

# Preliminary Outcomes of an Integrated Water Quality Assessment for Port Vila, Efate (Vanuatu)

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## Background

The Commonwealth Marine Economies (CME) Programme is being delivered on behalf of the UK Government by a partnership of UK government marine expertise: the United Kingdom Hydrographic Office (UKHO), the Centre for Environment, Fisheries and Aquaculture Science (Cefas) and the National Oceanography Centre (NOC).

This project in Vanuatu, as part of the CME Programme, has focused on the development of a water quality monitoring program. For Vanuatu and, in particular around Port Vila, modeling and mapping on water quality issues has become increasingly more important as population, tourism and coastal infrastructure grow and expand. Cefas scientists,

responding to concerns identified in collaboration with national and regional stakeholders around water quality issues, are working with the Vanuatu Government and Pacific regional bodies to gather the evidence required for an integrated assessment of water quality and human health issues.

Accurate water quality data enables national decision makers and local stakeholders to plan how to use and manage the bay's natural resources for sustainable marine economic development for a range of purposes, such as diving and other tourism activities or the identification of areas suitable for aquaculture sites. This ensures multi-use activity whilst protecting the marine environment into the future.

In Vanuatu, Cefas combined the mapping and modeling of chemical and biological pollutants to create multi-layered data which will be used to inform management of the bay area. Integration of environmental data from around Port Vila provided a robust assessment of the 'health' of the marine environment, will be useful in achieving a successful long term management strategy for the marine systems.

This project focused on the integration of in-field water quality data, satellite imagery, and a 2D hydrodynamic model to demonstrate the flow and extent of the pollutants from the multiple storm water drains entering Port Vila. The modeling was simulated using high resolution bathymetric data collected by UKHO under the CME programme.

Integrated analysis of the water quality data identified the coastal hot spots for Port Vila, and showed that urban run-off is a serious issue in the coastal area.

Outputs of the modeling showed that the movement of the pollutants is influenced by the location of drains, and identified the priority actions around the storm-water drains that could be taken to reduce the pollution inputs into the bay.



The CME team collecting water quality data to provide information for evidence based decisions.

## Water quality outcomes

Water quality and contaminant data was collected between May and August 2016, with the majority of the sampling occurring within Port Vila, Mele Bay and the lagoons to focus on the issues around urban and industrial run-off (Figure 1). In addition, there was a small sampling effort in Northern Efate to look at any water quality issues in the northern less urbanised coastline. Parameters collected and analysed through the project include water quality data such as salinity, light attenuation, turbidity, nutrients, suspended solid and phytoplankton biomass (chlorophyll-a). Data was also collected and analysed for contaminants and microbial water quality with passive samplers being deployed in key impact areas to measure low level contamination of pollutants. In the northern areas, concentrations of nutrients, suspended sediments and phytoplankton biomass were generally low, reflecting the limited riverine influence during the 2015/16 wet season and the larger distance from the urban areas of Port Vila. The northern samples were collected in May 2016, after an extended dry season, and thus are representative of low to no flow river conditions. Further sampling during the onset of the wet season would provide additional information on longer term land-based water quality impacts on North Efate reefs.

Although the sampling in Northern Efate showed no sign of toxicity and low turbidity, associated with the lower rates of urbanisation, the elevated nutrients at Samoa Point (Figures 2 and 3 – V27-29) indicate influence runoff, most likely associated with the septic systems of the coastal houses and villages.

Data collected within Mele Bay and Port Vila demonstrates a more variable water quality gradient, with the highest concentrations of nutrients and phytoplankton biomass measured at the near shore sites reflecting the proximity to the stormwater outlets that drain the urban areas of Port Vila.

