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.

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[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

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[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

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[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		CASE 2		CASE 3		CASE 4	
	2001 MAX	2001 AVG	2010 MAX	2010 AVG	2010 MAX	2010 AVG	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	2001	2010	2010	2010	2010	2030	2030
	MAX	AVG	MAX	AVG	MAX	AVG	MAX	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

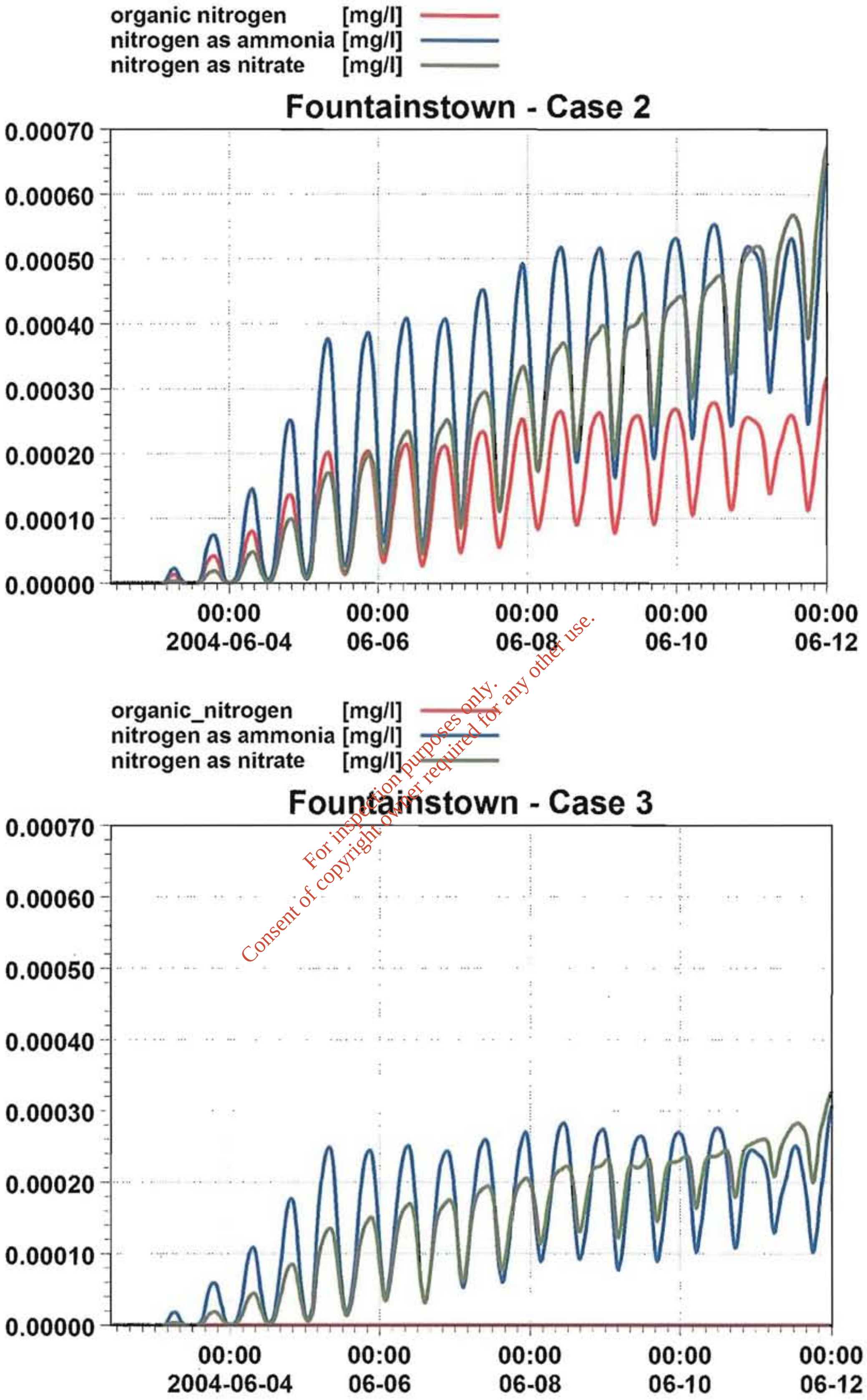


Fig. 6.1 Fountainstown

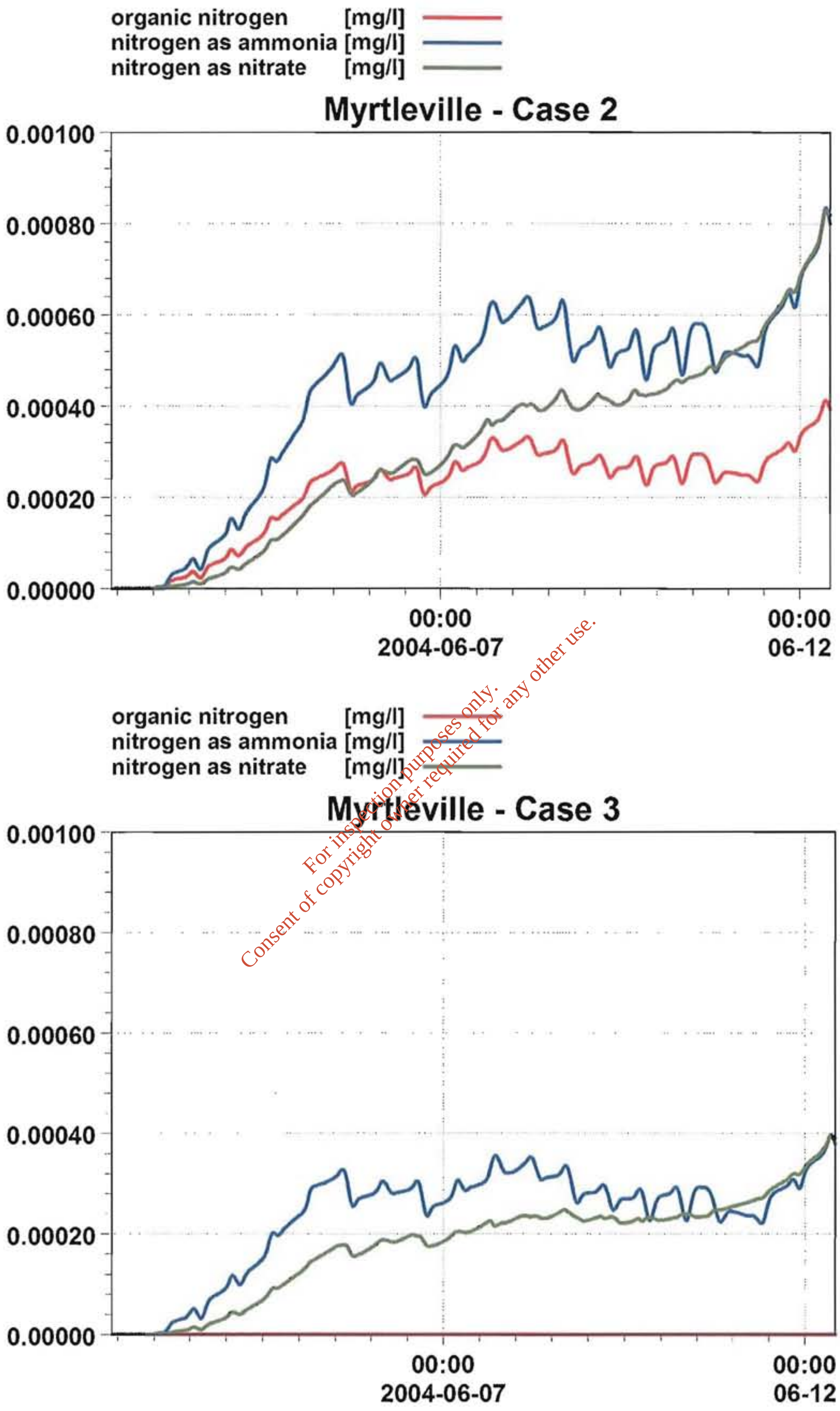


Fig. 6.2 Myrtleville

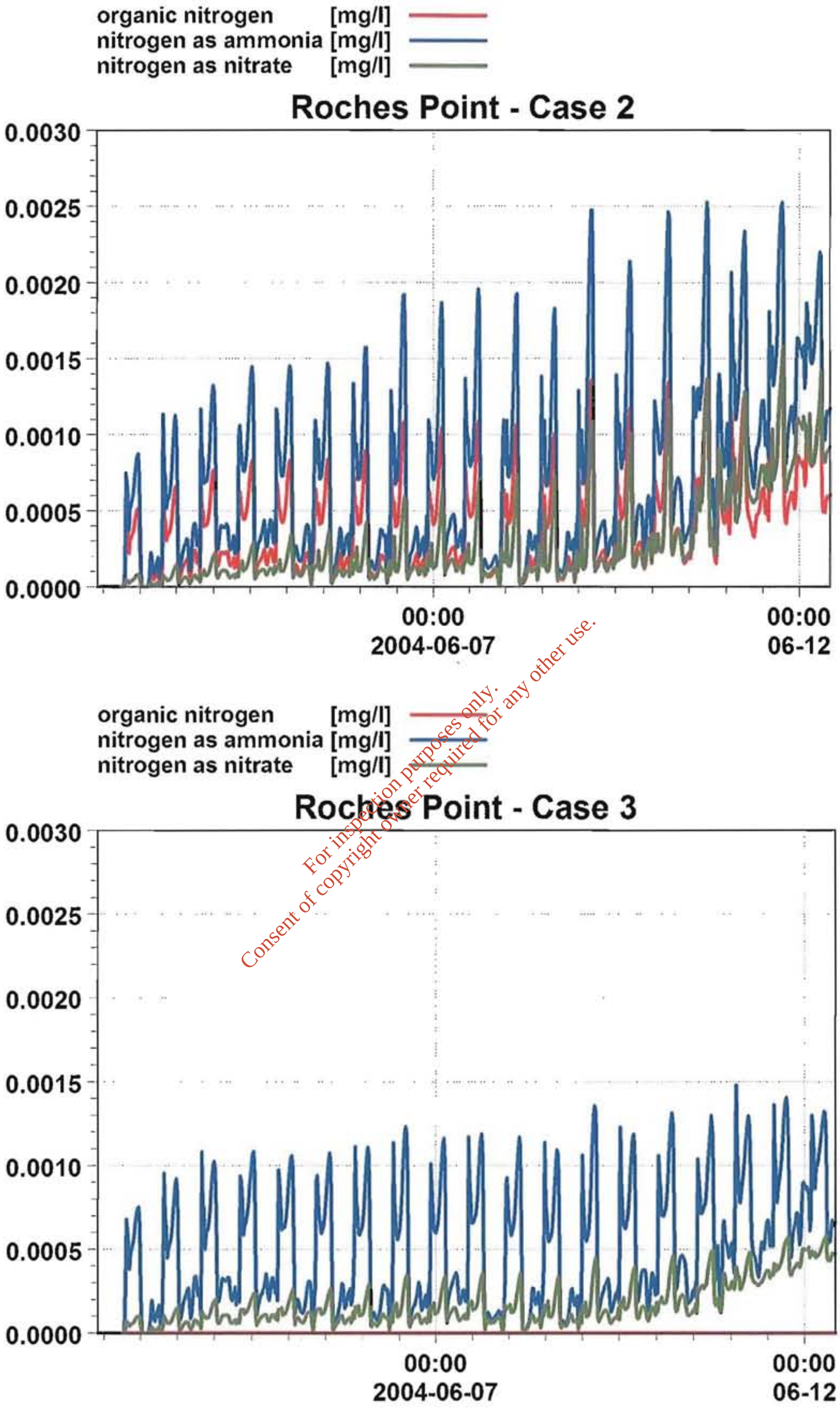
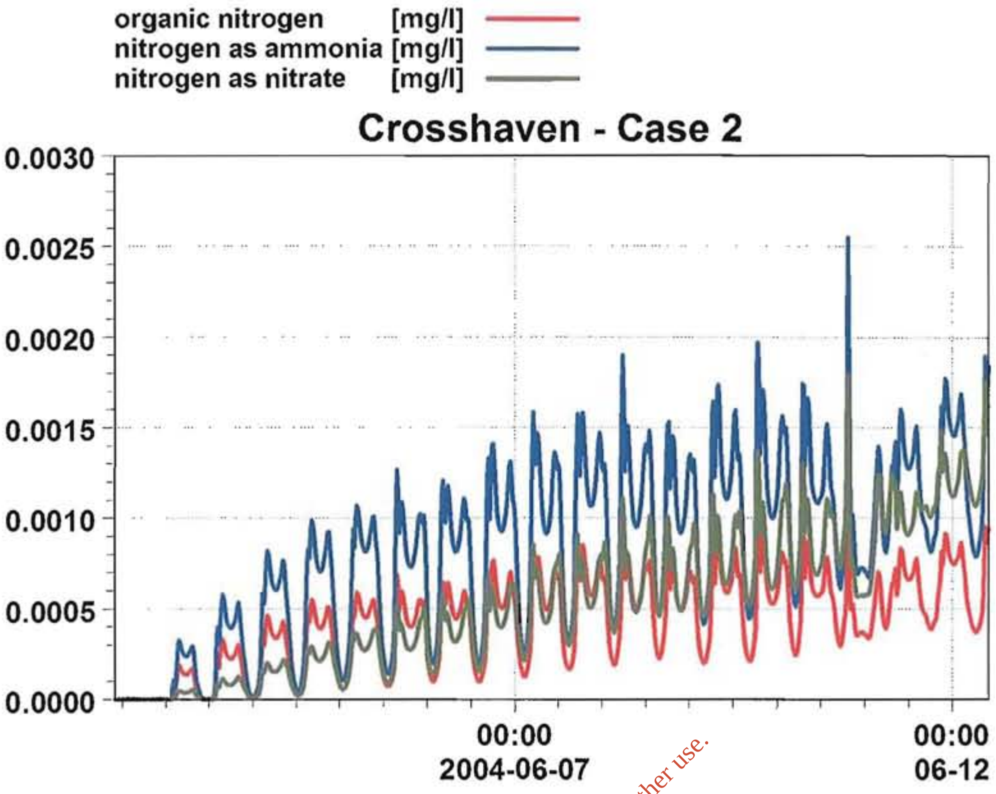


