



Eutrophication modelling of a tidally influenced mangrove area in Bali subject to major dredging and reclamation activities

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Abstract

A large fashionable tourist resort area is under construction at Benoa Bay, Bali. The location is an island called Turtle Island, which is an enlargement of the existing Serangan Island. Extensive dredging operations of surrounding sea bed are needed for land reclamation, resulting in a general change in current pattern and water exchange for the Benoa Bay and the strait between the coast and Turtle Island. Prediction of the water quality before and after construction was accomplished in order to find the preferable of three layouts from an environmental point of view.

The existing Serangan Island is relatively small, with no tourism and inhabited by a small number of local people. The shallow waters around the island are covered by benthic vegetation. A coral reef to the east of Serangan Island forms a border to the ocean.

The water quality in terms of benthic vegetation, concentrations of phytoplankton, nutrients, dissolved oxygen and water turbidity was modelled using the MIKE 21 eutrophication model.

The water quality was predicted to improve in the strait between the coast and the island due to increased flushing of the dredged channels. On the other hand, the improved flushing resulted in a larger spreading of the nutrients and deterioration of the water quality north and south of the proposed construction site. Lagoons proposed for leisure crafts also showed a deterioration of the water quality. For a lagoon close to a conservation area of the reef a large decrease in submerged vegetation was predicted. One layout was finally recommended as the optimal combining the various modelling results and results of other related studies.



1 Introduction

Tourism is seen as a sector with a high potential for development in many places around the world. This includes South-East Asia, where warm climate, beautiful beaches and an exotic and varied underwater flora and fauna e.g. coral reefs make the coastal area particularly attractive to tourism. Exploitation of these resources may involve large reclamation operations providing the land for resorts etc. This creates immediately a potential conflict between the expectations of the tourists for undisturbed nature and the detrimental effects of the dredging and reclamation.

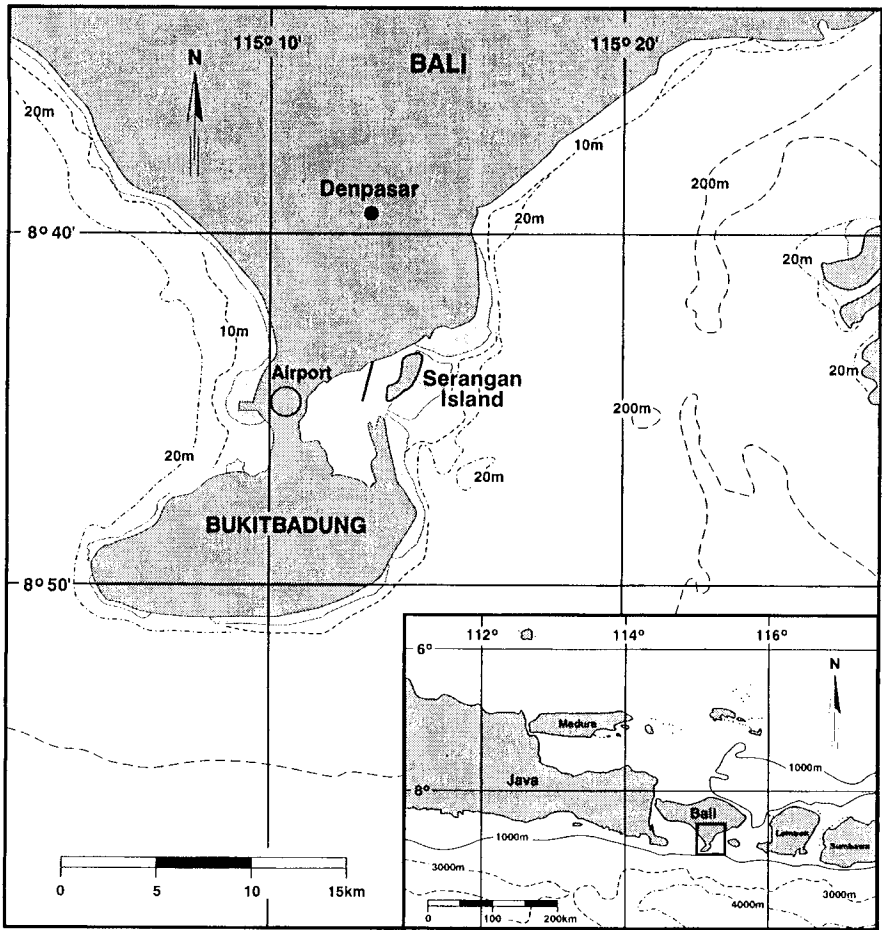
Environmental impact assessments are required for such activities in most cases. One way of overcoming the conflict between disturbance and preservation of the environment is to design a reclamation with a minimum of environmental impact by e.g. using models for prediction of the impact (Bach et.al. [1], Brøker et.al. [2]); and to mitigate impacts of the dredging operations by planning and applying feedback monitoring to control the effects during the construction phase (Gray & Jensen [3]).

