Appendix 6: Dispersion Modelling of Nutrients in Honiara 2022

Date: September 22nd, 2022
Our reference: POC-2076
Version: V.1.0

Dispersion modelling of nutrients in Honiara

Solomon Islands

Final Report

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Changes

Version	Changes	Authors	Checked by	Date
V1.0	Initial version	Marc Pavec	Jean-Pierre Mazé	22/09/2022

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1. INTRODUCTION

An urban sanitation project in Honiara (Solomon Islands) plans to collect wastewaters of the city, and to reject those waters at sea after treatment by two outfalls.

In a first stage of the project in 2019 and 2020, Actimar has performed a modelling of the bacteriological impact of these outfalls. In this follow-up of the study, the impact is studied in terms of nutrients: Nitrogen and Phosphorus.

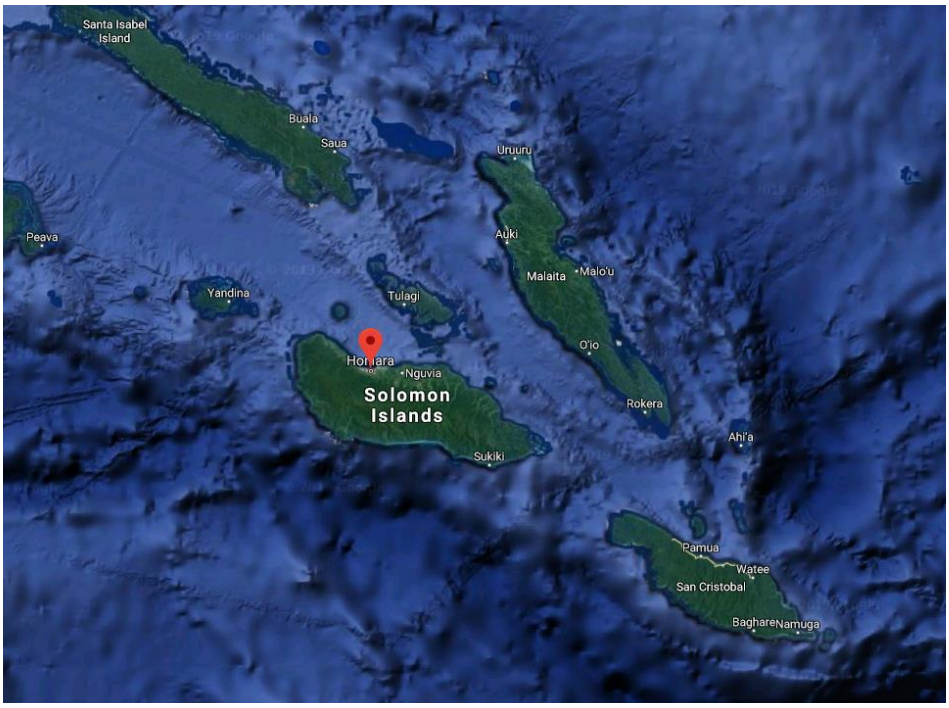


Figure 1-1: Location of the project

The numerical model built and validated by Actimar for the first study has been refined in the area of the project to represent more accurately the plume dispersion.

The modelling system is described in the first part of the report, the discharge characteristics and the computation hypothesis are then described. The results in terms of nutrients concentration are then presented.

2. INPUT DATA ANALYSIS

2.1 BATHYMETRY

Bathymetric data are needed to construct the model grids. Local bathymetric maps are available along three narrow corridors around the planned outfalls, marine charts provide a few soundings in the area, and a global large-scale bathymetry (GEBCO, (see **Erreur ! Source du renvoi introuvable.**) can be used for offshore areas. A mix has been done between those different sources to build the model grid.

2.2 WIND

The NCEP-CFSR hindcast has been used to characterize the wind conditions over the area. The NCEP (National Centers for Environmental Prediction) conducted several climate reanalyses since the 1990s.

The global NCEP-CFSR (Climate Forecast System Reanalysis) was designed as a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system to provide the best estimate of the state of these coupled domains.

The CFSR dataset has a global horizontal resolution of around 0.3° and an hourly temporal resolution for the period 1979-2010. On March 2011, NCEP upgraded CFS to version 2. The CFSV2 analysis.

Data assimilated in CFSR reanalysis are both historical and operational archives of observations and newly reprocessed sets of observations being produced at meteorological research centres around the world.

The CFSR global reanalysis and CFSV2 real time data provide a wide range of meteorological parameters including hourly wind speed at 10 m height (u and v components in m/s), temperature at 2 m height, specific humidity at 2 m and pressure at mean sea level. The data are available an hourly temporal resolution and for 5 pressure levels. The CFSR output products are available on a 0.3° regular grid. The CFSV2 operational results are distributed on a regular grid about 0.2° resolution.

Atmospheric conditions of the year 2017 are used for the simulations.

2.3 Tide

2.3.1 Database

A database of tidal components needs to be applied at the boundaries of the largest model. FES 2014 is used for that purpose. FES2014 is the version of the FES (Finite Element Solution) tide model developed in 2014. It is a fully revised version of the global hydrodynamic tide solutions. The new model has been developed, implemented and validated by the LEGOS, NOVELTIS and CLS, within a CNES funded project.

FES2014 takes advantage of longer altimeter time series, improved modelling and data assimilation techniques, and more accurate ocean bathymetry. Special efforts have been dedicated to address the major non-linear tides issue and to the determination of accurate tidal currents. FES2014 solution shows strong improvement compared to previous versions, particularly in coastal and shelf regions.

32 tidal constituents are distributed on 1/16° grids (amplitude and phase). These constituents have been used to compute water level elevations at our model boundaries.

2.3.2 Measurements IOC

A tidal gauge at Honiara provides measurements of sea level (http://www.ioc-sealevelmonitoring.org/). Data have been extracted in January 2019 (Figure 2-1). The plot shows a daily oscillation of the level with small perturbations probably linked to a weak semi-diurnal component. A long-term oscillation of the tidal amplitude of about 2 weeks is also observed, corresponding to the classical alternation between neap tides and spring tides.

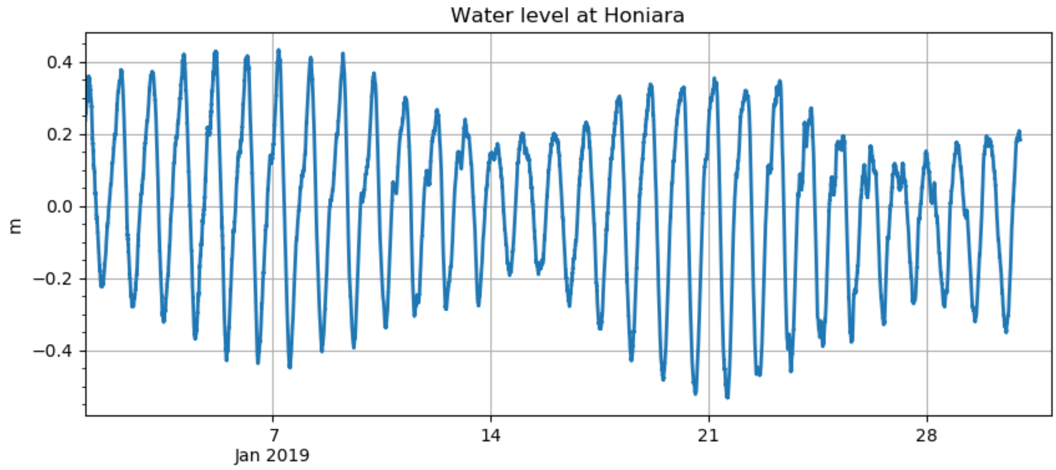


Figure 2-1 - water level relative to mean sea level at honiara

3. MODEL SET-UP

3.1 SEAMER CODE

The 3-dimensionnal hydrodynamic model used for this study is SEAMER.

SEAMER is a derivative code from MARS model of IFREMER (French Research Institute for Exploitation of the Sea). The codes evolved individually since the 90’s and SEAMER is now maintained by ACTIMAR.

This model solves the Navier–Stokes equations under the conventional Boussinesq and hydrostatic assumptions. SEAMER uses a finite-difference grid.

The main features of the models are:

- Tidal induced currents
- Wind induced currents
- Density currents from a schematic thermohaline stratification

The model does not take into account a regional circulation from an OGCM (Oceanic General Circulation Model) as the dynamics in the area is mainly local.

3.2 MODEL CONFIGURATION

The model uses the principle of nested grids. It means that the modelling system consists in a series of embedded hydrodynamic models, from the regional scale (resolution of a few kilometres) to a local model (resolution of about 30 m) around the area of interest.

The large-scale models, mainly dedicated to the propagation of tide, are 2-dimensional, while the local model is 3-dimensional.