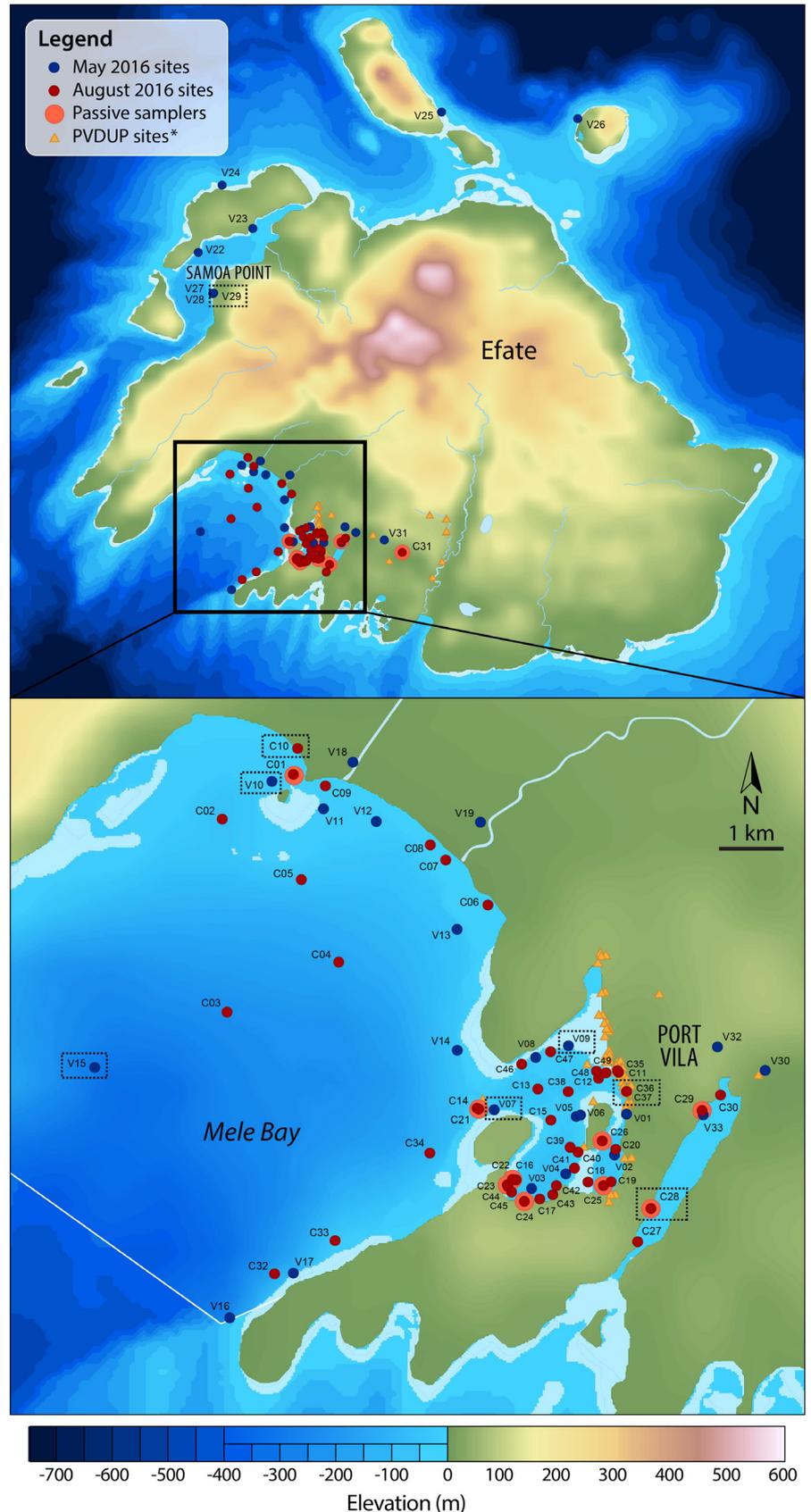
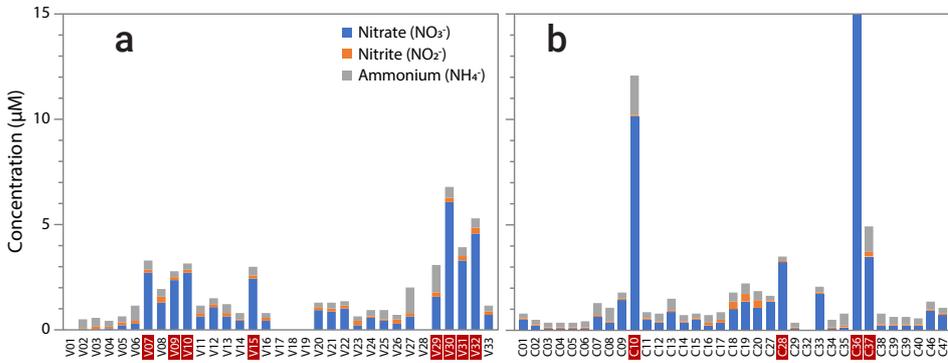


