Chapter 6 Nitrogen Results

6.1 Introduction

Nitrogen in different forms is an important nutrient in the coastal zone. Changes in the speciation and distribution of nitrogen can increase or decrease primary production by phytoplankton and macrophytes rooted to the bed of an estuary or harbour. We have chosen to examine the impact of the proposed treatment plant on such forcing by using a linear cascade model containing three species of nitrogen: organic nitrogen, ammonia and nitrate. The model quantifies the relative effect of the scheme on the concentration of these three species throughout the harbour and adjacent coast over a test period of ten days[37]. The relative effect is with respect to an unaltered background concentration of each species of nitrogen.

6.2 The cascade model

Each species of nitrogen is conceptualised as a concentration in milligrams per litre of atomic nitrogen[38], namely, nitrogen in the form of organic nitrogen (N_org) in raw or treated sewage, or as nitrogen in the form of ammonia (N_NH4), or as nitrogen in the form of inorganic nitrate (N_NO3).

We assume that an adapted flora of microflora, such as *Nitrosomonas* and *Nitrobacter,* is present to mediate the transformation of organic nitrogen to ammonia and the subsequent nitrification of ammonia to inorganic nitrate. We then speak of a cascade of reactions. We further assume that the concentrations of the different species of nitrogen are sufficiently dilute so that these reactions

[37] A ten day period is sufficiently long to determine the relative change resulting from the construction of the treatment plant.

[38] This makes all stoichiometric constants unity.

proceed at rates that are a constant times the upstream concentration[39]. In other words, we assume first order kinetics for all reactions, an assumption, which makes the model linear. Consequently, superposition applies, and we can model the effect of the treatment plant separately from the overall dynamics of nitrogen in the harbour. The results reported in this chapter are estimates of the change in forcing, expressed as changes in the concentrations of the three species of nitrogen, due to the proposed treatment plant. They are estimates of relative changes compared to the background concentrations of nitrogen which is unspecified. We leave the judgement of the wider consequences of these relative changes in nutrient forcing to the marine ecologists advising the project.

6.3 The kinetics of the cascade

We assume that the instantaneous rate at which organic nitrogen is transformed to ammonia is 20% per day of the instantaneous concentration of organic nitrogen. The effect of this is to decrease the concentration of N_org and increase the concentration of N_NH4 at this identical instantaneous rate.

We also assume that the instantaneous rate at which ammonia is nitrified to nitrate is 20% per day of the instantaneous concentration of ammonia. The effect of this is to decrease the concentration of N_NH4 and increase the concentration of N_NO3 at this identical instantaneous rate.

We further assume that the corresponding instantaneous rates at which ammonia and nitrate are individually removed in "primary production" is 5% of their instantaneous concentrations respectively. These two low rates allow the concentrations of ammonia and nitrate to accumulate throughout the harbour and to disperse within and outside the harbour.

[39] At higher values of concentration, such as those occurring in wastewater treatment plants, the specific rates are usually assumed to decline hyperbolically to a maximum value. It is also necessary to model the dynamics of the nitrifying bacteria. Such models exhibit non-linear kinetics and are referred to as *Michaelis-Menton* models. Superposition does not apply.

The concentrations of the three species of nitrogen in the discharges to the harbour before treatment have been taken as 15mg/l (N_org), 25mg/l (N_NH4) and 1mg/l (N-NO3) respectively. In the model these are multiplied by the flow rates in for Case 1 and Case 2 in Table 4-2 to give the mass flow rates of the three species of nitrogen discharging into the model estuary at those outfalls considered in the study. All other outfalls contribute to the background concentration and are not modelled.

After treatment, the concentrations are assumed to be 0mg/l (N_org), 12.5mg/l (N_NH4) and 1mg/l (N-NO3) respectively, a removal efficiency of two thirds of total nitrogen. These are multiplied by the flow rates in case 3 of Table 4-2 to give the mass discharge of the different species of nitrogen. The only non-zero discharge is through the diffuser just inside the mouth of the harbour. The reader should note the assumption that the treatment plant transforms all organic nitrogen to ammonia[40].

We have included a sensitivity analysis which considers a more conservative removal efficiency of the treatment plant. After treatment, the concentrations are assumed to be 15mg/l (N_org), 12.5mg/l (N_NH4) and 1mg/l (N-NO3). respectively, a removal efficiency of one third of total nitrogen.

A summary of the assumed concentrations for the three cases considered is presented in the table below.

Nutrient	Raw Sewage	After treatment	Sensitivity Analysis
Organic Nitrogen (N_org)	15mg/l	0mg/l	15mg/l
Ammonia (N_NH4)	25mg/l	12.5mg/l	12.5mg/l
Nitrate (N-NO3)	1mg/l	1mg/l	1mg/l

Table 6-1 Assumed concentrations for the three cases

[40] J.A. Baeza, D. Gabriel, J. Lafuente, "Effect of internal recycle on the nitrogen removal efficiency of an anaerobic/anoxic/oxic (A2/O) wastewater treatment plant (WWTP)", Process Biochemistry 39 (2004) 1615–1624

J.P.J. O'Kane, *Estuarine Water Quality Management with moving element models and optimization techniques*. Pitman, London. 1980. Pp155.

Since the model is linear[41], different efficiencies of removal by treatment can be found by rescaling both the after-treatment concentrations, and the results, by the same constant.

Case 4 also requires the use of rescaling. The scaling factor is 1.431.

Historic wind and river inflows for ten days (2nd June – 12th June 04) have been used to drive the model; but a repeating spring tide has been applied along the two open boundaries outside the harbour mouth. This tidal condition is consistent with the data from the Proudman model for a period of five days before and after a high spring tide. The model has been run for ten days and the results examined in two successive five-day periods. The results are presented in the following section.

6.4 The results – time-series at fifteen points of interest

The two species of nitrogen of most importance for primary production are the concentrations of ammonia and nitrate. These two time series[42], for the fifteen points of interest given in Table 4-3, are shown over the following pages. Organic Nitrogen is also plotted.

The first graph on the page highlights the concentrations of ammonia, nitrate and organic nitrogen for "**case 2** before treatment[43]". The graph beneath shows the corresponding concentrations of ammonia, nitrate and organic nitrogen after treatment has been introduced (**case 3**). The differences between the plots on each page show a marked reduction in relative concentrations of ammonia and nitrate in all fifteen points compared to the unspecified background following the

[41] Much more detailed models of nitrogen exist in the literature; but in the absence of an intensive programme of high frequency measurements in the field and laboratory experiments in micro- or mesocosms, a simple model is the appropriate for an engineering intervention designed to improve the quality of the harbour and its adjacent coastal waters.

[42] Organic nitrogen is not shown (a) because of 100% removal by the treatment plant, and (b) to ensure an easier interpretation of the graphs by reducing the number of lines to two.

[43] To calculate case 3 multiply the values by 1.38, the scaling factor.

introduction of treatment. In other words the desired improvement has been demonstrated and quantified in the model under the specified conditions of tide, river flow and wind.

The maximum and averaged concentrations for Organic Nitrogen, Ammonia and Nitrate at the locations of interest for each case are presented in the following tables. All the concentrations are expressed in mg/l.

	Nitrogen							
	CASE 1 2001 MAX	2001 AVG	CASE 2 2010 MAX	2010 AVG	CASE 3 2010 MAX	2010 AVG	CASE 4 2030 MAX	2030 AVG
Fountainstown	0.000233	0.000100	0.000321	0.000138	0	0	0	0
Myrtleville	0.000299	0.000161	0.000413	0.000222	0	0	0	0
Roches Point	0.000990	0.000296	0.001366	0.000408	0	0	0	0
Crosshaven	0.000960	0.000315	0.001325	0.000434	0	0	0	0
Ringaskiddy	0.001327	0.000873	0.001831	0.001204	0	0	0	0
Monkstown	0.001343	0.000815	0.001853	0.001125	0	0	0	0
Oyster F - NC	0.000583	0.000090	0.000805	0.000124	0	0	0	0
Marlogue Point	0.001514	0.000301	0.002090	0.000416	0	0	0	0
Oyster F - OH	0.000640	0.000201	0.000884	0.000277	0	0	0	0
Cobh	0.002157	0.001230	0.002976	0.001697	0	0	0	0
Spike Island	0.001283	0.000481	0.001770	0.000663	0	0	0	0
Shoreline	0.000974	0.000255	0.001344	0.000352	0	0	0	0
Up. Outfall	0.003411	0.000479	0.004708	0.000660	0	0	0	0
West Passage	0.001885	0.001020	0.002601	0.001408	0	0	0	0
Lough Mahon	0.001824	0.000916	0.002517	0.001264	0	0	0	0

Table 6-2 Maximum and Averaged Nitrogen Concentrations

	Ammonia							
	CASE 1		CASE 2		CASE 3		CASE 4	
	2001 MAX	2001 AVG	2010 MAX	2010 AVG	2010 MAX	2010 AVG	2030 MAX	2030 AVG
Fountainstown	0.000475	0.000200	0.000655	0.000276	0.000309	0.000145	0.000443	0.000208
Myrtleville	0.000606	0.000314	0.000836	0.000434	0.000396	0.000239	0.000567	0.000342
Roches Point	0.001832	0.000534	0.002529	0.000737	0.001478	0.000506	0.002115	0.000725
Crosshaven	0.001847	0.000603	0.002549	0.000832	0.000790	0.000368	0.001130	0.000527
Ringaskiddy	0.002649	0.001690	0.003655	0.002332	0.000272	0.000176	0.000390	0.000252
Monkstown	0.002673	0.001588	0.003688	0.002192	0.000291	0.000164	0.000417	0.000235
Oyster Farm - NC	0.001188	0.000189	0.001640	0.000261	0.000272	0.000041	0.000389	0.000059
Marlogue Point	0.002874	0.000594	0.003966	0.000820	0.000502	0.000126	0.000718	0.000181
Oyster Farm - OH	0.001273	0.000412	0.001756	0.000569	0.000595	0.000133	0.000851	0.000190
Cobh	0.003986	0.002284	0.005501	0.003152	0.001363	0.000493	0.001950	0.000705
Spike Island	0.002480	0.000905	0.003422	0.001249	0.001072	0.000434	0.001534	0.000621
Shoreline	0.001918	0.000489	0.002647	0.000675	0.000749	0.000429	0.001072	0.000345
Up. Outfall	0.005952	0.000867	0.008214	0.001196	0.005359	0.000675	0.007669	0.000966
West Passage	0.003595	0.001918	0.004962	0.002646	0.000641	0.000176	0.000884	0.000243
Lough Mahon	0.003478	0.0017320	0.00480	0.002390	0.000336	0.000008	0.000464	0.000112

Table 6-3 Maximum and Averaged Ammonia Concentrations

	Nitrate							
	CASE 1		CASE 2		CASE 3		CASE 4	
	2001 MAX	2001 AVG	2010 MAX	2010 AVG	2010 MAX	2010 AVG	2030 MAX	2030 AVG
Fountainstown	0.000495	0.000177	0.000684	0.000244	0.000332	0.000142	0.000332	0.000142
Myrtleville	0.000603	0.000228	0.000832	0.000315	0.000394	0.000182	0.000394	0.000182
Roches Point	0.001147	0.000206	0.001582	0.000285	0.000578	0.000168	0.000578	0.000168
Crosshaven	0.001298	0.000393	0.001792	0.000542	0.000545	0.000228	0.000545	0.000228
Ringaskiddy	0.002591	0.001208	0.003576	0.001666	0.000423	0.000210	0.000423	0.000210
Monkstown	0.002556	0.001186	0.003527	0.001637	0.000418	0.000203	0.000418	0.000203
Oyster F - NC	0.001314	0.000236	0.001813	0.000325	0.000376	0.000068	0.000376	0.000068
Marlogue Point	0.001960	0.000502	0.002705	0.000692	0.000493	0.000145	0.000493	0.000145
Oyster F - OH	0.001313	0.000437	0.001812	0.000603	0.000476	0.000159	0.000476	0.000159
Cobh	0.002934	0.001168	0.004048	0.001612	0.000616	0.000268	0.000616	0.000268
Spike Island	0.001870	0.000511	0.002581	0.000705	0.000603	0.000235	0.000603	0.000235
Shoreline	0.001651	0.000318	0.002279	0.000439	0.000500	0.000277	0.000500	0.000277
Up. Outfall	0.001585	0.000349	0.002188	0.000482	0.000863	0.000214	0.000863	0.000214
West Passage	0.002615	0.001096	0.003609	0.00151	0.000533	0.000180	0.000738	0.00024
Lough Mahon	0.002545	0.001050	0.003512	0.001450	0.000421	0.000110	0.000582	0.000152

Table 6-4 Maximum and Averaged Nitrate Concentrations

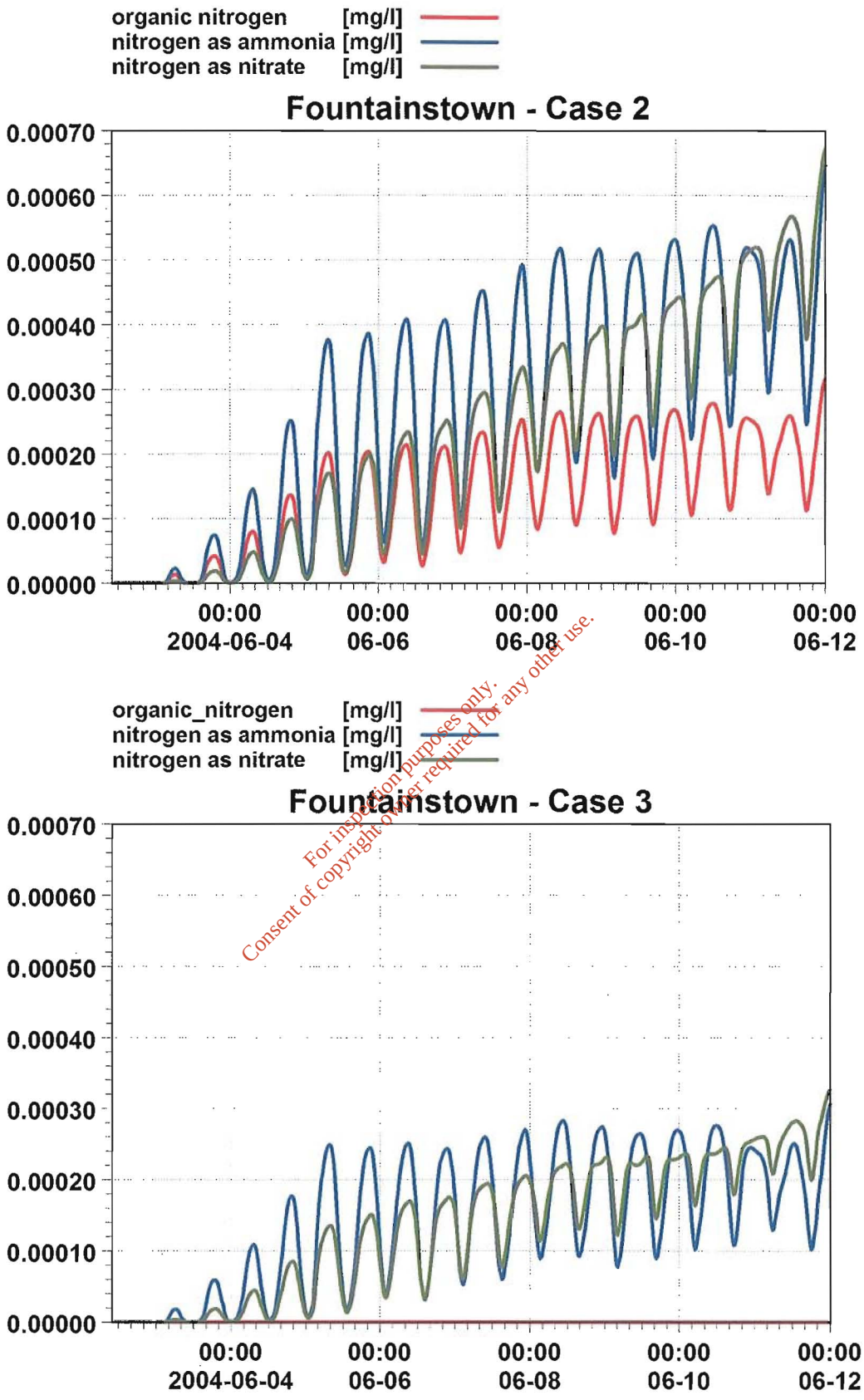
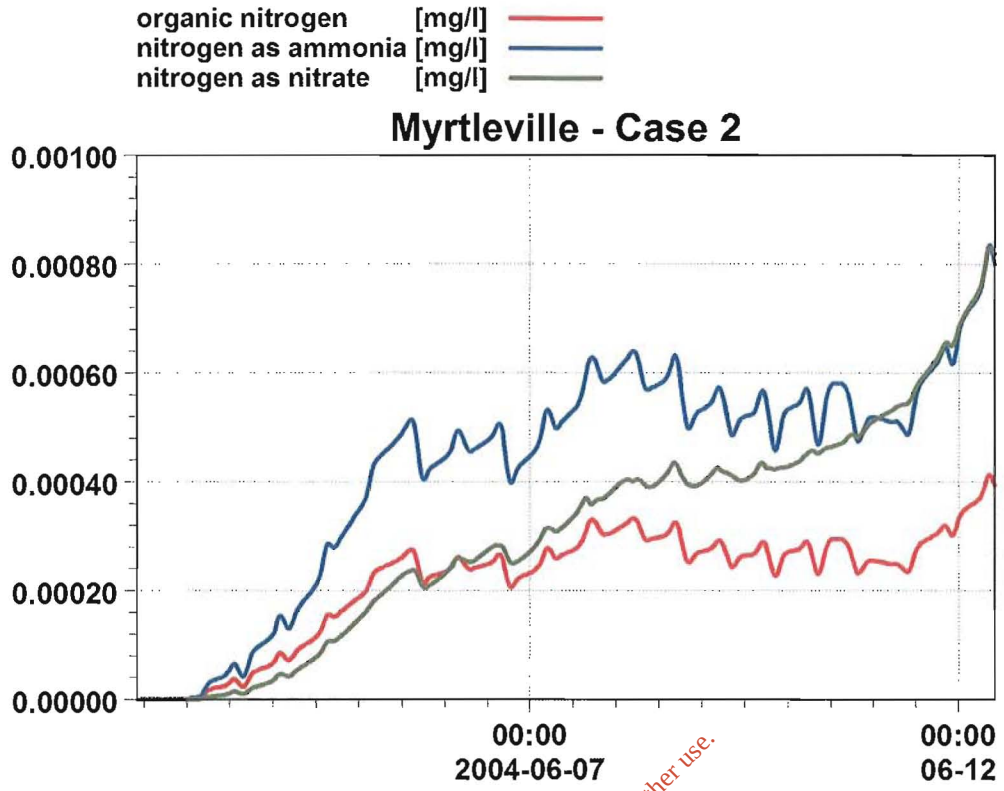