This paper describes the methods and outcome of a specific part of the environmental impact assessment for a reclamation project at Bali namely the impact on water quality, phytoplankton and the benthic vegetation. Considerations concerning hydraulic impacts, morphology and sediment spreading in the construction phase are described elsewhere (Driscoll et.al. [4]).

2 Materials and Methods

2.1 Study Site

The tourism development area will be located at an island called Turtle Island, which is an enlargement of an existing Serangan island situated at the entrance to Benoa Bay, Bali, Indonesia (Figure 1). The existing Island is relatively small, with no tourism and inhabited by small number of local people. The shallow waters around the Island are inhabited by macrophytes. A coral reef to the east of Serangan Island forms a border to the ocean. The water on the coral reef flats and slopes is clear, has low nutrient levels, and is well saturated with respect to oxygen. This area seems largely unaffected by plumes from Benoa Bay. From aerial photos it appears that the benthic vegetation dominated by seagrass (Hunting [5]) is concentrated in many small areas with high density, surrounded by areas with almost no benthic vegetation.



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Figure 1. The study site including the southern part of Bali and the Serangan Island.

Benoa Bay is a tidally influenced shallow lagoon (25-30 km²) covered by mangroves in the innermost parts and with some patchy distributed submerged rooted vegetation in the gullies. The tidal flats dry out at low water. Channels that never dry traverse the bay. On tidal flats random distributed spots of macroalgae occur. The water in the bay is slightly turbid and under-saturated with respect to oxygen (Hunting [5]). Total nitrogen (N) and phosphorus (P) concentrations are in the order of 1.3 mg N/l and 0.3-0.6 mg P/l, and 5-27 mg/l BOD₅.

Extensive dredging operations of surrounding sea bed is needed for the planned land reclamation, which is expected to result in a general

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change in current pattern and water exchange for the Benoa Bay and the strait between the coast and Turtle island. Three different layouts were investigated. The size and shape of Turtle Island is the same for all three layouts (Figure 2). Layout #1 has borrow areas north of Turtle Island (area A) and a short channel half of the maximum length in the area between the island and the mainland until the bridge crossing over to Turtle Island. Layout #2 is as Layout #1, but with an additional borrow area between the Turtle Island and the mainland (area B1) and a channel at full length down to the south channel and Benoa Port. Layout #3 is as Layout #2, but with construction of a large harbour in the area between the Turtle Island and the mainland (extension of Benoa Port). Turtle Island is planned to have three artificial lagoons for leisure crafts, (lagoon B & C) and beaches (lagoon A). Due to tourism and natural preservation interests the area with a varied fauna and flora at the reef east of the present Serangan Island has to be preserved.