Fig. 6.3 Roches Point



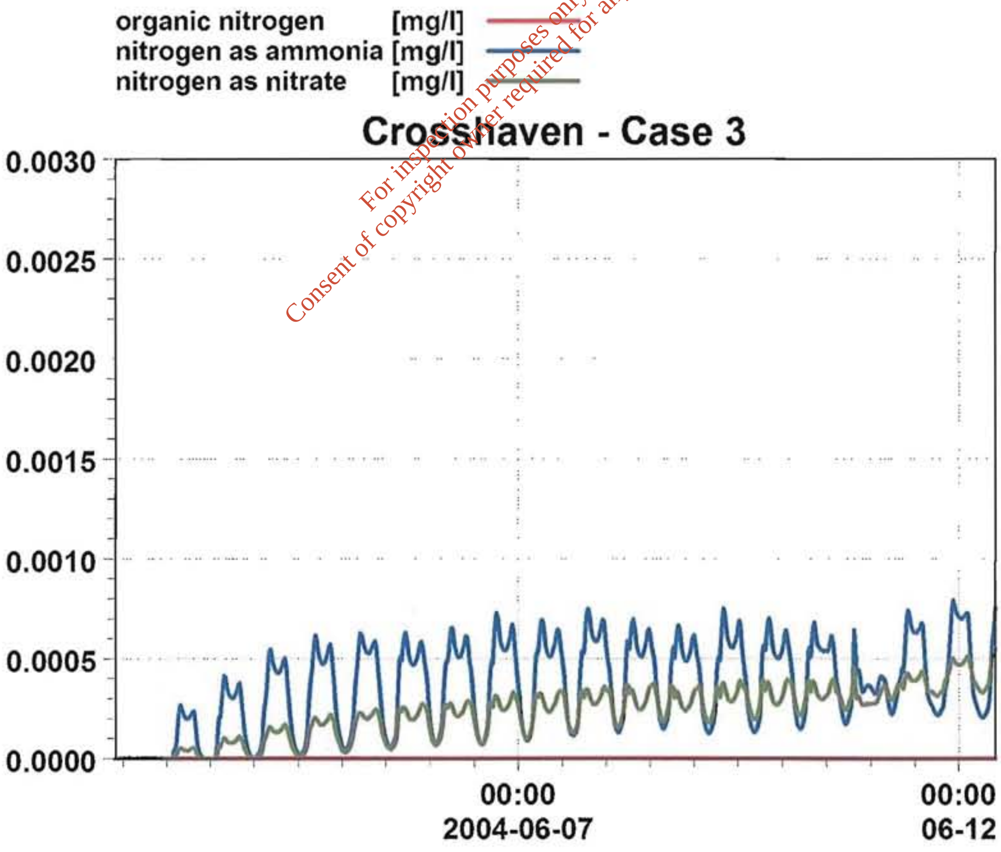


Fig. 6.4 Crosshaven

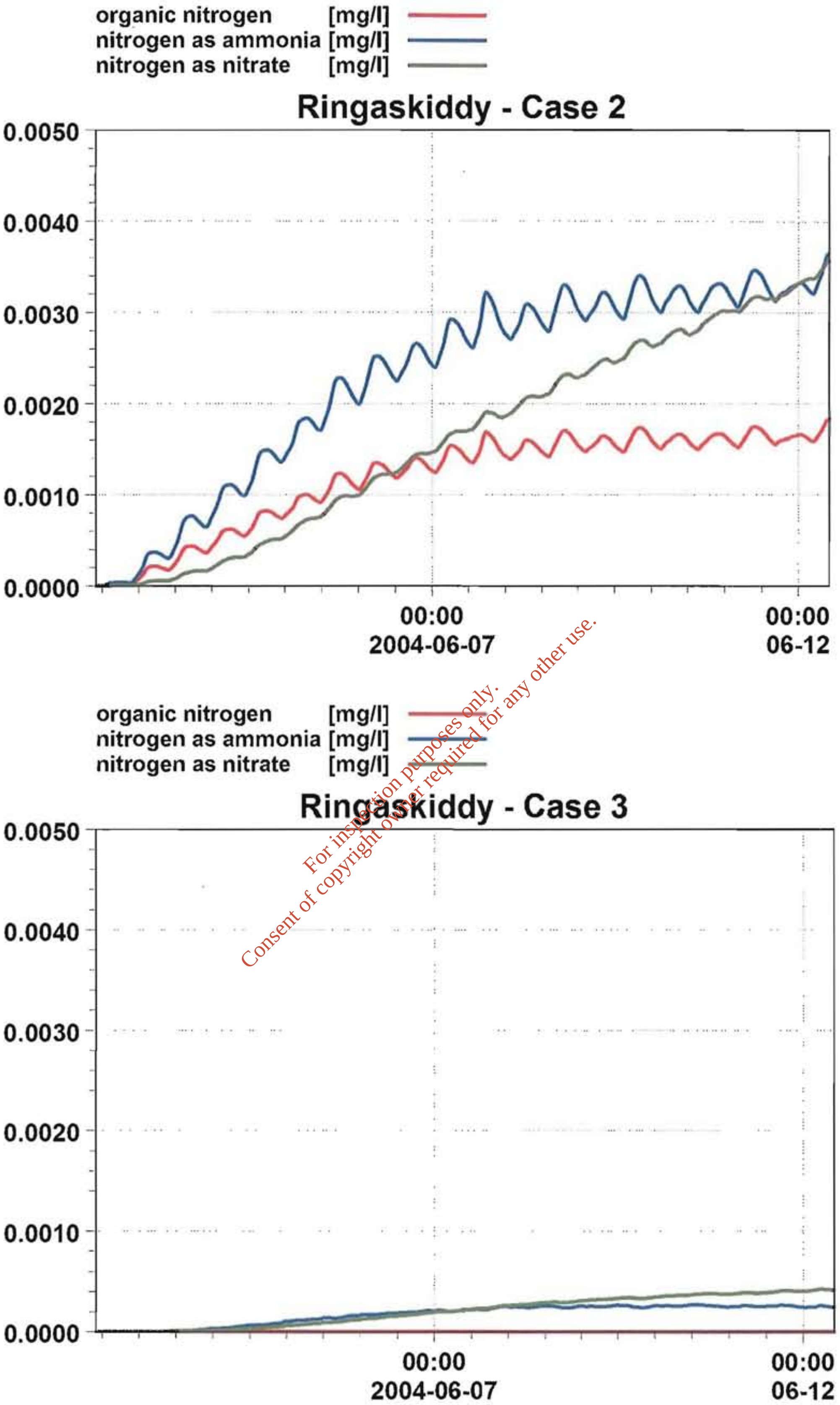


Fig. 6.5 Ringaskiddy

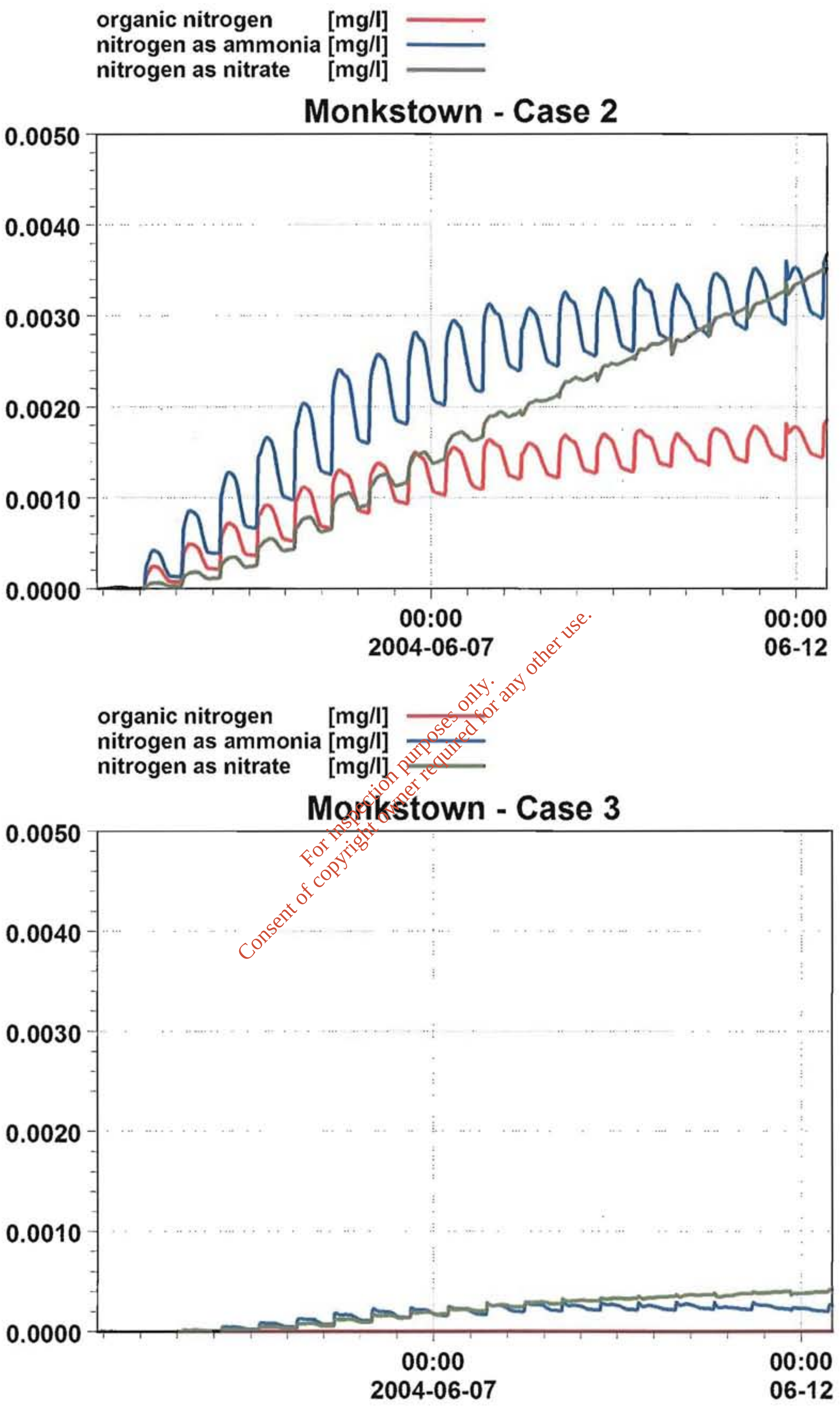


Fig. 6.6 Monkstown

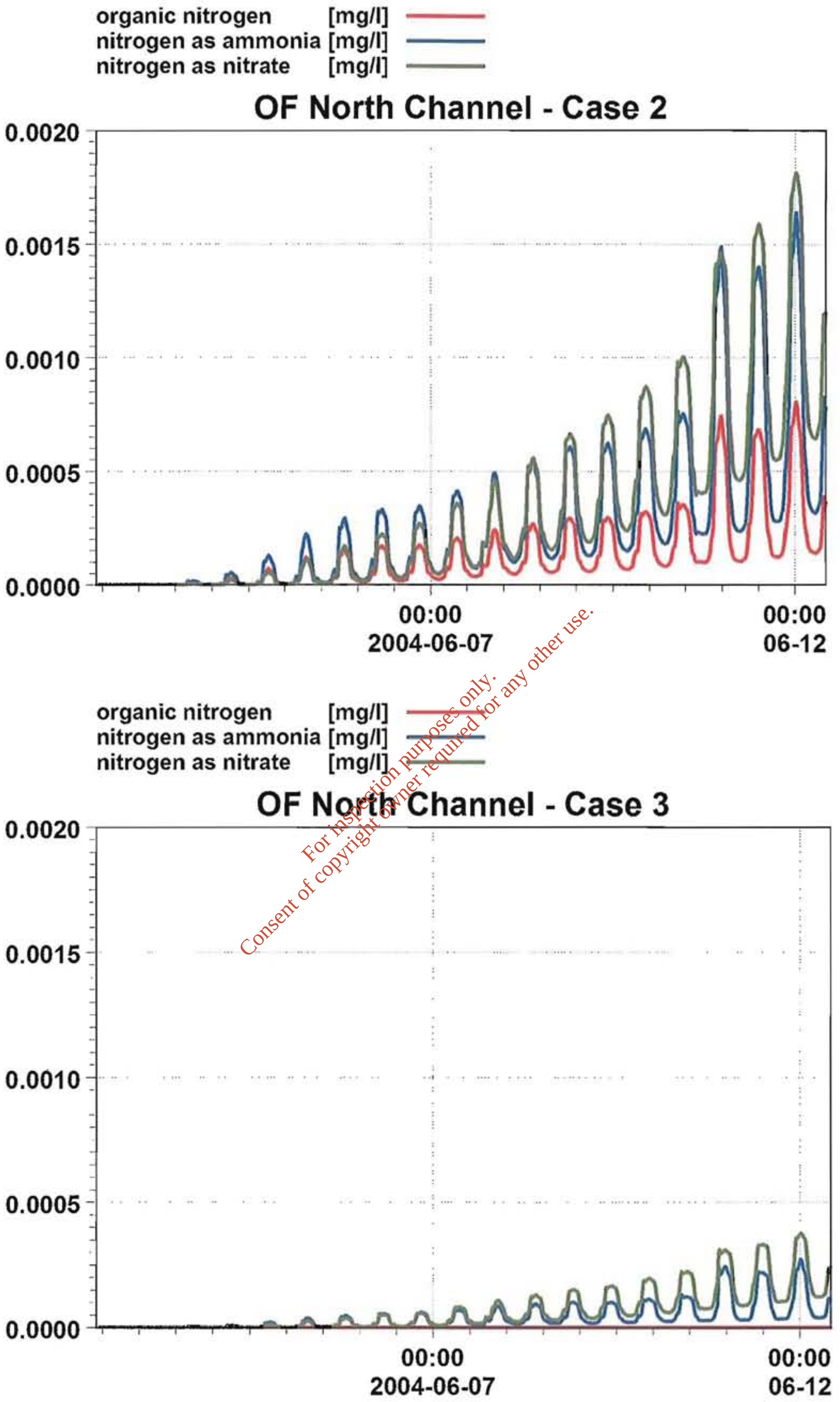


Fig. 6.7 OF – North Channel

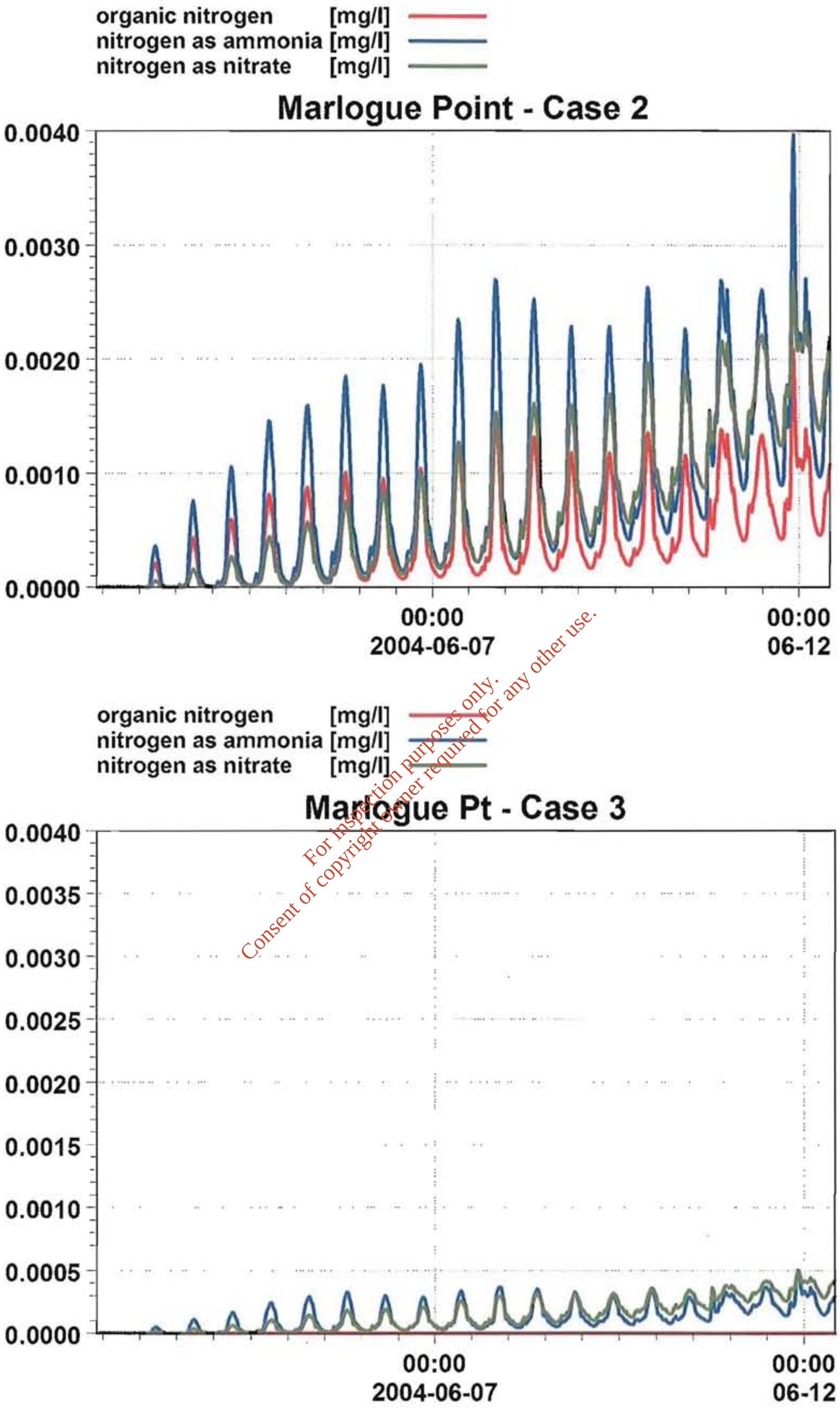


Fig. 6.8 Marlogue Point

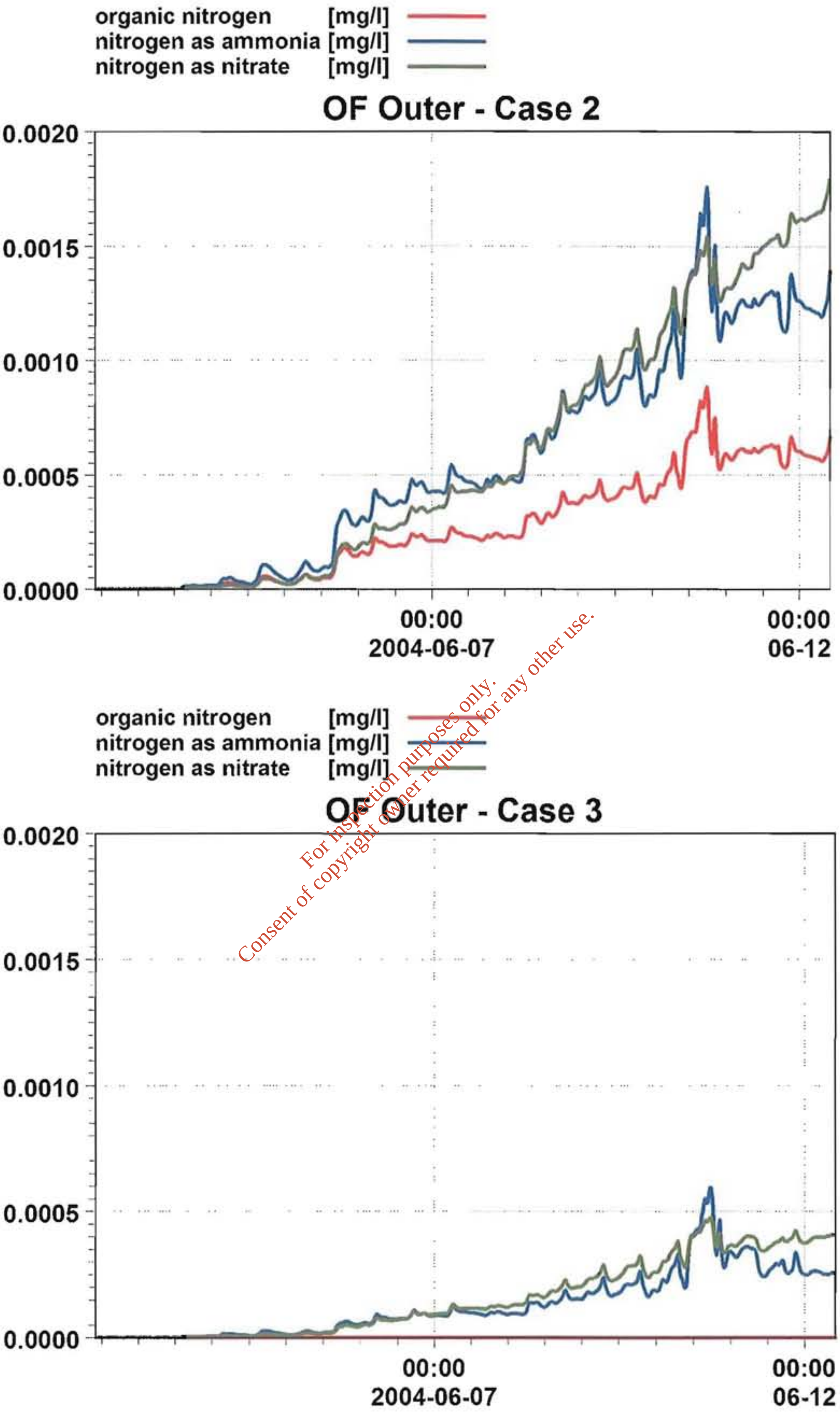