The 3-dimensional grid uses 10 vertical layers. The grid dimensions are summarized in the following figure and table. The first 4 grids are similar to the ones used for the previous study, a fifth grid with a 30-m resolution has been added for a more precise zoom over Honiara.

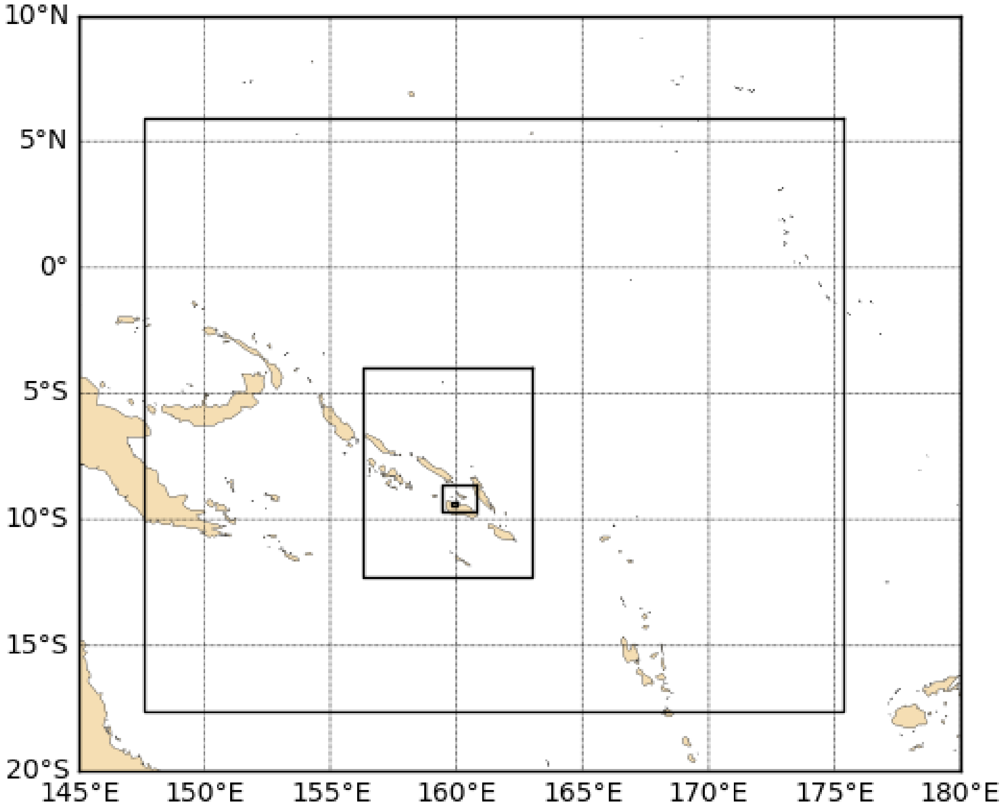


Figure 3-1: Nested model (ranks 0 to 3)

Table 3-1: Nested model's configurations

Rank	0	1	2	3	4
Type	2D	2D	2D	2D	3D (10 levels)
Mesh size (m)	10000	2000	400	100	30
Min longitude	147.5735931	156.2872514	159.4493212	159.8194271	159.8609067
Max longitude	175.3315354	163.0246160	160.7967941	160.0565823	160.0466240
Min latitude	-17.6108398	-12.3022502	-9.6703417	-9.4382365	-9.4369121
Max latitude	5.9628971	-3.9410172	-8.6347955	-9.2847836	160.0466240
Number of mesh in longitude	310	376	376	264	681
Number of mesh in latitude	263	468	291	173	399
Boundary condition	FES2014	Rank 0	Rank 1	Rank 2	Rank 3

The bathymetry described in §2.1 has been interpolated on the 5 grids, the resulting bathymetry for the local 3D model is presented on Figure 3-2.

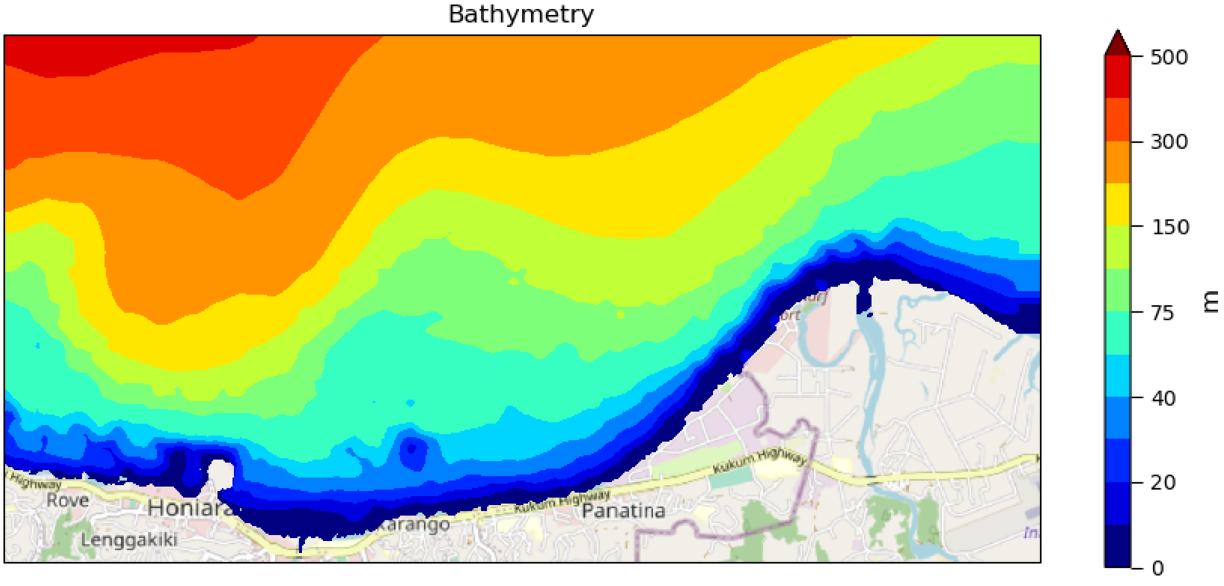


Figure 3-2 - Model bathymetry for the rank 4 – zoom on the area of the discharges.

3.3 BOUNDARY CONDITIONS AND FORCINGS

Wind conditions are applied on every model (ranks 0 to 4).

Tidal components are imposed at the boundaries of the largest model (rank 0).

3.4 MODEL VALIDATION

The validation in terms of water level has already been presented in the previous studies. The new grid added for the last zoom does not significantly modify the performance of the modelling system

The model is validated only against water level measurements. The model has been run for the month of January 2019, during the period of measurements shown on Figure 2-1.

No vertical stratification and no atmospheric forcing have been used for these validation runs.

The direct comparison of modelled data against measured data is presented on Figure 3-3. This first figure shows that the phase of the tide is perfectly reproduced by the model. The amplitude is well represented too, with some little discrepancies especially on high tides. The alternation between neap tides and spring tides is also very well reproduced by the model. The observed discrepancies can have two main origins:

- A too coarse bathymetry. In coastal areas, the tide is strongly governed by the bathymetry. The bathymetry used in this study is maybe not able to reproduce all the local features of the bathymetry.
- Atmospheric effects. Water level can be affected by changes in wind and pressure. As no atmospheric forcing has been used in this validation run, these effects cannot be represented.

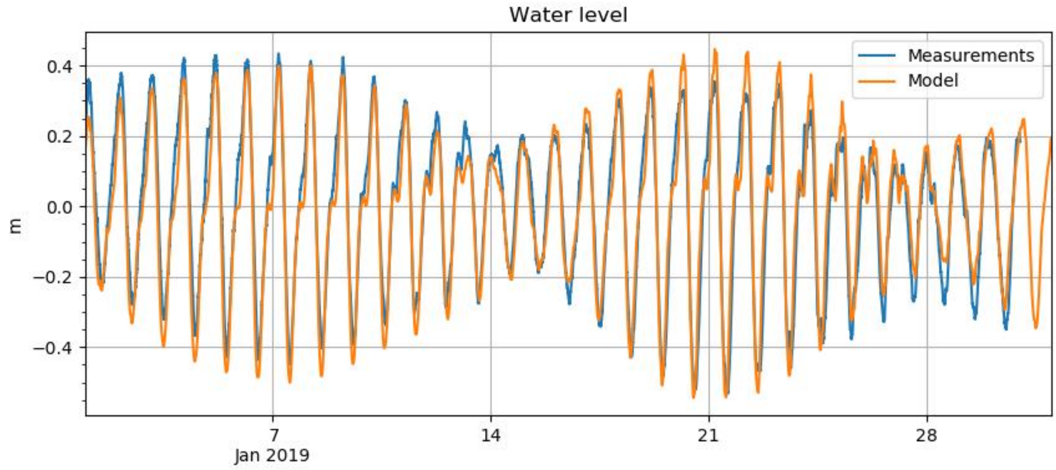


Figure 3-3 - Comparison between model and measurements for water level

To refine this first analysis, a statistical analysis has been made. The results are presented on Figure 3-4. The Root Mean Square Error (RMSE) of the model for the complete dataset over more than 4600 observations during January 2019 is 0.07 m, with a bias of 0.01 m. The plots confirm the very good performance of the model in the whole range of observed levels.