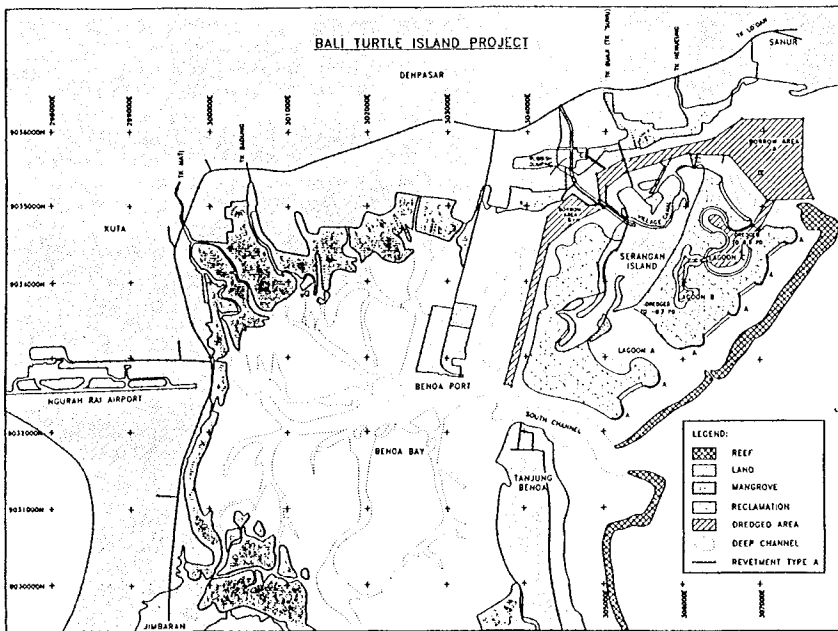
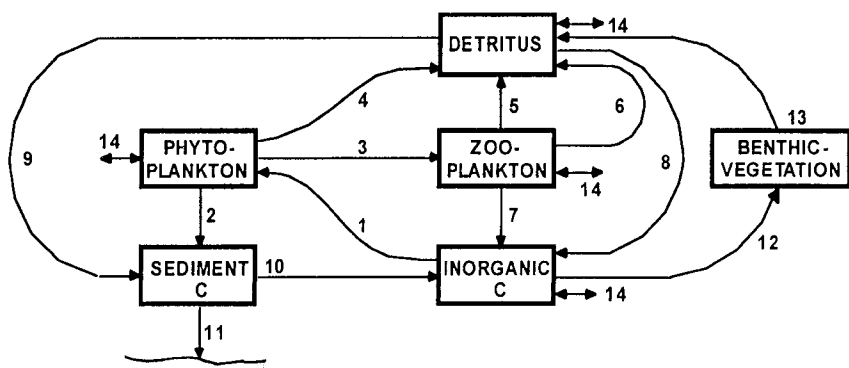


Figure 2. A sketch showing the original Serangan Island and the Turtle Island development, Layout #2.



- | | |
|---------------------------------|--------------------------------------|
| 1. production, phytoplankton | 8. mineralisation of detritus |
| 2. sedimentation, phytoplankton | 9. sedimentation of detritus |
| 3. grazing | 10. mineralisation of sediment |
| 4. extinction, phytoplankton | 11. accumulation in sediment |
| 5. excretion, zooplankton | 12. production, benthic vegetation |
| 6. extinction, zooplankton | 13. extinction, benthic vegetation |
| 7. respiration, zooplankton | 14. exchange with surrounding waters |

Figure 3 State variables and processes in the eutrophication model.

2.2 The Ecological Model

Quantification of the effects on water quality in terms of rooted benthic vegetation, macroalgae, concentrations of phytoplankton, nutrients and oxygen was made modelling the important components and processes using the MIKE 21 EU (Eutrophication) model.

The MIKE21 model is a comprehensive 2-dimensional modelling system solving the Navier Stokes equations and the mass transport equation using the finite difference method (Warren & Bach [6]). The eutrophication module describes the condition in an area by using a number of state variables including carbon, nitrogen and phosphorus in phytoplankton, zooplankton, detritus and benthic vegetation and, with regard to nitrogen and phosphorus, also the dissolved form in the water. Dissolved carbon in the water, i.e. carbon dioxide, is not included explicitly in the model because dissolved carbon is normally present in excessive amounts. The model describes the seasonal and spatial variations of the state variables. The seasonal variations depend on a number of forcing functions: hydraulic conditions, influx of light, water



temperature, nutrient loadings, and the conditions in the surrounding areas (boundary conditions).