Fig. 6.9 OF – Outer Harbour

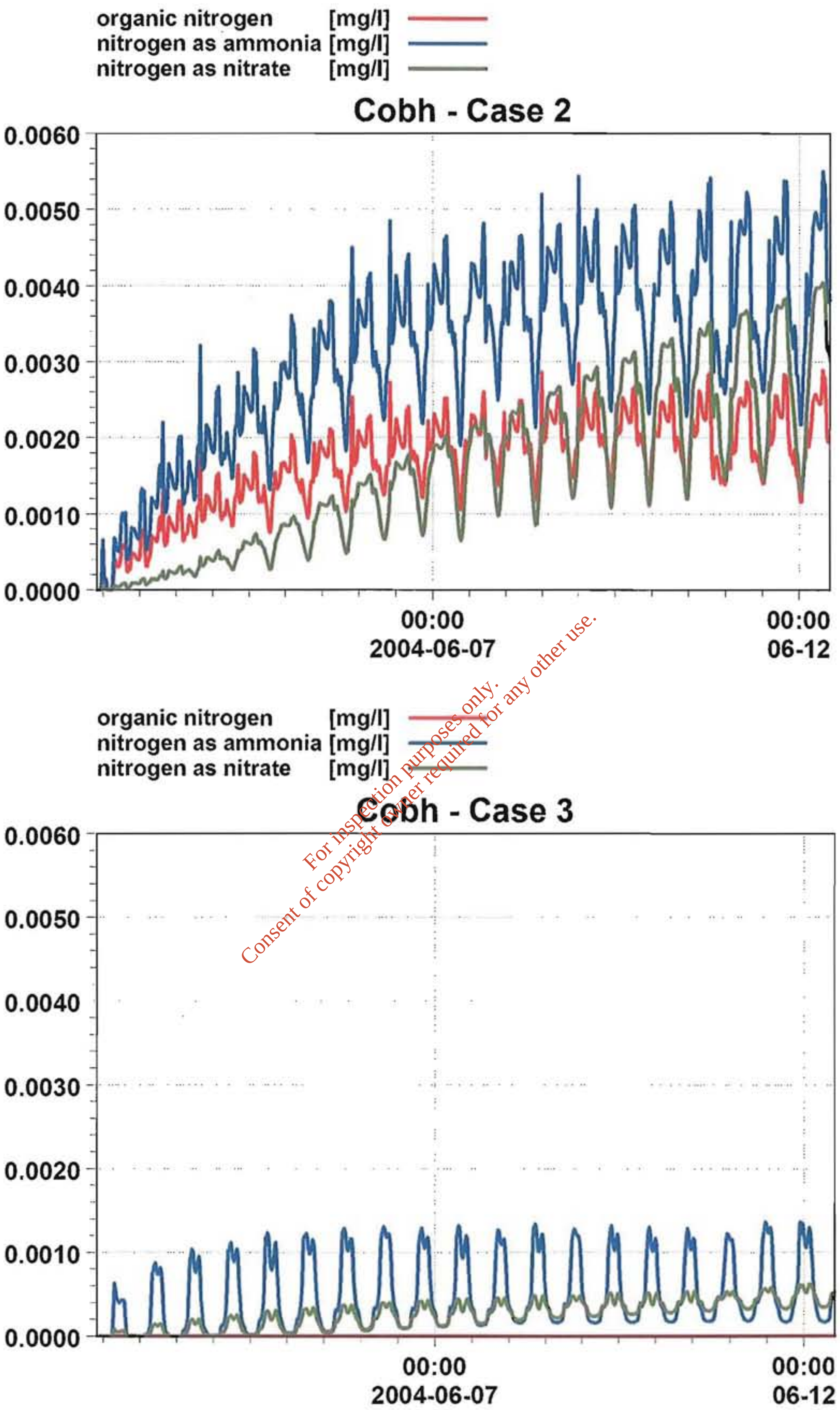

organic nitrogen [mg/l]
nitrogen as ammonia [mg/l]
nitrogen as nitrate [mg/l]
Cobh - Case 2
0.0060
0.0050
0.0040
0.0030
0.0020
0.0010
0.0000
00:00
2004-06-07
00:00
06-12
organic nitrogen [mg/l]
nitrogen as ammonia [mg/l]
nitrogen as nitrate [mg/l]
Cobh - Case 3
0.0060
0.0050
0.0040
0.0030
0.0020
0.0010
0.0000
00:00
2004-06-07
00:00
06-12