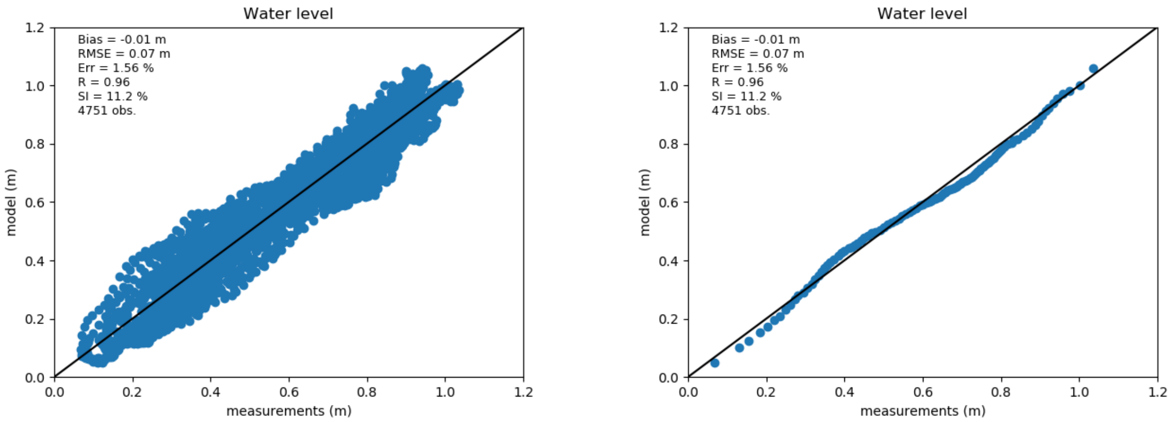


Figure 3-4 - Scatter plot (left) and QQ-plot (right) for water level

4. DISCHARGE MODELLING

4.1 SCENARIOS

4.1.1 METOCEAN SCENARIOS

The simulation has performed over the year 2017 as wind conditions for this year have been considered representative of a typical year. Realistic tidal forcings and atmospheric conditions for 2017 have been considered.

4.1.2 DISCHARGE SCENARIOS

4 discharge scenarios have been studied, corresponding to different stages of the sanitation project implementation. The flow rate and the concentration are summarized in Table 1. As the simulation is conducted over a complete year, hourly variations in the flow rate are considered negligible on the concentration plume. Only daily rates are then considered.

Table 1 - Flow rate and concentration for the 4 discharge scenarios

Scenario	**Daily flow rate (L/s)**		**Concentration**	
	Ranadi	NRH	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Phase 1A (2025)	98.6	42.4	40	10
Phase 1B (2030)	109	48.4	40	10
Phase 2 (2035)	152	66.3	40	10
Phase 3 (2050)	281	0	40	2

As no simple method can be applied to determine the decay rate of Nitrogen and Phosphorus in seawater, we have made the choice to consider conservative tracers. It means that there is no physical or biological degradation of Phosphorus and Nitrogen in the water during the simulation. The concentration rate decreased only by mixing and dissipation processes. This is a very strong assumption, but it ensures that the modelled concentration will be greater than the real one. So, if the concentration is acceptable for the modelled processes, it will also be acceptable in the real environment.

If the modelled concentration is not acceptable for water quality standards, another method with an approximative decay rate could be used.

4.2 RESULTS

Three types of results are presented in this section:

Maximum concentration maps

Results are presented as maps of maximum concentration over the water column through the whole simulation. These maps do not represent an instantaneous state of the plumes but can be seen as the maximum envelope of the plumes for the simulated period. The maximum concentration is always reached at the surface as the plume is composed of freshwater.

Exceedance time of thresholds

The maps represent the percentage of time the concentration is over a given threshold for a typical year. The thresholds are 200 µg/L for Total Nitrogen and 25µg/L for Phosphorus.

Percentiles

The percentile 90 is plotted for Phosphorus and Nitrogen. The percentile 90 means that the concentration is over this concentration 10% of a typical year.

In addition to these results, monthly maps have been established. They are not included in this version of the report for ease of reading, but they can be added in a future version of the report or delivered as numerical independent files.