A total of 16 state variables are used, 11 of which comprise the pelagial and the remaining 5 the benthic vegetation. The state variables and processes in the biological system are illustrated in Figure 3 and described in detail elsewhere (Bach [7], Bach et.al. [8]). The advective-diffusive transport is calculated using the MIKE21 AD model by an interactive coupling of the two models (Vested et.al. [9]). The MIKE21 AD model is on the other hand fed currents and water levels by the MIKE21 HD model from which the transport is calculated. The sediment is modelled implicitly as a pool to which fluxes of nutrients arrive due to settling of organic matter and from which fluxes of nutrients reach the water due to mineralisation.

2.3 Model set-up and forcing

The model area covers Benoa Bay, the Turtle Island/Serangan Island, Sanur Beach to the north and the reef and a part of the ocean to the east (Figure 4). The grid spacing of the finite difference model is 120 m.

Two different seasons of the hydrodynamic conditions exist mainly due to variation in rainfall. The model includes the wet season and the dry season by applying differences in rainfall and land based run-off (Table 1), but using the same oceanic current regime as boundary conditions. The hydrodynamic model was calibrated using data from April-May 1996 (Driscoll et.al. [4]). These data were also used for the eutrophication model simulations. The model simulations covered one month for each of the seasons.

Table 1. Land based run-off: the measurements obtained from a field campaign in April 1996 used for the hydrodynamic model calibration, the annual average and the values applied for the wet and dry seasons.

April meas. m ³ /sec	Mean annual m ³ /sec	Mean wet season m ³ /sec	Mean dry season m ³ /sec
3.90	7.81	19.49	2.41

The data available for model set-up and calibration was very limited. Aerial photos showing the distribution of vegetation were used to a.o. determine the initial conditions for the benthic vegetation. Some older data on nutrients and oxygen concentrations exist and these were used also as indications of the concentration levels (Hunting [5]). The boundary

conditions could not be derived from measurements directly. The available data were used to determine realistic oceanic values.

At present, sewage from about 320.000 people is discharged into an area covering Benoa Bay and an area just north of the bay. In year 2010 this population is expected to increase to 369.000 inhabitants. The load estimates were made using standard contribution per capita since no measurements or detailed estimates could be found. The load was distributed between the dry and wet season according to the rainfall/land based run-off as indicated in Table 1. The annual load for the present situation was estimated at 1526 tonnes N/year and 333 tonnes P/year.

Typical values for temperature (27°C) and light irradiation ($40 \text{ E/m}^2/\text{day}$) were derived from local sources.

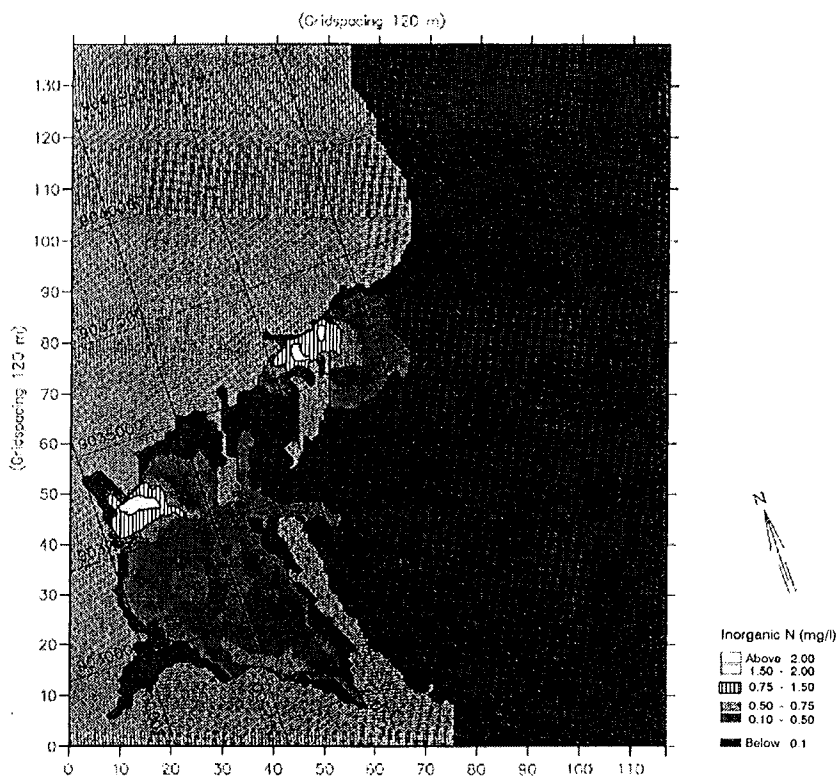


Figure 4 Average inorganic nitrogen concentration (mg/l) during the wet season for the existing situation.