Fig. 6.10 Cobh

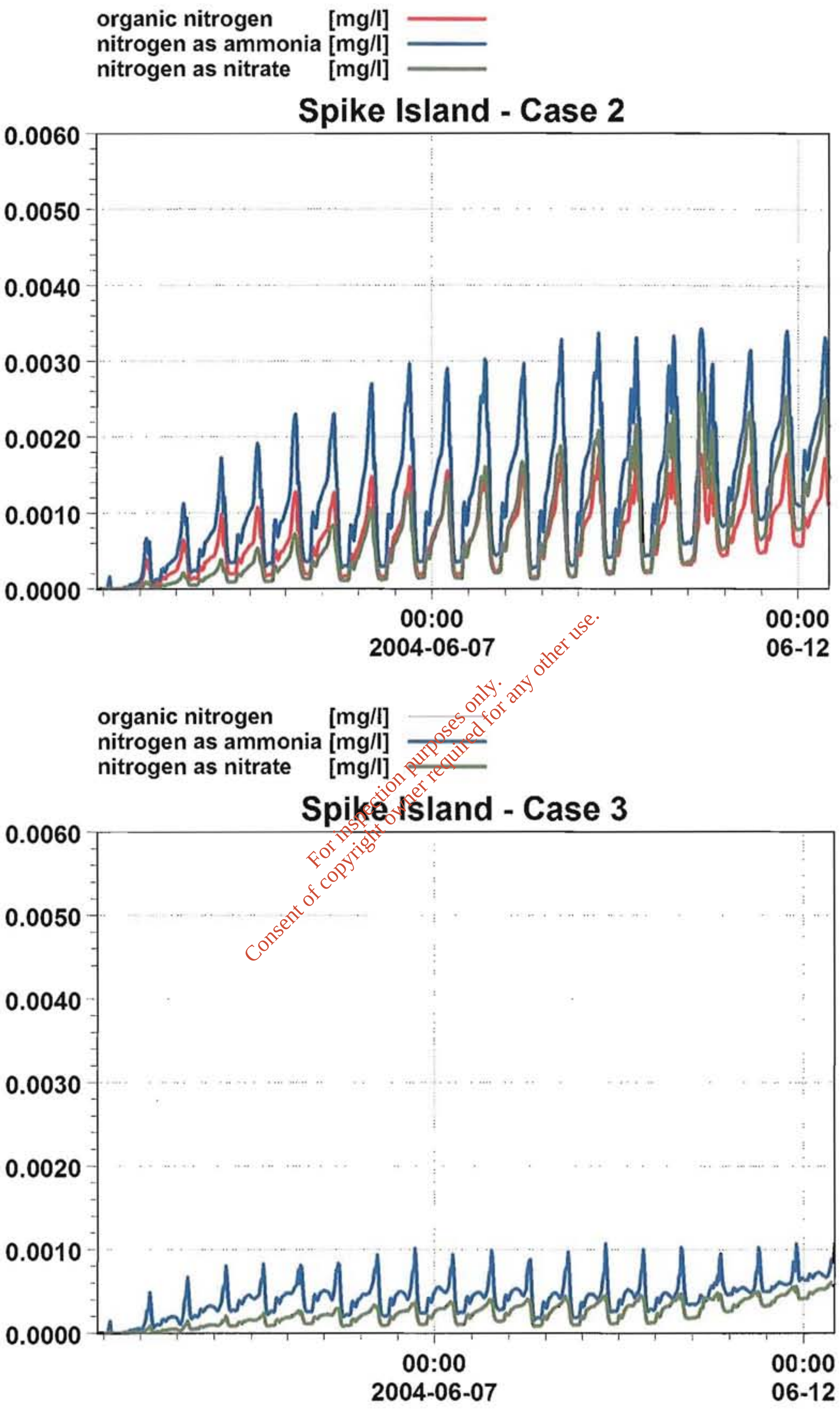
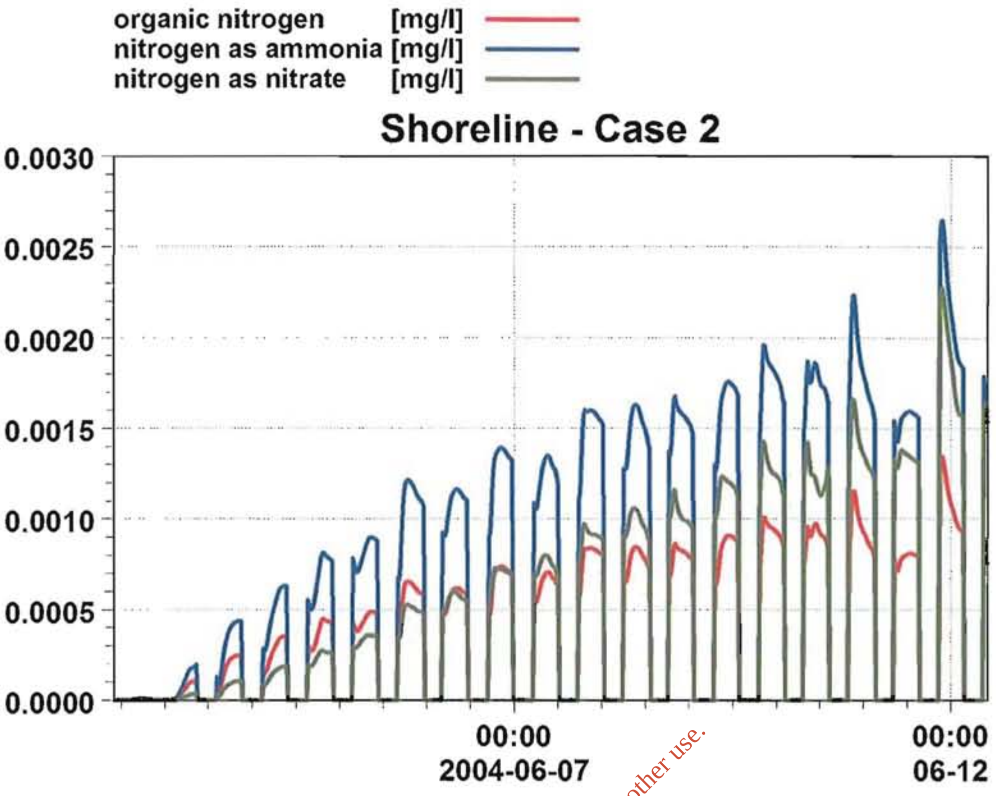


Fig. 6.11 Spike Island



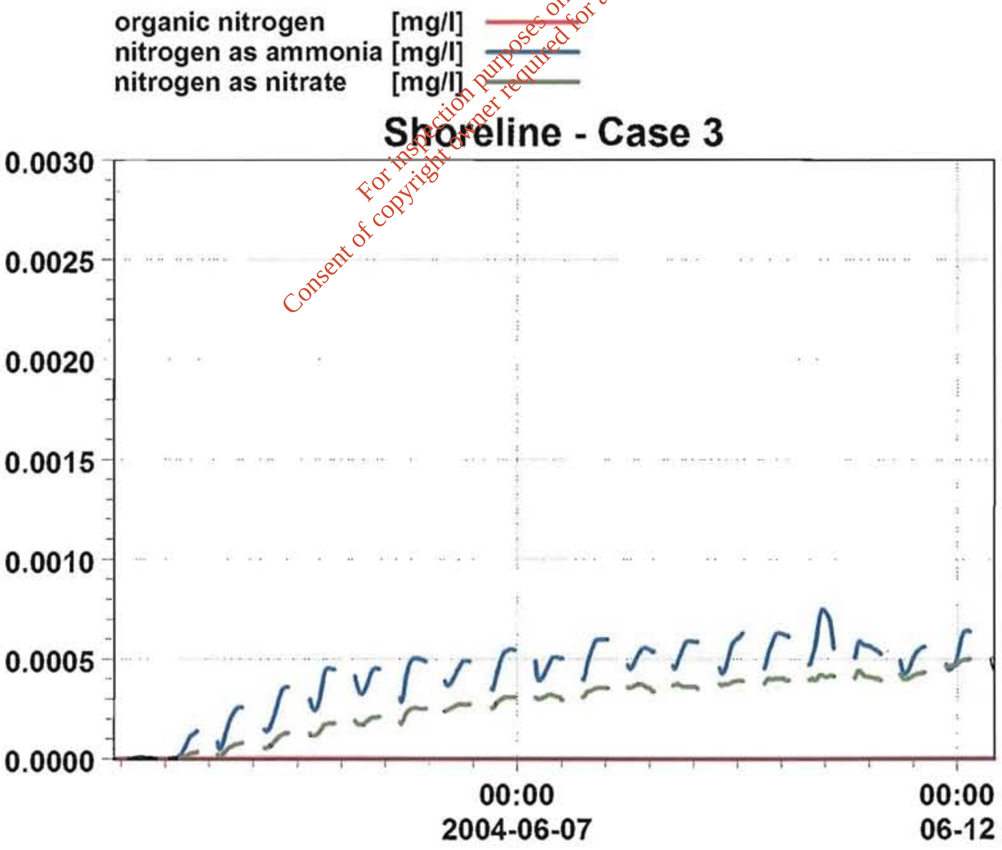
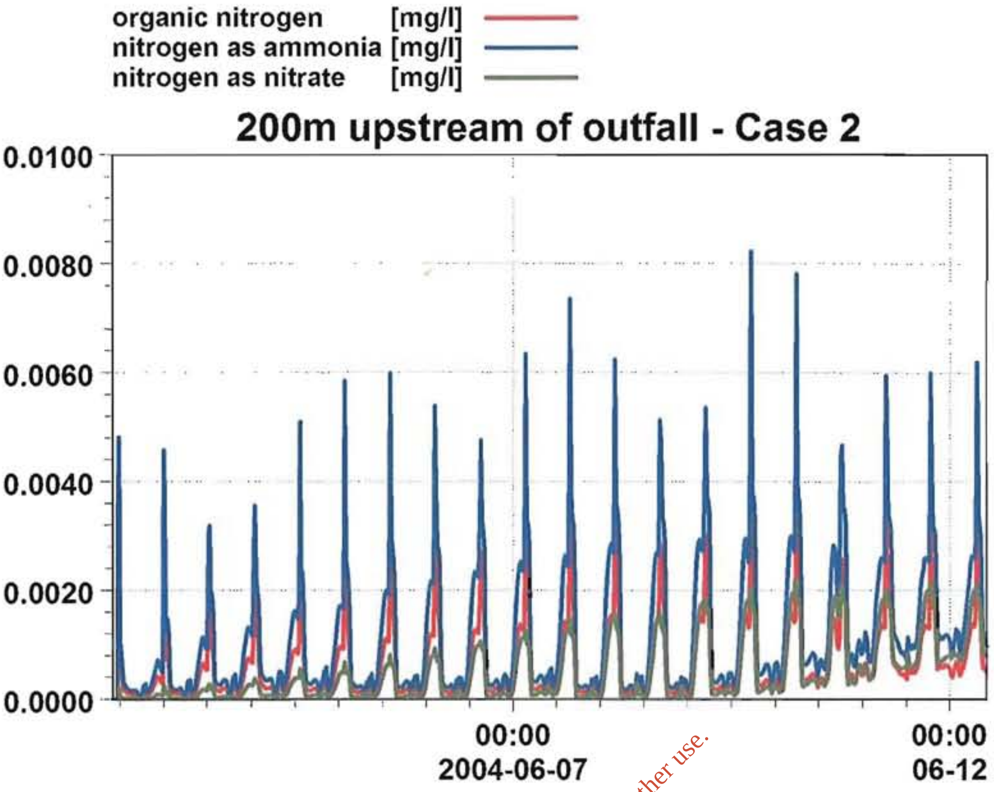