Fig. 6.1 Fountainstown



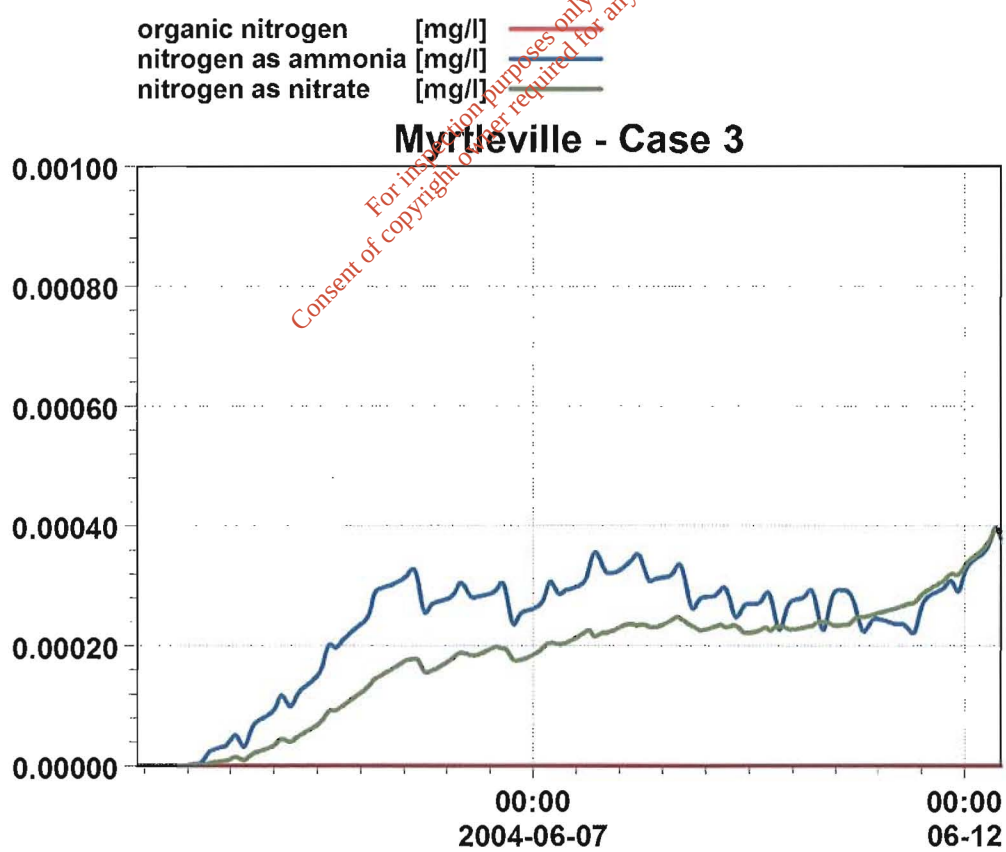


Fig. 6.2 Myrtleville

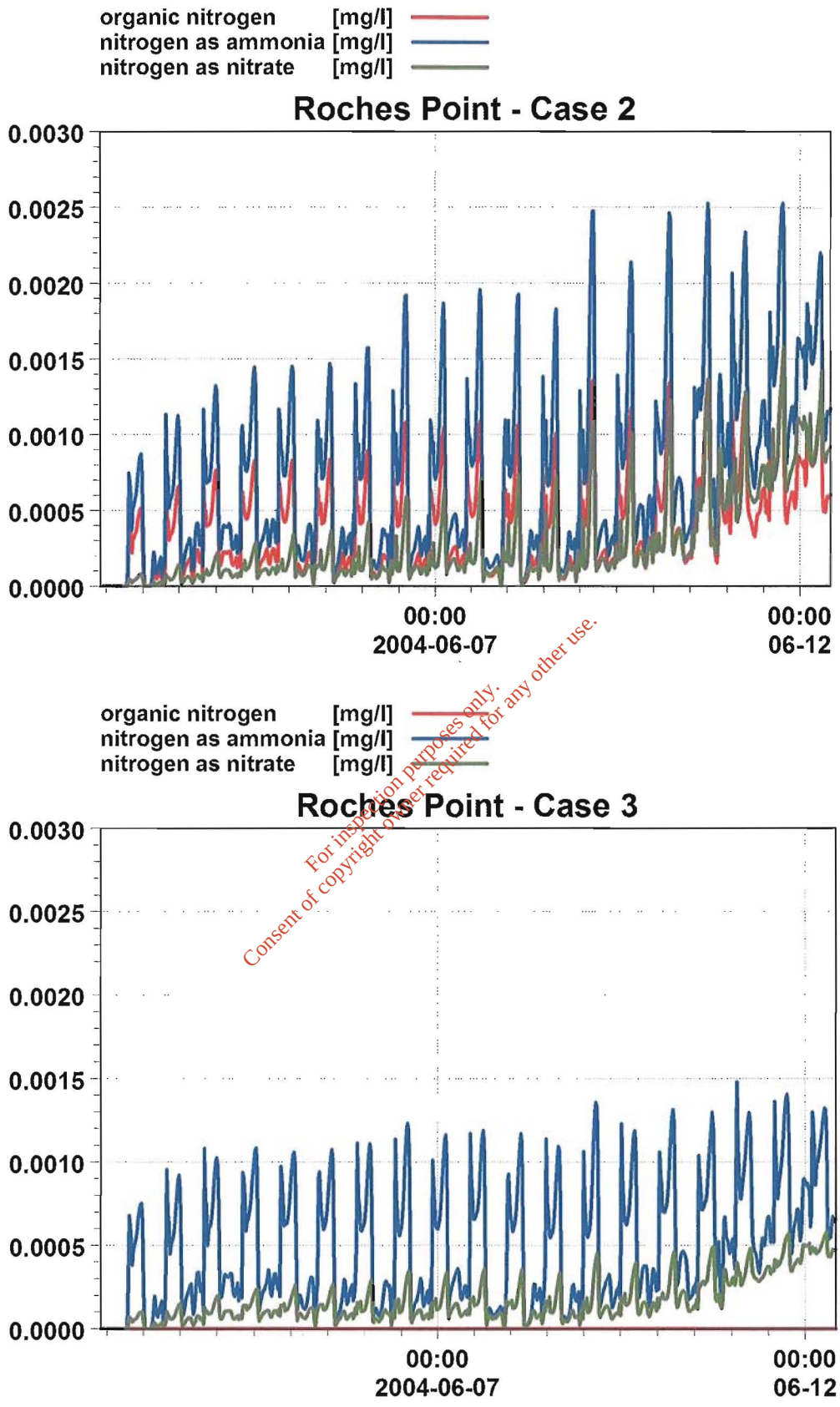


Fig. 6.3 Roches Point

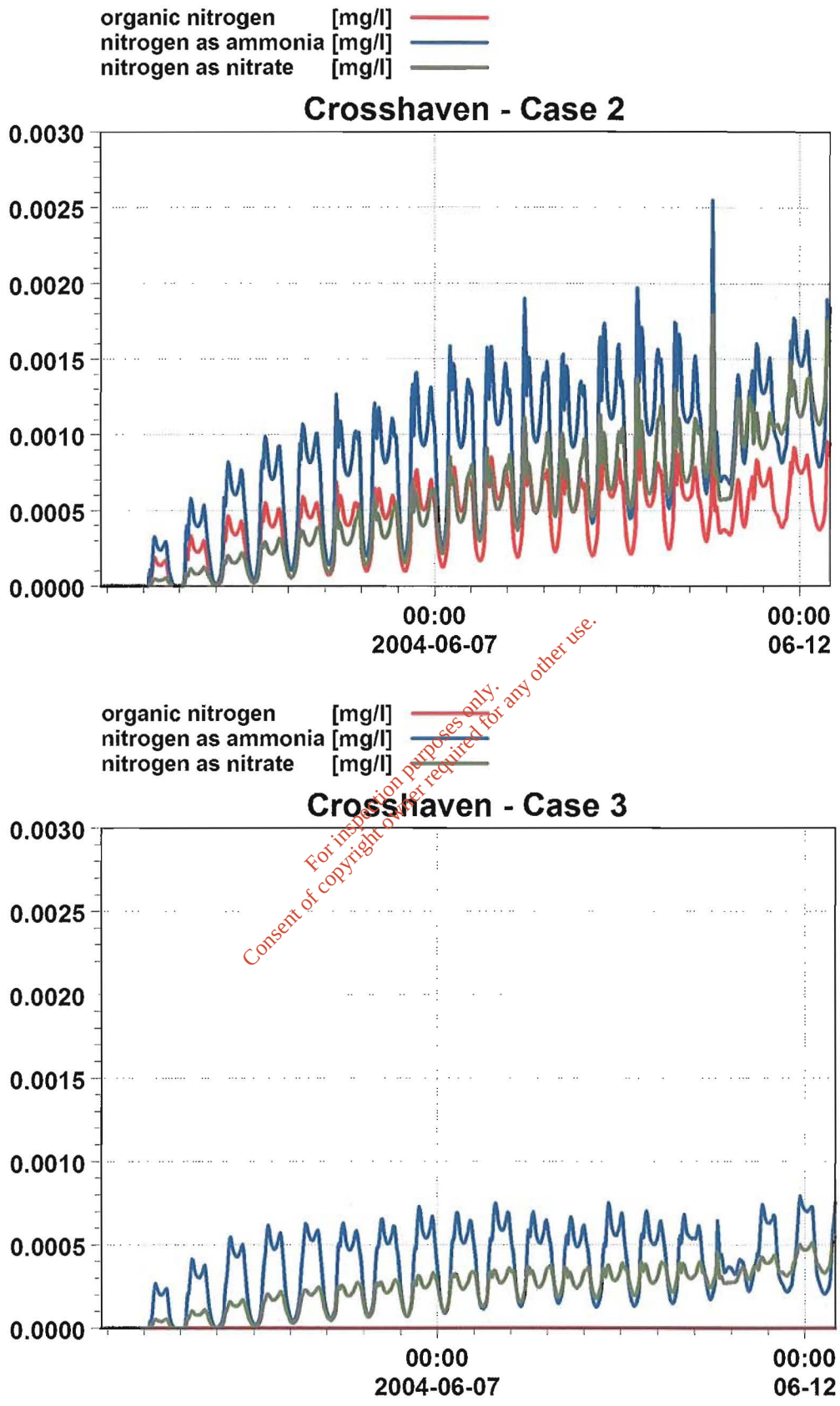
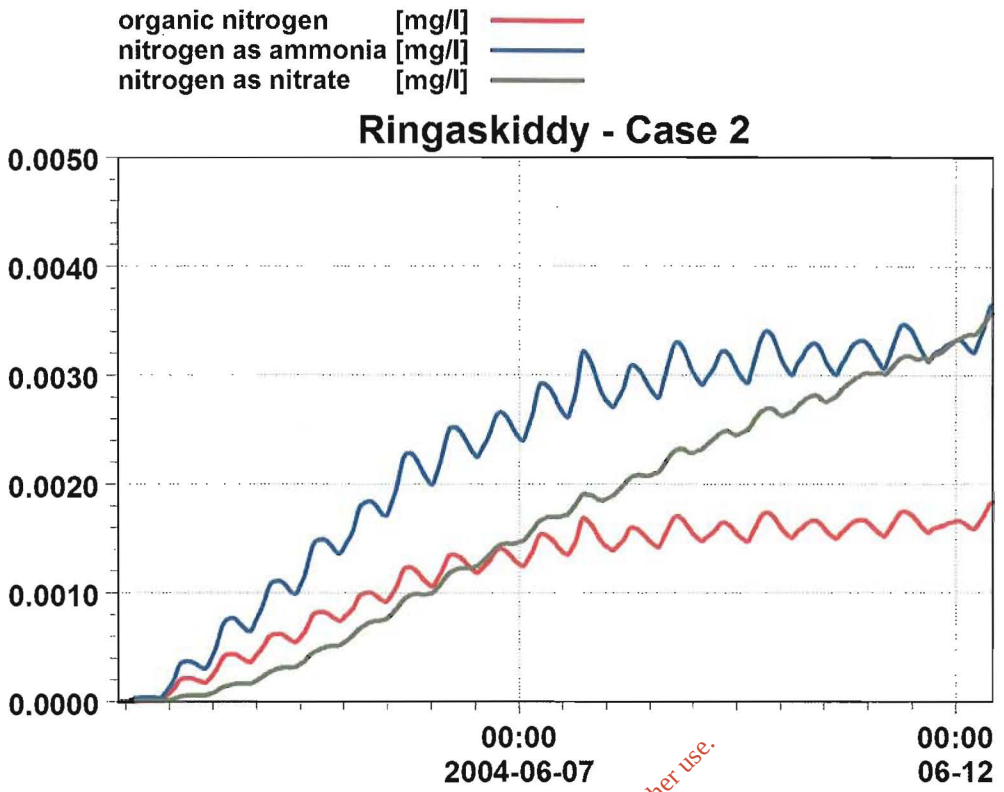


Fig. 6.4 Crosshaven



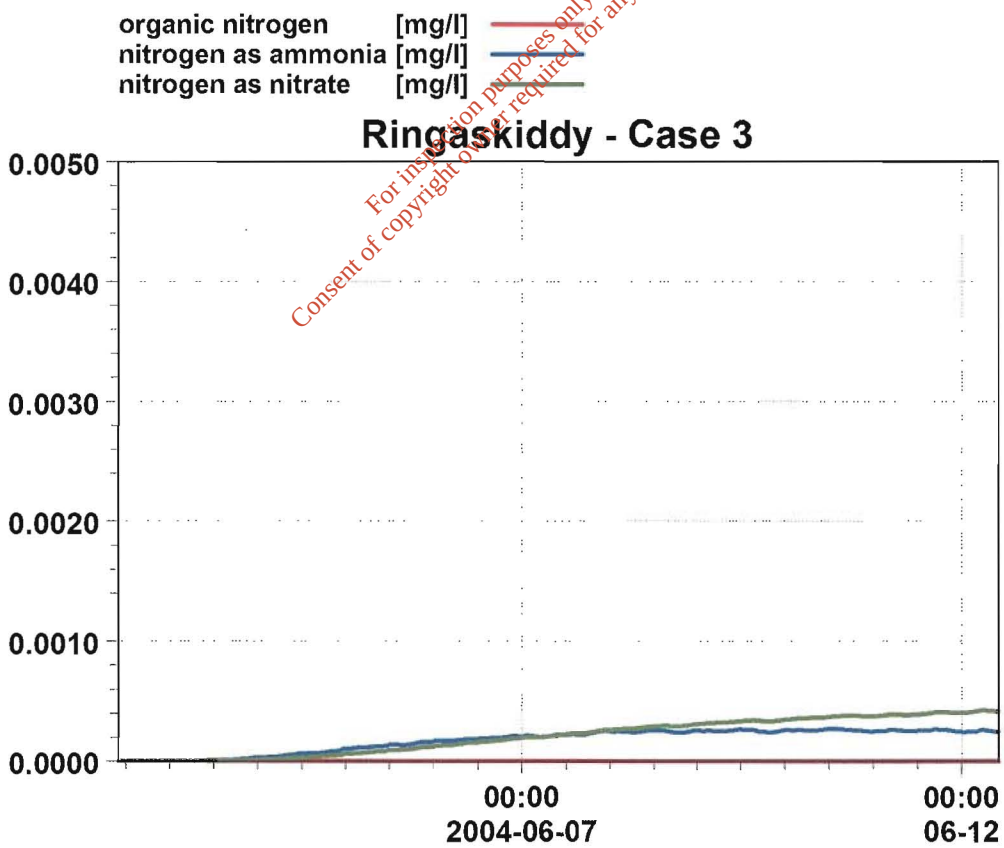
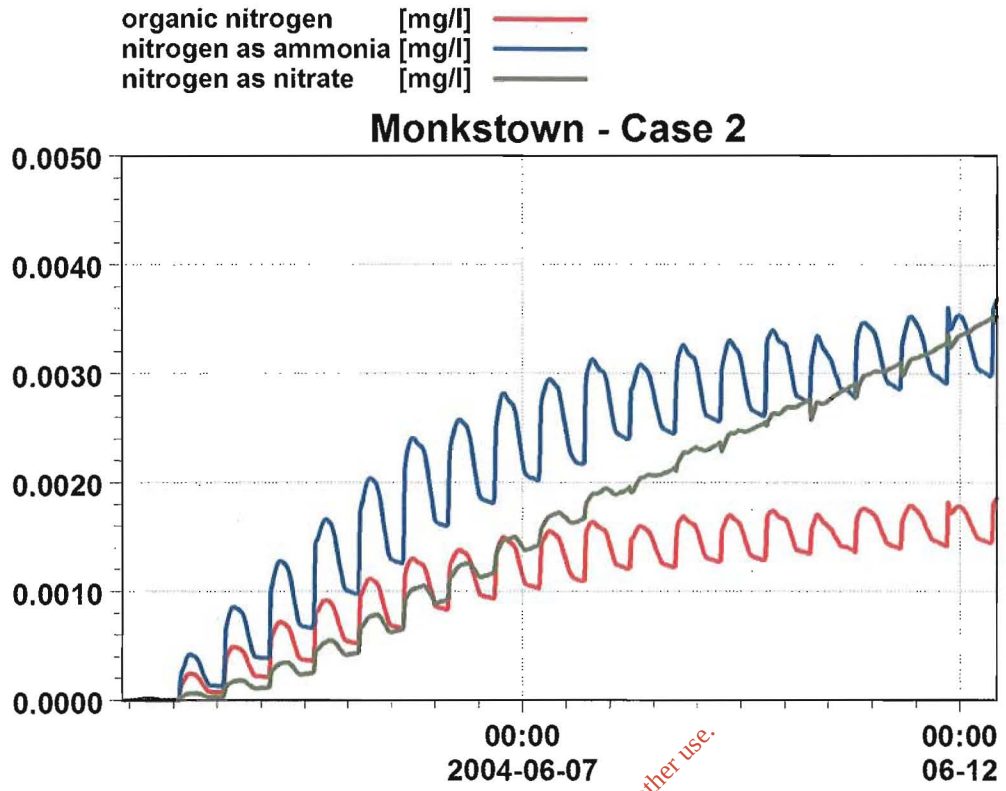