4.2.1 Phase 1A – Maximum concentration

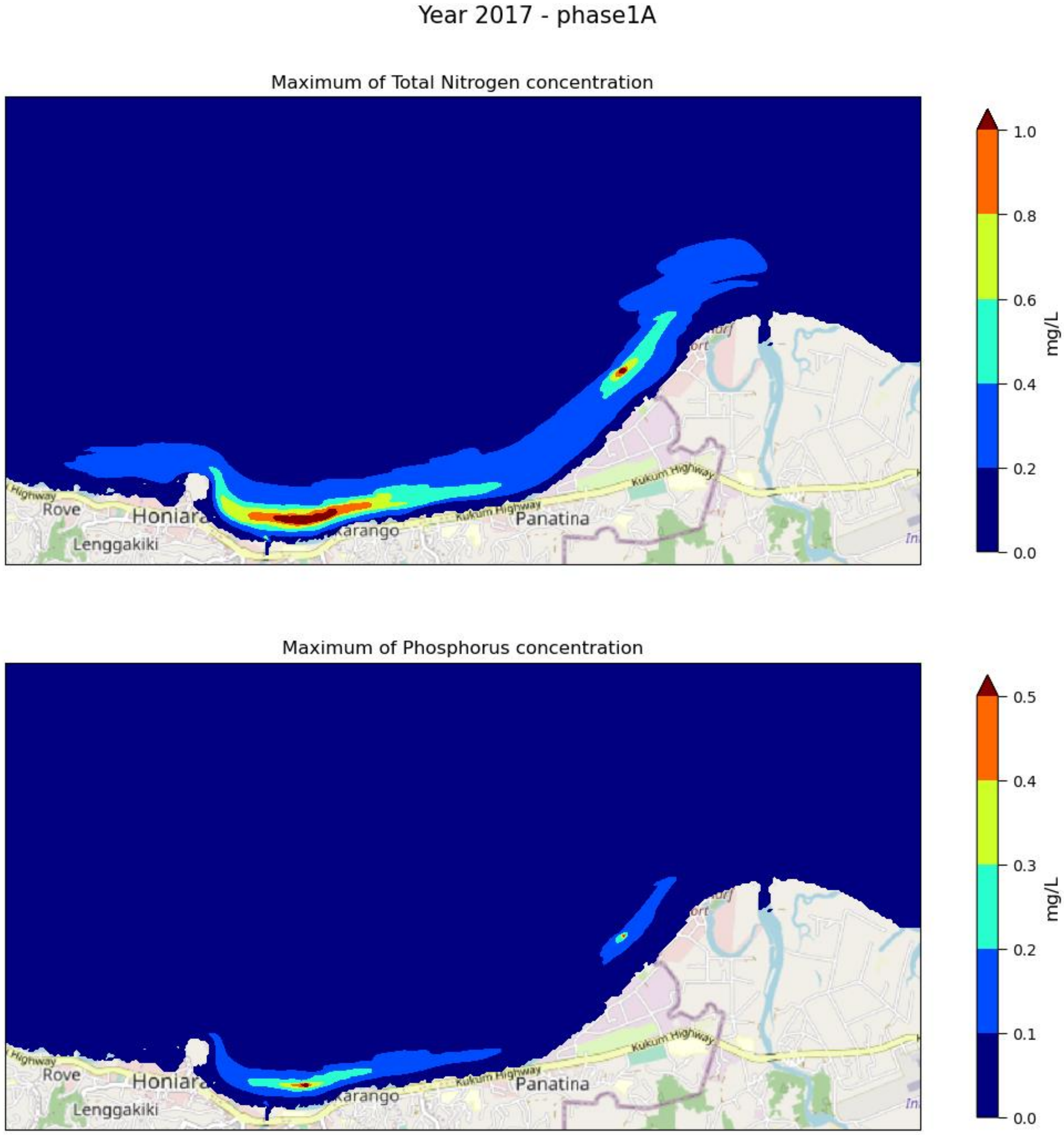


Figure 5 - Maximum of nutrients concentration for year 2017 - Phase 1A

4.2.2 PHASE 1A – EXCEEDANCE MAPS

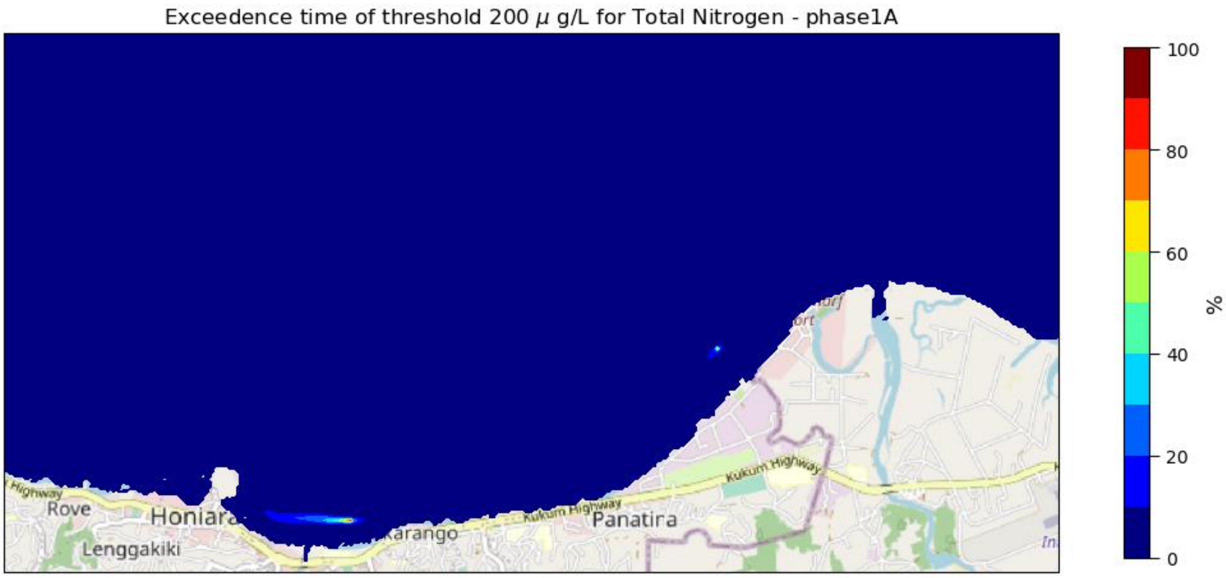
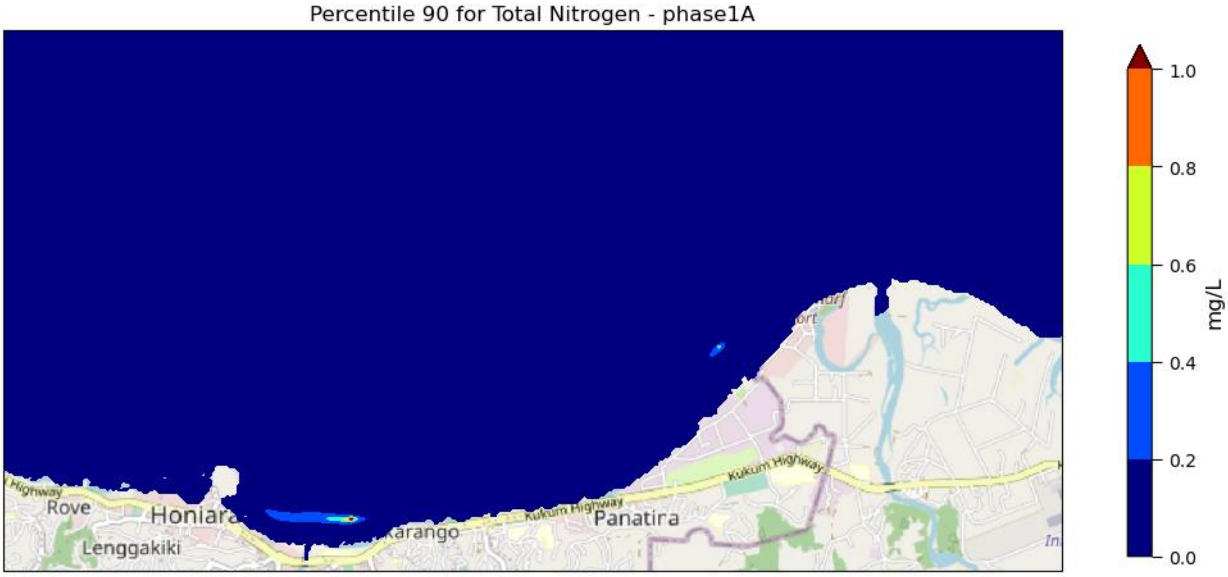


Figure 6 - Percentage of time the concentration is over 200µg/L for Nitrogen and over 25 µg/L for Phosphorus over the year 2017 – Phase 1A

4.2.3 Phase 1A – Percentiles



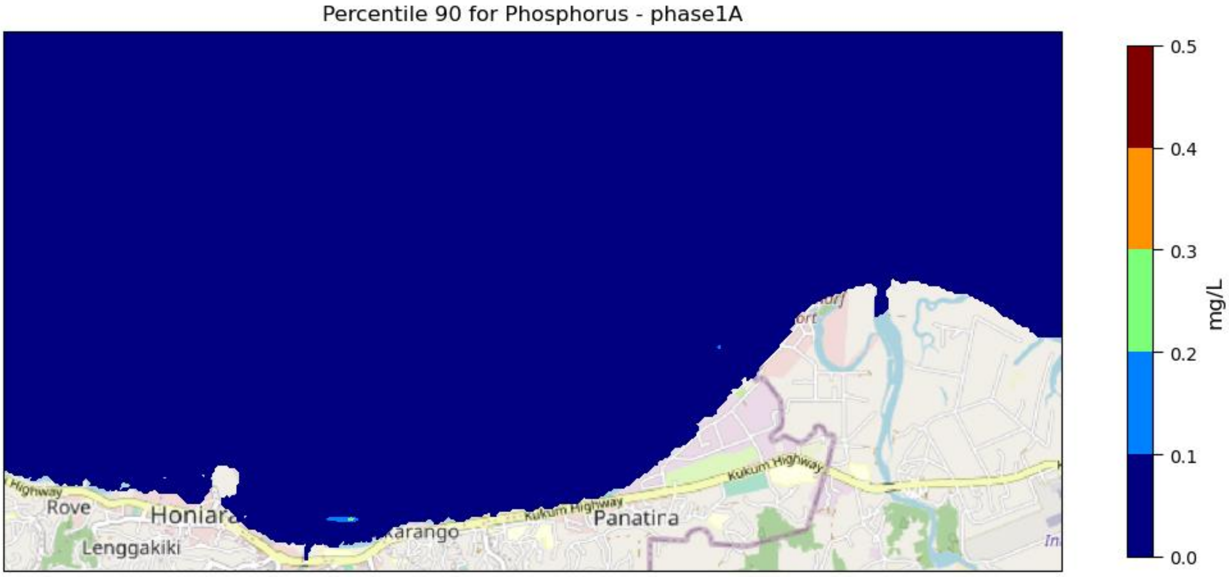


Figure 7 - Percentile 90 of the concentration in Nitrogen and Phosphorus – Phase 1A