Fig. 6.12 Shoreline closest to outfall



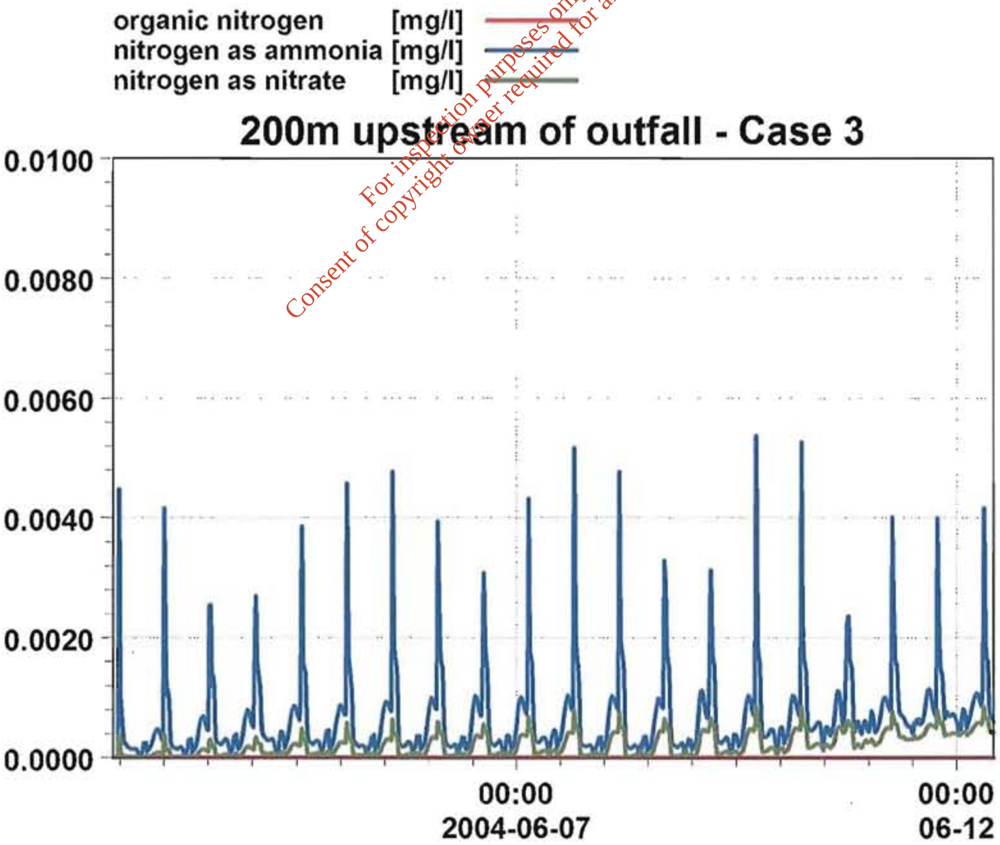


Fig. 6.13 200m upstream of outfall

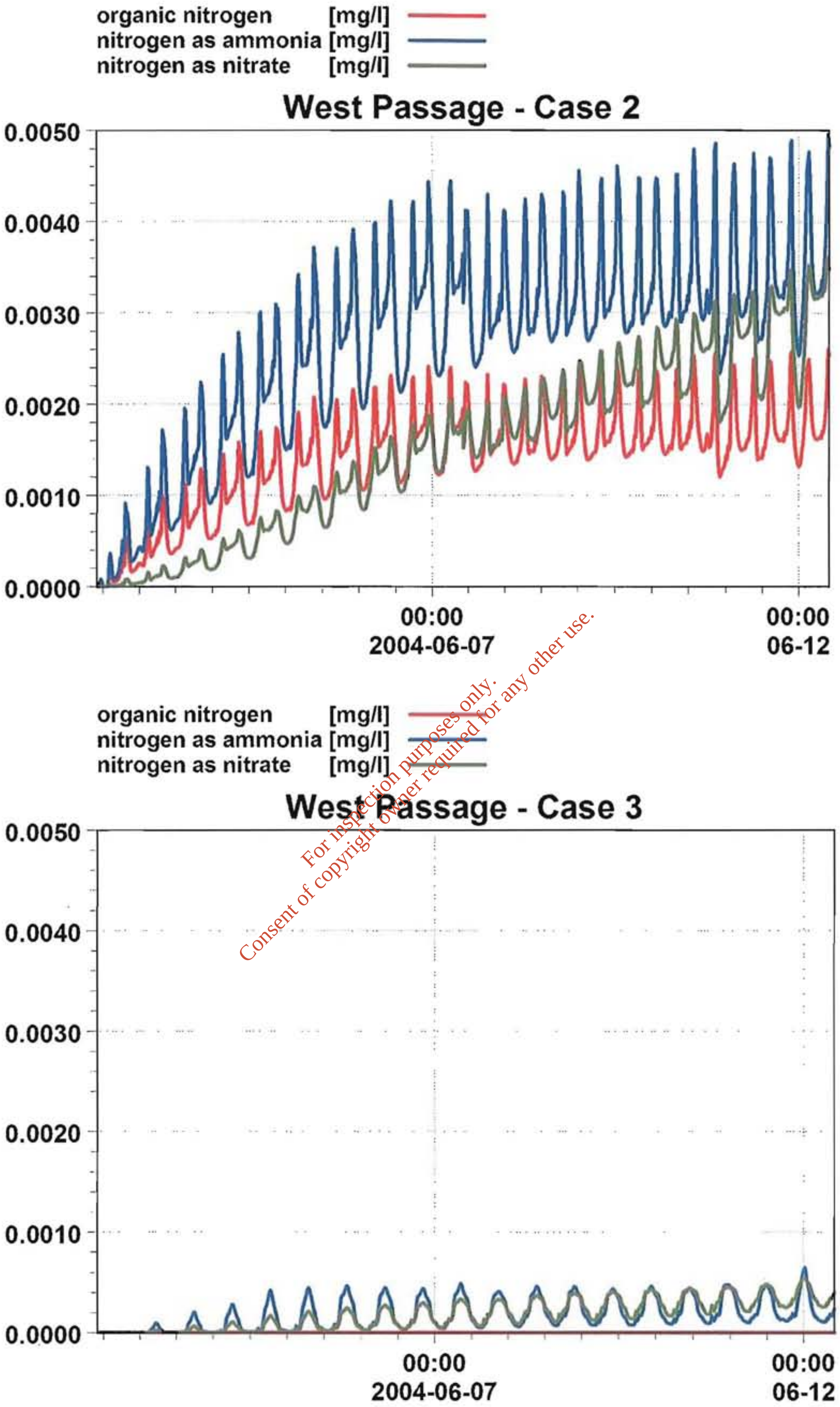
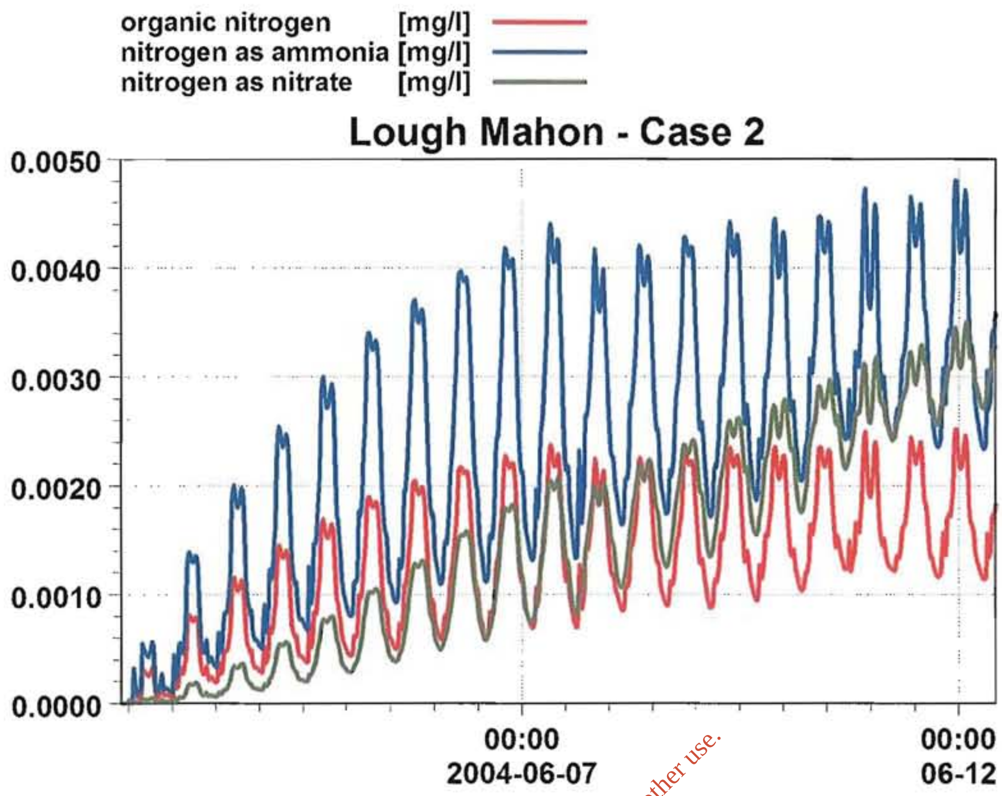


Fig. 6.14 West Passage



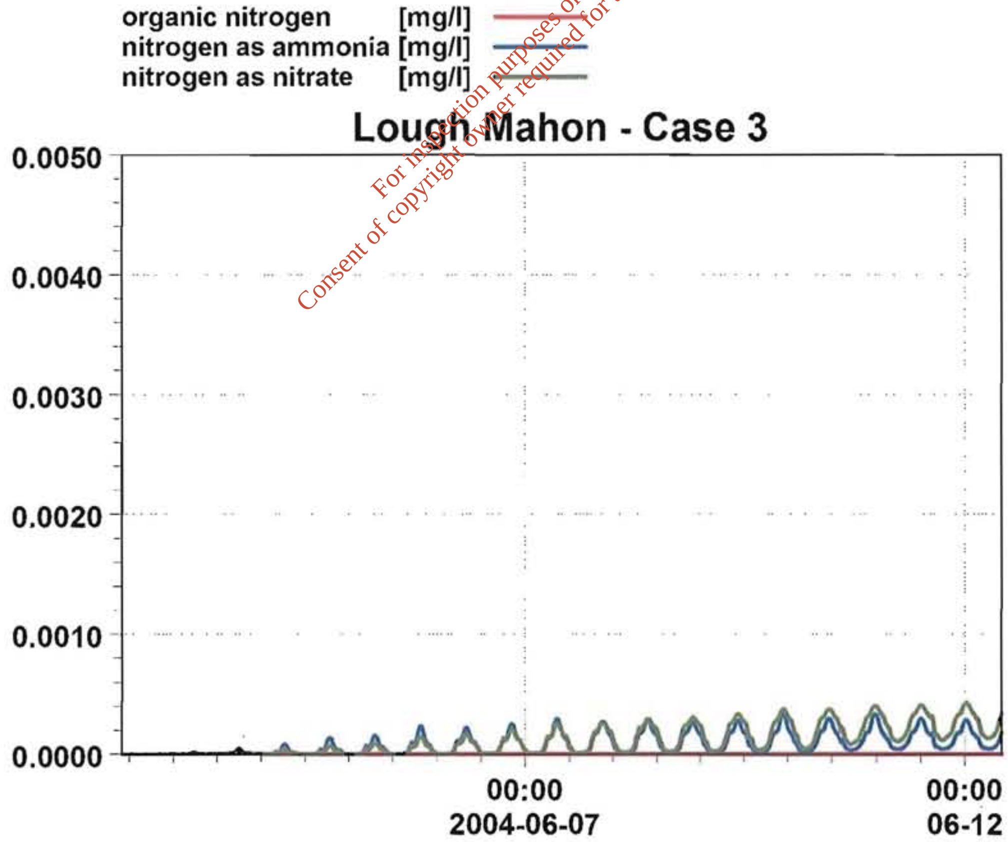


Fig. 6.15 Lough Mahon

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.

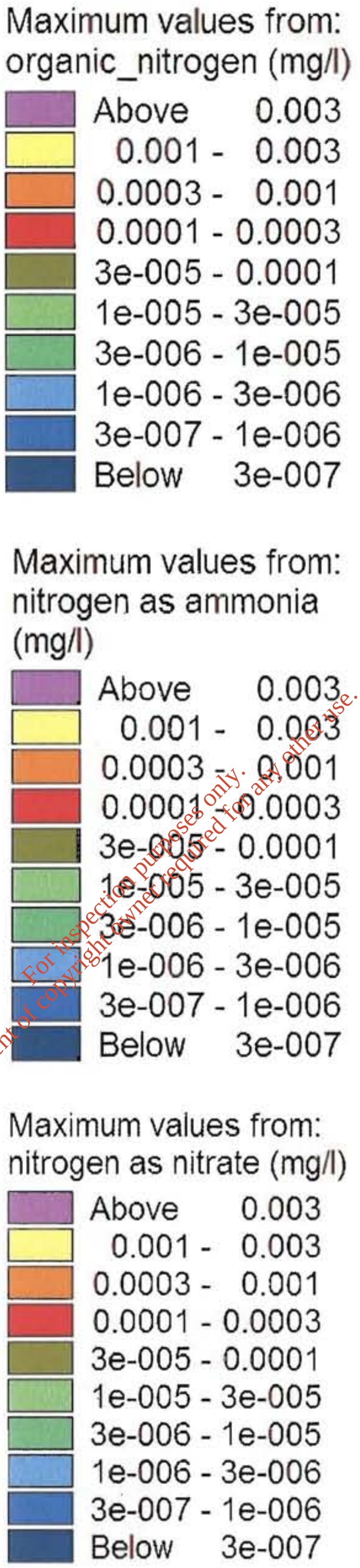
The four figures follow the same pattern in the presentation of results. The top two spatial plots in each figure show the "before and after" cases (2 and 3) for the concentration of organic nitrogen. The middle two spatial plots in each figure show the "before and after" cases (2 and 3) for the concentration 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.



Maximum values from:
organic_nitrogen (mg/l)

🟪	Above	0.003
🟨	0.001 -	0.003
🟧	0.0003 -	0.001
🟥	0.0001 -	0.0003
🟫	3e-005 -	0.0001
🟩	1e-005 -	3e-005
🟩	3e-006 -	1e-005
🟦	1e-006 -	3e-006
🟦	3e-007 -	1e-006
🟦	Below	3e-007

Maximum values from:
nitrogen as ammonia
(mg/l)

🟪	Above	0.003
🟨	0.001 -	0.003
🟧	0.0003 -	0.001
🟥	0.0001 -	0.0003
🟫	3e-005 -	0.0001
🟩	1e-005 -	3e-005
🟩	3e-006 -	1e-005
🟦	1e-006 -	3e-006
🟦	3e-007 -	1e-006
🟦	Below	3e-007

Maximum values from:
nitrogen as nitrate (mg/l)

🟪	Above	0.003
🟨	0.001 -	0.003
🟧	0.0003 -	0.001
🟥	0.0001 -	0.0003
🟫	3e-005 -	0.0001
🟩	1e-005 -	3e-005
🟩	3e-006 -	1e-005
🟦	1e-006 -	3e-006
🟦	3e-007 -	1e-006
🟦	Below	3e-007

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

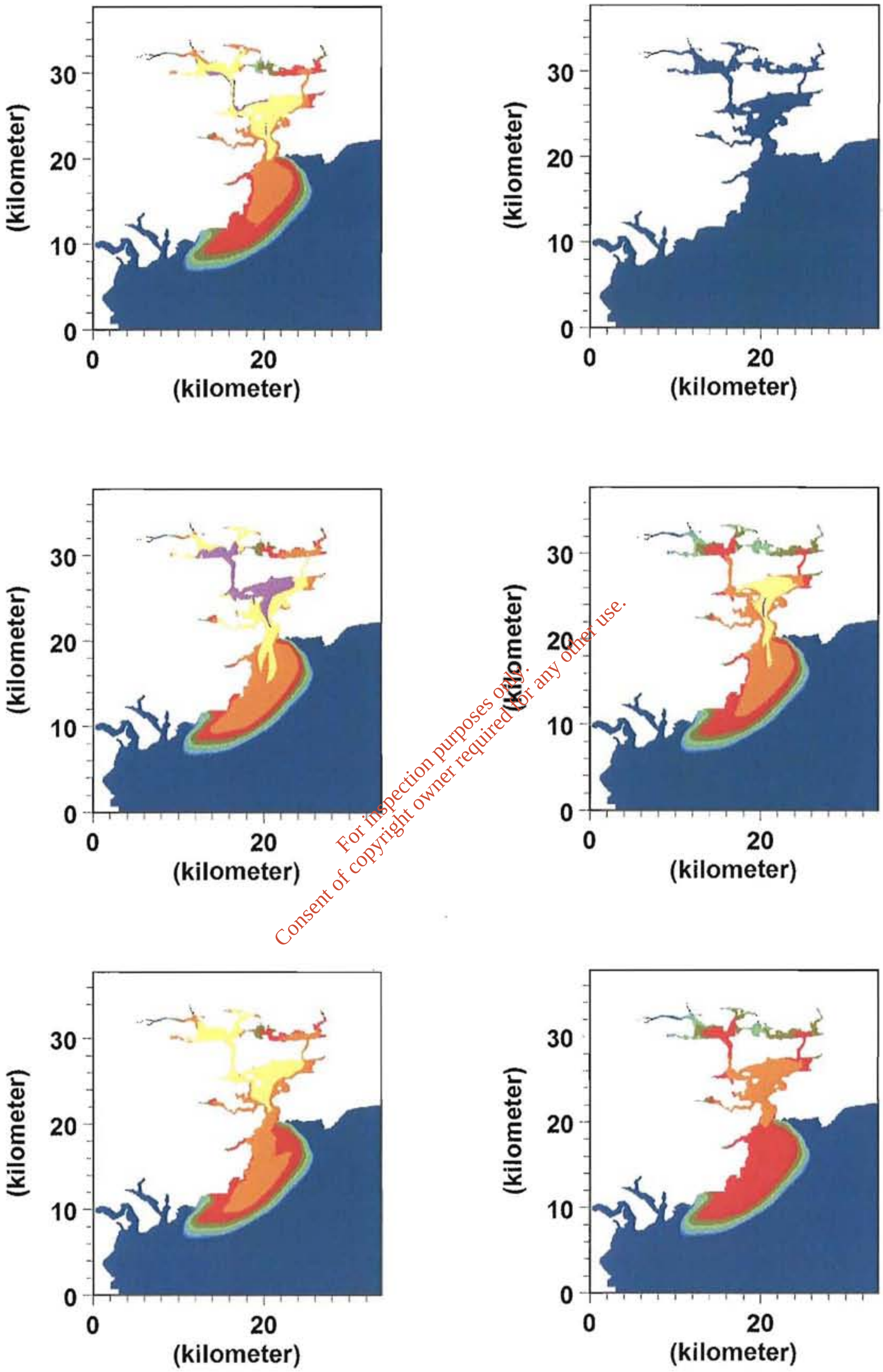


Fig. 6.17 Before and after WWT – maximum concentrations during first 5 day period