Fig. 6.5 Ringaskiddy



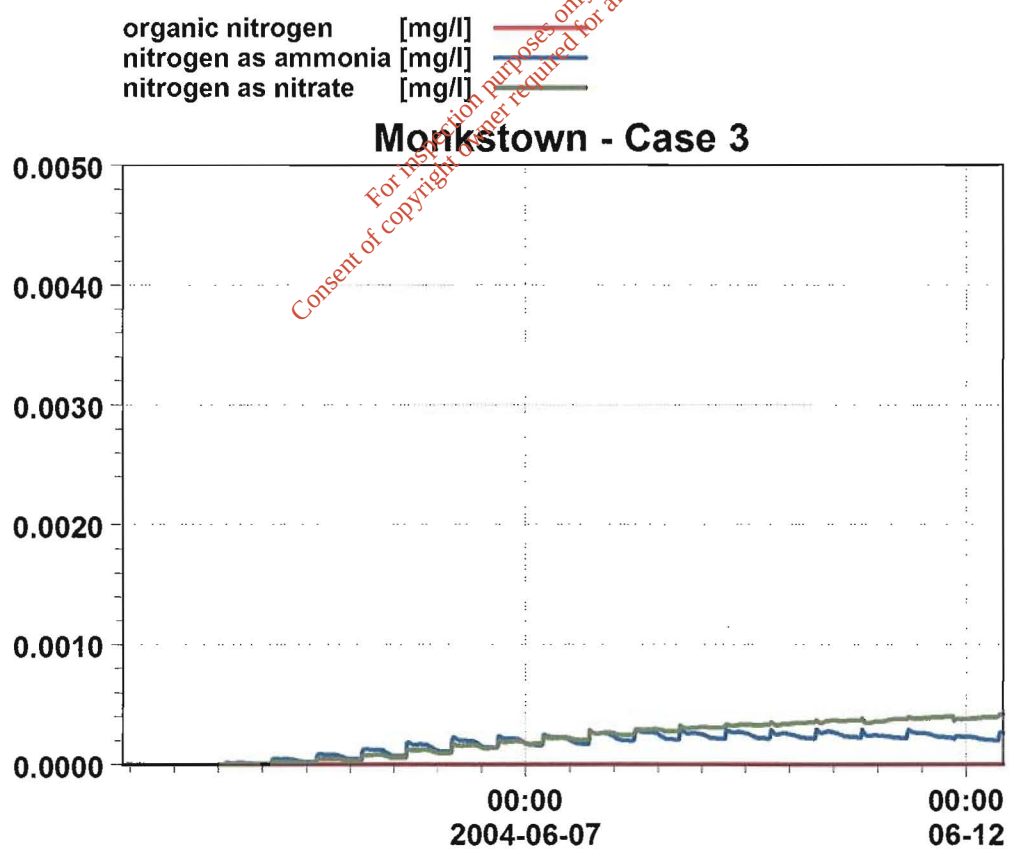


Fig. 6.6 Monkstown

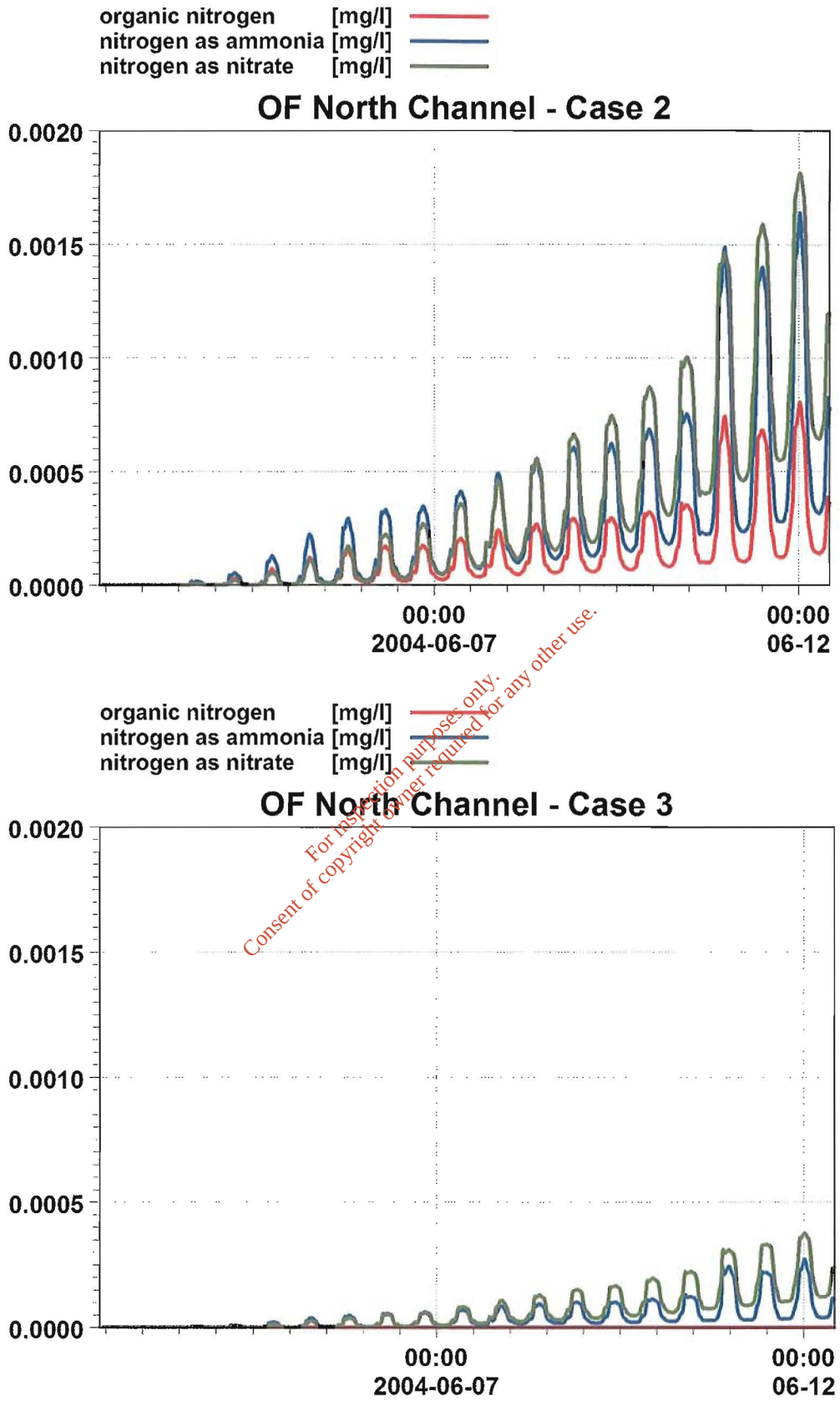


Fig. 6.7 OF – North Channel

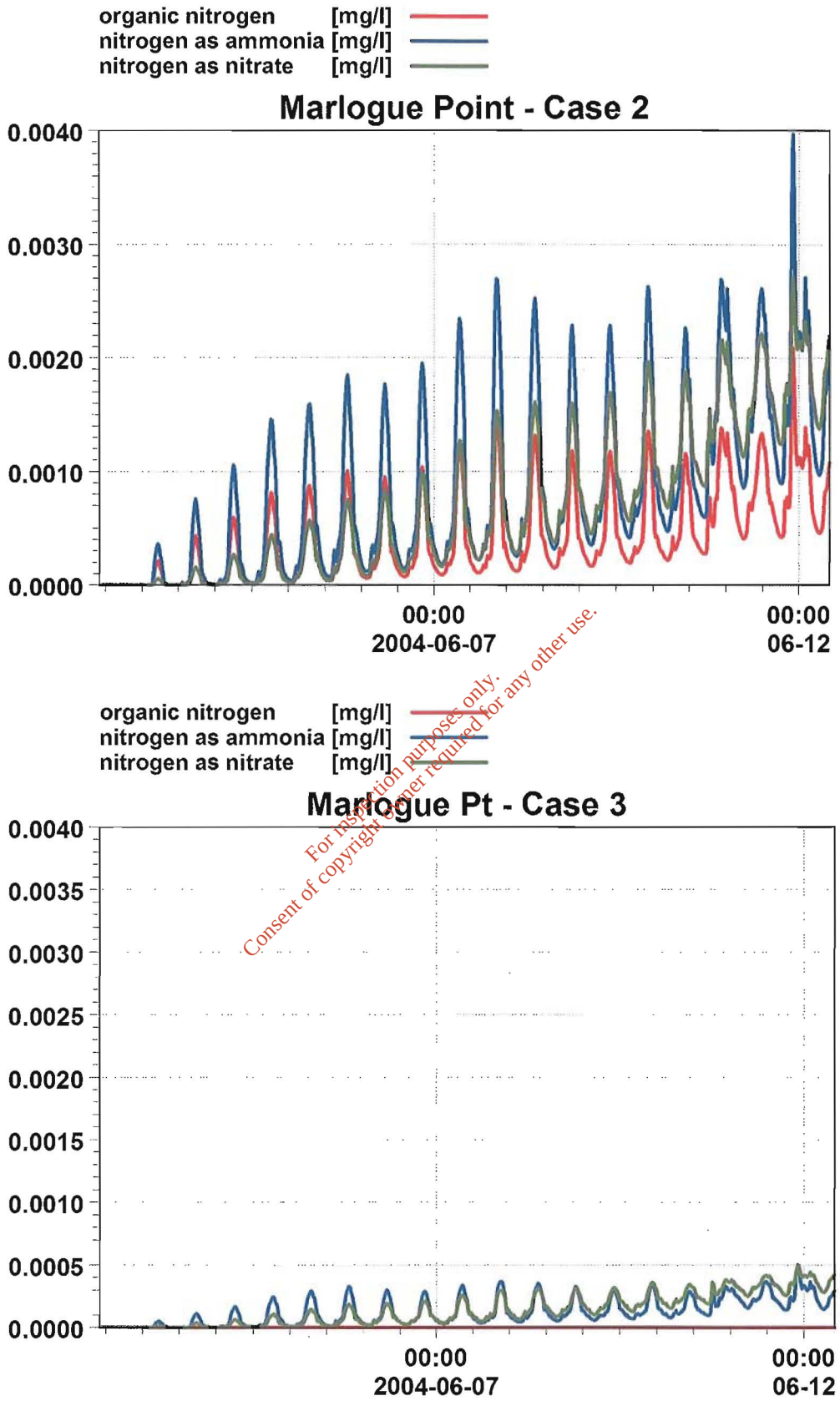
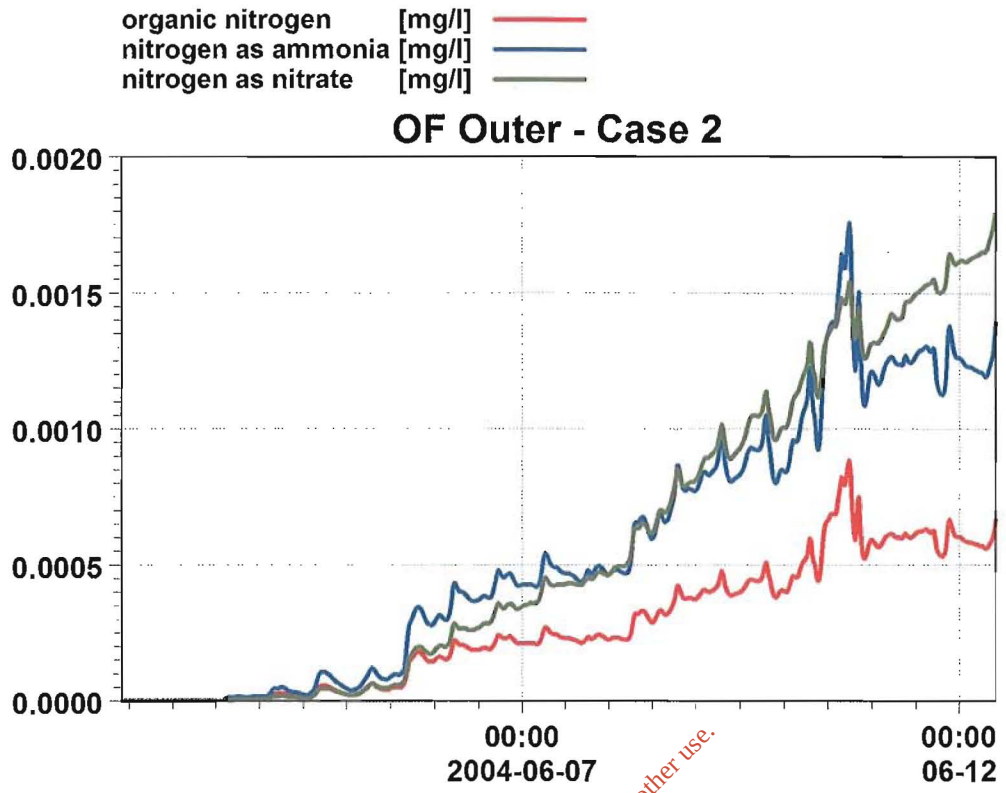


Fig. 6.8 Marlogue Point



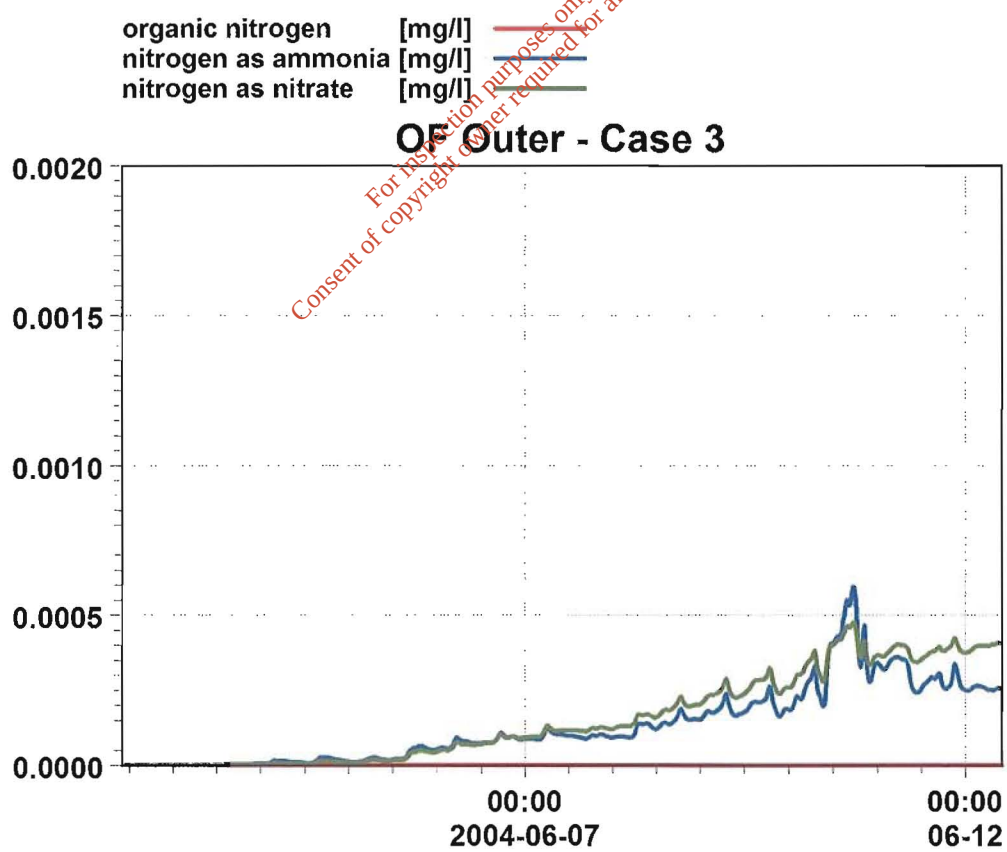
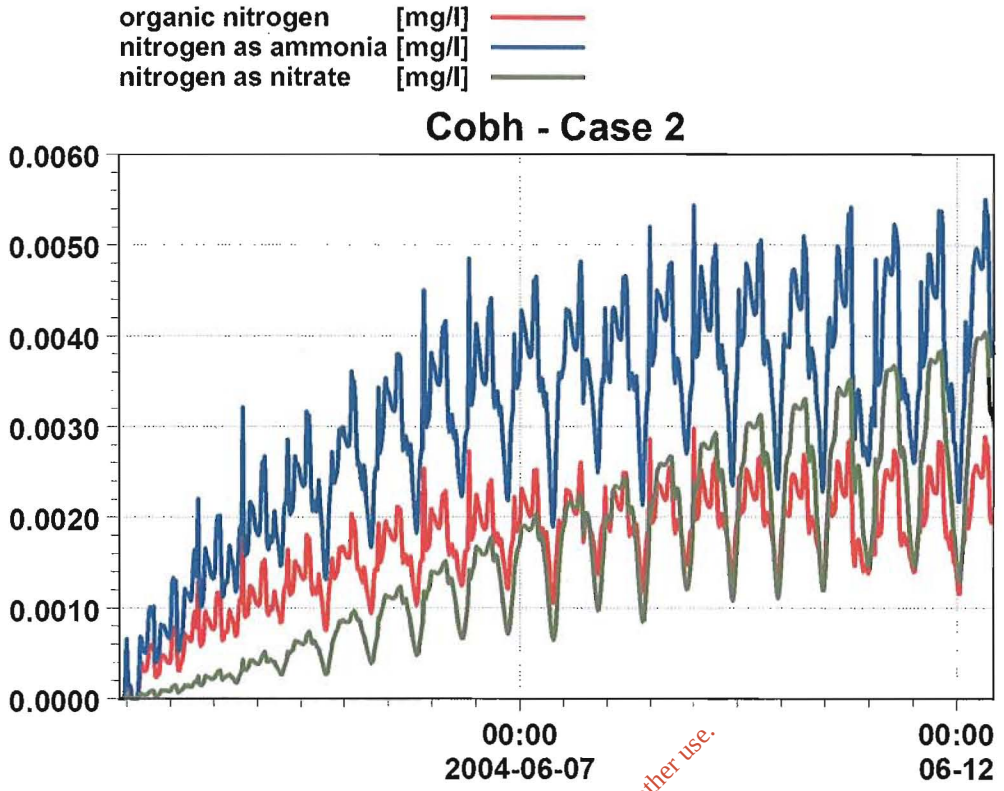


Fig. 6.9 OF – Outer Harbour



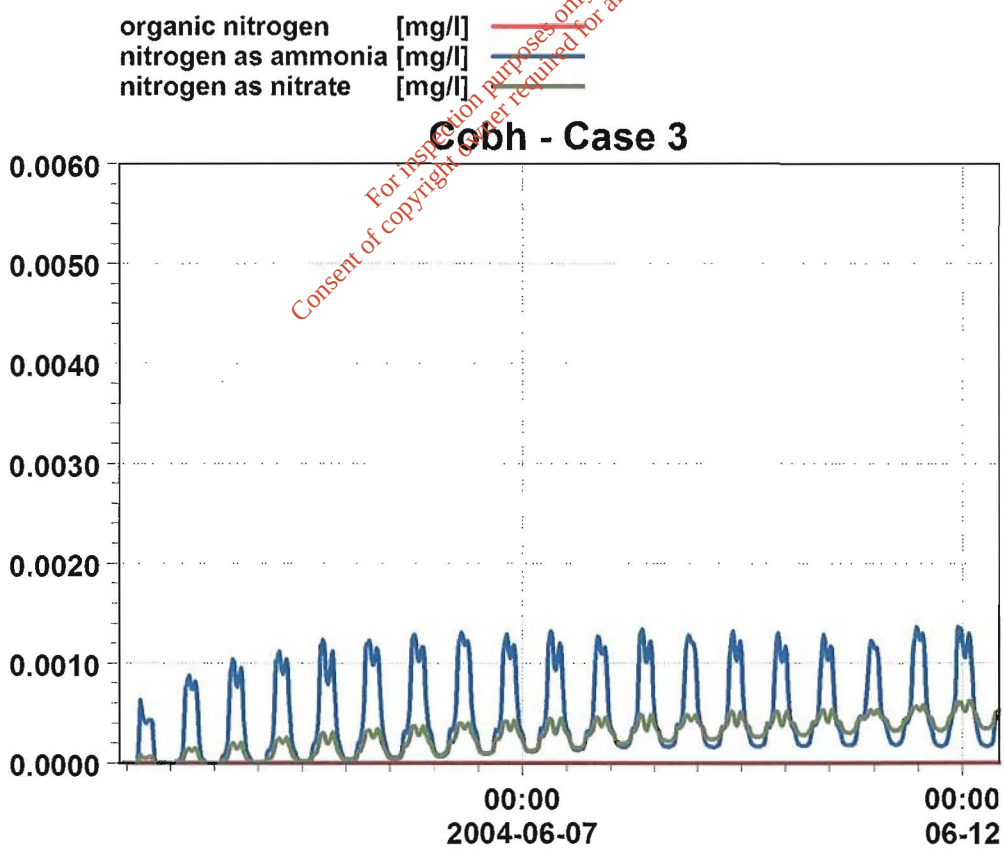
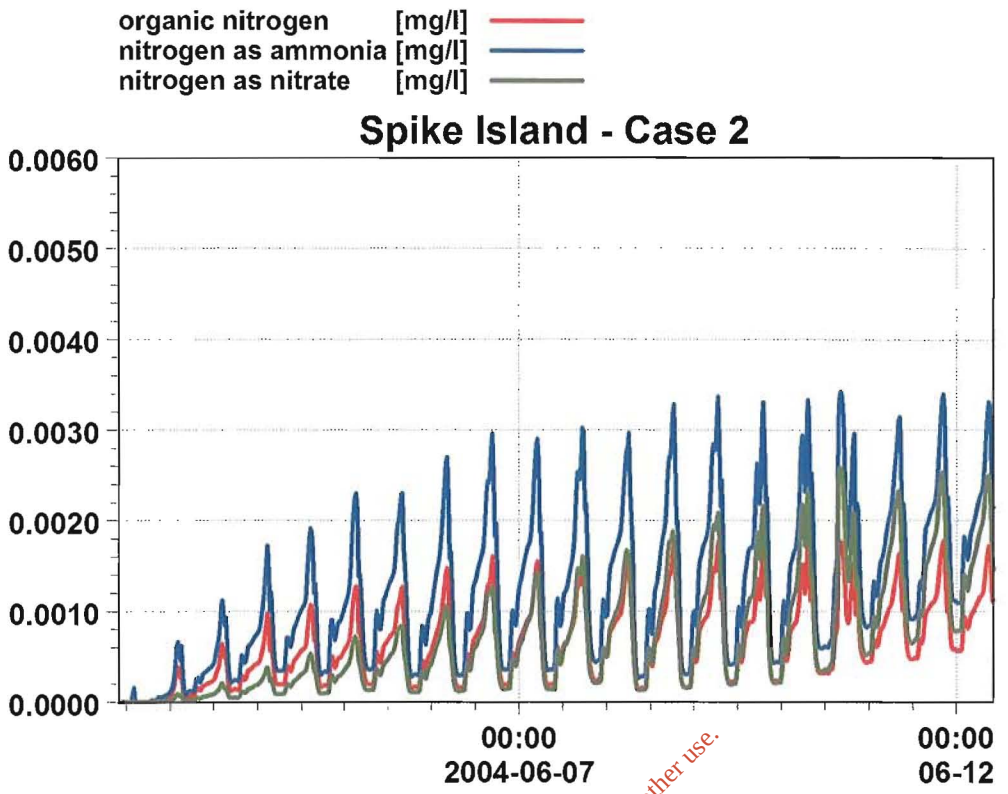