3 Results

It was decided that the impact assessment should be made comparing the situation with and without the reclamation at the point in time where the development would be ready i.e. around the year 2010. Five different situations were investigated.

1. Future situation, no tourist resort, year 2010 and nutrient load
2. Future situation, tourist resort with layout #1, year 2010 nutrient load
3. Future situation, tourist resort with layout #2, year 2010 nutrient load
4. Future situation, tourist resort with layout #3, year 2010 nutrient load

As an example of the simulation results for the existing situation the nitrogen concentration during the wet season is shown in Figure 4.

Comparison of simulated water quality between year 1996 and year 2010 with no tourist resort shows increased concentrations of nutrients, decreased water transparency and increased concentration levels for phytoplankton (2-5%).

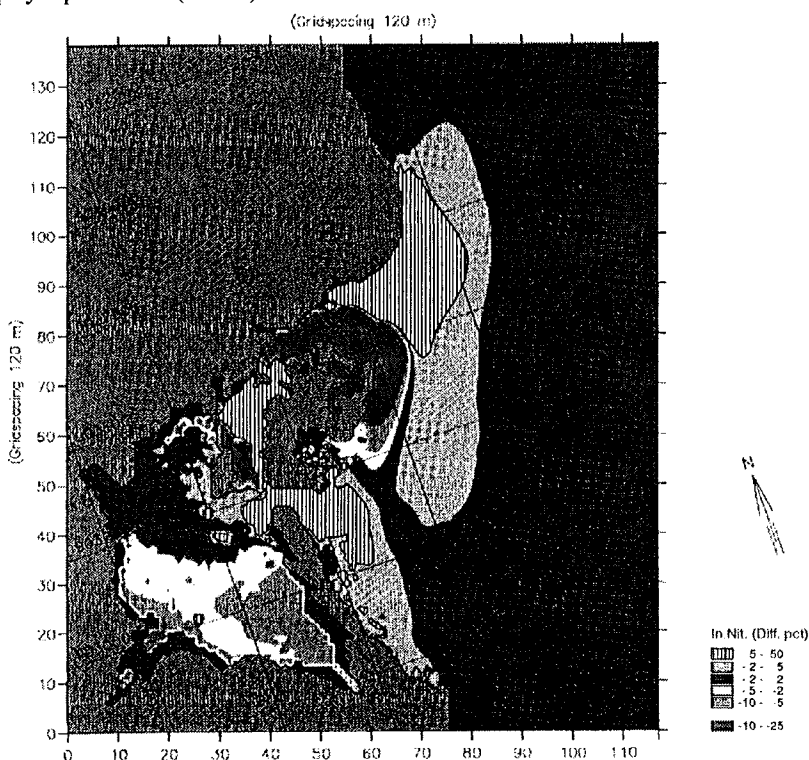


Figure 5 Percent change year 2010, inorganic nitrogen concentration.
Layout #2, wet season.

Deterioration (5-10% decrease) is predicted for rooted submerged vegetation in Benoa bay and an area north of the Serangan Island, where two major sources enter the coast. The impact is highest during the wet season due to a higher load of BOD and nutrients from land.

The 3 layouts change the currents around the Turtle Island resulting in an increased transport of pollutants towards the sea caused by deepening of the channels and borrow areas (Driscoll et.al. [4]). According to the model predictions, the water quality improves in the borrow areas north of Turtle Island in all 3 layouts due to increased water exchange (Figure 5, Figure 6). Decrease in nutrient and chlorophyll-a concentrations and increase in secchi disc depth are predicted. The benthic vegetation coverage decreases due to the removal of parts of the seabed. The water quality in the strait between Turtle Island and the mainland is worsened concerning the nutrient concentrations, but the plankton biomass decreases due to the dilution with water from the borrow areas.