Figure 1: Water Quality data was collected around Efate over two field trips, with the main focus being issues of urbanisation and stormwater drainage in Port Vila. \* Port Vila Urban Development Programme sites.

Water quality data collected over both field trips show stable measurements of temperature and salinity. The initial sampling in May had higher temperatures but lower salinity, reflecting the seasonal influences and recent rainfall

associated with the spring period.

Depth of sampling plays an important role with many of the water quality concentrations high in the surface waters and reducing at depth (Figure 5).



**Figure 2:** Dissolved inorganic nitrogen (DIN) concentrations in (a) autumn and (b) winter. Sites with the highest DIN concentrations are highlighted above and in Figure 1.

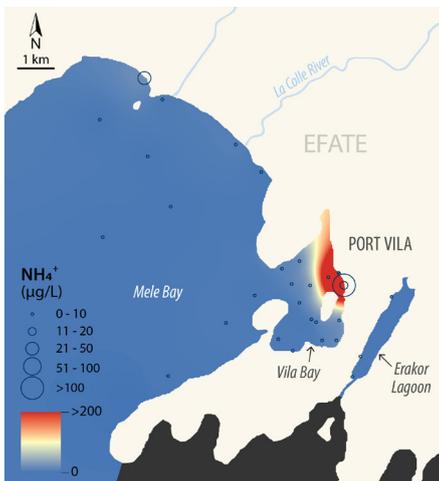
However, productivity (related to phytoplankton activity) is higher at around 5 to 10 meters reflecting a depth with optimal light and nutrient (food) availability. Increases in turbidity are seen at sites in Mele Bay and in the lagoons, both areas which support seagrass habitats (Figure 5).

Nutrient data collected around Port Vila show a gradient of change related to the proximity of site to the Port Vila coast line and the influence of the storm water drains. High nutrient concentrations were measured inshore at areas close to stormwater drains (Figures 1 and 2) and reflect the high pollution potential of non-treated sewage and stormwater runoff into the Bay, which has the potential to further impact on the nearshore seagrass beds. Work done in conjunction with Vanuatu Government, who regularly sample the storm drains, also show high nutrient concentrations associated with the storm water drainage system. Additionally, these results show frequent exceedances of the

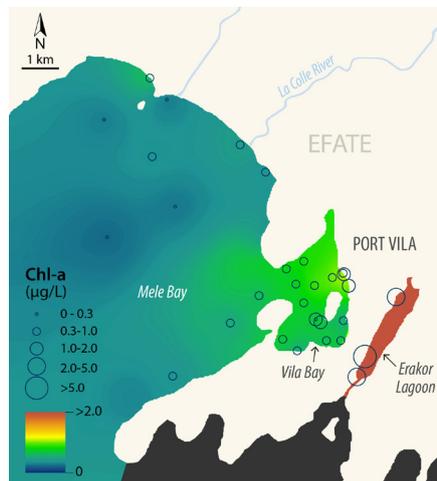
international microbial guidelines raising concerns for human health issues.

Heat maps provide a visual tool to identify the sites with highest concentrations of the water quality parameters (Figures 3 and 4). Interpolation analysis of the water quality data clearly shows the hot spots adjacent to Port Vila and suggests that urban runoff could be a serious issue for the surrounding coastal ecosystems. The areas directly affected by water quality are typically the sites closest to the storm water outputs, and would be receiving water contaminated by sewage and urban runoff.

The program identified that most water quality issues are focused around the coastal areas adjacent to Port Vila and the storm water drains. The adjacent coastal areas support many recreational activities, including community swimming and diving and inshore subsistence fishing. These high pollution discharges have the potential to impact on human health and the coastal ecosystems.