Fig. 6.10 Cobh



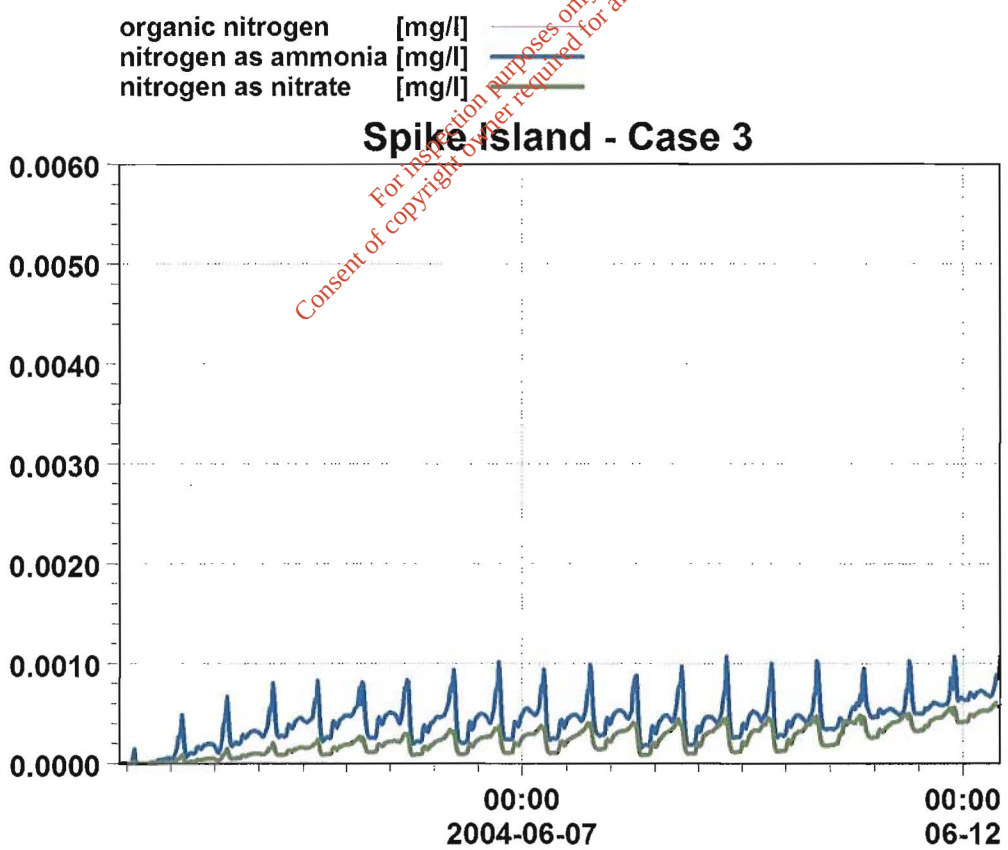
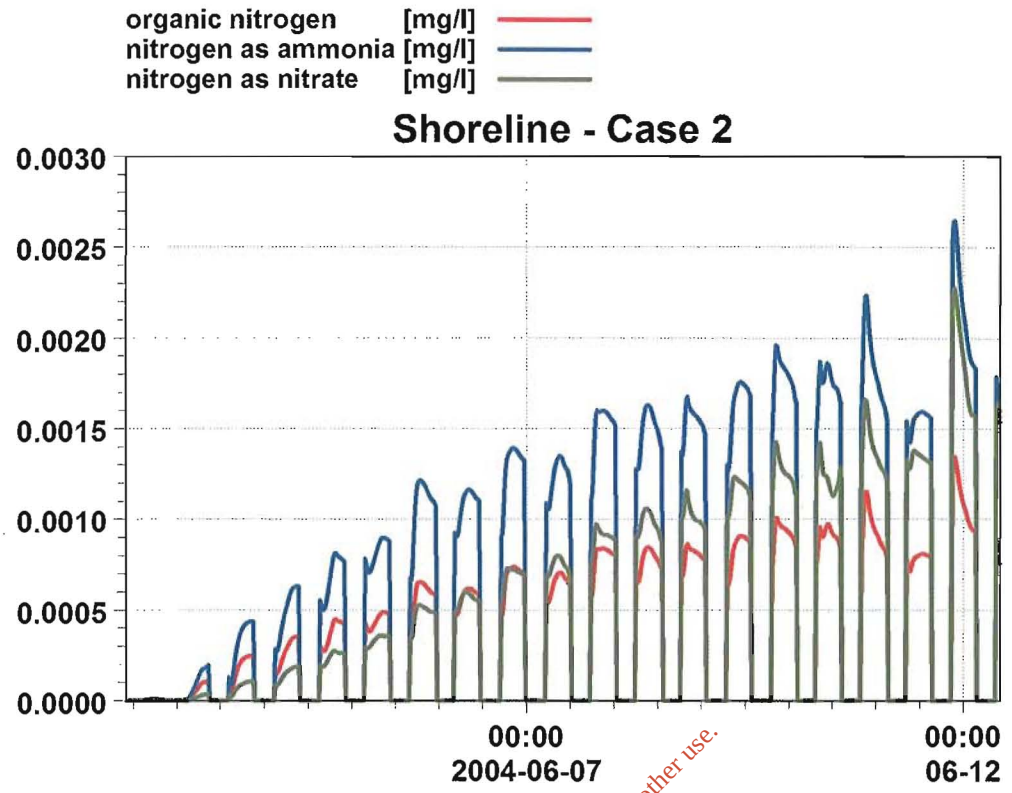


Fig. 6.11 Spike Island



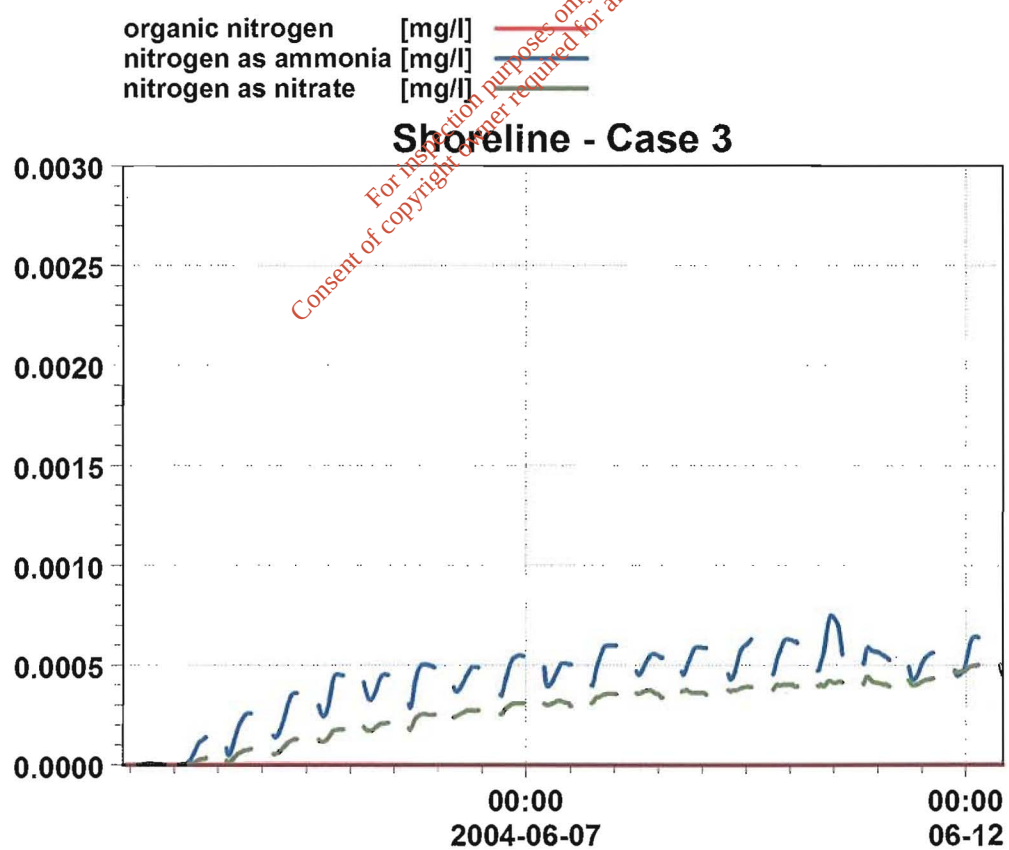
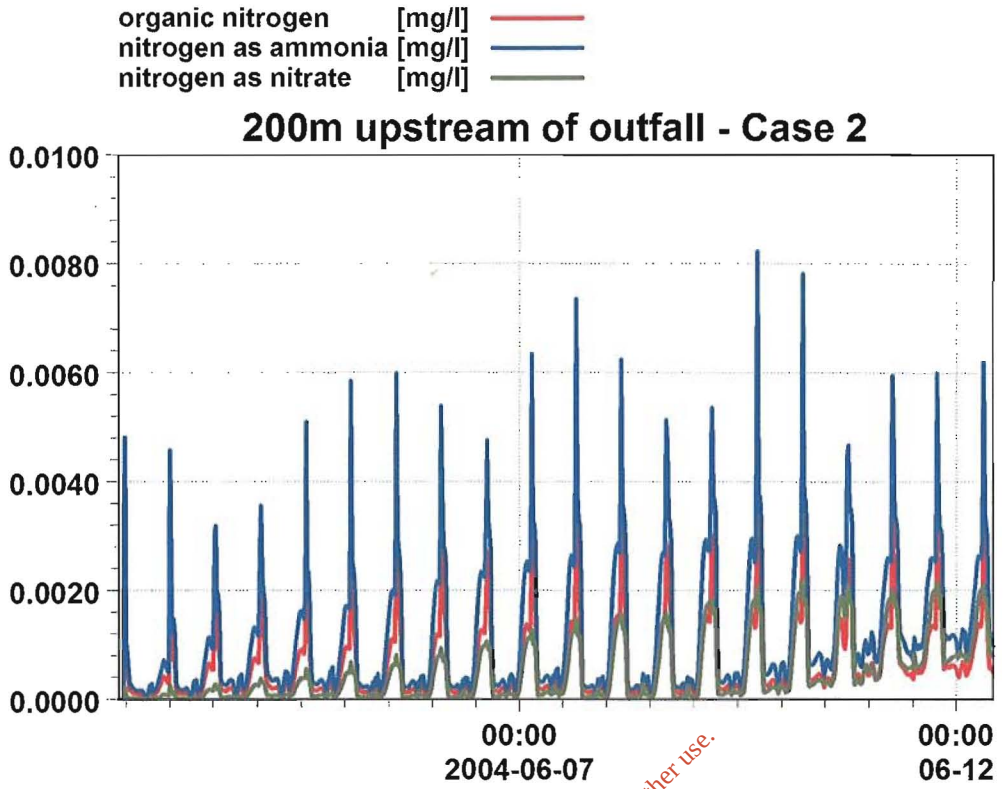


Fig. 6.12 Shoreline closest to outfall



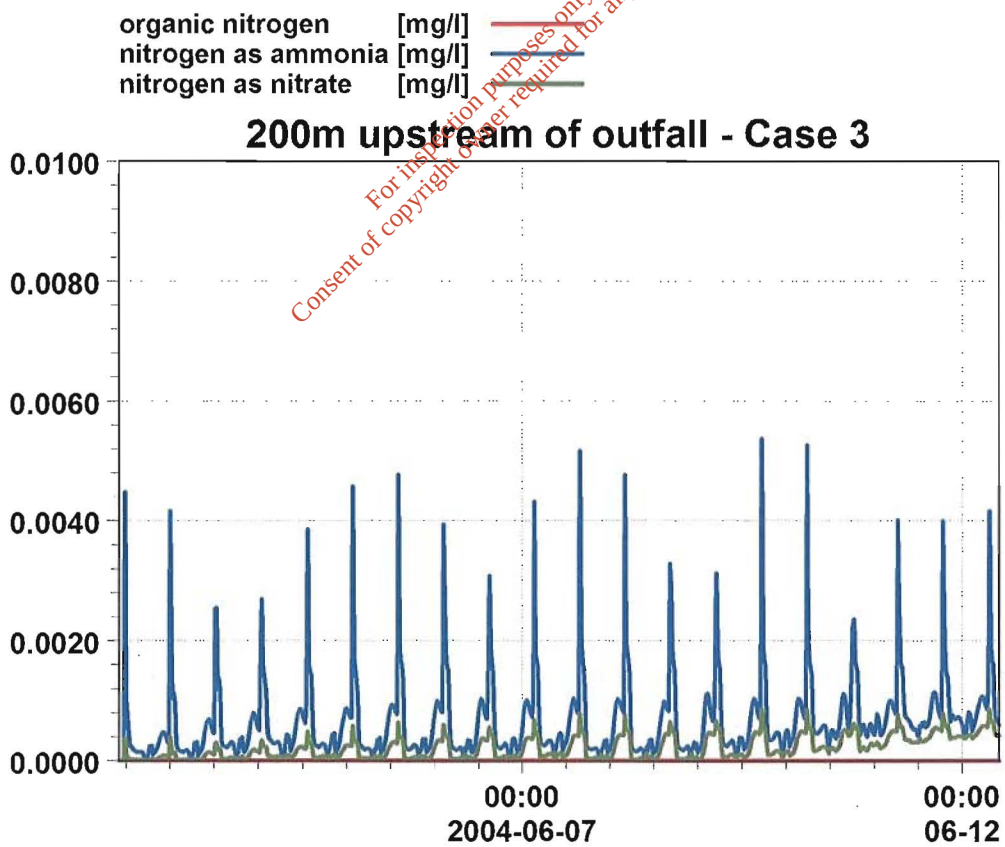
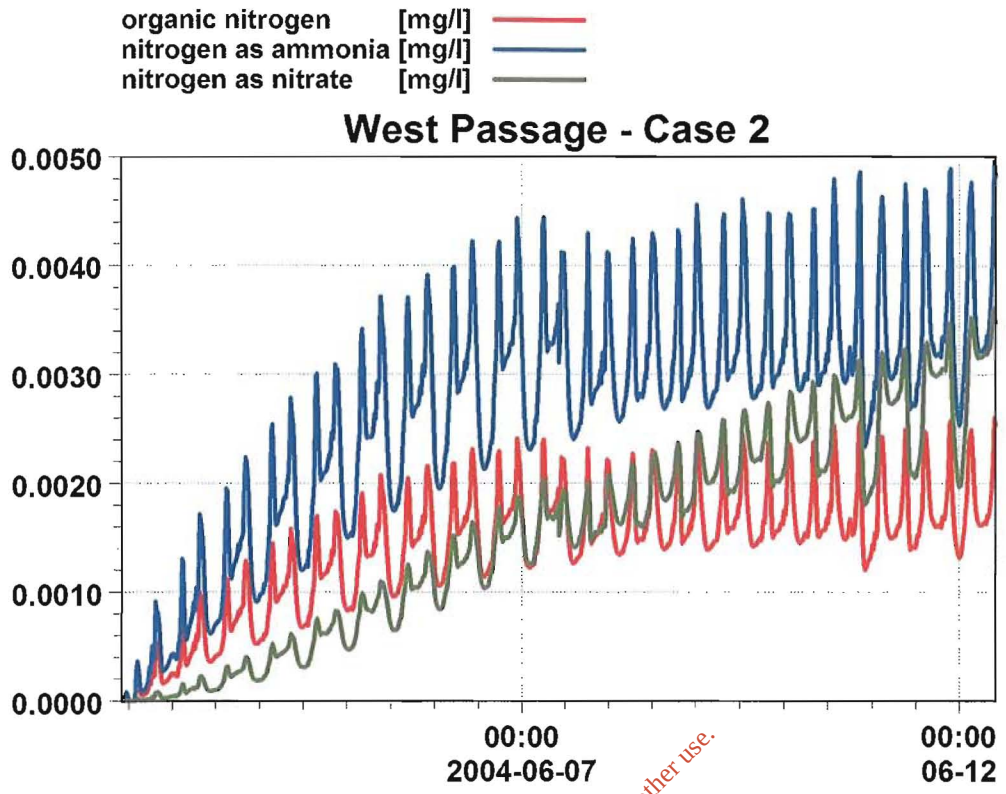


Fig. 6.13 200m upstream of outfall



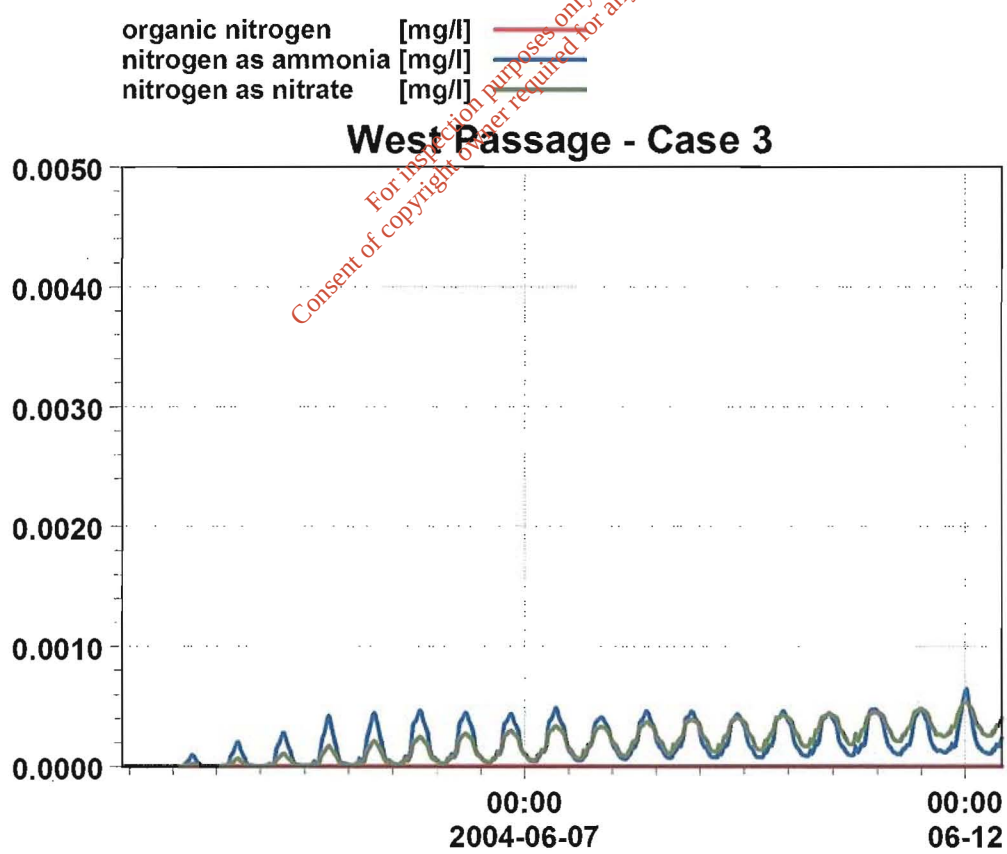
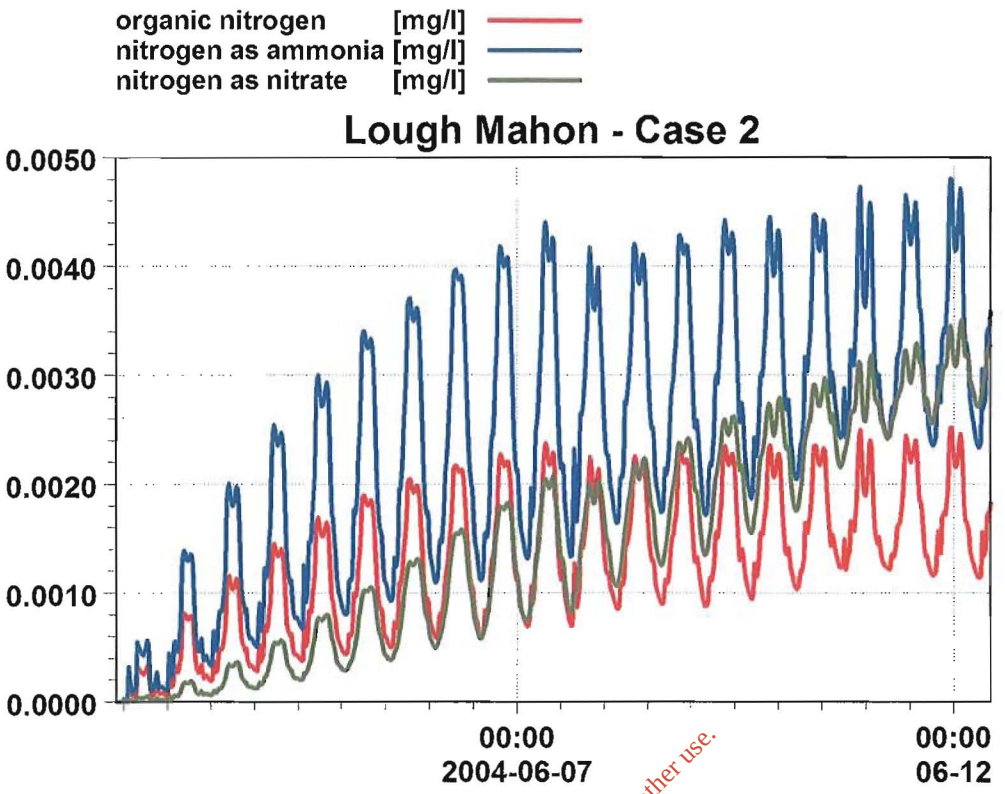


Fig. 6.14 West Passage



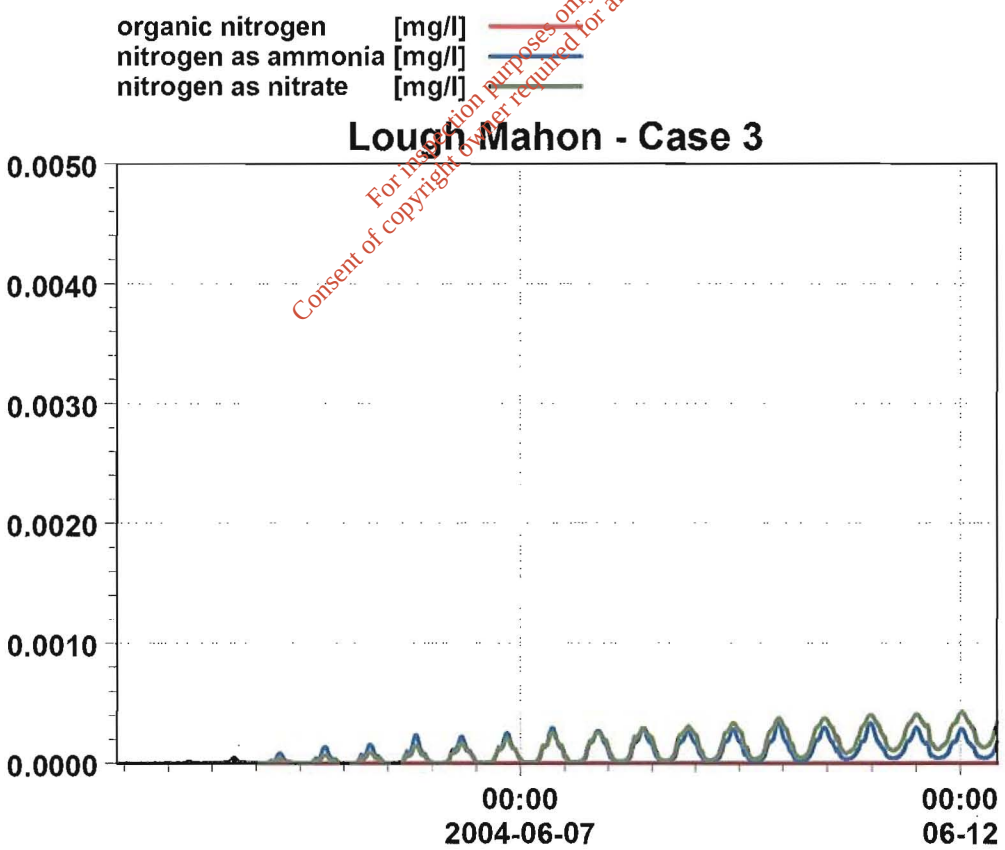


Fig. 6.15 Lough Mahon

6.5 The results – spatially varying maps of concentration

The spatial extent of the improvement is demonstrated in the following four plots. The preceding Fig. 6.16 shows the common colour scales for organic nitrogen, ammonia and nitrate in the four spatial figures. The colour scale is an approximate log scale with a factor of roughly three between each colour band. It produces good spatial separation in the different bands of concentrations.