4.2.4 Phase 1B – Maximum concentration

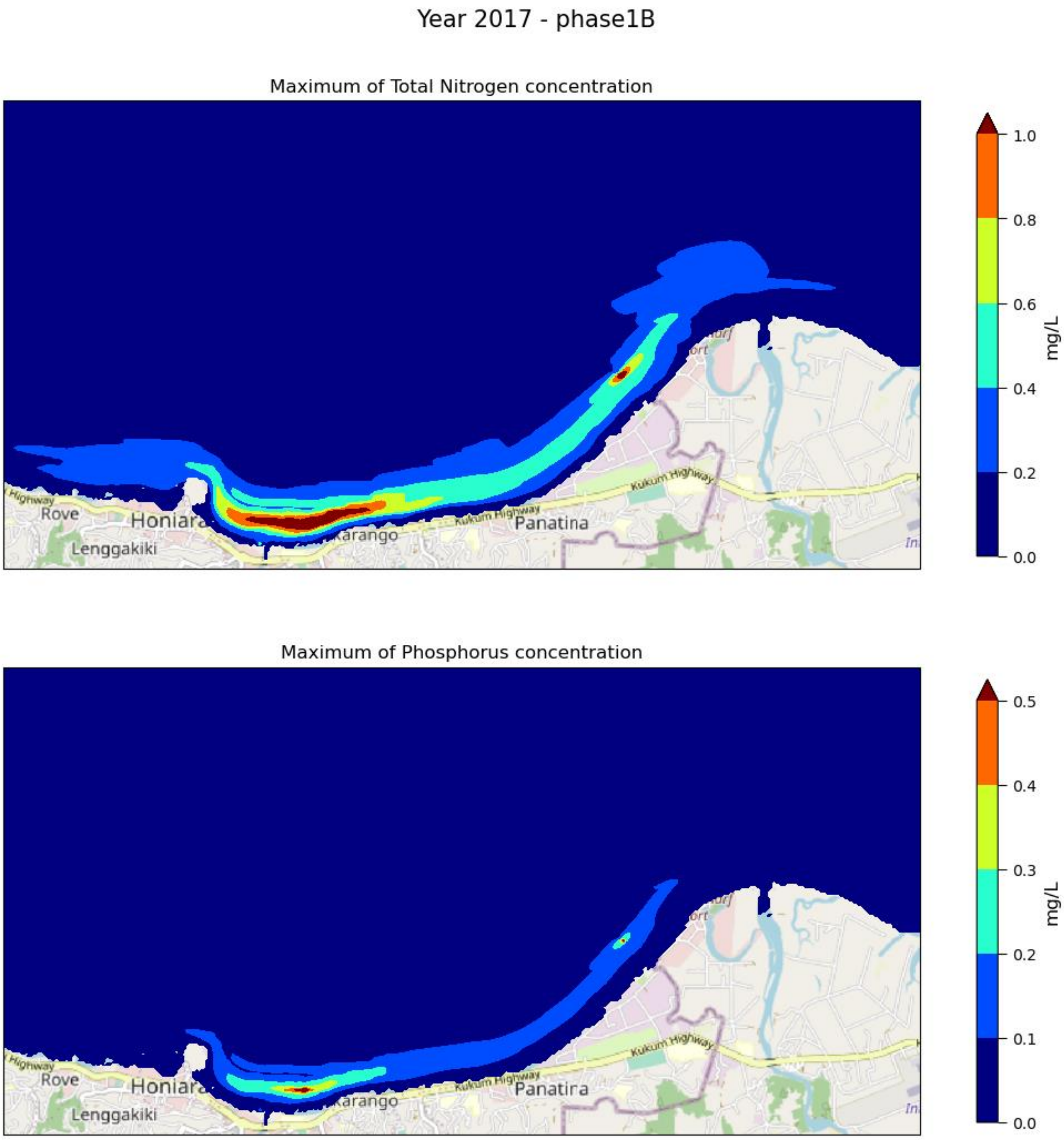


Figure 8 - Maximum of nutrients concentration for year 2017 - Phase 1B

4.2.5 Phase 1B – Exceedance maps

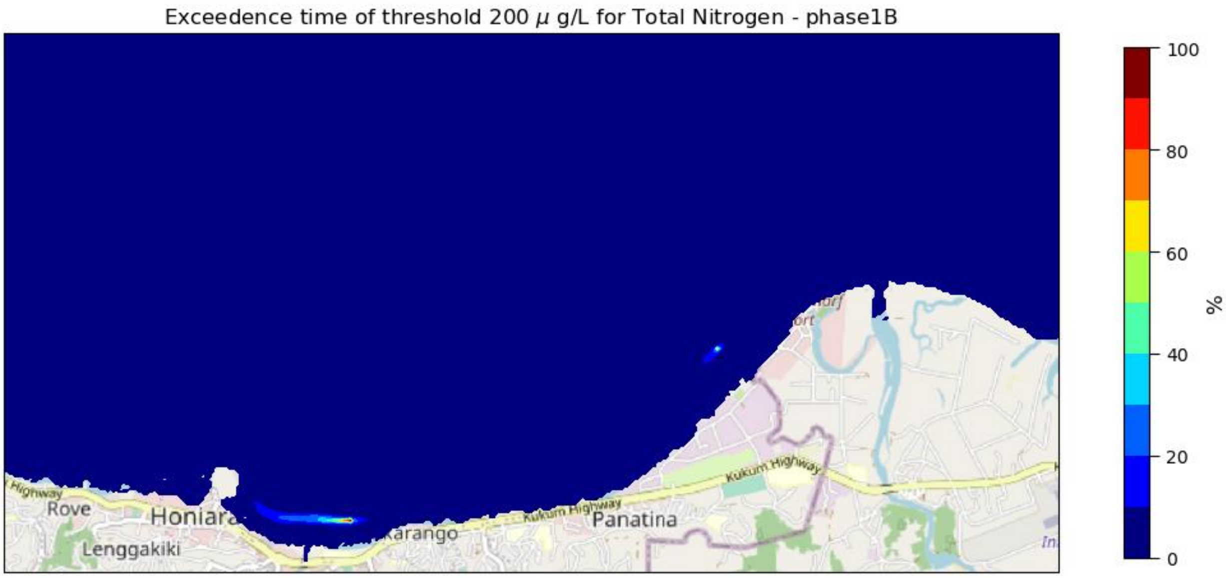


Figure 9 - Percentage of time the concentration is over 200µg/L for Nitrogen and over 25 µg/L for Phosphorus over the year 2017 – Phase 1B

4.2.6 Phase 1B – Percentiles

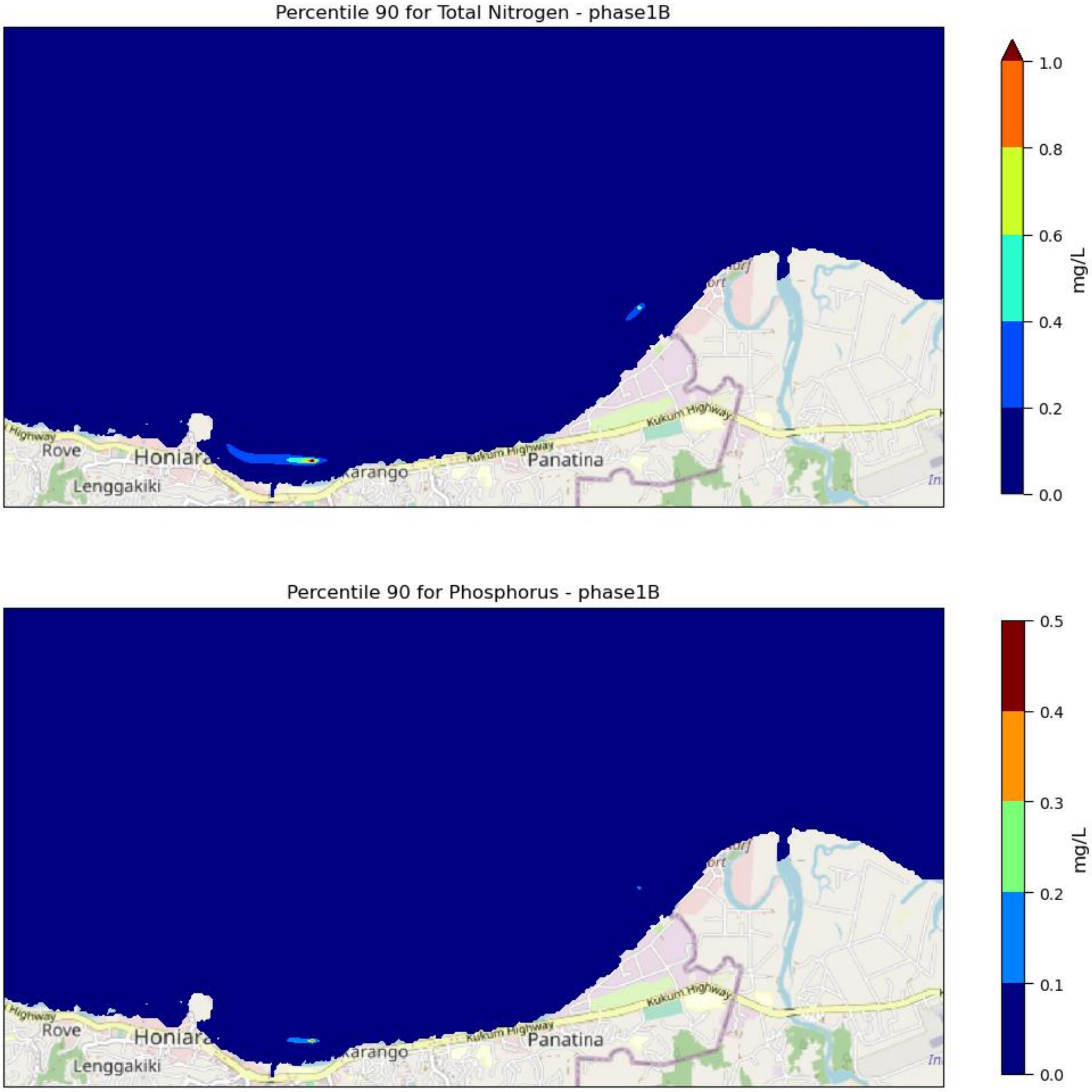


Figure 10 - Percentile 90 of the concentration in Nitrogen and Phosphorus – Phase 1B