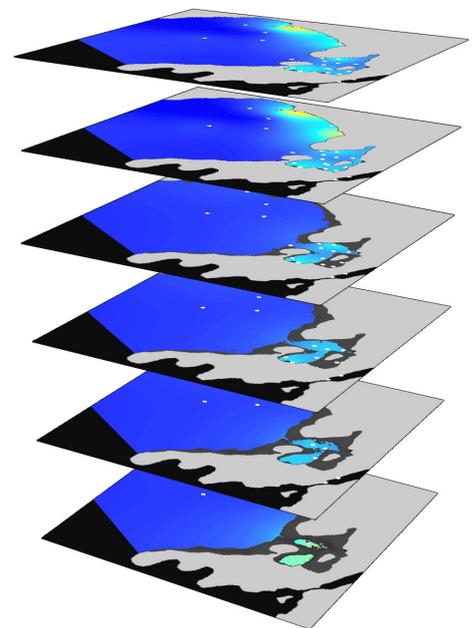
**Figure 3:** Heat map for ammonium (August 2016).



**Figure 4:** Heat map for chlorophyll-a (August 2016).



Sampling with the profiler measuring salinity, temperature, light and chlorophyll at depth.



**Figure 5:** Turbidity levels (ftu) at 5 different depths for Port Vila and Mele Bay. Turbidity was interpolated from samples taken in August. Sampling sites are shown as white dots.

## Remote sensing

Satellite imagery provides useful tools for monitoring coastal water quality and synoptic information that can be used in conjunction with in-situ monitoring and modelling to provide integrated assessments of water quality. This preliminary study aimed to test the potential of using freely-distributed satellite data to monitor the coastal water quality around Efate. It focused primarily on the Port Vila-Mele Bay region, as a case study.

Coastal water types were mapped using two years of daily MODIS true color imagery. The medium resolution (1 pixel: 500 m x 500 m) MODIS data was reclassified to water types defined by their colour properties and typical of water quality gradients existing

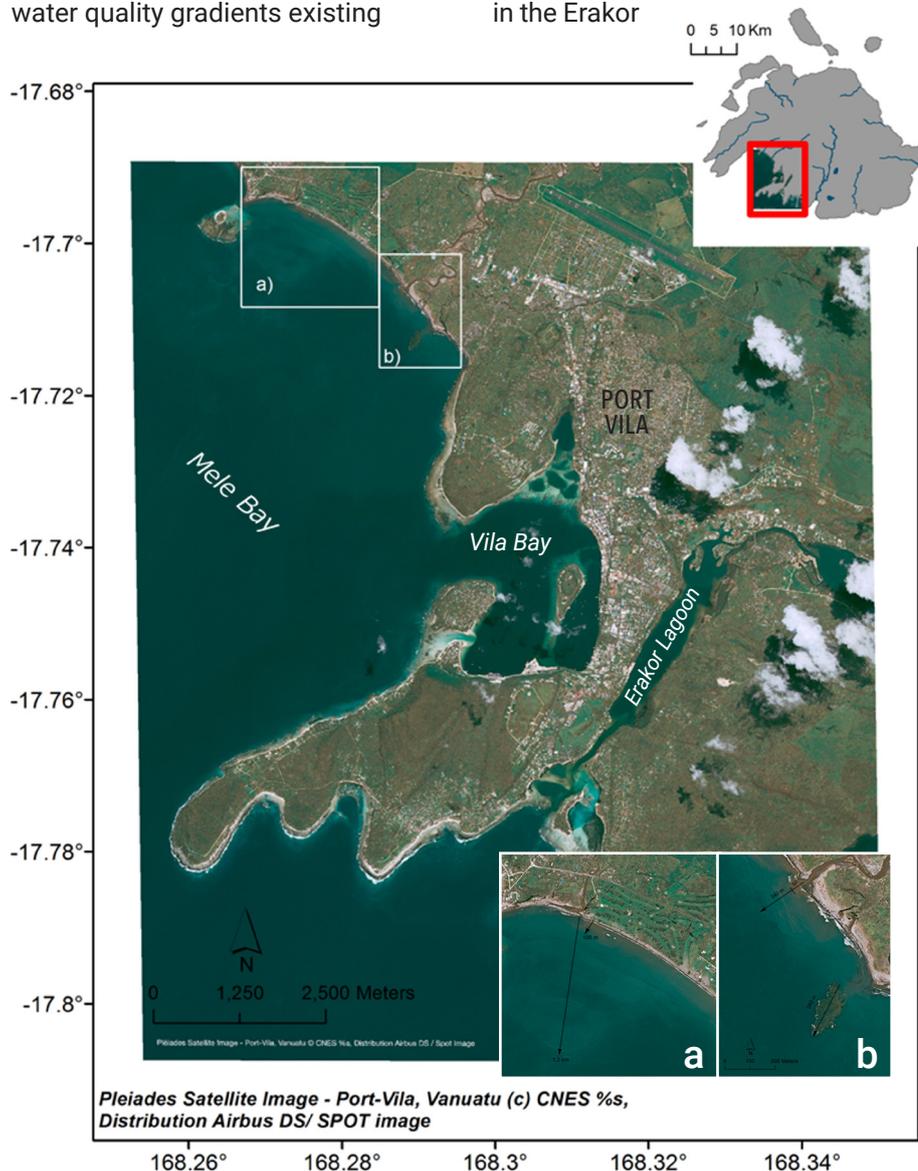
across coastal waters. Preliminary validation of the MODIS-derived water type maps performed well, with spatial variation in water quality measured in-situ captured by the color classification.