The four figures follow the same pattern in the presentation of results. The top two spatial plots in each figure show the "before and after" cases (2 and 3) for the concentration of organic nitrogen. The middle two spatial plots in each figure show the "before and after" cases (2 and 3) for the concentration of ammonia. The bottom two spatial plots in each figure show the "before and after" cases (2 and 3) for the concentration of nitrate. The colour scale is the same in all cases: mg/l of atomic nitrogen.

Fig. 6.17 shows the maximum concentrations reached everywhere during the first five day period.

Fig. 6.18 shows the maximum concentrations reached everywhere during the following five day period.

Fig. 6.19 shows the mean concentrations reached everywhere during the first five day period.

Fig. 6.20 shows the mean concentrations reached everywhere during the following five day period.

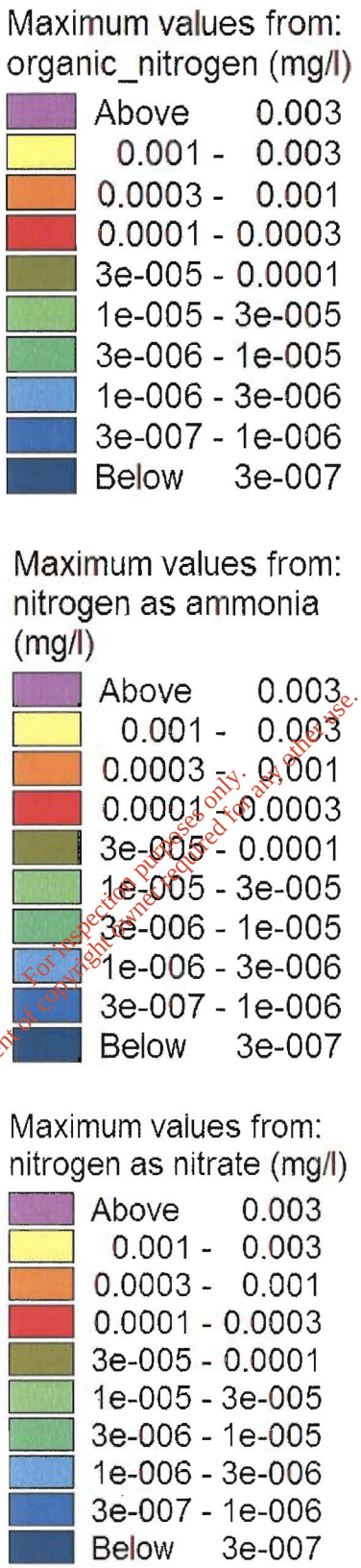


Fig. 6.16 Colour palette for the spatially varying maps of concentration

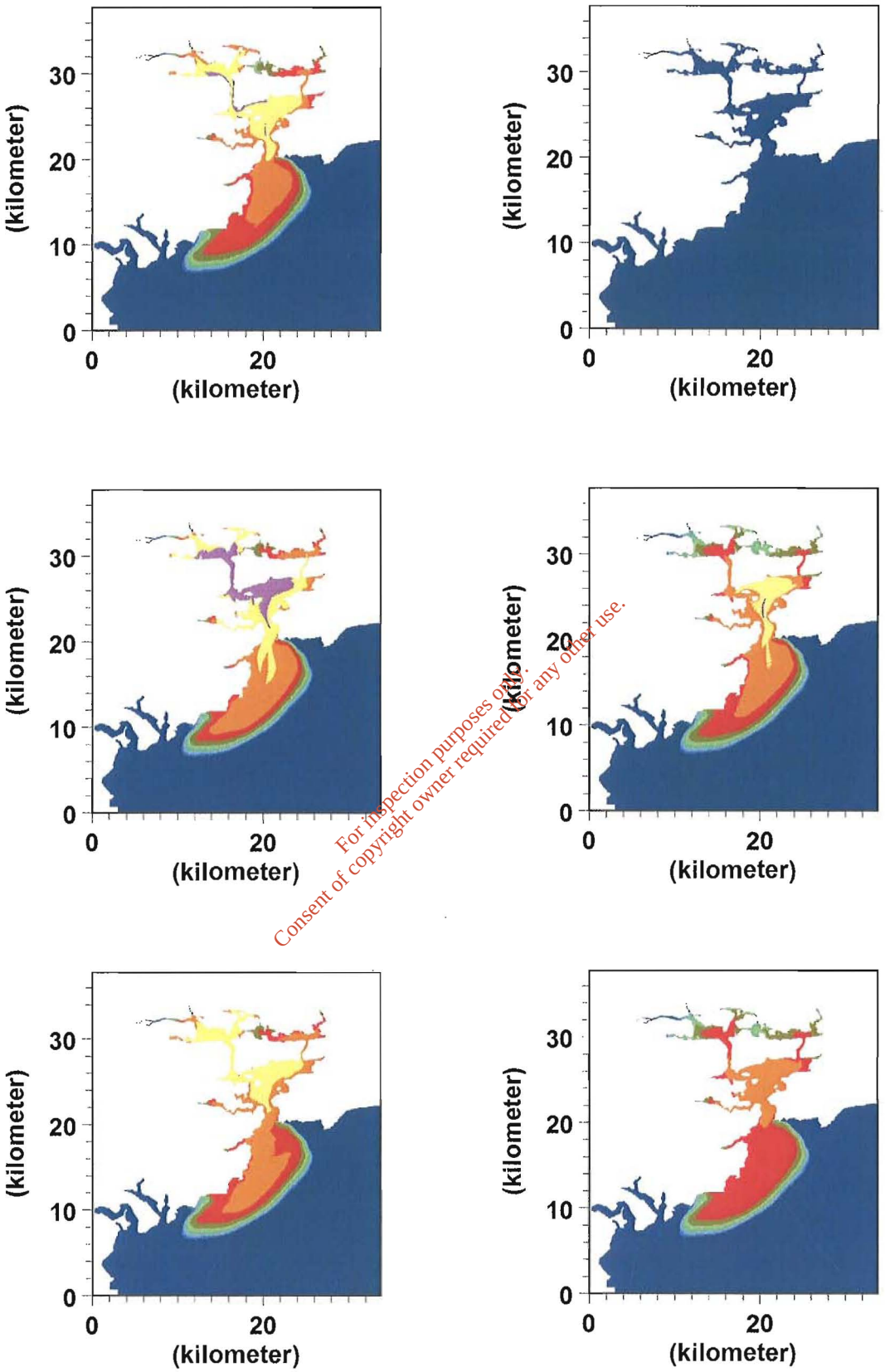


Fig. 6.17 Before and after WWT – maximum concentrations during first 5 day period

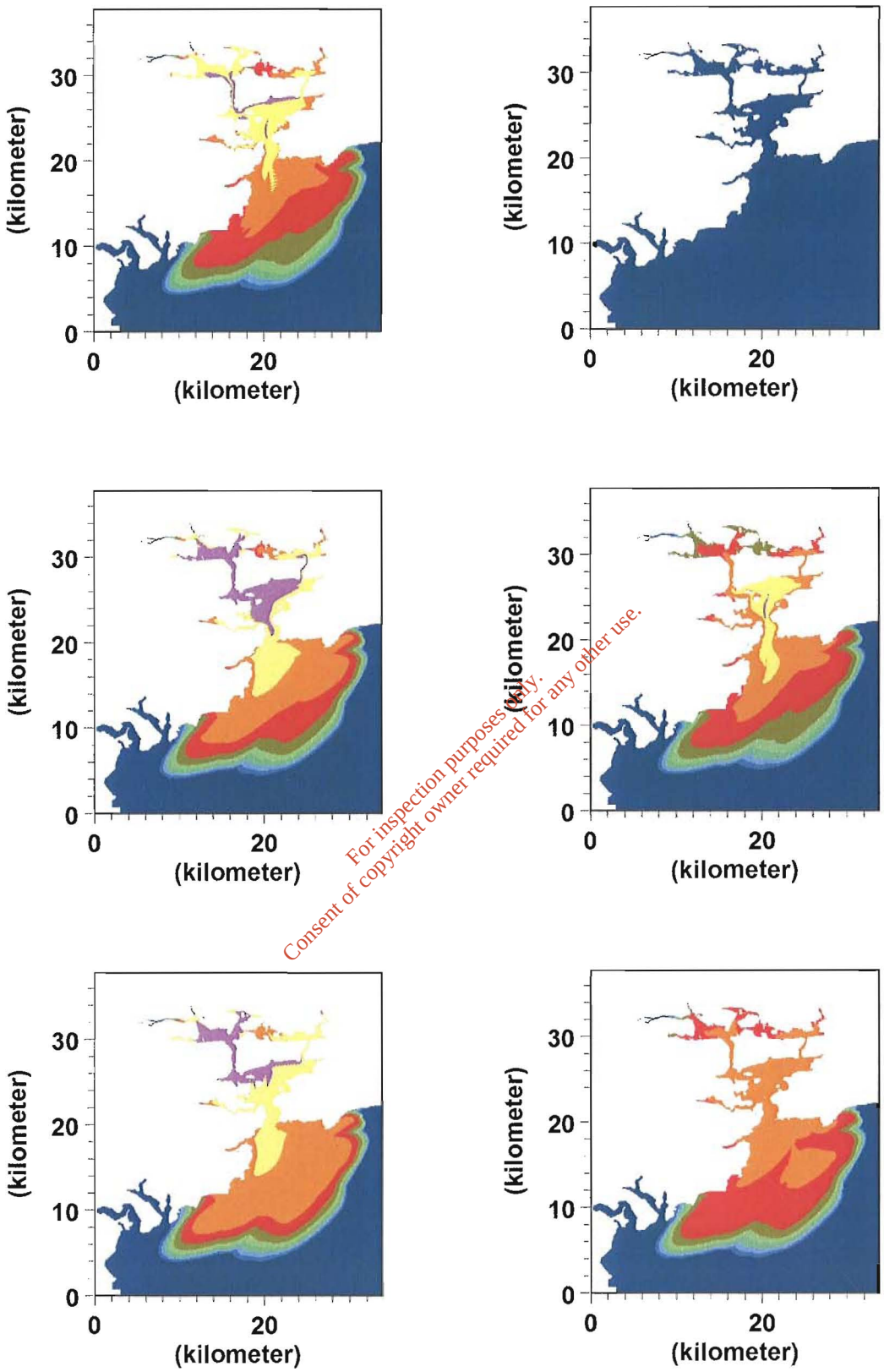


Fig. 6.18 Before and after WWT – maximum concentrations during second 5 day period

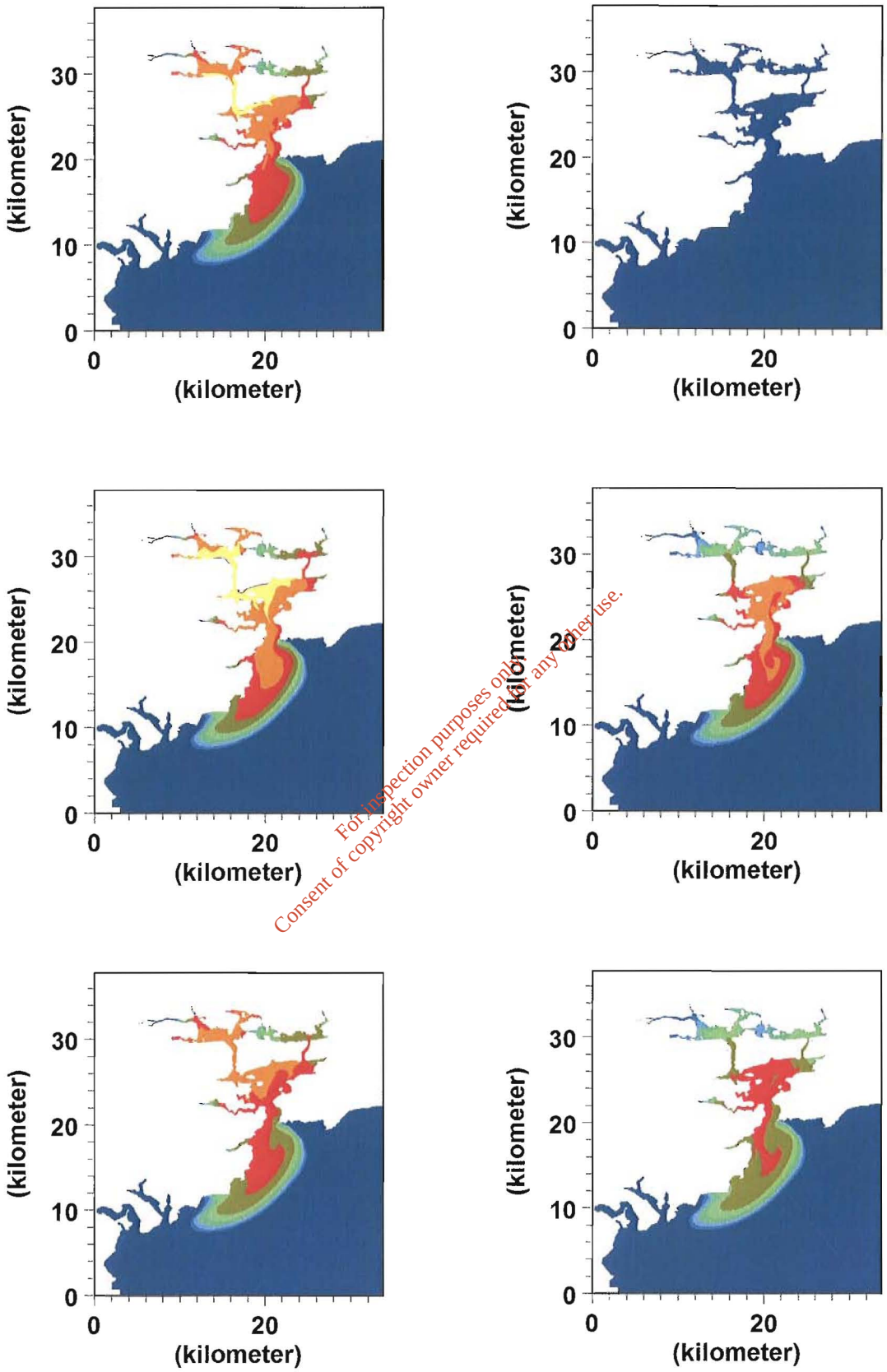


Fig. 6.19 Before and after WWT – mean concentrations during first 5 day period

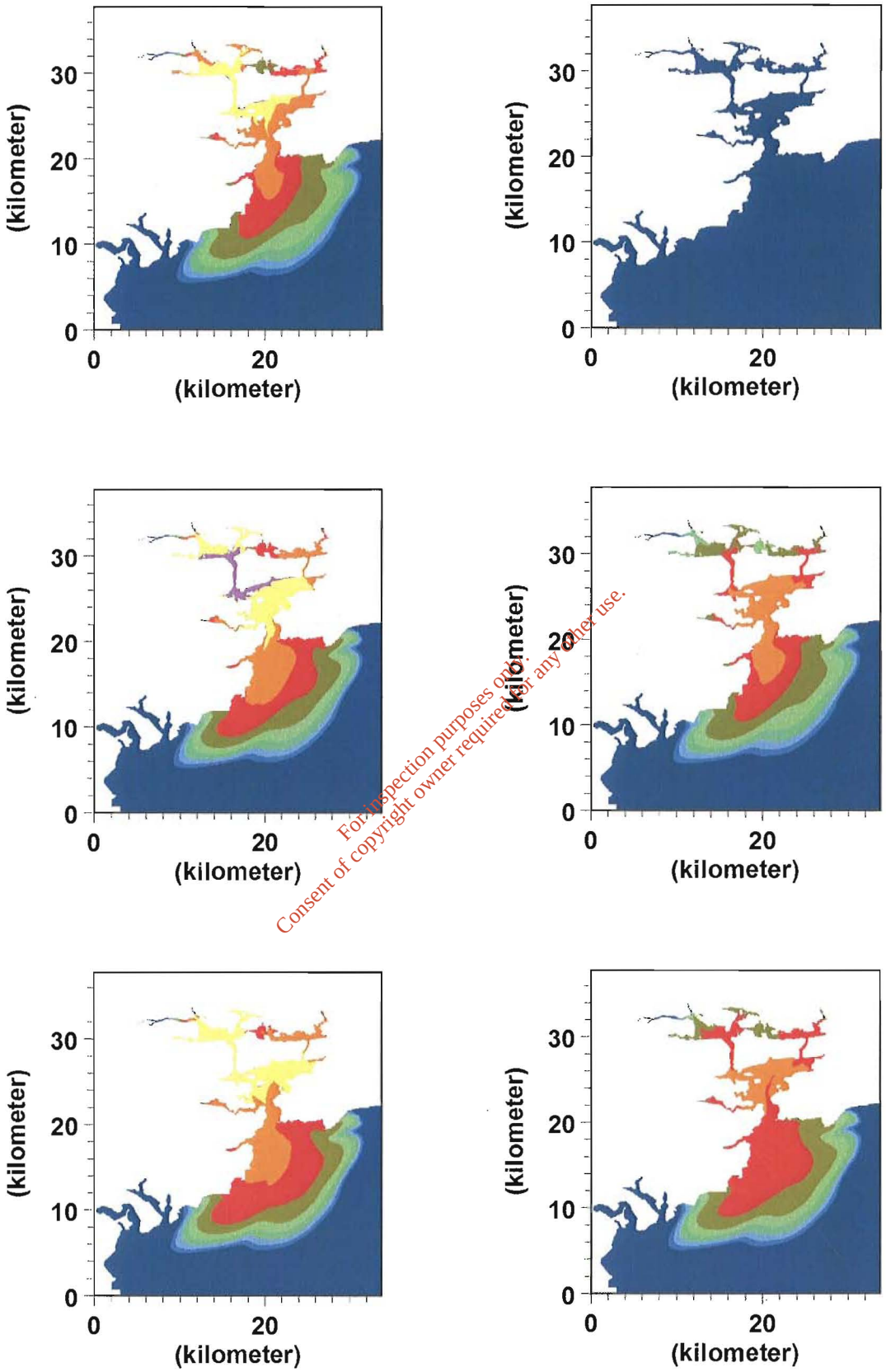


Fig. 6.20 Before and after WWT – mean concentrations during second 5 day period

These plots show that the proposed scheme will reduce considerably the forcing on primary production in the inner harbour (Lough Mahon) and in the North Channel behind Great Island. There is also an improvement throughout the Outer Harbour with the possible exception of the immediate vicinity of the diffuser itself. The model does not resolve the near-field of the diffuser and results from our model very close to the diffuser may not be accurate.

6.6 Sensitivity Analysis

We have included a sensitivity analysis which considers a more conservative removal efficiency of the treatment plant. After treatment, the concentrations are assumed to be 15mg/l (N_org), 12.5mg/l (N_NH4) and 1mg/l (N-NO3) respectively, a removal efficiency of one third of total nitrogen.

A summary of the assumed concentrations for the three cases considered is presented in the table below.

Nutrient	Raw Sewage	After treatment	Sensitivity Analysis
Organic Nitrogen (N_org)	15mg/l	0mg/l	15mg/l
Ammonia (N_NH4)	25mg/l	12.5mg/l	12.5mg/l
Nitrate (N-NO3)	1mg/l	1mg/l	1mg/l

Table 6-5 Assumed concentrations for the three cases

The time series for the points of interest are presented over the next few pages. Two separate plots are included for each location. The first plot presents the variation in concentration of organic nitrogen, ammonia and nitrate for the sensitivity analysis. To aid the reader in making a comparison between the two different removal efficiencies the timeseries from section 6.4 are included in the second plot. The reader should be aware that the scale on both plots for each point is the same. The scaling does however differ to the plots presents in section 6.4 for the first higher removal efficiency assumption.

The maximum concentrations for the sensitivity analysis for each of the fifteen points are presented in the following three tables.