4.2.7 PHASE 2 – MAXIMUM CONCENTRATION

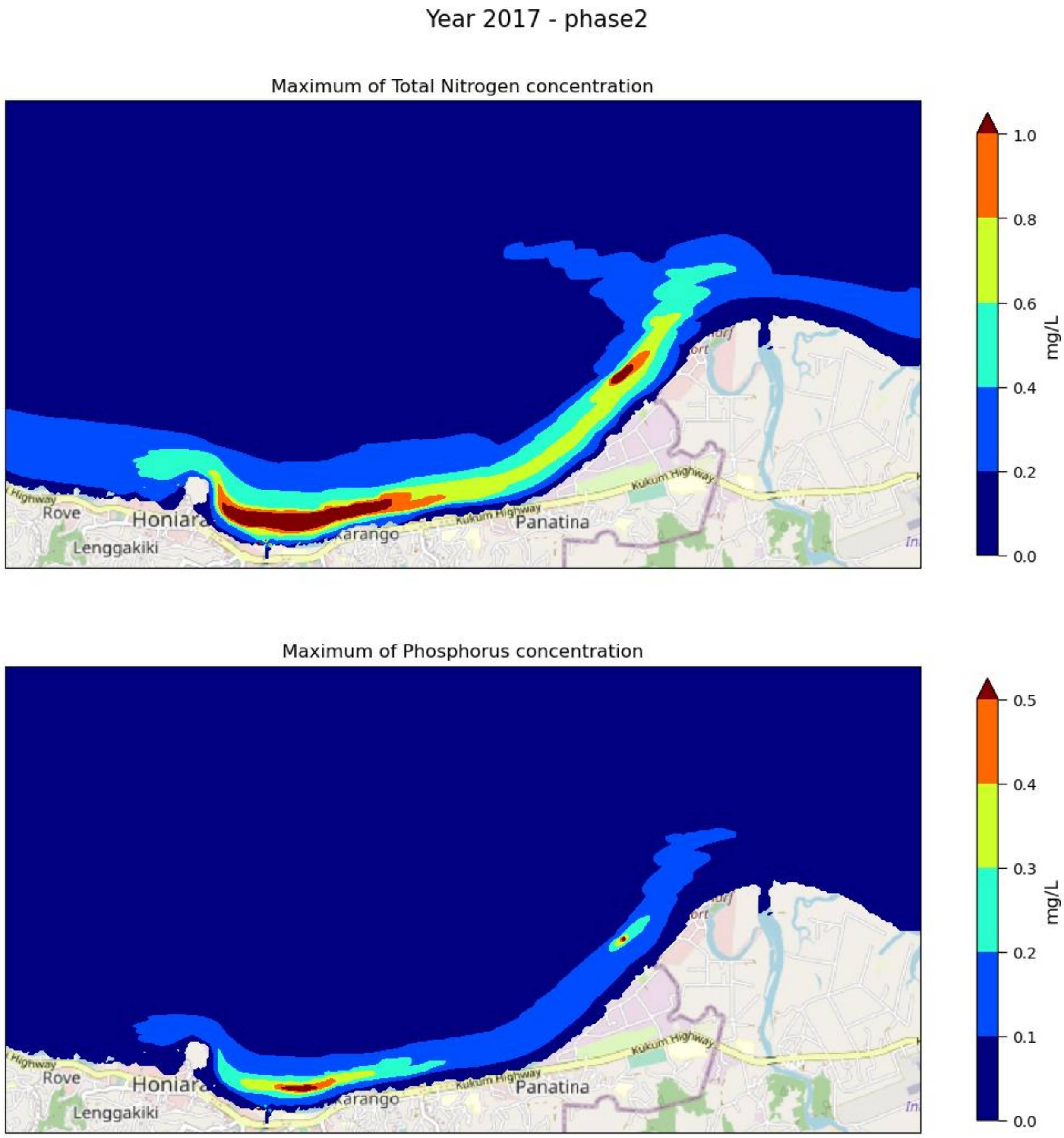


Figure 11 - Maximum of nutrients concentration for year 2017 - Phase 2

4.2.8 Phase 2 – Exceedance maps

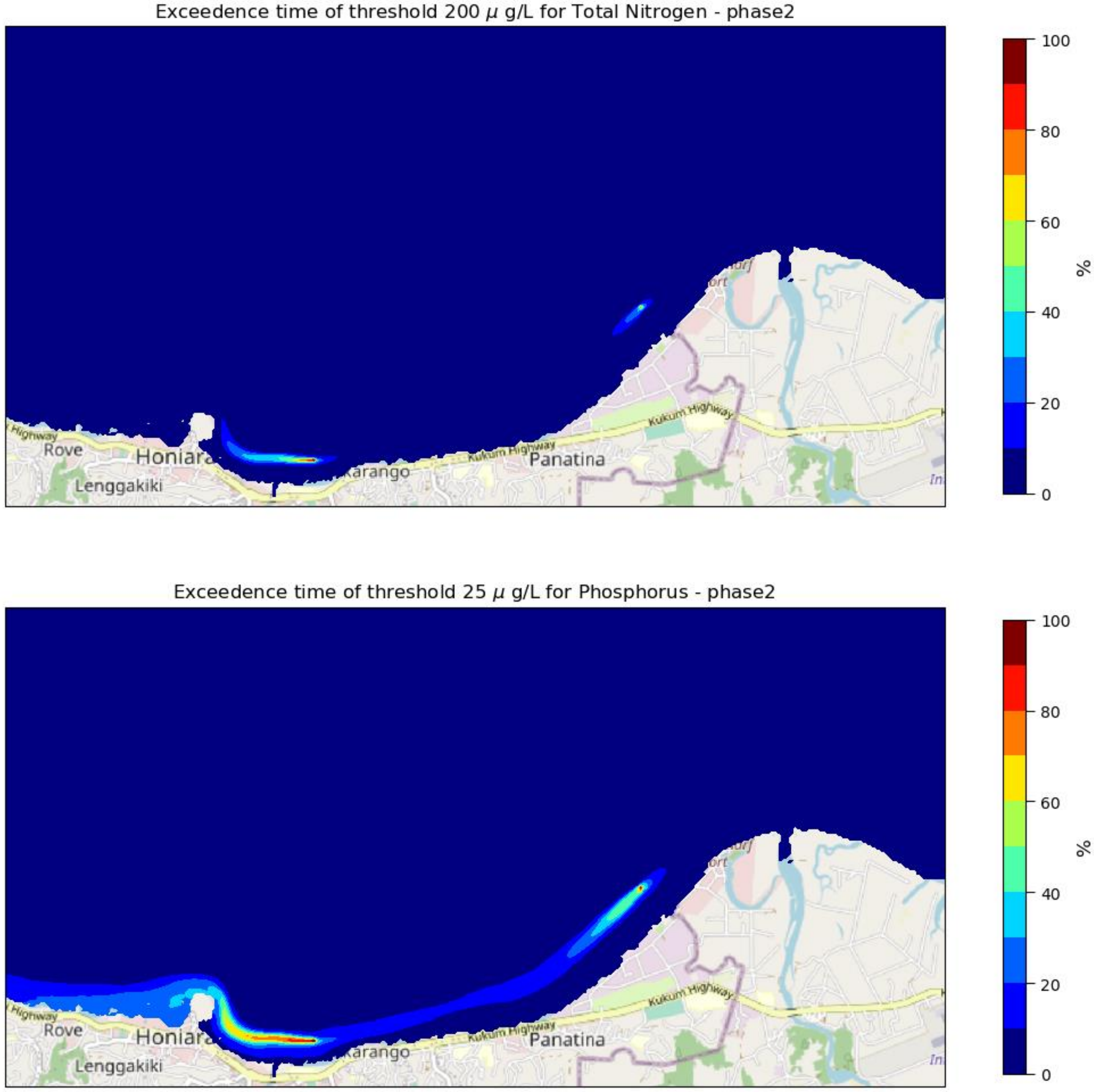


Figure 12 - Percentage of time the concentration is over 200µg/L for Nitrogen and over 25 µg/L for Phosphorus over the year 2017 – Phase 2