The analysis of the MODIS data allowed (1) to give large-scale water quality context to in-situ campaigns (sky/cloud cover permitting) and (2) to illustrate the average, large scale, coastal water quality conditions as well as the inter-annual and seasonal variations in water conditions in the Port Vila-Mele Bay region.

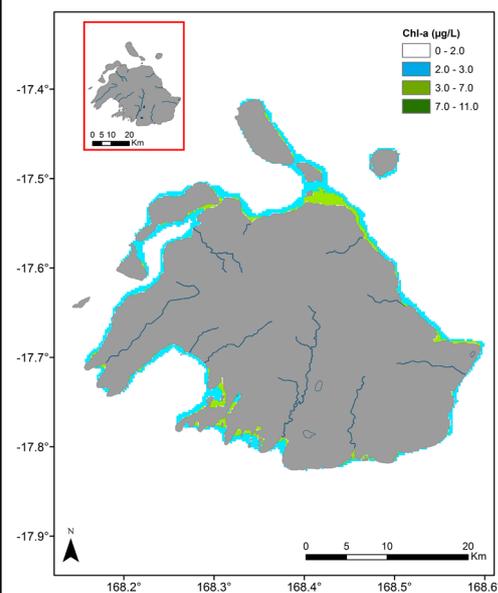
The variability across year was limited, with very similar mean water quality conditions mapped in 2015 and 2016. Coastal waters east of Mele Bay and in the Erakor

lagoon looked however slightly more turbid in 2015 than in 2016. Similarly, seasonal changes in water quality conditions were not very marked. River influence wasn't visible in the MODIS data during the dry season and wet seasons of 2015 and 2016. However, spatial analysis of a high resolution image of the floods post cyclone Pam (March 2015, Figure 6), revealed clear colour changes associated with a flood plume.

Results from the preliminary analysis were promising and provided methods to map water quality around Efate over greater geographical scales and longer time periods. As an example, Figure 7 shows a MODIS-derived map of chlorophyll-a for the whole of the Efate coast. The preliminary analyses only represented the average (not extreme) water quality conditions over a relatively short time period (2 years) and it is expected that the variability in water quality would be increased during more extended wet season conditions. While further analyses are needed to validate the methods and to determine if higher resolution satellite data are needed for mapping flood plumes, this preliminary study proved the potential of using satellite images coupled with in-situ data to monitor the coastal water quality around Efate.