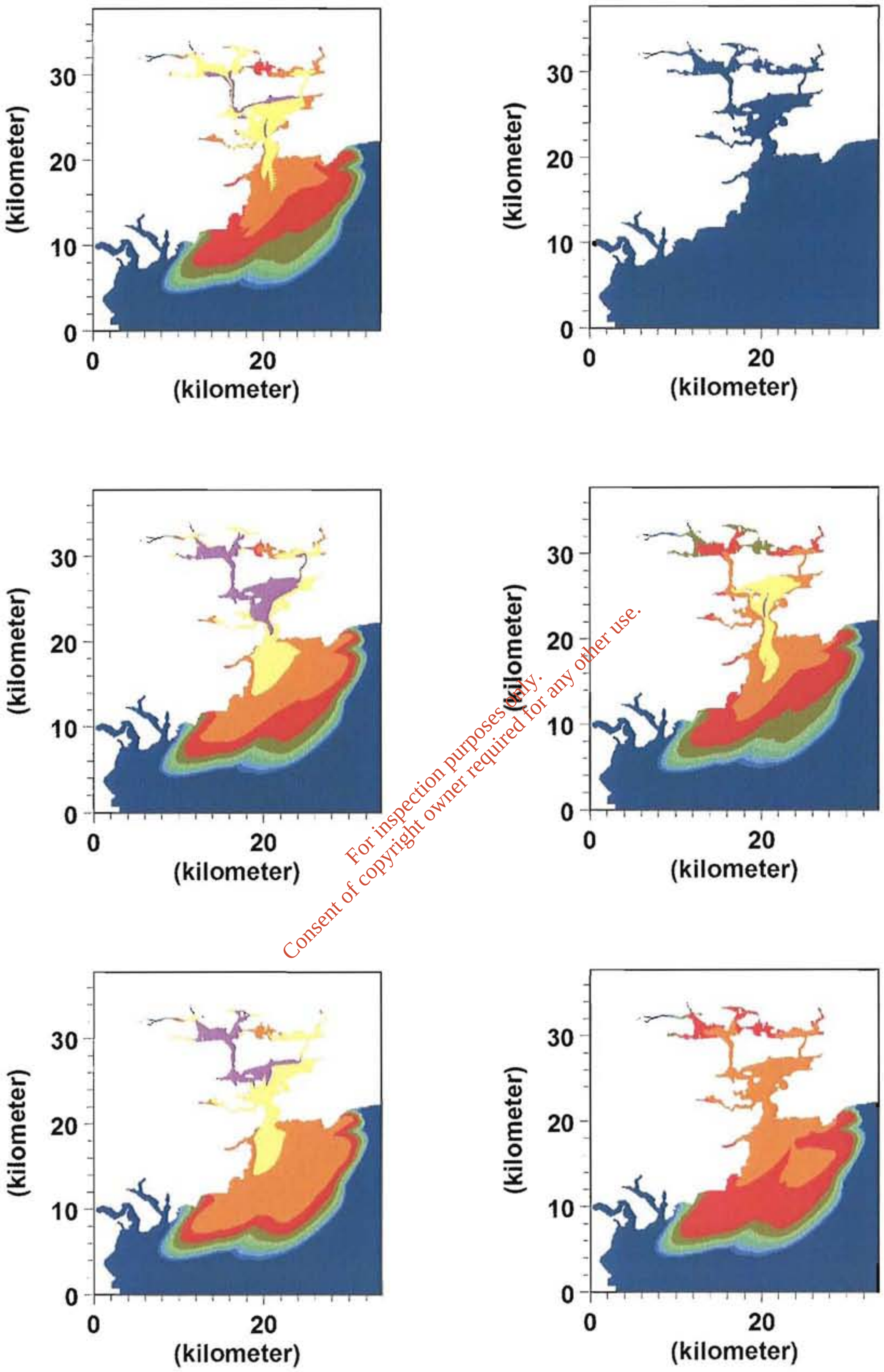


Fig. 6.18 Before and after WWT – maximum concentrations during second 5 day period

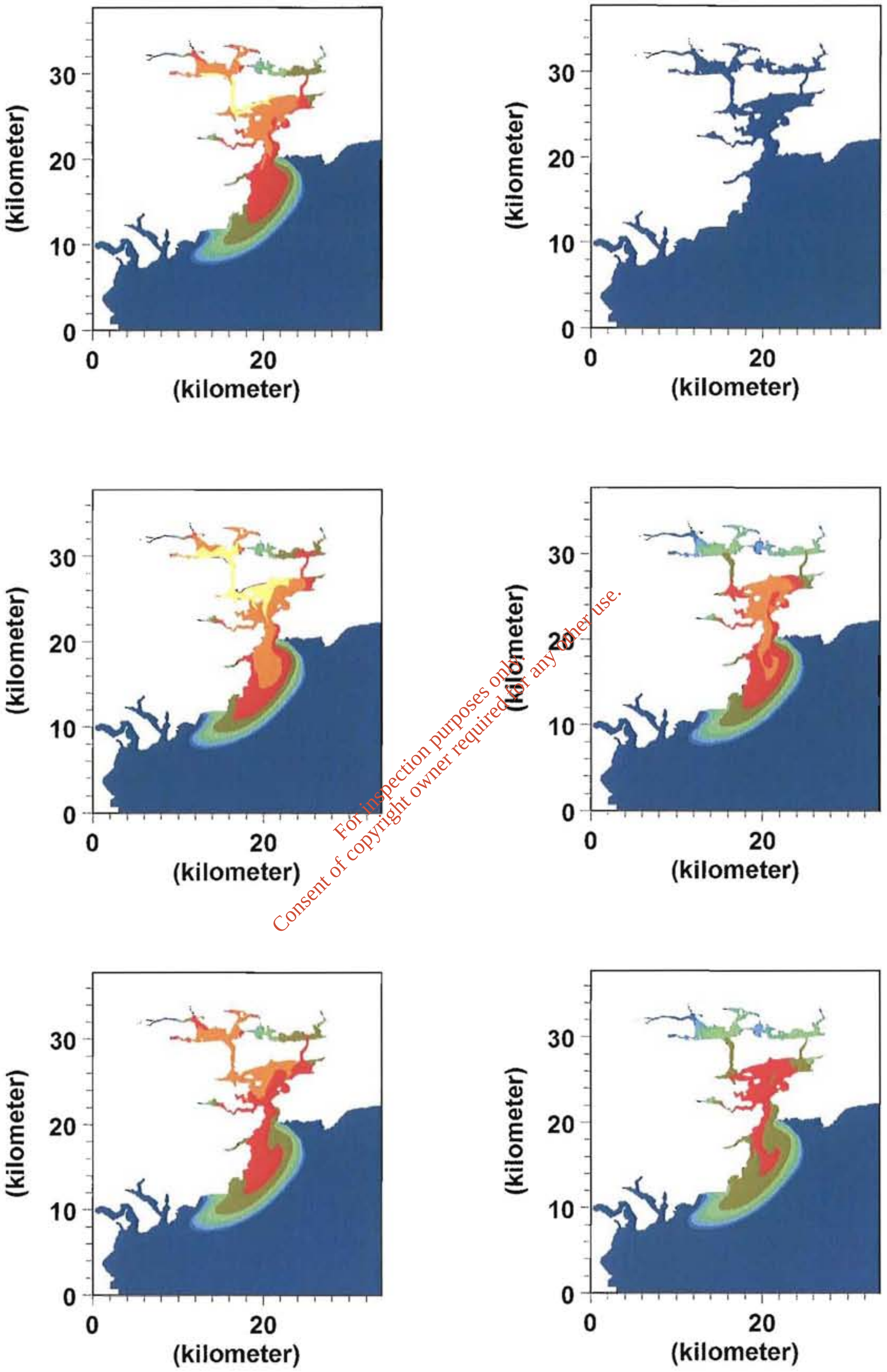


Fig. 6.19 Before and after WWT – mean concentrations during first 5 day period

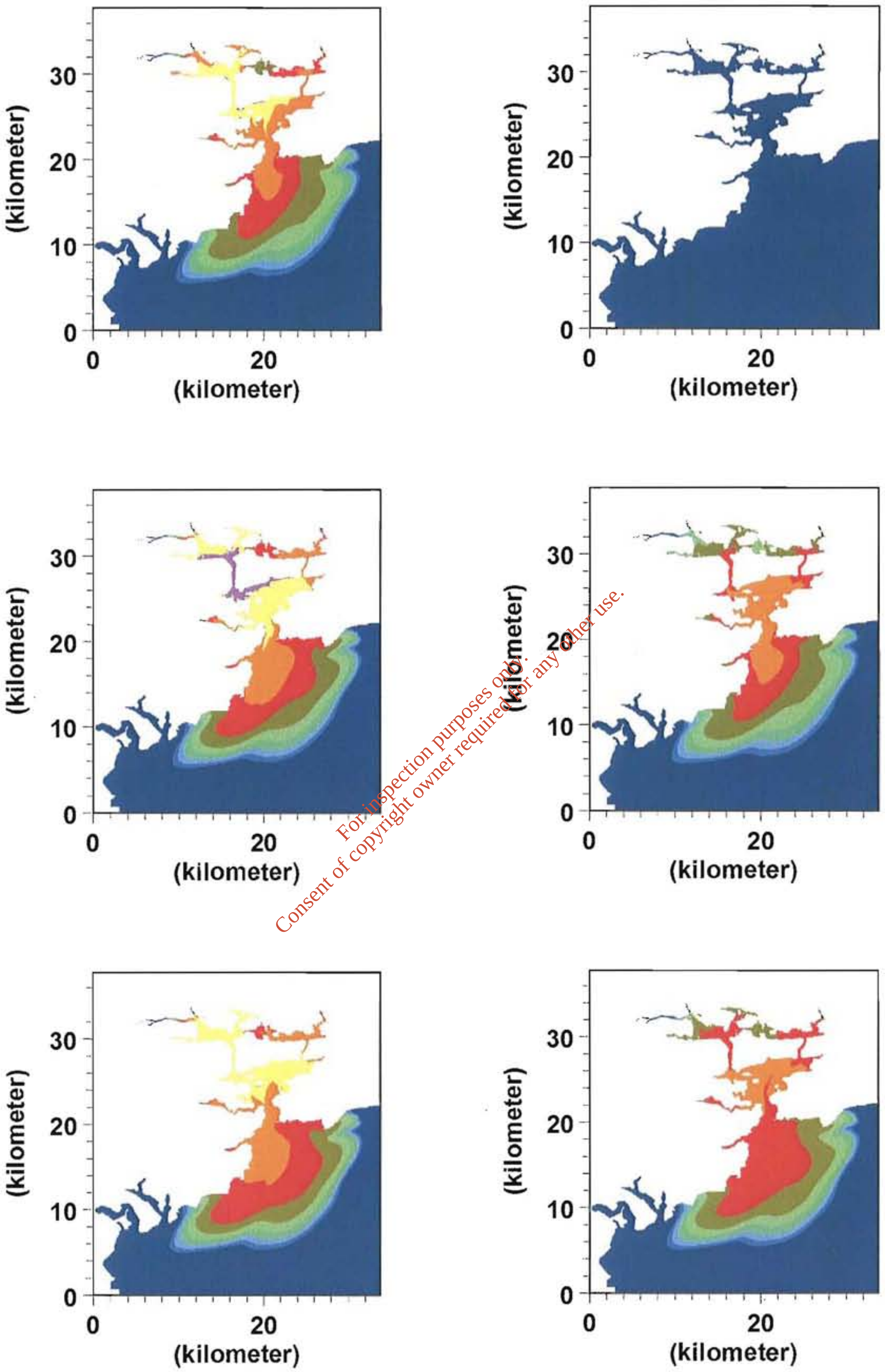


Fig. 6.20 Before and after WWT – mean concentrations during second 5 day period

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		CASE 4	
	First assumption	Sensitivity assumption	First assumption	Sensitivity assumption
	MAX	MAX	MAX	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		CASE 4	
	First assumption	Sensitivity assumption	First assumption	Sensitivity assumption
	MAX	MAX	MAX	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.

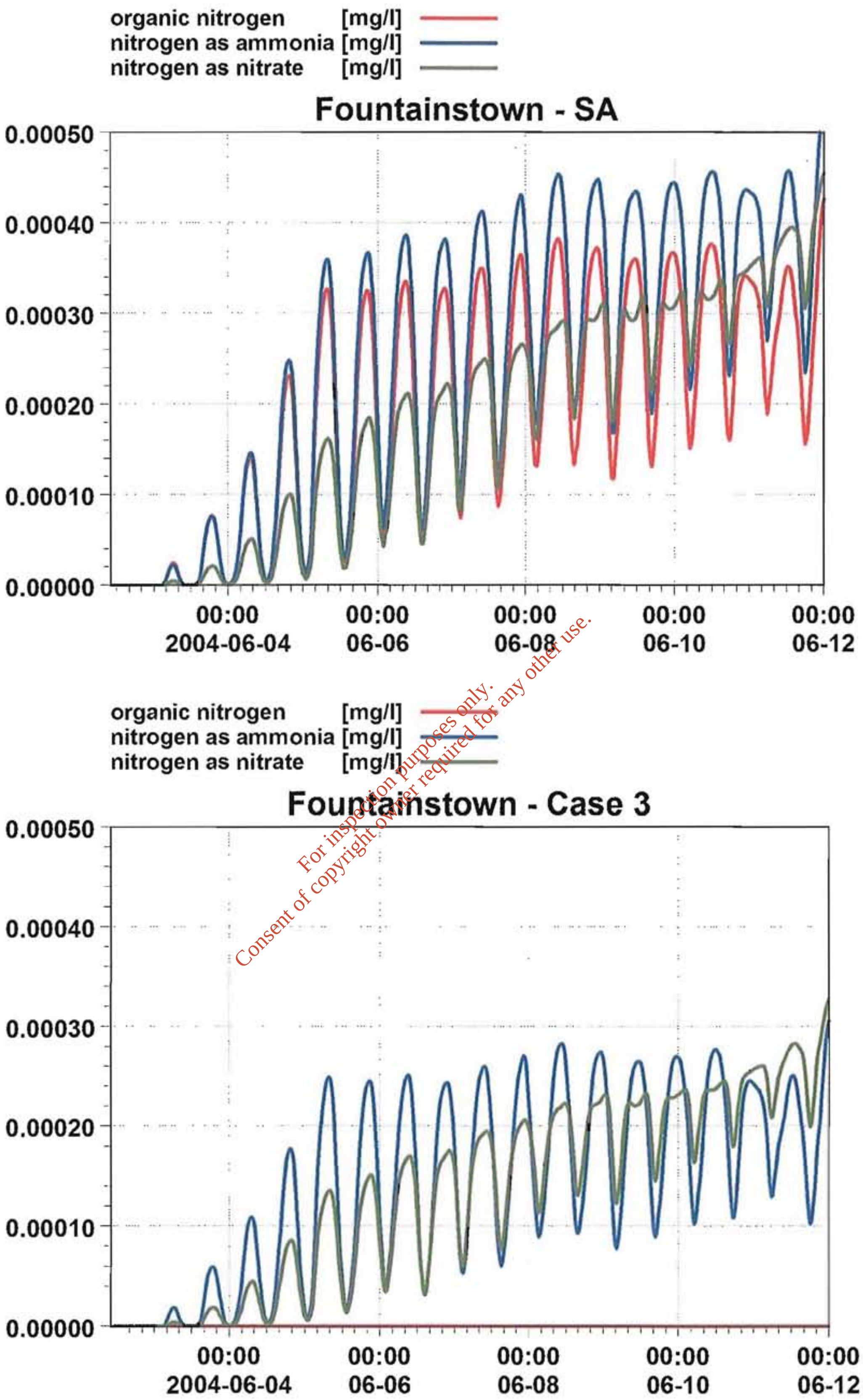
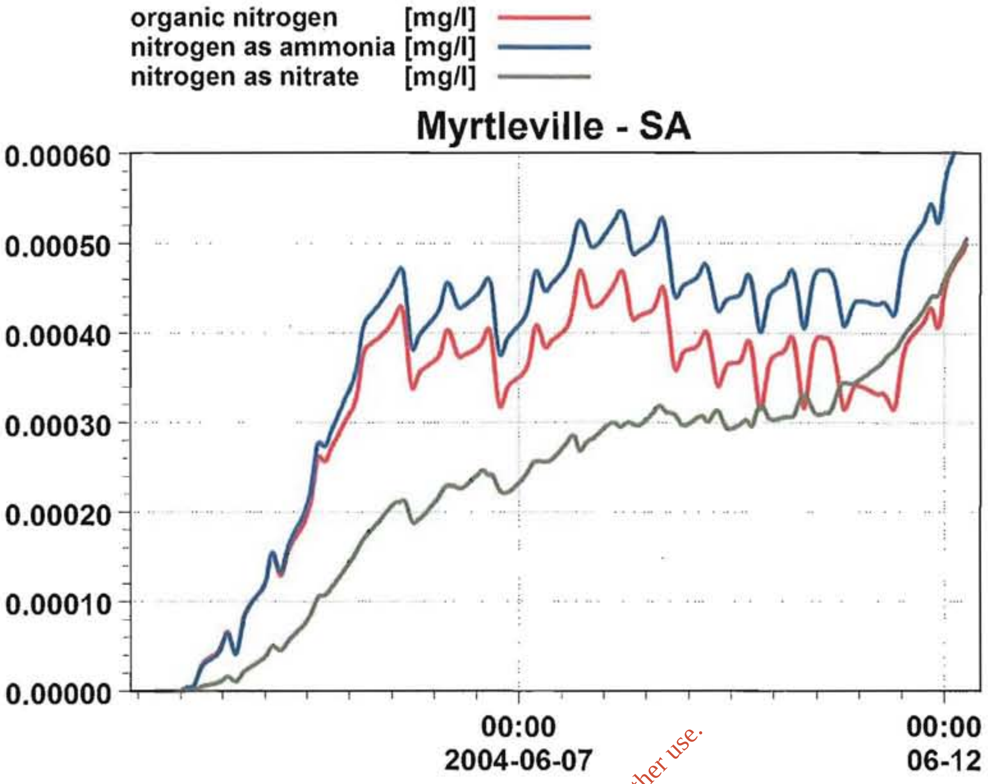


