately prior and following the period of 'missingness'.

Appendix D : Modified IFD method

The use of turbidity trigger-values to monitor and manage water quality during dredging campaigns is a well-established, industry best-practice that is consistent with the methods and procedures outlined in the Australian and New Zealand Water Quality Management Strategy (ANZECC/ARMCANZ 2000). Recent large-scale dredging projects in Australia have adopted an approach outlined in McArthur et al. (2002) which enhances the trigger-value method by utilising the concepts of allowable *duration* and *frequency* as an adjunct to the *intensity* of turbidity. Recent work by Fox (2016) has identified flaws in the implementation of the McArthur et al. (2002) methodology. Accordingly, LPC propose to follow the procedure outlined in Fox (2016) which addresses these issues.

A key observation in the Fox (2016) report is that the three quantities (*Intensity, Frequency,* and *Duration*) are inter-related. Thus, for a given rate of exceedence, these three parameters cannot be altered arbitrarily and independently of each other as was assumed by McArthur et al. (2002). The approach outlined by Fox (2016) which LPC proposes to adopt, proceeds as follows:

(i) Frequency-duration curves for both background only and background + predicted incremental turbidity will be established for exceedence levels in the range 50-100%. The exceedence probability determines the *intensity* level which is a percentile of the relevant distribution (background or background + dredge). It is proposed that Tiers 1 to 3 will be identified as the 80^{th}., 95^{th}., and 99^{th}. percentiles respectively of the site-specific distribution of background + dredge turbidity.;

(ii) The curves identified in (i) will then be used to establish the corresponding annual[1] *frequency* and *durations* for each of the three tiers. The difference between the *frequency* and *duration* parameters determined from an analysis of background data only and those determined from the background + dredge data represents the permissible change in the turbidity profile at the nominated Tier level.

Further details are provided in section 4.6 of The Report.

[1] These annual parameters may be scaled to any convenient timeframe (eg. monthly, quarterly etc.)