	Nitrogen			
	CASE 3 First assumption MAX	Sensitivity assumption MAX	CASE 4 First assumption MAX	Sensitivity assumption MAX
Fountainstown	0	0.000432	0	0.000618
Myrtleville	0	0.000500	0	0.000715
Roches Point	0	0.001779	0	0.002546
Crosshaven	0	0.001038	0	0.001486
Ringaskiddy Ferry	0	0.000393	0	0.000562
Monkstown Creek	0	0.000413	0	0.000592
Oyster Farm - NC	0	0.000390	0	0.000558
Marlogue Point	0	0.000689	0	0.000986
Oyster Farm - OH	0	0.000809	0	0.001157
Cobh	0	0.001831	0	0.002620
Spike Island	0	0.001385	0	0.001982
Shoreline	0	0.000976	0	0.001397
Upstream Outfall	0	0.006471	0	0.009260
West Passage	0	0.000870	0	0.001245
Lough Mahon	0	0.000471	0	0.000673

Table 6-6 Maximum concentrations of Nitrogen for both treatment plant removal assumptions

	Ammonia			
	CASE 3 First assumption MAX	Sensitivity assumption MAX	CASE 4 First assumption MAX	Sensitivity assumption MAX
Fountainstown	0.000309	0.000553	0.000442	0.000791
Myrtleville	0.000396	0.000631	0.000567	0.000903
Roches Point	0.001478	0.001785	0.002115	0.002555
Crosshaven	0.00079	0.001156	0.001130	0.001654
Ringaskiddy Ferry	0.000272	0.000543	0.000389	0.000778
Monkstown Creek	0.000291	0.000560	0.000416	0.000801
Oyster Farm - NC	0.000272	0.000526	0.000389	0.000753
Marlogue Point	0.000502	0.000850	0.000718	0.001216
Oyster Farm - OH	0.000595	0.000954	0.000851	0.001365
Cobh	0.001363	0.001858	0.001950	0.002659
Spike Island	0.001072	0.001472	0.001534	0.002106
Shoreline	0.000749	0.001060	0.001072	0.001517
Upstream of Outfall	0.005359	0.005683	0.007669	0.008132
West Passage	0.000641	0.001027	0.000917	0.001470
Lough Mahon	0.000336	0.000614	0.000481	0.000879

Table 6-7 Maximum concentrations of Ammonia for both treatment plant removal assumptions

	Nitrate			
	CASE 3		CASE 4	
	First assumption	Sensitivity assumption	First assumption	Sensitivity assumption
	MAX	MAX	MAX	MAX
Fountainstown	0.000332	0.00046149	0.000475	0.000661
Myrtleville	0.000394	0.0005058	0.000564	0.000724
Roches Point	0.000578	0.00073657	0.000828	0.001055
Crosshaven	0.000545	0.00067713	0.000780	0.000970
Ringaskiddy Ferry	0.000423	0.00064122	0.000606	0.000918
Monkstown Creek	0.000418	0.00060934	0.000599	0.000873
Oyster Farm - NC	0.000376	0.00056257	0.000538	0.000806
Marlogue Point	0.000493	0.00070098	0.000706	0.001004
Oyster Farm - OH	0.000476	0.00064305	0.000682	0.000921
Cobh	0.000616	0.00081516	0.000882	0.001167
Spike Island	0.000603	0.00074446	0.000863	0.001066
Shoreline	0.0005	0.00067418	0.000716	0.000965
Upstream of Outfall	0.000863	0.00105842	0.001236	0.001516
West Passage	0.000533	0.00074542	0.000763	0.001067
Lough Mahon	0.000421	0.00062927	0.000603	0.000901

Table 6-8 Maximum concentrations of Nitrate for both treatment plant removal assumptions

The time series of concentration for each of the 15 points of interest are presented on the following pages.