Fig. 6.21 Fountainstown



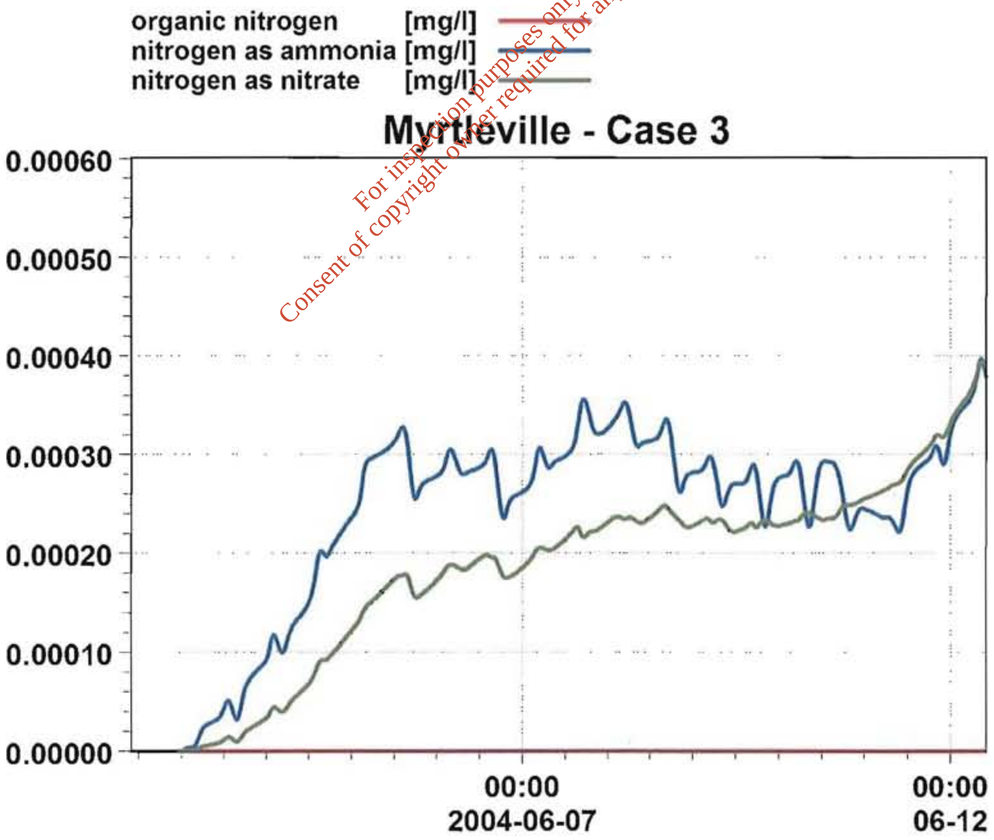


Fig. 6.22 Myrtleville

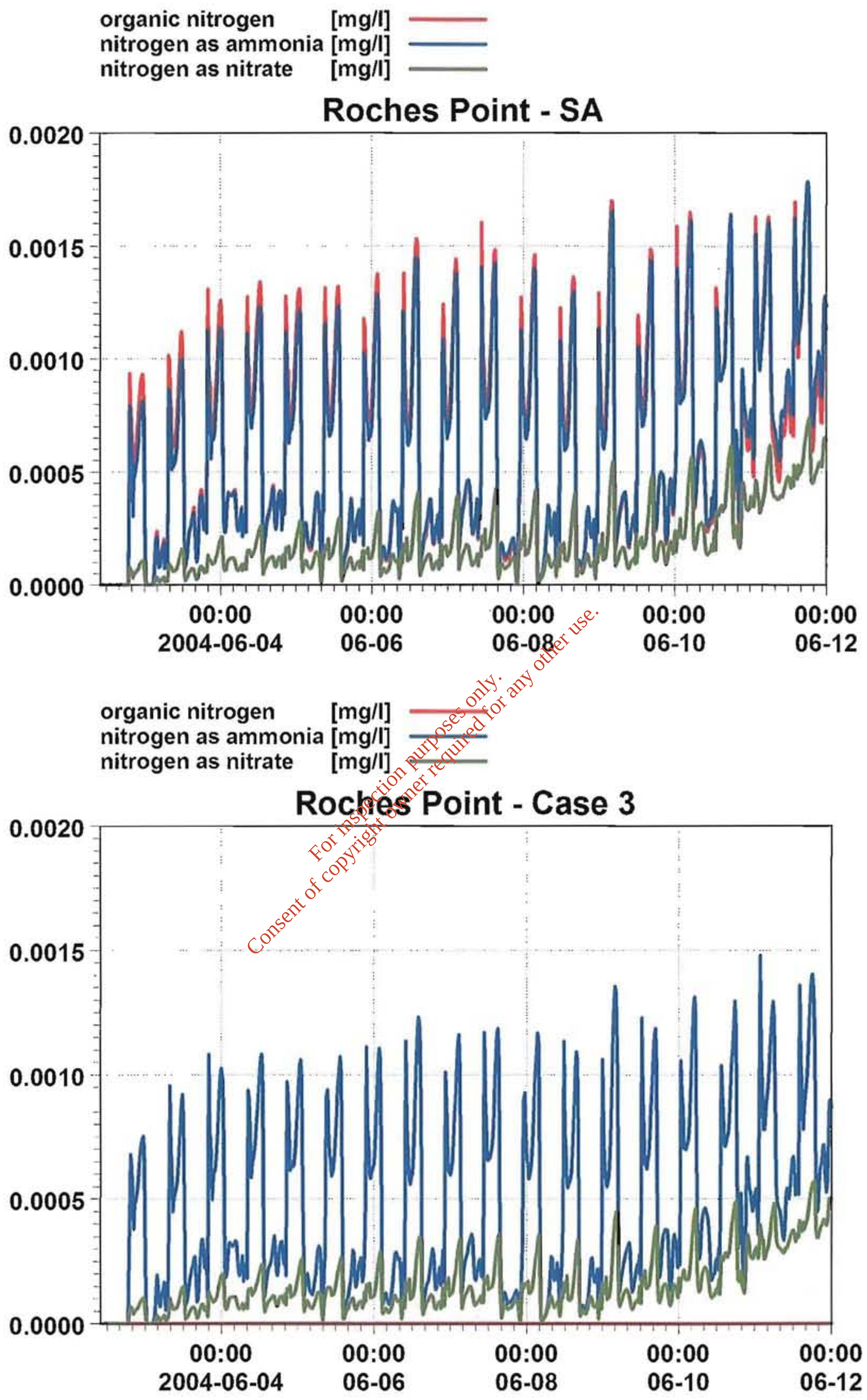


Fig. 6.23 Roches Point

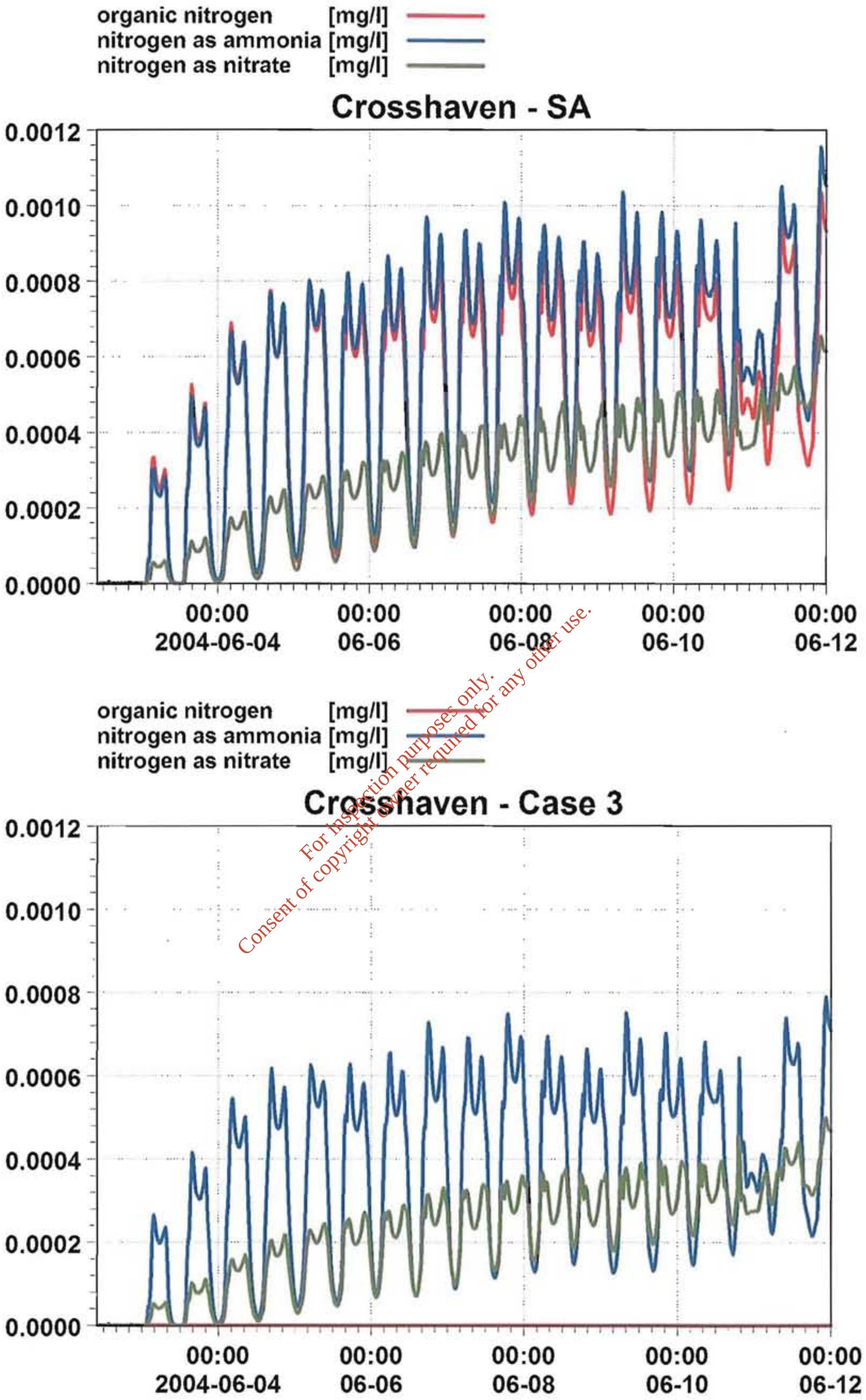


Fig. 6.24 Crosshaven

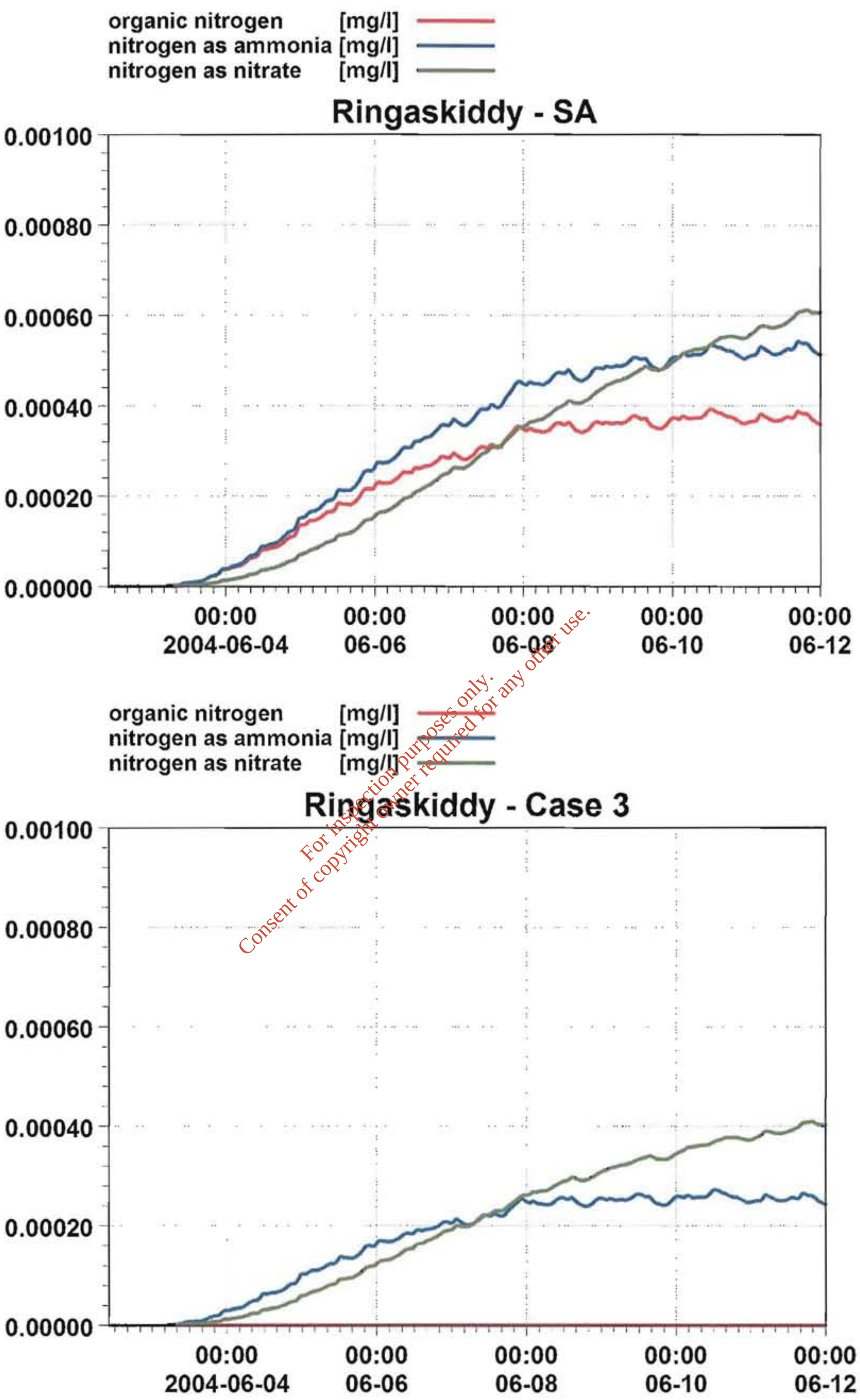