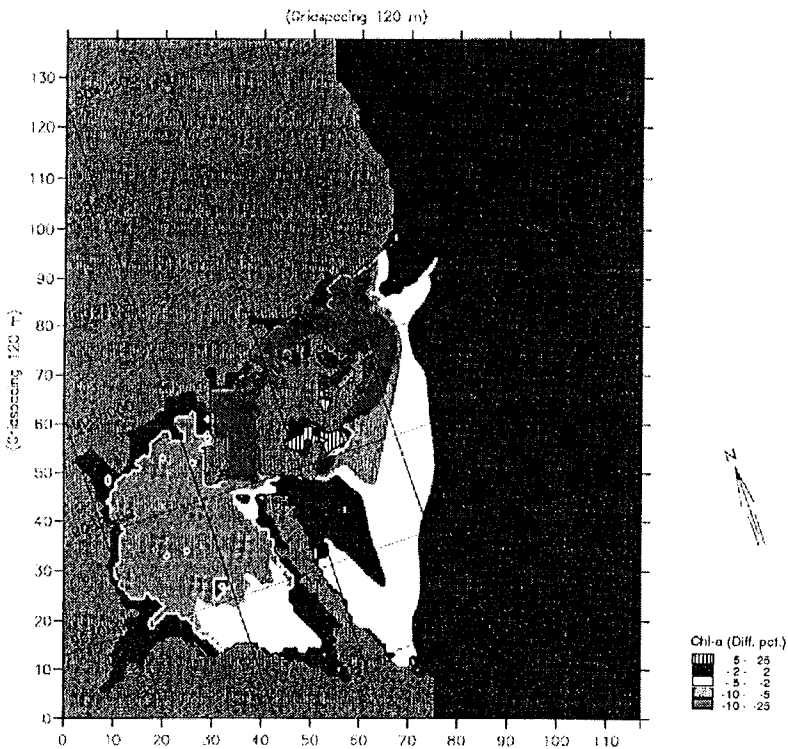


Figure 6 Percent change year 2010, chlorophyll-a concentration, Layout #2, dry season

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Improvements are predicted on the reef outside the tourist beaches on the east side of the Island e.g. the secchi disc depth increases. The water quality becomes worse in layout #1 in Benoa Bay, whereas it improves in layout #2 and #3.

The water quality off Sanur beach on the main land north of the Island is affected negatively for the wet season (Figure 5), but not significantly affected in the dry season. The reason for this impact is the increased water exchange that will lead to and increased transport and spreading of pollutants in the area in general. The lower concentrations of pollutants in the borrow areas are opposite to the increased concentrations in the area north of the island.

The water quality in lagoon B and C to be used for leisure crafts is predicted to be poor for all layouts. The water quality in lagoon A close to the conservation area of the reef is predicted to deteriorate in all layouts, with decrease in submerged vegetation biomass and coverage.

4 Discussion and Conclusion

Ranking the three layouts, the best solution in terms of water quality is achieved by Layout #2. The conclusion was similar for the other parts of the investigation even though the results of e.g. flushing calculations did not show exactly the same results in terms of changes as the eutrophication model. The flushing calculations were aimed at calculating retention times in the area of a pollutant (conservative tracer) and water exchange rates. An initial concentration of 100 was applied and the dilution simulated assuming a zero concentration at the boundaries.

The differences between this approach and the approach using the eutrophication model are caused by the fact that the interactions between the components are included explicitly in the eutrophication model.

Furthermore, the correct concentration gradients are obtained in the area because the sources are positioned according to the reality. The results have shown that it is important to model the relevant components specifically and that results of flushing calculations are not necessarily representative for what is actually going to happen.

The study elucidated the fact that the protection of the seagrass areas and the coral reefs is very important. A feedback monitoring programme (Gray & Jensen, [3]) was consequently designed and implemented for the construction phase using eelgrass and some specific corals as feedback variables. During the first period of construction sediment plume modelling was accomplished to facilitate planning of the dredging

work and the biological monitoring programme. For the rest of the construction period the monitoring programme includes only the biological variables.

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