**Figure 6:** Pléiades optical Satellite Image of Port-Vila, Vanuatu, captured the 16th of March 2015 (resolution 50 cm) : Enlargements: (a) South of Hideaway Island (b) around the La Colle River (Copyright: CNES 2015, Distribution Airbus DS).



**Figure 7:** Concentrations of chlorophyll-a for the coast of Efate, mapped by validation of ocean colour with the in-situ water quality data collected in the CMEP program.

## Hydrodynamic modeling

A 2D depth-averaged hydrodynamic model has been developed using the hydrodynamic software Telemac2D (v7p1). The model domain has been built using an unstructured and extends between 168.772°E – 167.944°E and 17.329°S – 17.947°S (Figure 8a). In Mele Bay, the resolution is refined to approximately 30 m and again refined further to approximately 10m in Vila Bay (Figure 8b). The bathymetry surrounding Efate is sourced from GEBCO with a resolution of 1.5km. In Mele Bay and Vila Bay, depths less than 25m have been sourced from optical clear satellite derived bathymetry, provided by EOMAP, with a spatial resolution of 10-30m. Depths deeper than 25m in Vila Bay were provided by the UKHO at a resolution of 5m. The hydrodynamics are forced along the open boundaries using tidal information from the OSU TPXO Pacific Ocean 1/12° regional model. After a spin up period of 5 days, the model was run for 30 days to cover a full spring-neap cycle.

As the model develops further through the accessing of accurate boundary conditions, the model will be able to assess a range of scenarios to develop future control measures. An example of the type of measures that could be implemented with the model is assessing the impact of reducing the flow from some or all of the stormwater outfalls that are currently discharging into Port Vila Bay. Figure 9 shows the comparison of the dispersion of ammonium (a dissolved nutrient acting as a proxy for sewage) after 30 days from only outfalls 1-4 and 5-8 separately. These different modelling scenarios can help provide information to managers for prioritising actions for reduction of pollutants.