4.2.9 Phase 2 – Percentiles

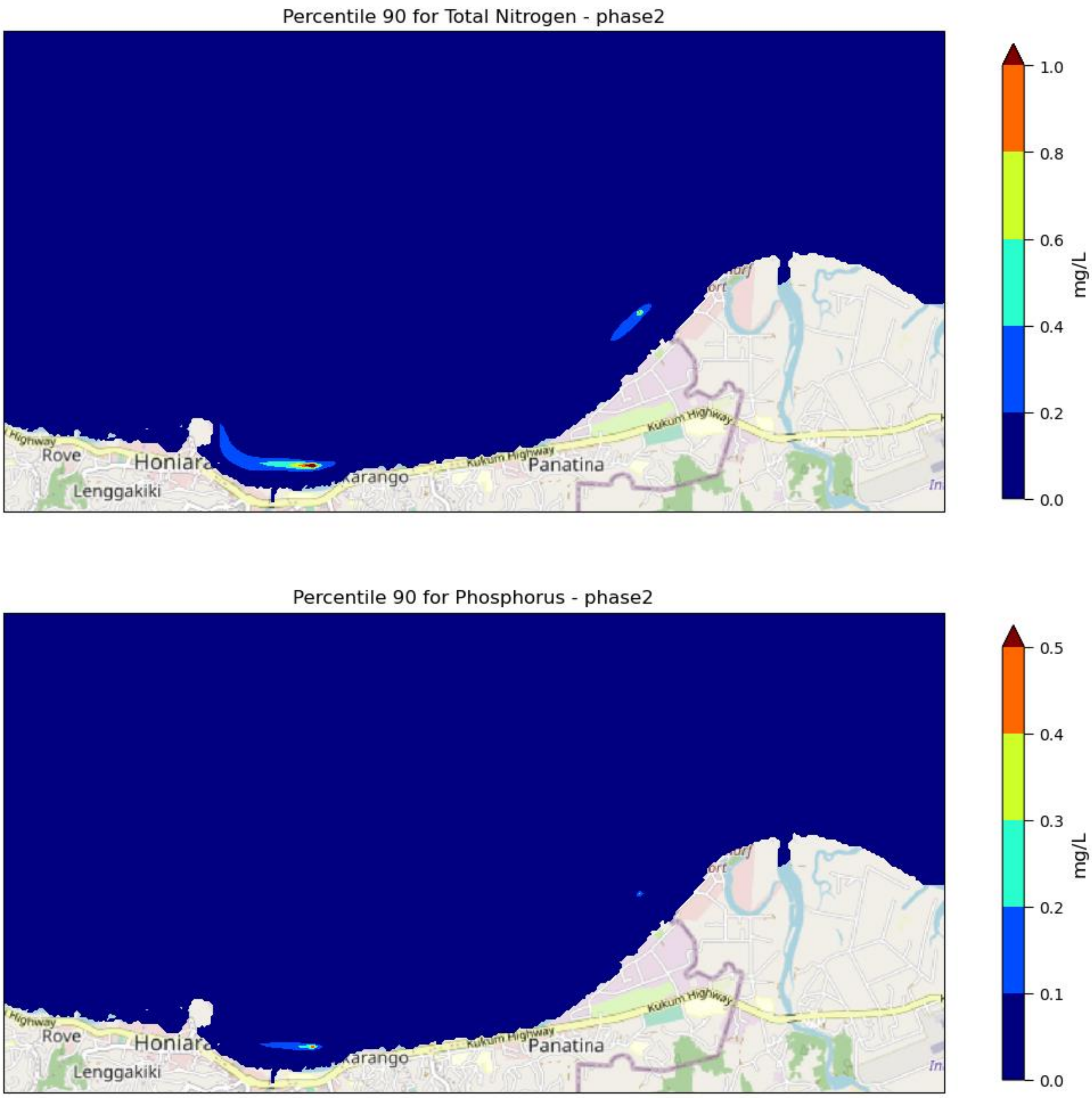


Figure 13 - Percentile 90 of the concentration in Nitrogen and Phosphorus – Phase 2

4.2.10 Phase 3 – Maximum concentration

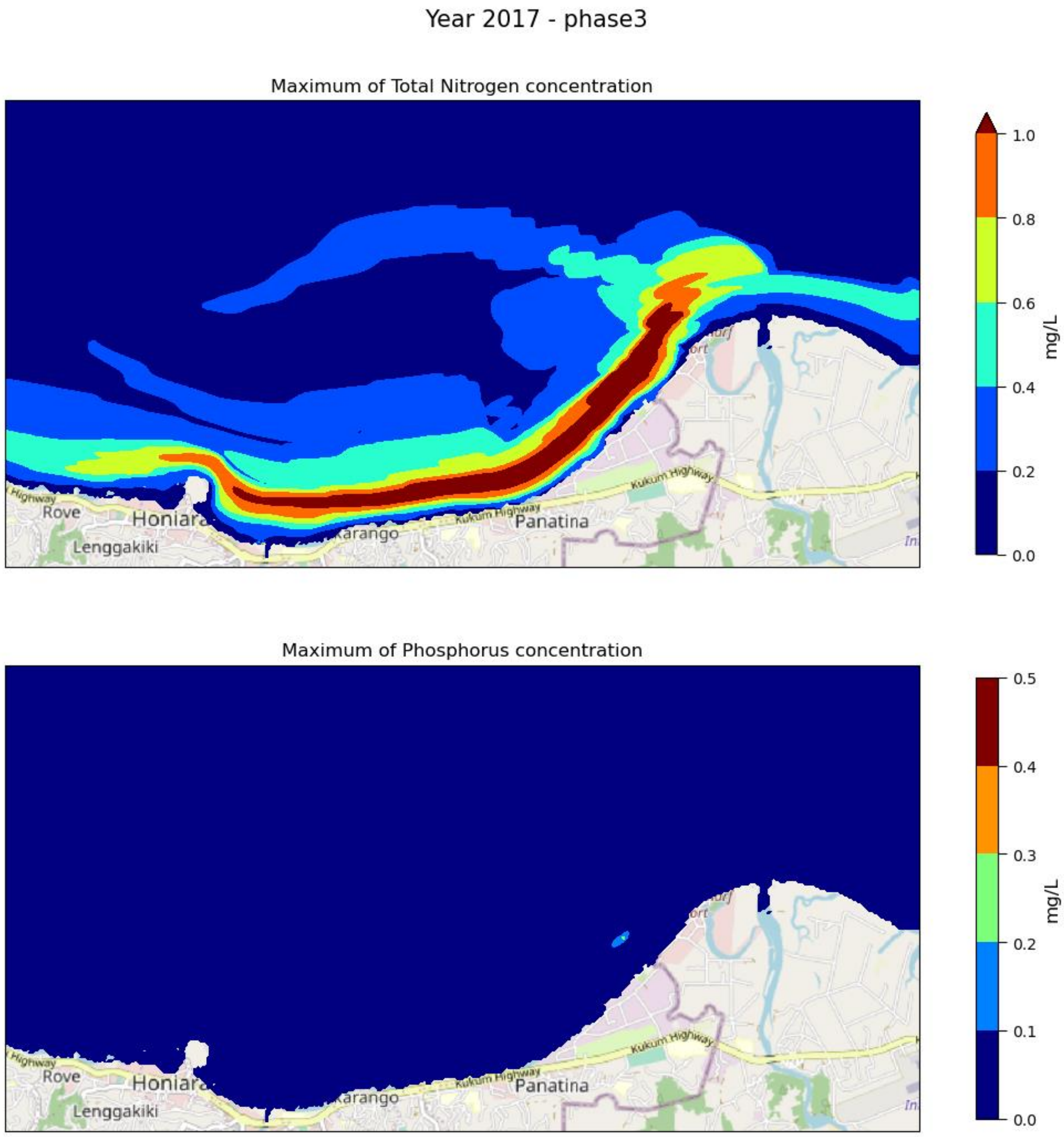
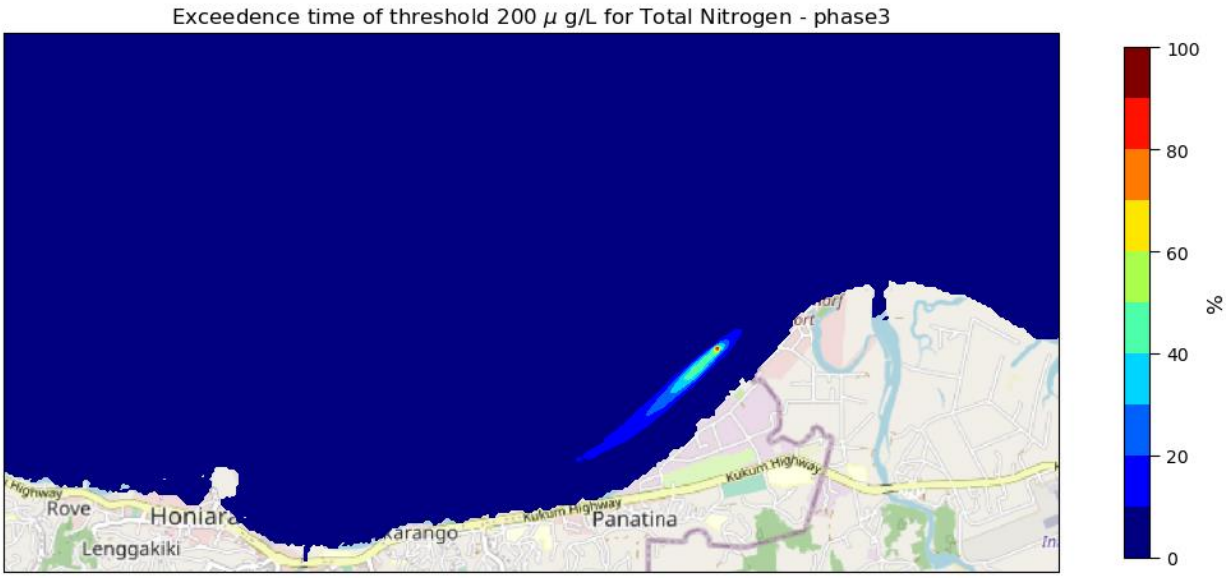