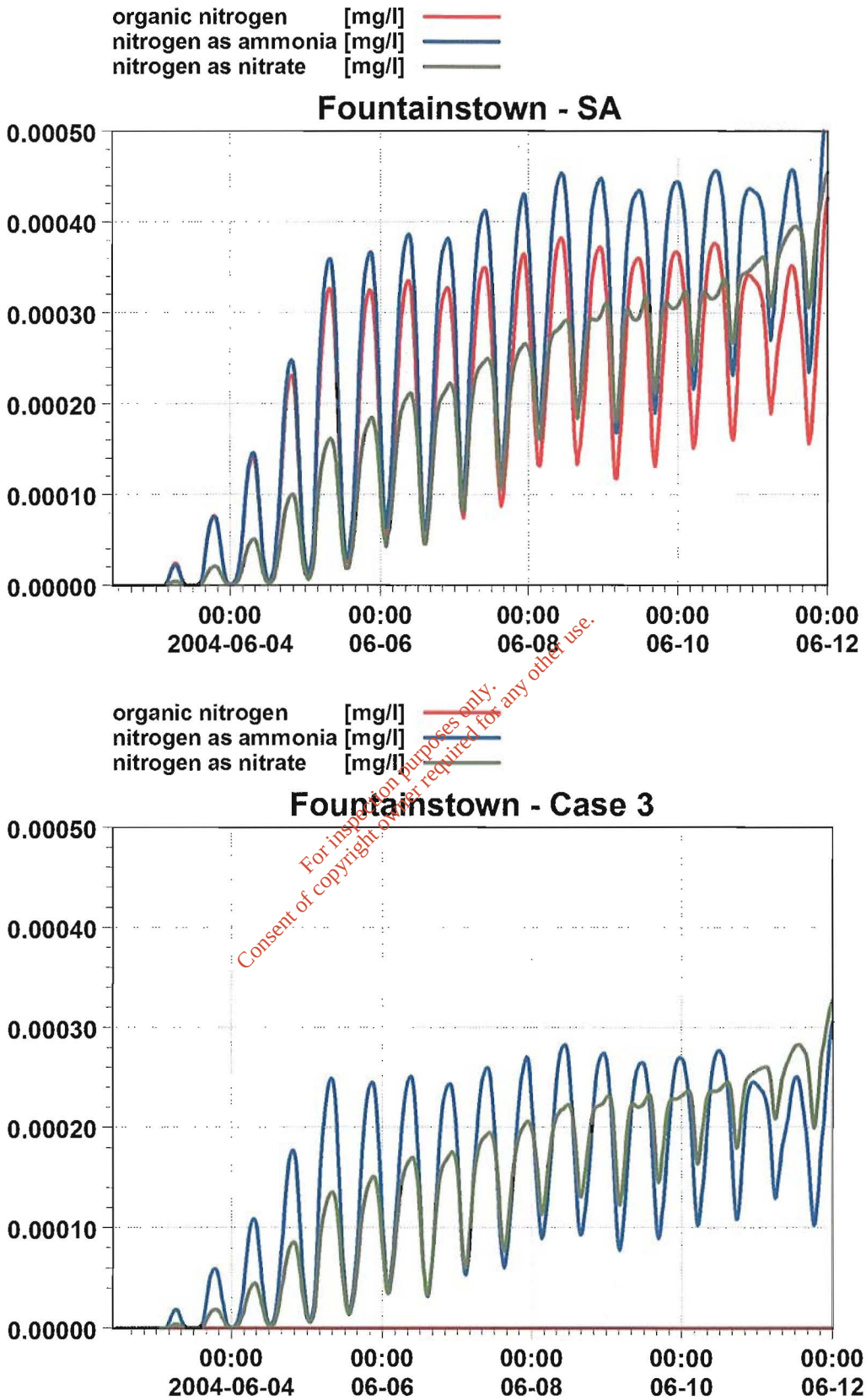


Fig. 6.21 Fountainstown

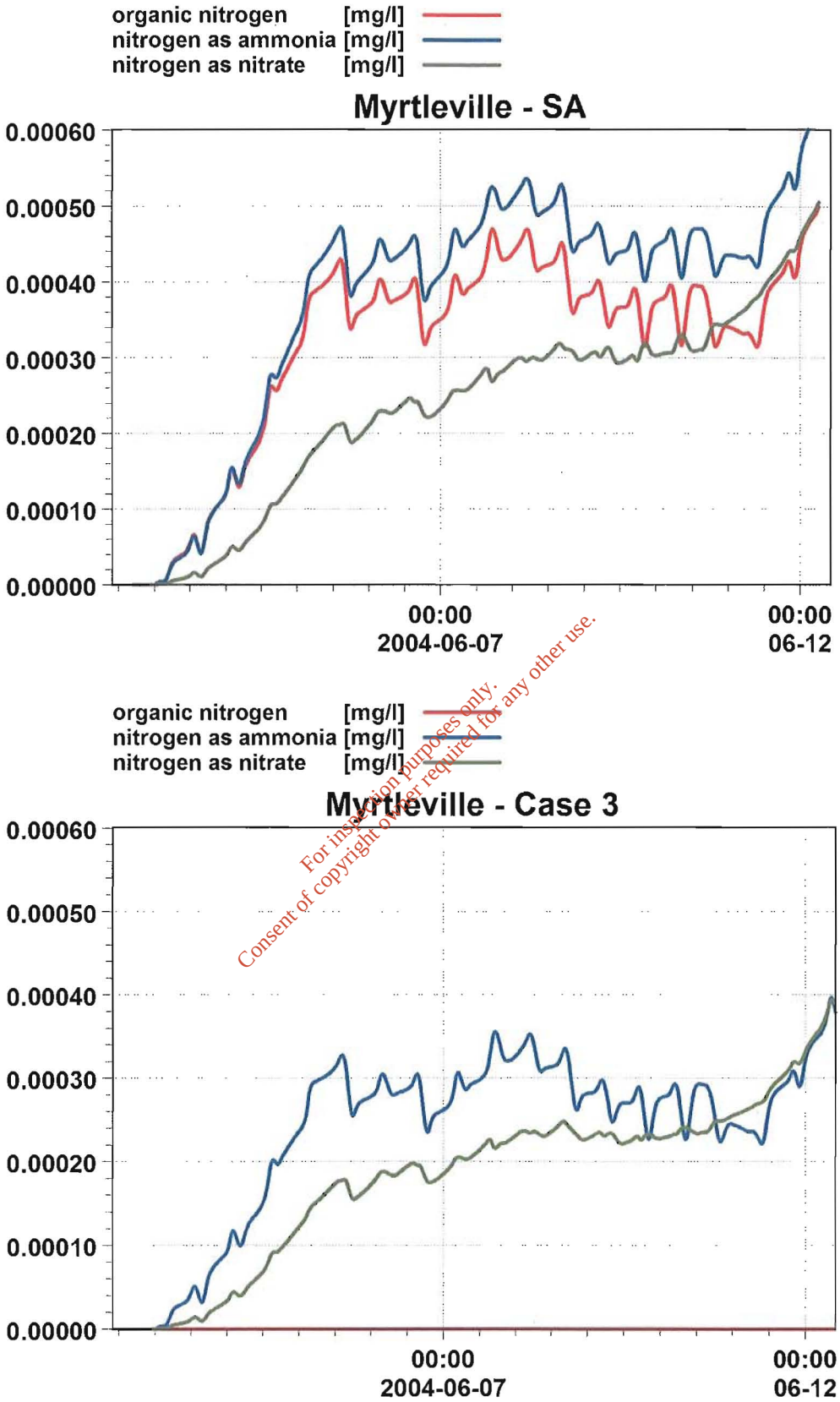


Fig. 6.22 Myrtleville

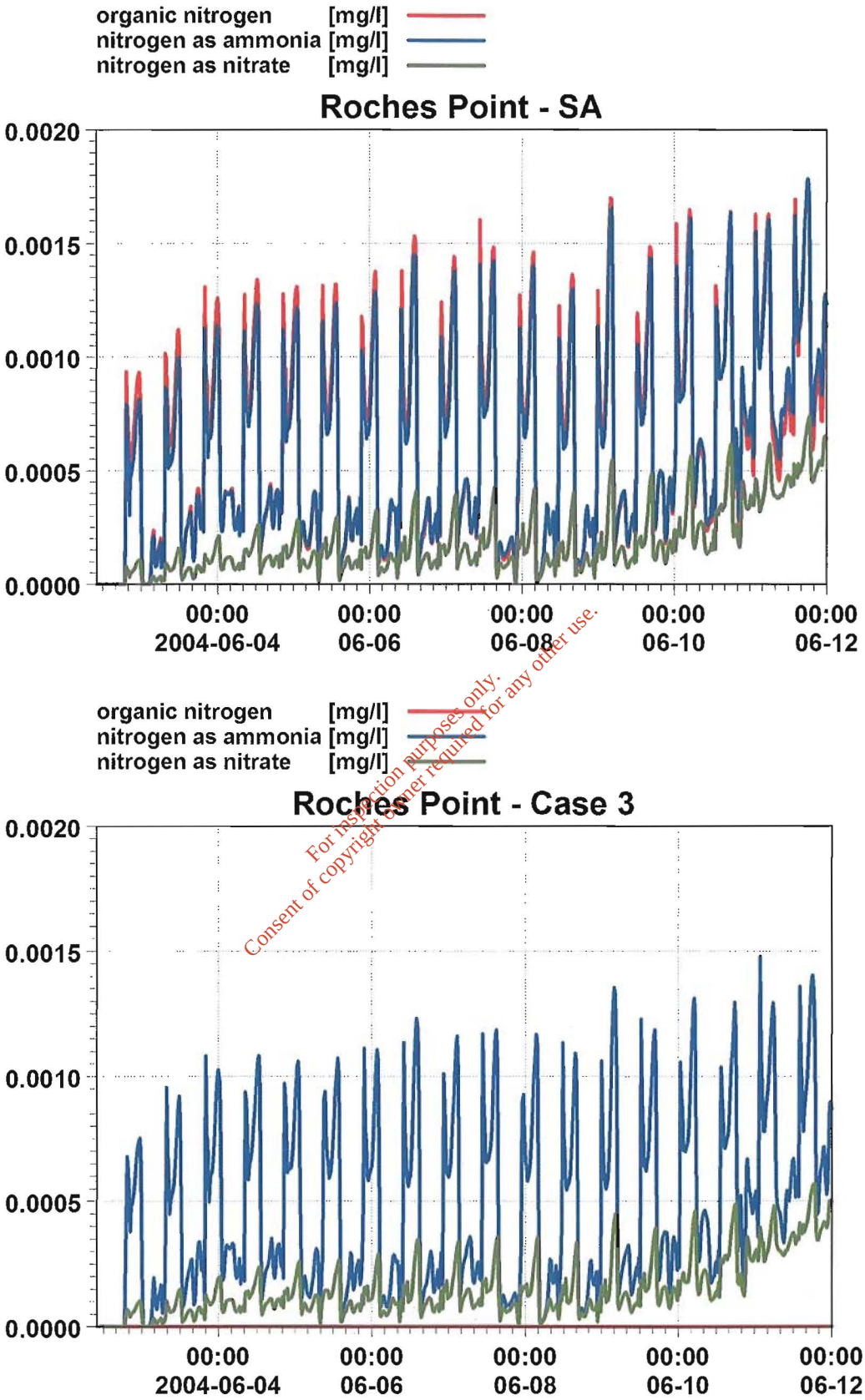


Fig. 6.23 Roches Point

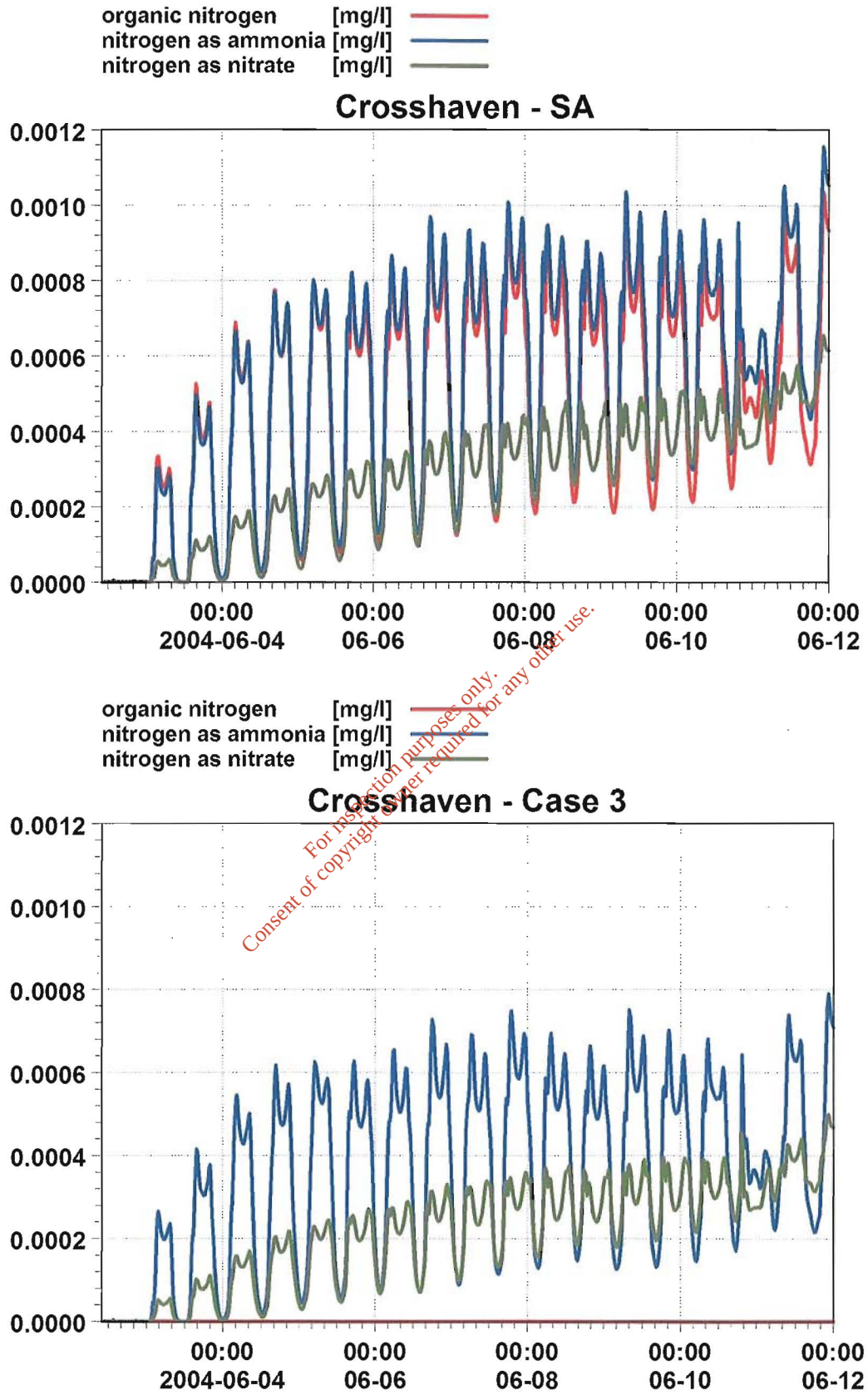


Fig. 6.24 Crosshaven

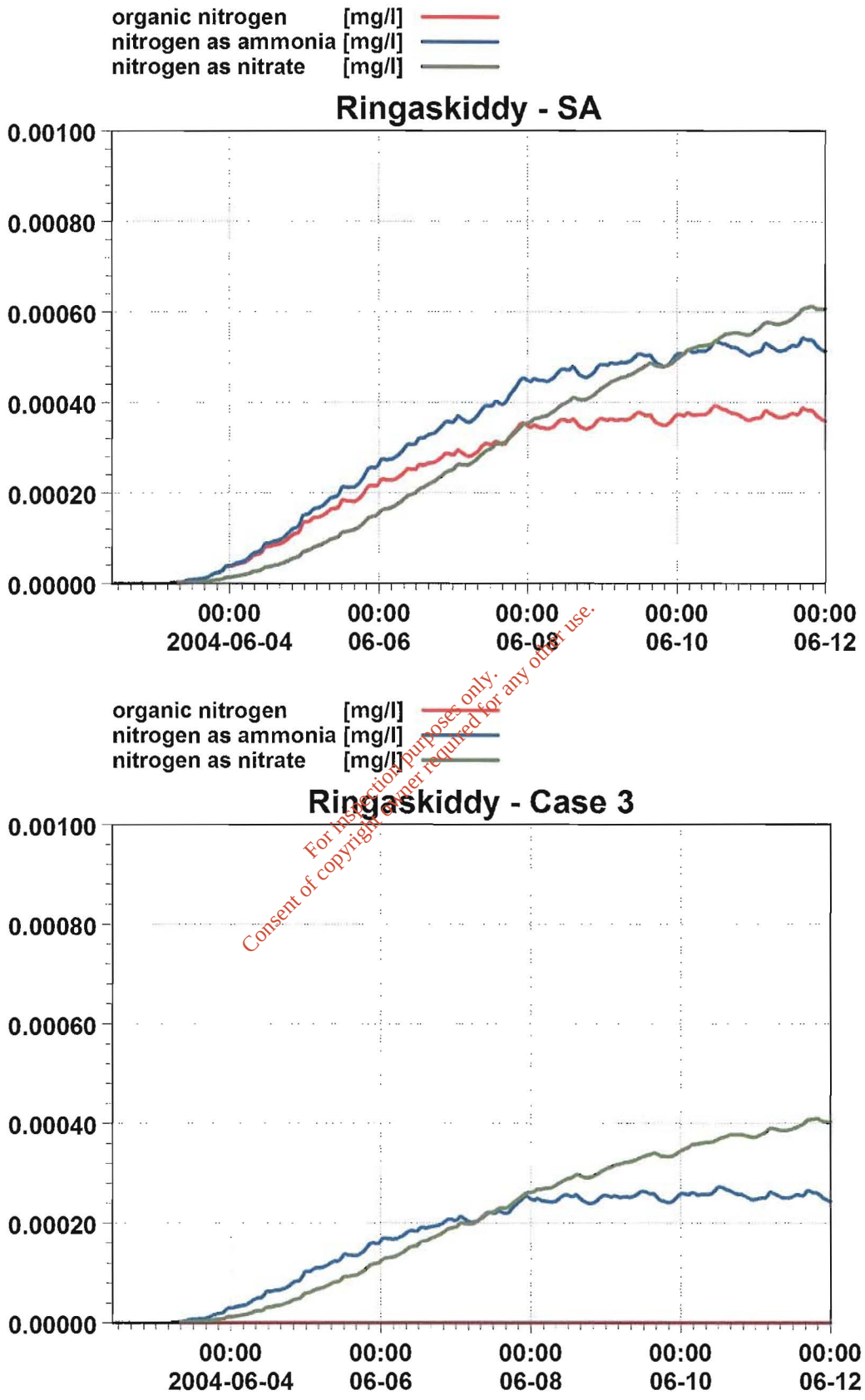


Fig. 6.25 Ringaskiddy

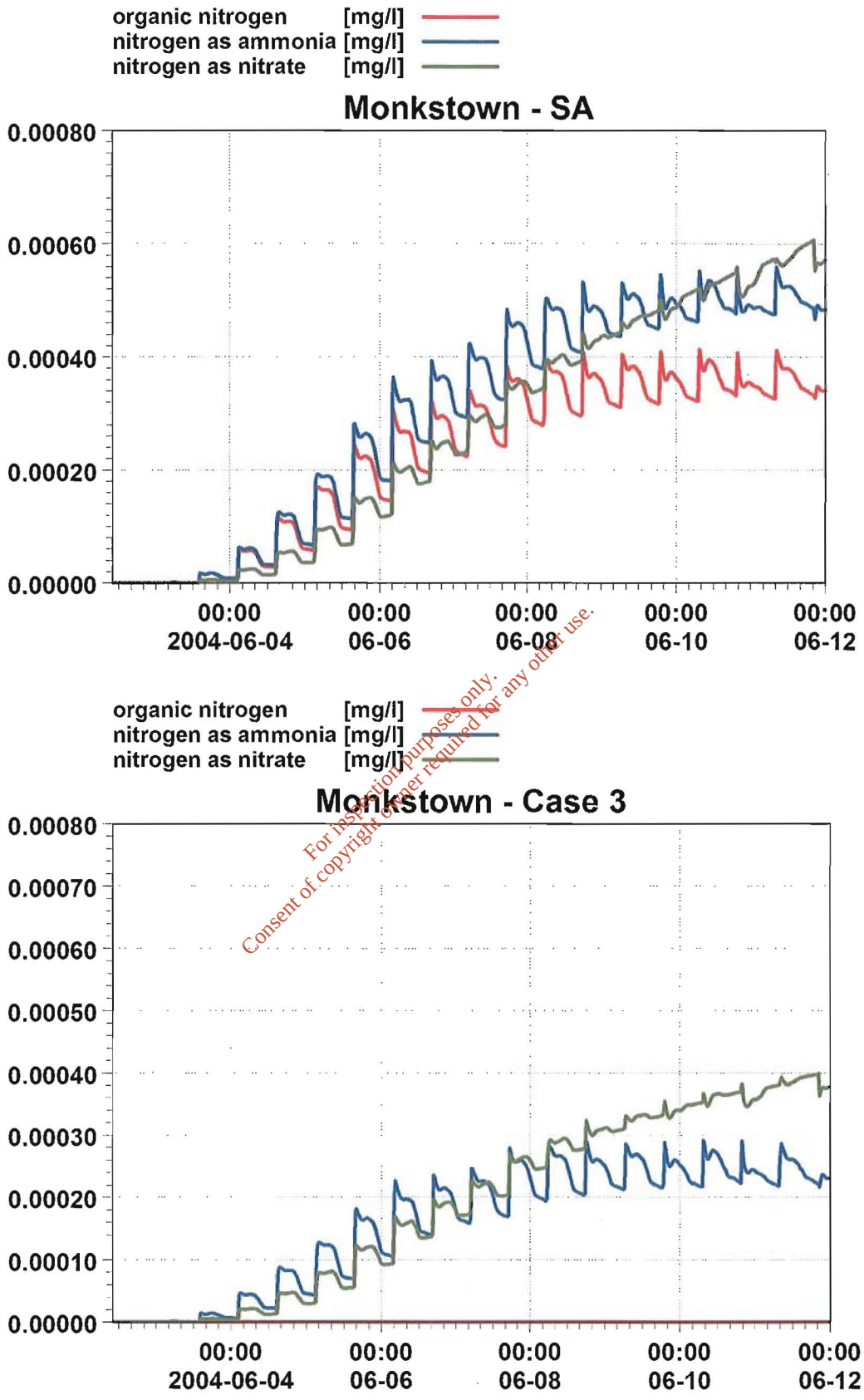


Fig. 6.26 Monkstown

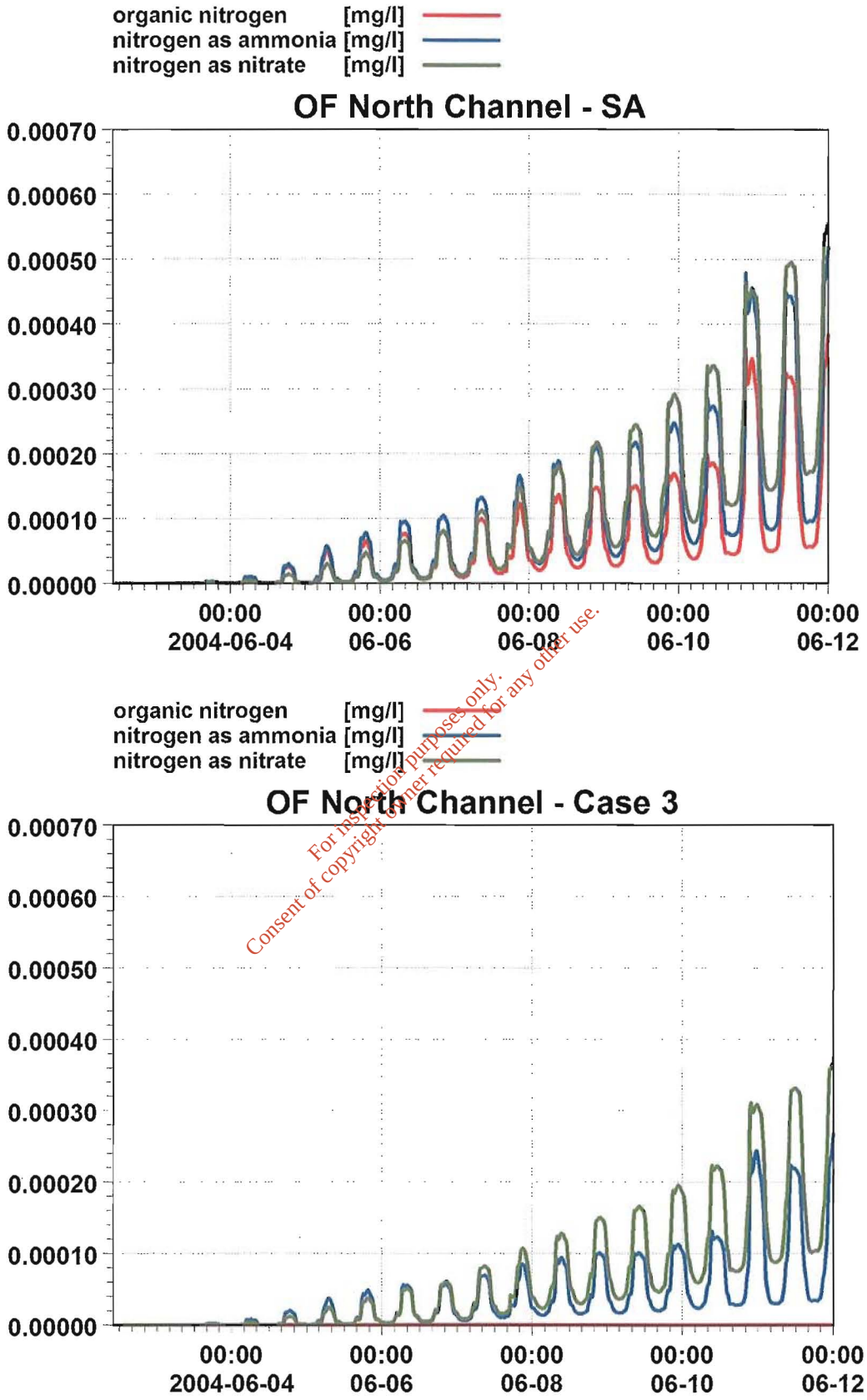


Fig. 6.27 OF North Channel

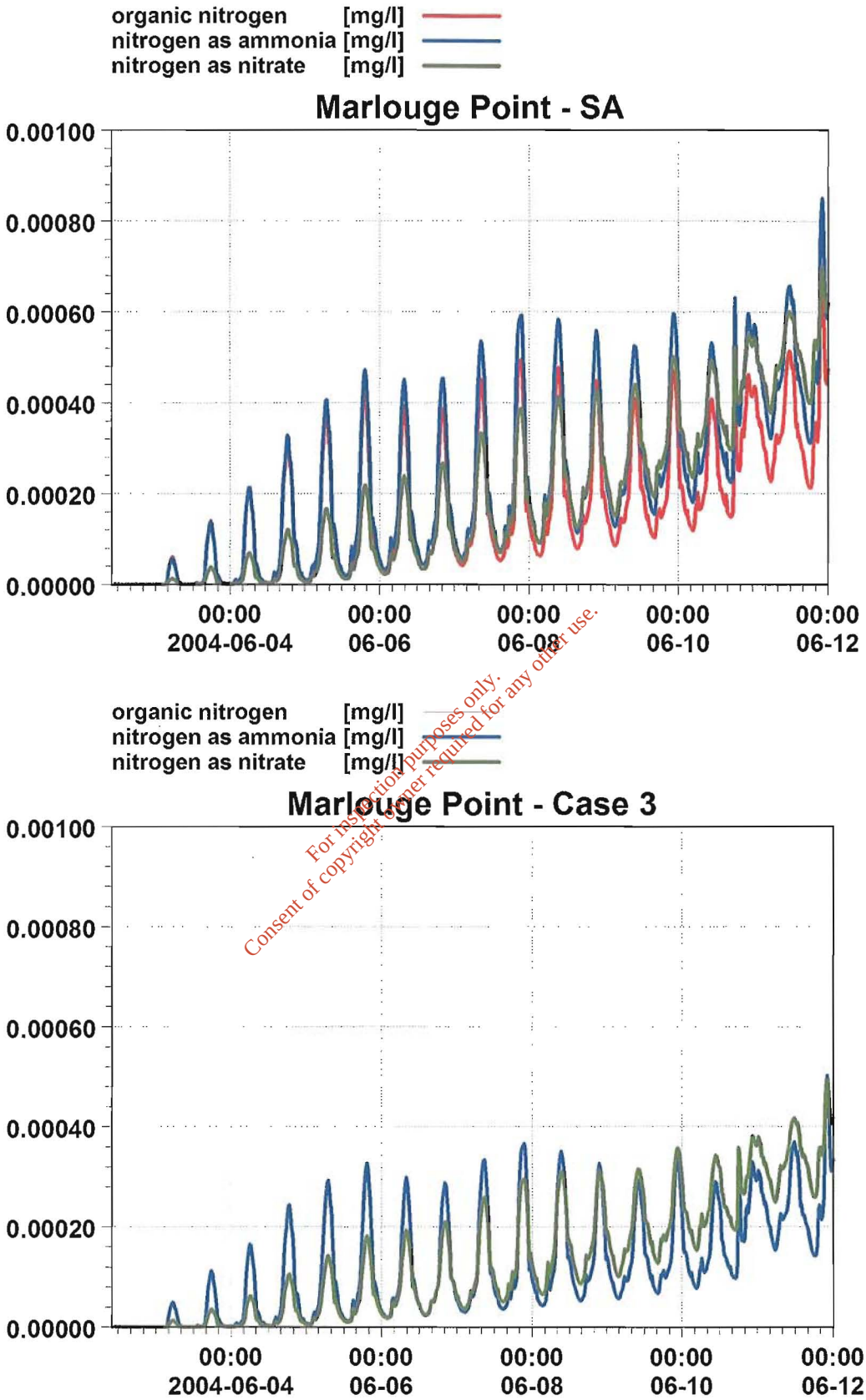


Fig. 6.28 Marlouge Point

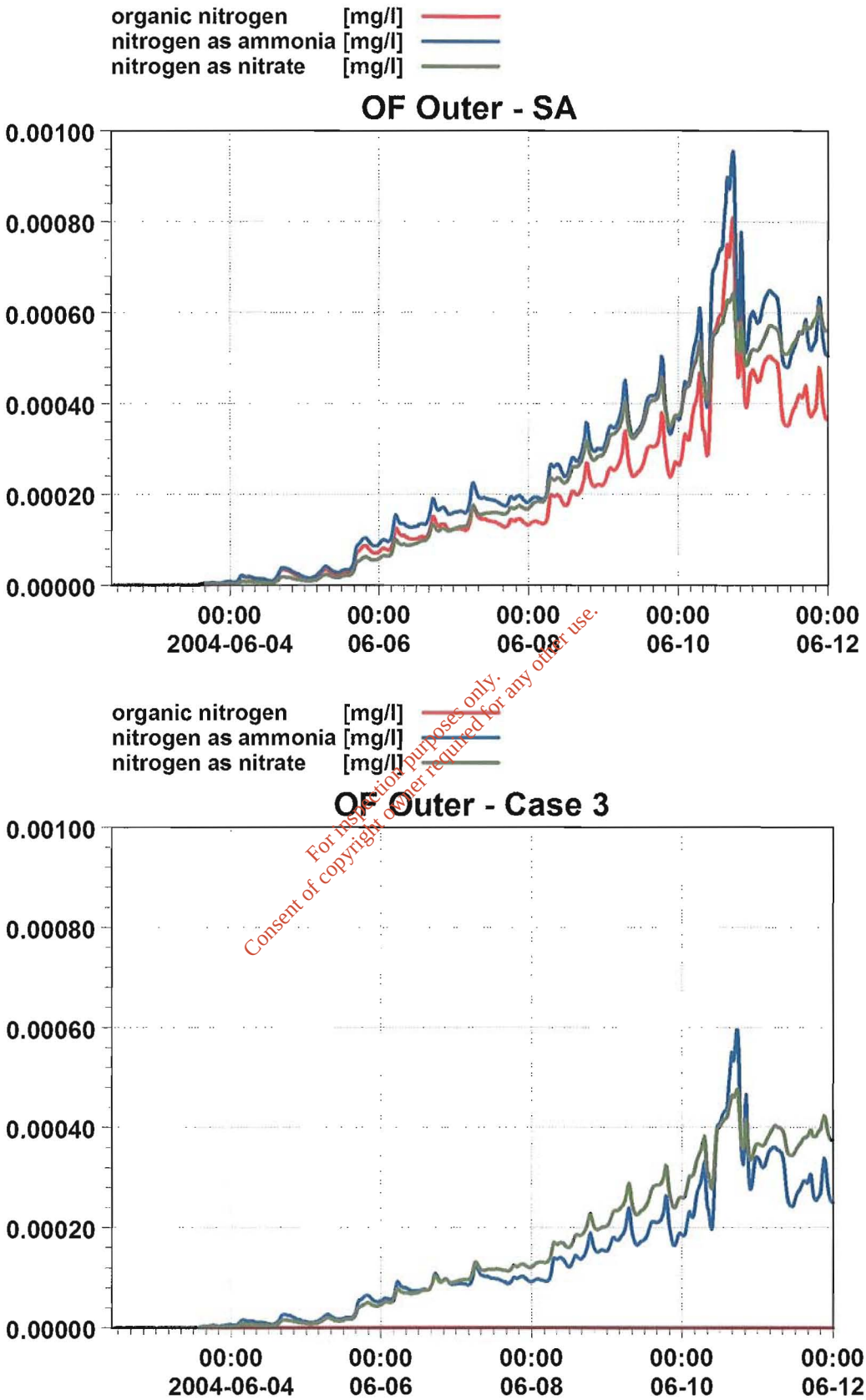
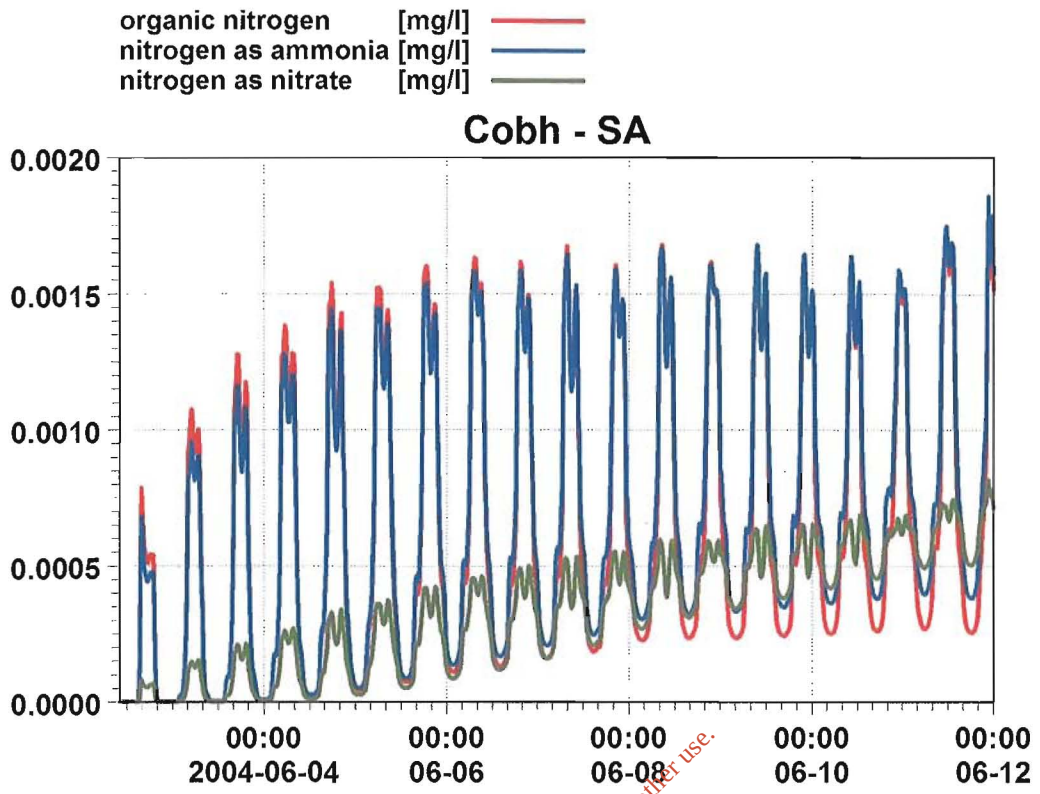