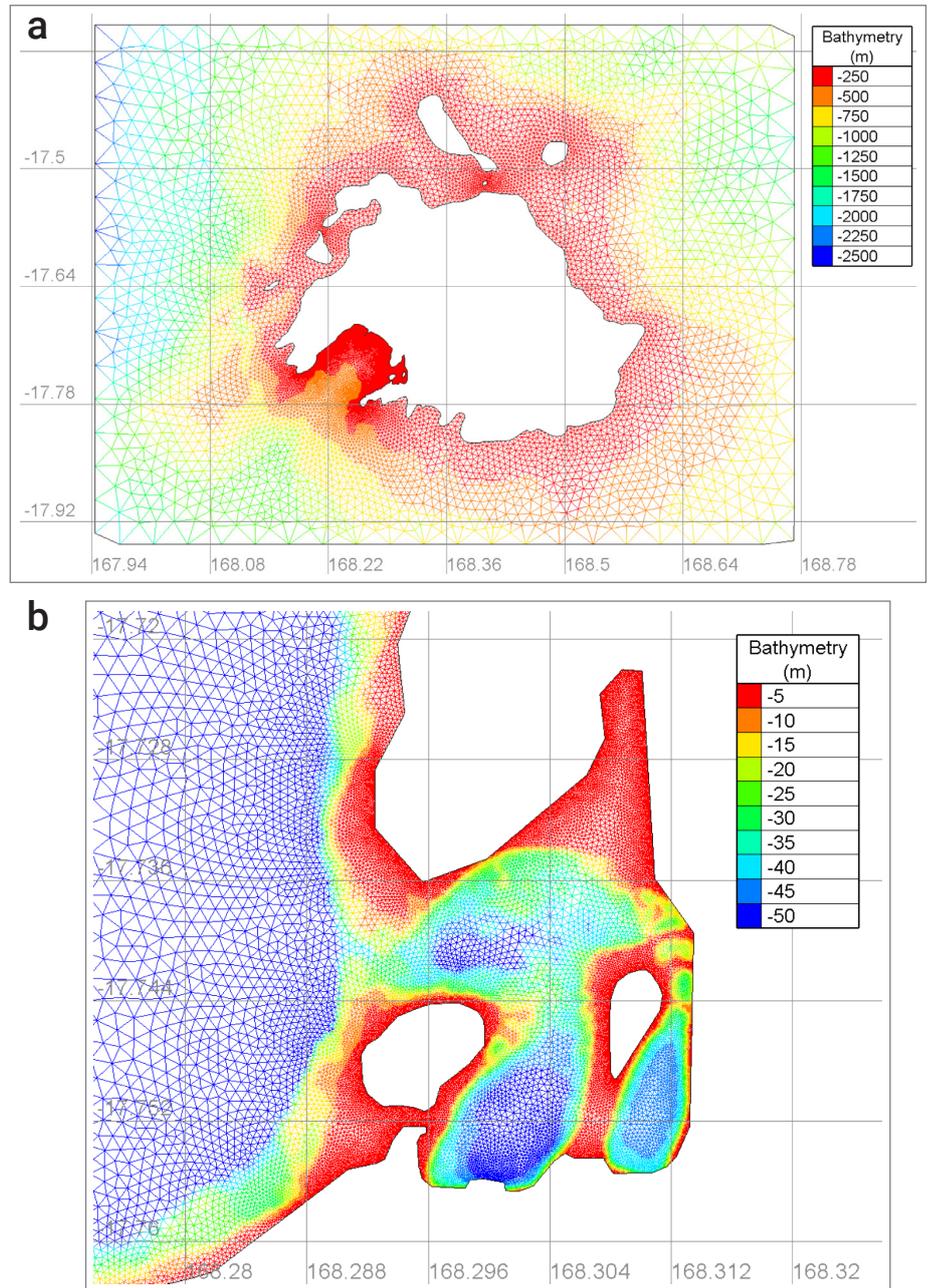


Figure 8: (a) Whole model domain and (b) zoomed into Vila Bay.

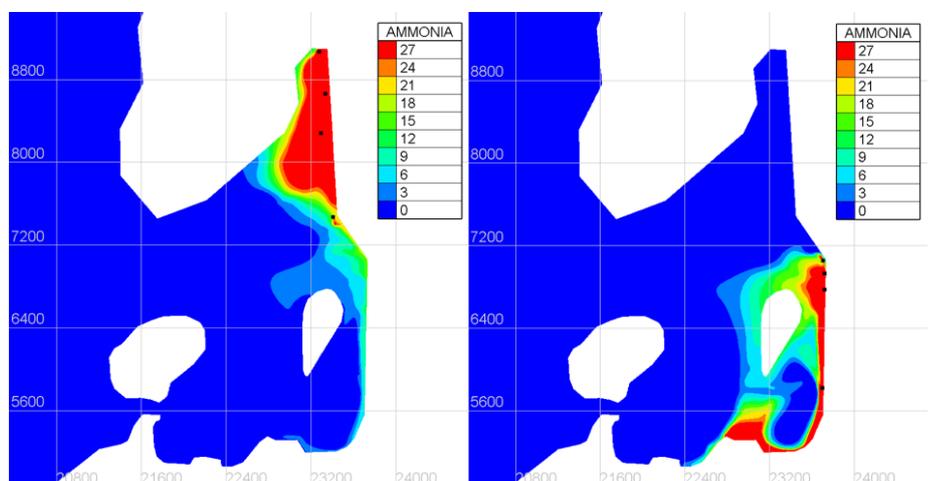


Figure 9: Comparison of the dispersion of ammonium after 30 days from only outfalls 1-4 (left) and outfalls 5-8 (right).

## Conclusion

Integrated assessments for tropical marine systems have been proven to be a successful long term strategy for managing the risks and impacts facing coral reef systems and coastal systems, including seagrass habitats. The 1-year project in Vanuatu now has the potential to provide an assessment of the 'health' of the marine environment under investigation by assessing the risk posed to the environment in question by diffuse and point source chemical /biological pollutants (particularly sewage contamination) set in the context of the larger global stressors of climate change.

The integrated assessment provided information that allows evidence-based management decisions to be taken which considers pollution exposure, resilience to climate change, and increases regional scientific capacity to protect Vanuatu's marine economic benefits and environments.