Figure 14 - Maximum of nutrients concentration for year 2017 - Phase 3

4.2.11 Phase 3 – Exceedance maps



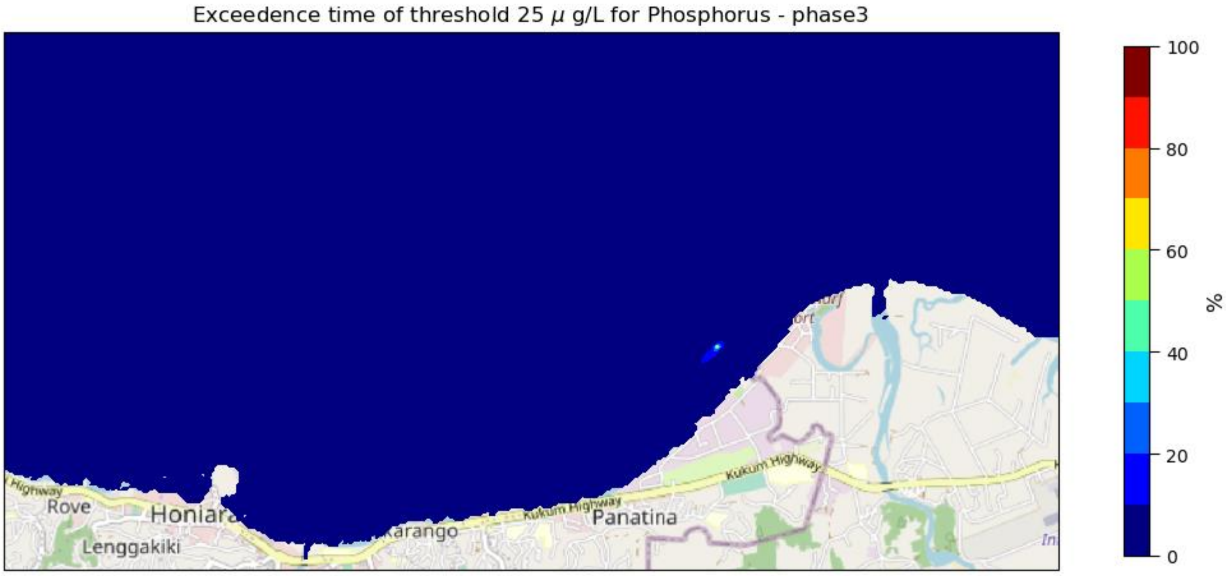
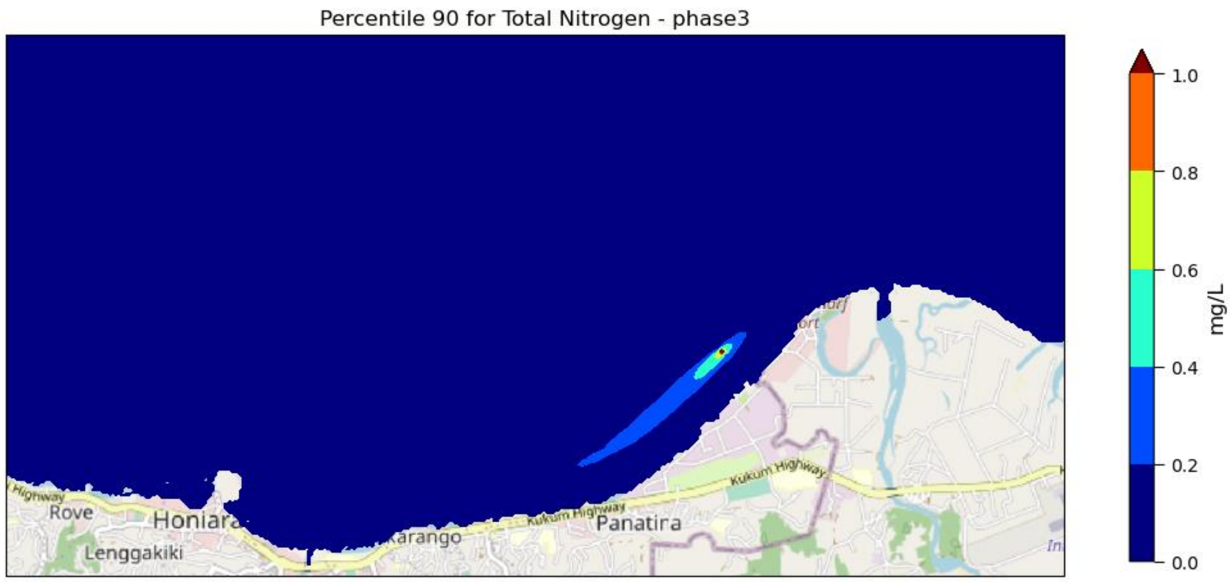


Figure 15 - Percentage of time the concentration is over 200µg/L for Nitrogen and over 25 µg/L for Phosphorus over the year 2017 – Phase 3

4.2.12 Phase 3 – Percentiles



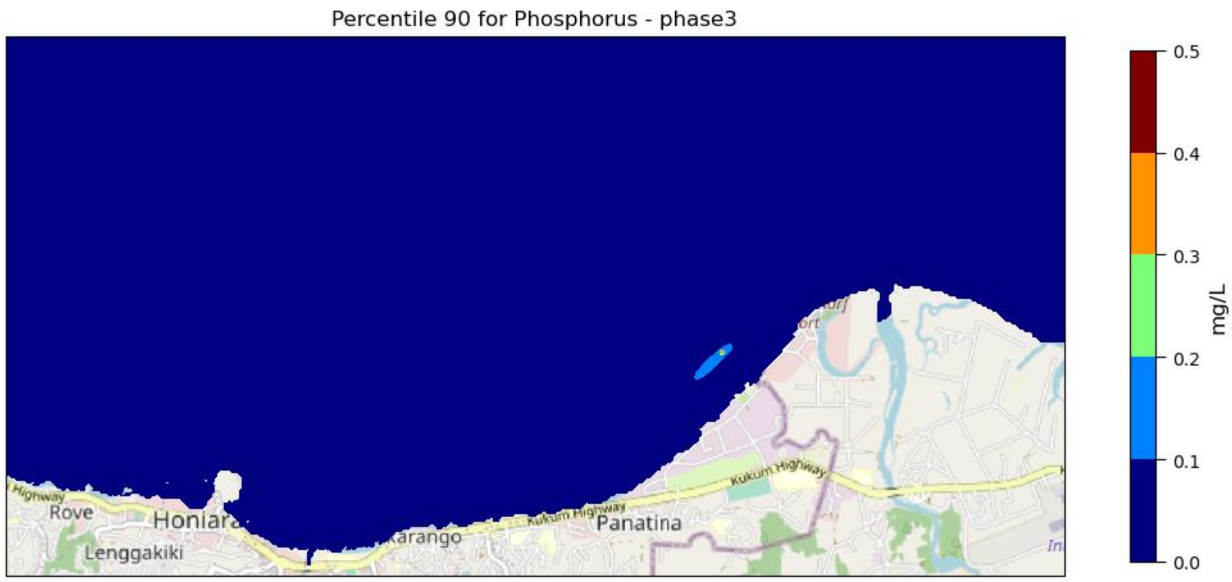


Figure 16 - Percentile 90 of the concentration in Nitrogen and Phosphorus – Phase 3

5. CONCLUSIONS

Simulations have been performed for Phosphorus and Nitrogen discharge over a complete year. Year 2017 has been chosen as it presents typical wind characteristics. Four horizons of discharge have been studied, from 2025 to 2050, with different flow rates and concentrations.

The results show plumes with a maximum around the outfalls and a dispersion from East to West in majority. Maps of maximum concentration can show a large plume for some scenarios, but exceedance and percentiles maps help to mitigate these results.

As expected, higher concentrations appear for NRH outfall which is located in shallow waters. In Ranadi, the depth of the water column allows a greater dispersion of the plume and consequently lower concentrations of nutrients. The plumes from the 2 outfalls can superpose in some situations, it is visible for example for Phosphorus concentration in Phase 2.

These results needs to be interpreted in terms of marine ecological impact.