Fig. 6.29 OF – Outer Harbour



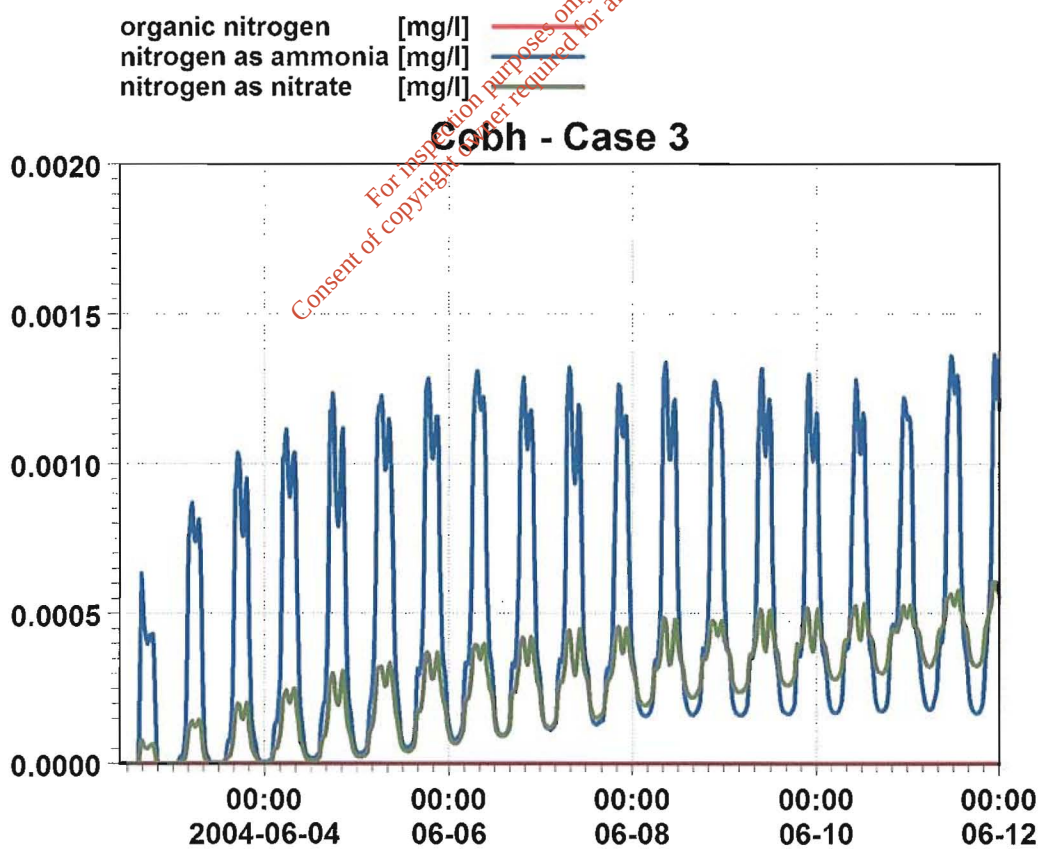


Fig. 6.30 Cobh

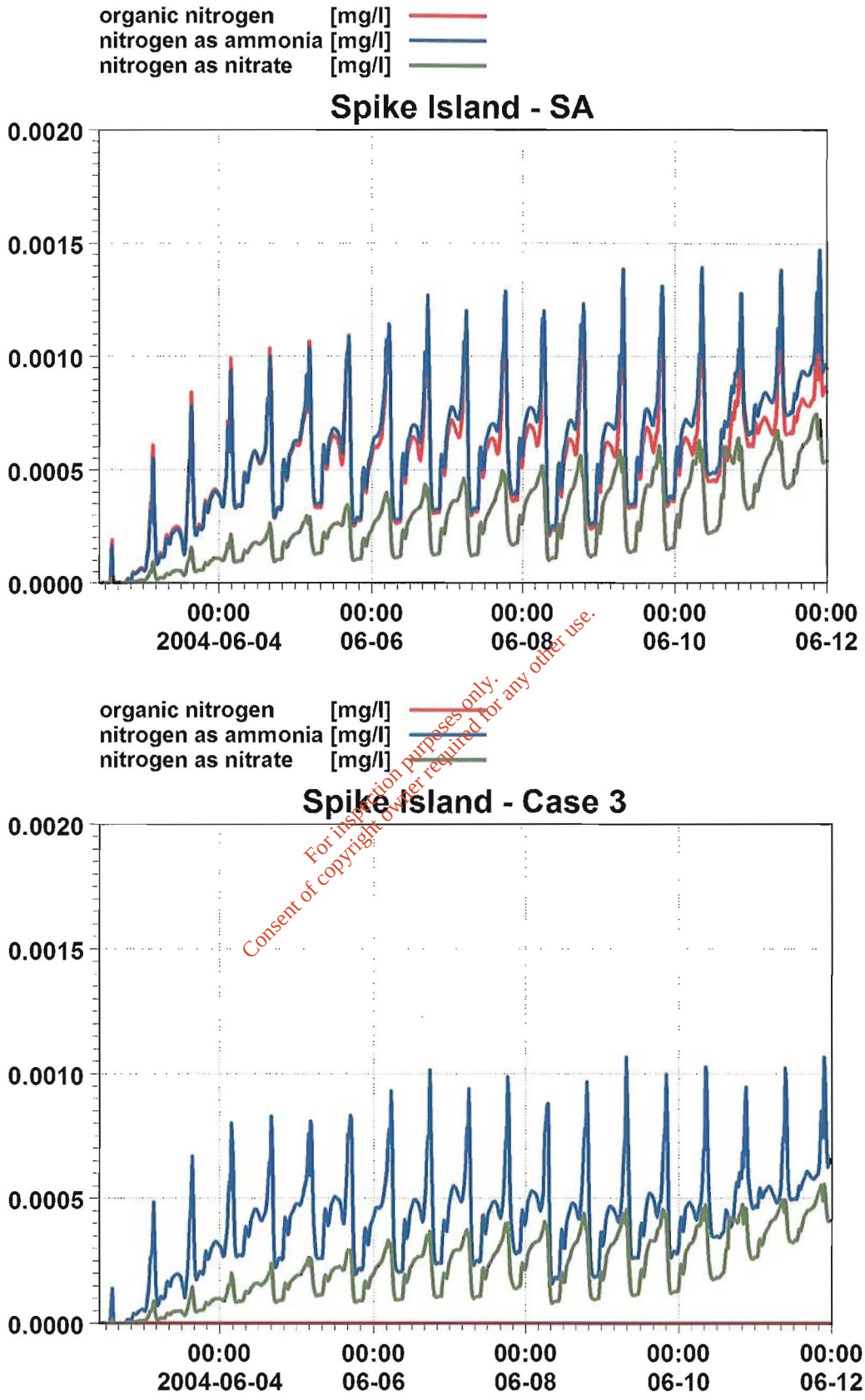


Fig. 6.31 Spike Island

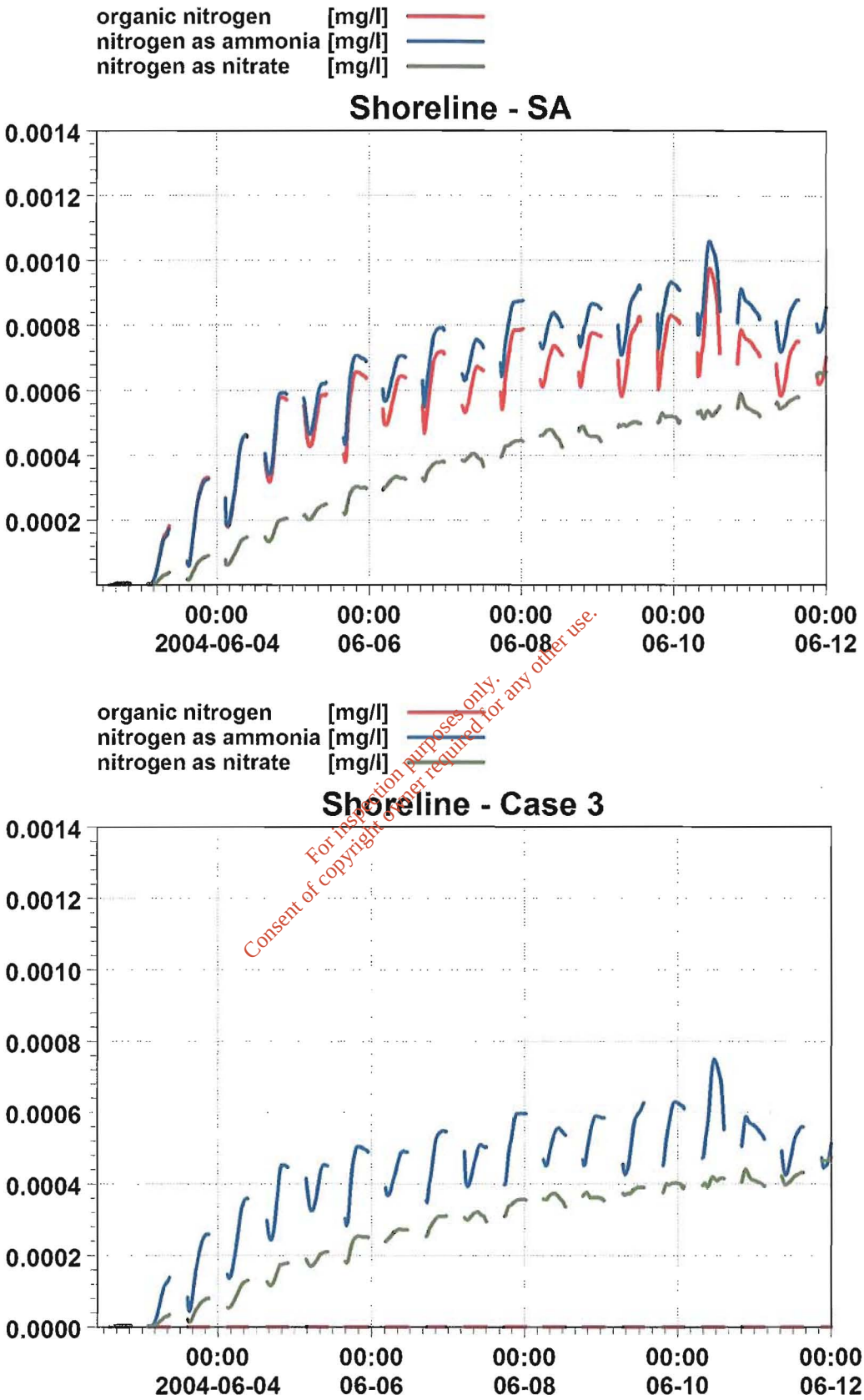


Fig. 6.32 Shoreline

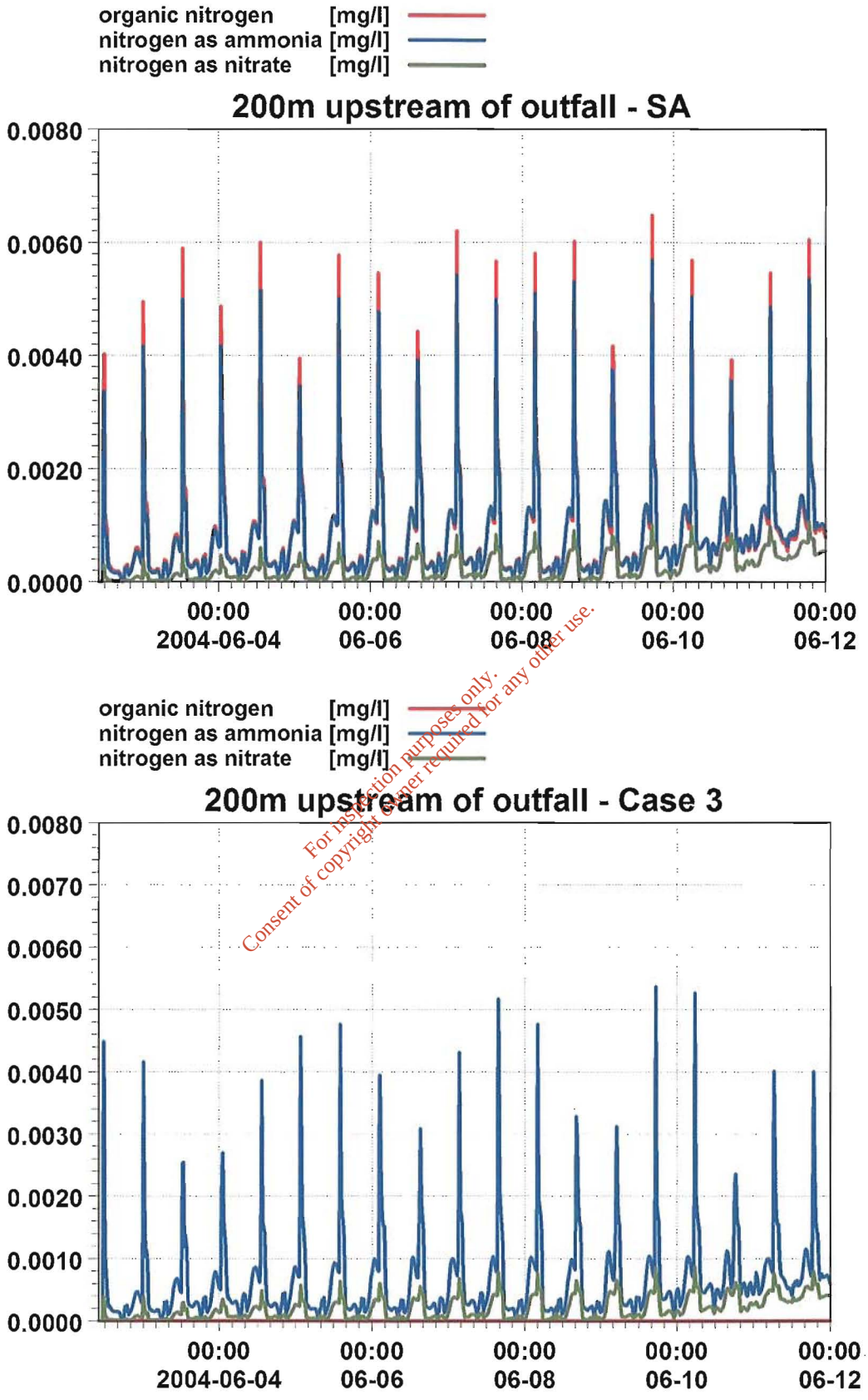


Fig. 6.33 200m upstream of outfall

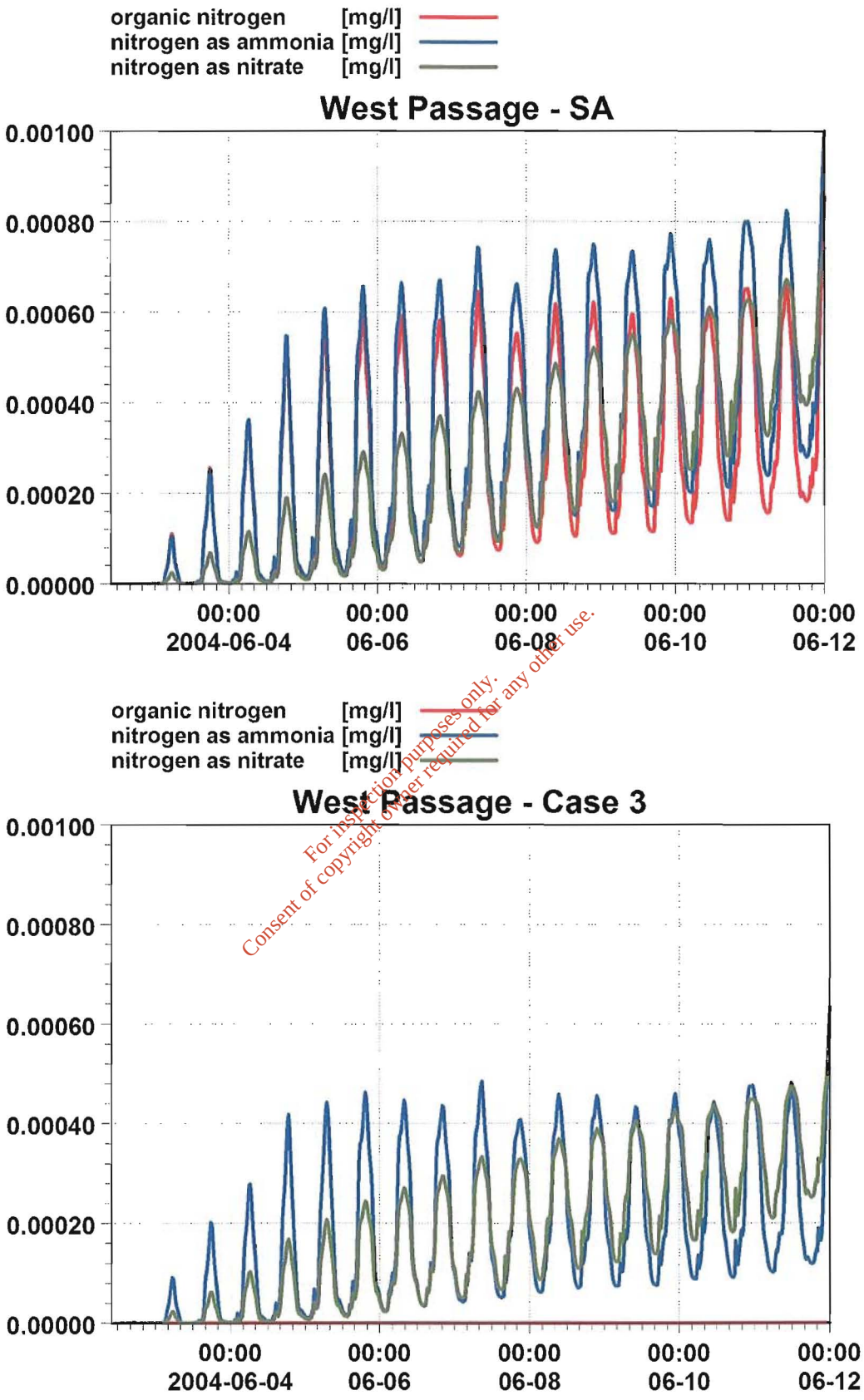


Fig. 6.34 West Passage

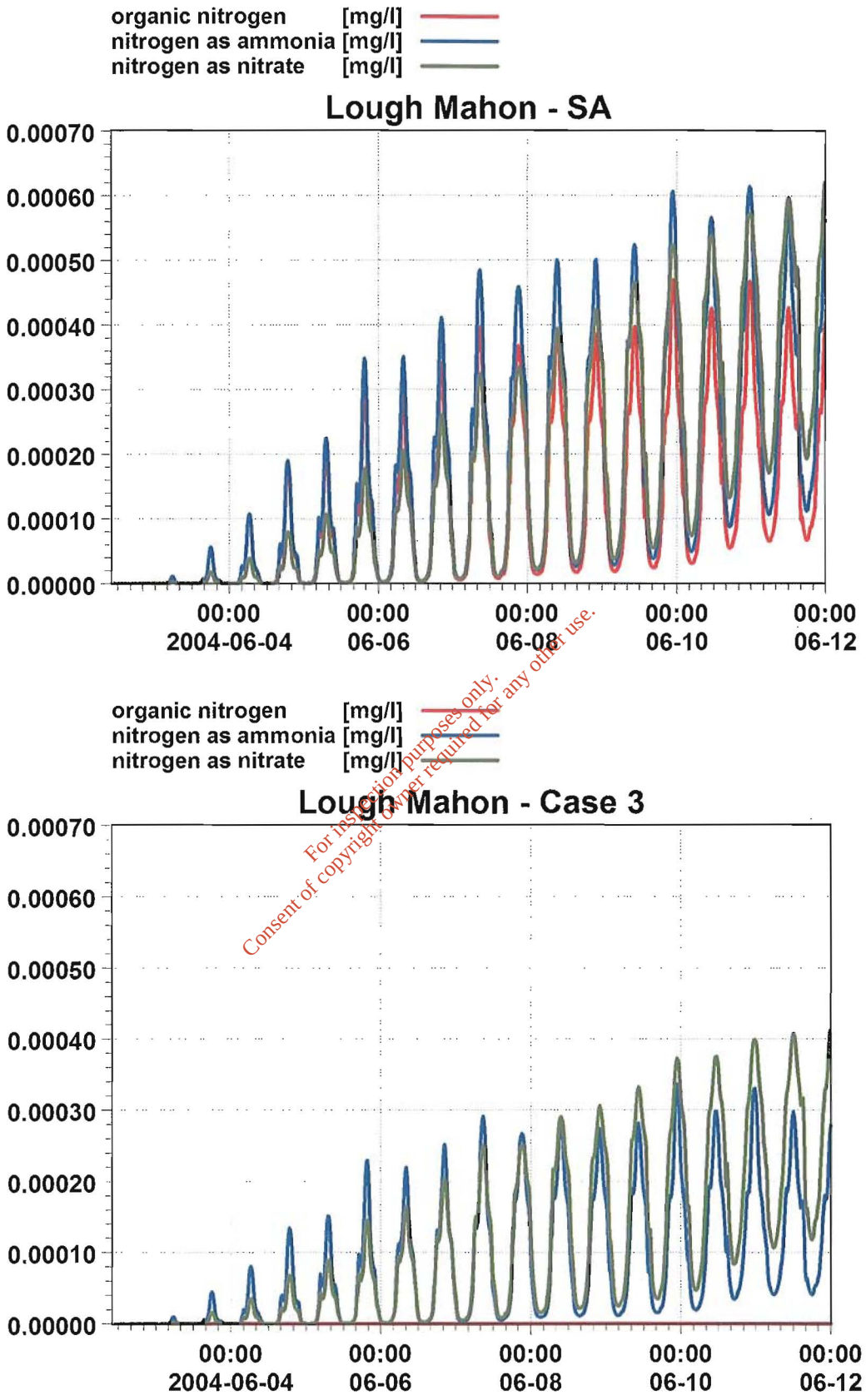


Fig. 6.35 Lough Mahon

We can see from the plots that the concentrations of all three species of nitrogen are higher when a more conservative removal efficiency is used in the model. We have assumed that no organic nitrogen is removed by the treatment plant in the sensitivity analysis. Therefore there are concentrations of organic nitrogen at each location in the sensitivity analysis as indicated by the plots. For the first assumption we assumed that all the organic nitrogen was removed so the concentrations were zero at all fifteen locations.

The removal efficiency of ammonia and nitrate is the same for both assumptions. The concentrations for these two species at the fifteen points of interest are however higher for the more conservative removal efficiency. This is to be expected as organic nitrogen is now being released from the plant and will lead to higher concentrations of ammonia and nitrate as organic nitrogen is converted to ammonia and ammonia is nitrified to nitrite in the linear cascade model.

6.7 Discussion and Conclusion

These plots show that the proposed scheme will reduce considerably the forcing on primary production in the inner harbour (Lough Mahon) and in the North Channel behind Great Island. There is also an improvement throughout the Outer Harbour with the possible exception of the immediate vicinity of the diffuser itself. The model does not resolve the near-field of the diffuser and results from our model very close to the diffuser may not be accurate.