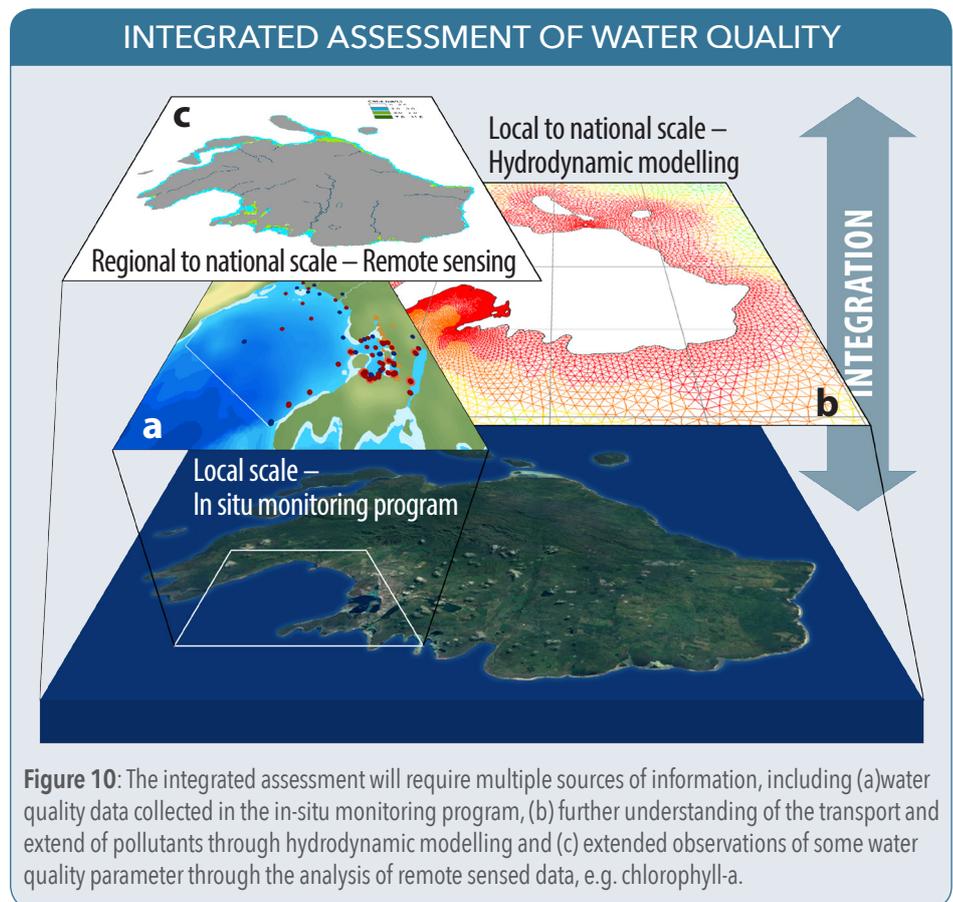
Furthermore, the data could be used to inform management and risk decision making in relation to the suitability of sites for the sustainable development of blue economies, including aquaculture and habitat mapping of seagrass.

We have incorporate several scales of information in our water quality

risk assessment based around the local pressures facing key coastal areas. This work provides information that can be used around decision making for human health and eutrophication issues. Further work will be to link the different scales of information into a cohesive management decision framework.

Management decisions that incorporate available knowledge of spatial patterns of the extent of disturbance regimes may have

the best chance of achieving management goals, such as supporting the natural resilience of reef systems. Maintaining an up-to-date understanding of exposure (from pollution) and resilience (to climate change) increases capacity for the adaptive, resilience based management that can maximize the chance Pacific ecosystems can continue to provide ecosystem goods and services as disturbance frequencies increase.



**Figure 10:** The integrated assessment will require multiple sources of information, including (a) water quality data collected in the in-situ monitoring program, (b) further understanding of the transport and extend of pollutants through hydrodynamic modelling and (c) extended observations of some water quality parameter through the analysis of remote sensed data, e.g. chlorophyll-a.



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<sup>1</sup><https://www.gov.uk/guidance/commonwealth-marine-economies-programme>

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