Fig. 6.25 Ringaskiddy

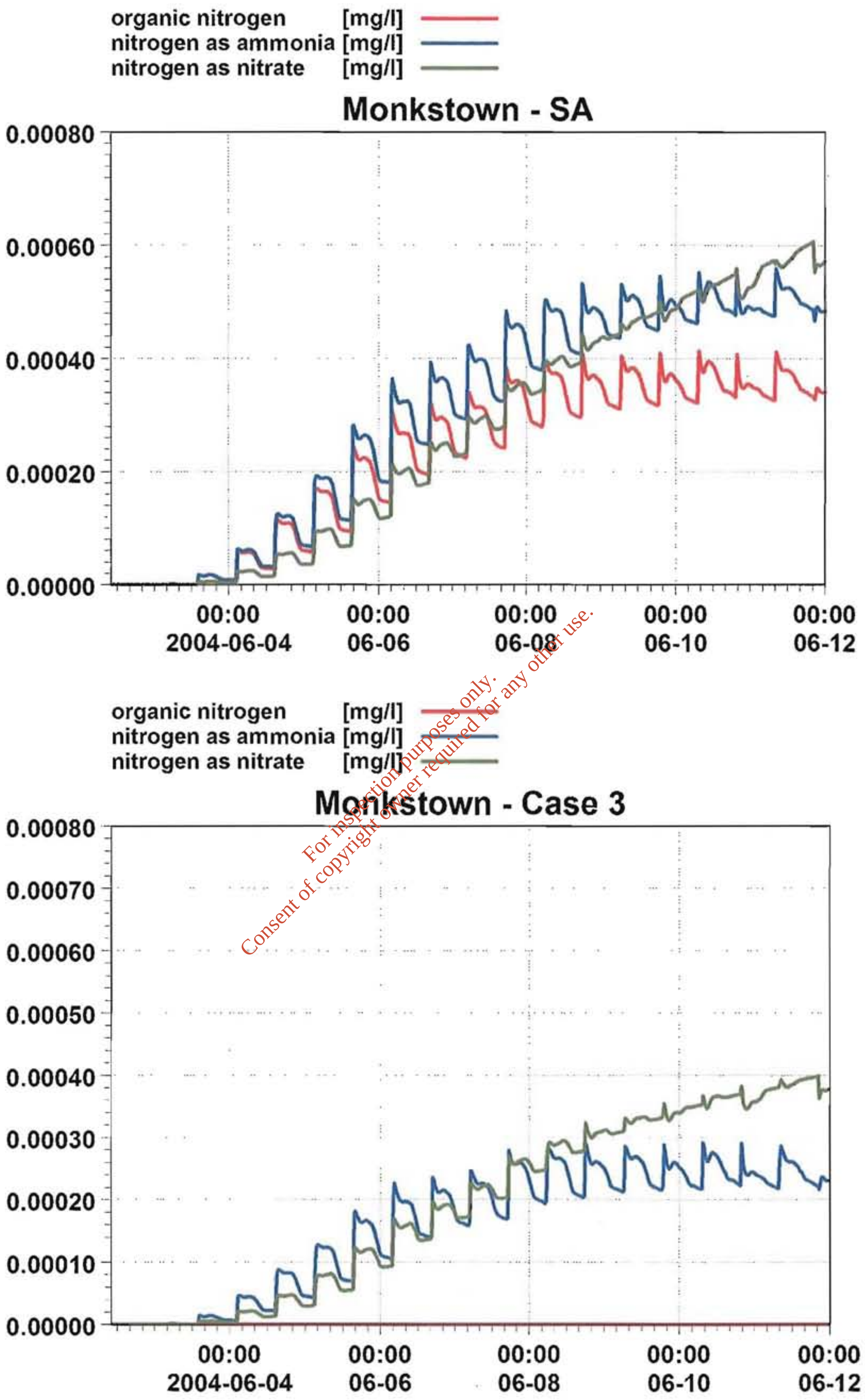
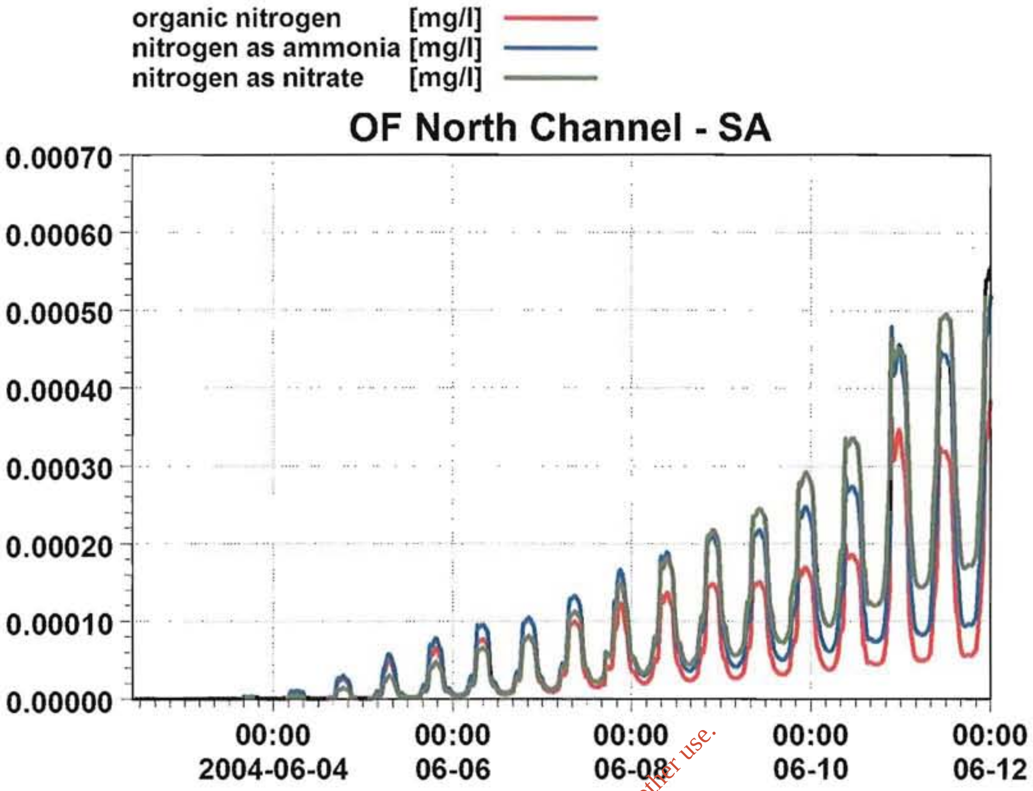


Fig. 6.26 Monkstown



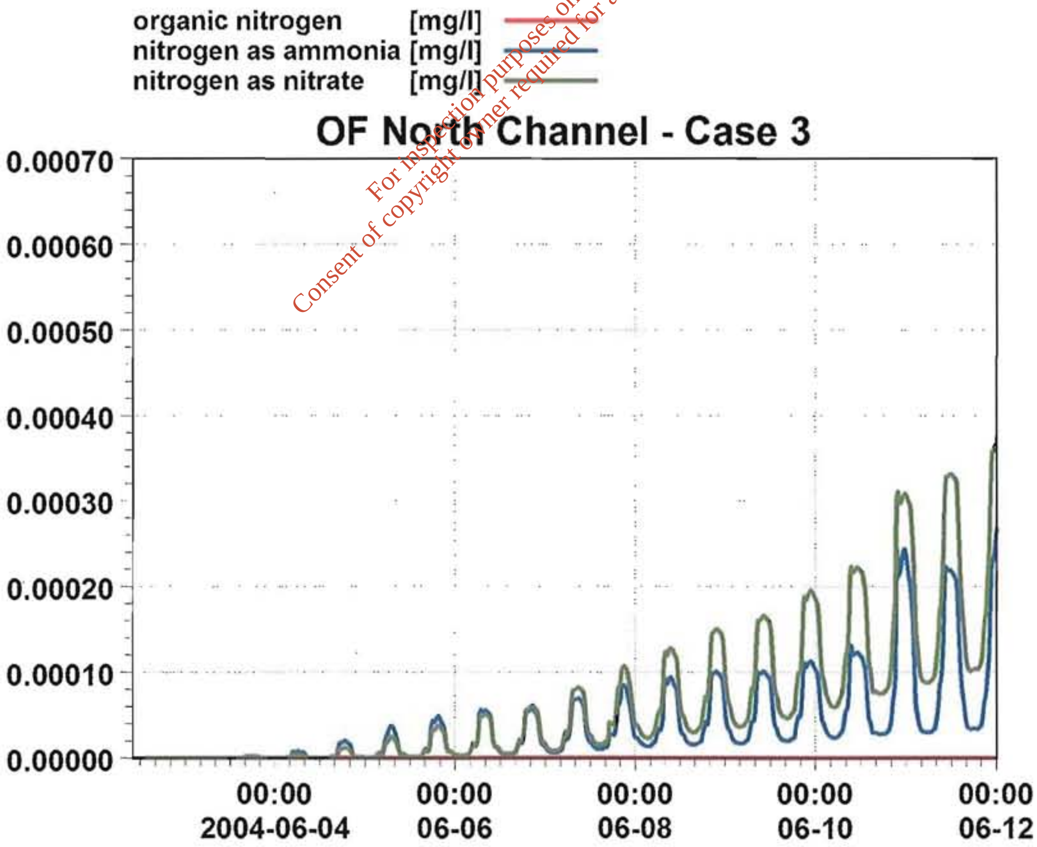
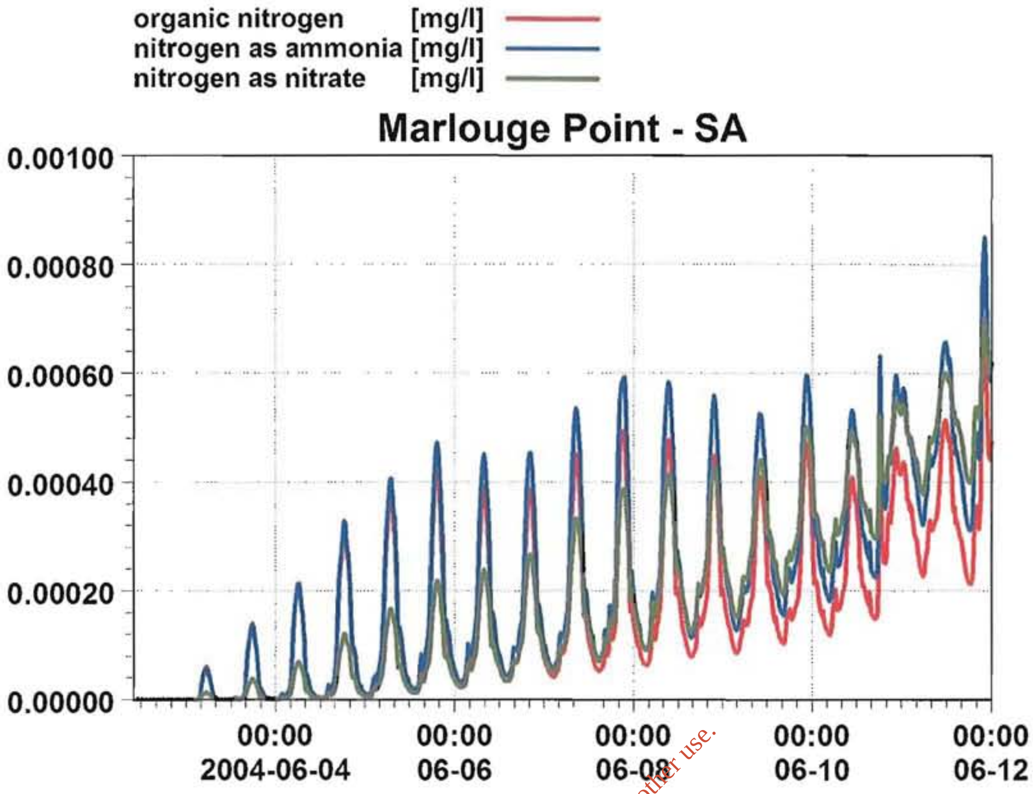


Fig. 6.27 OF North Channel



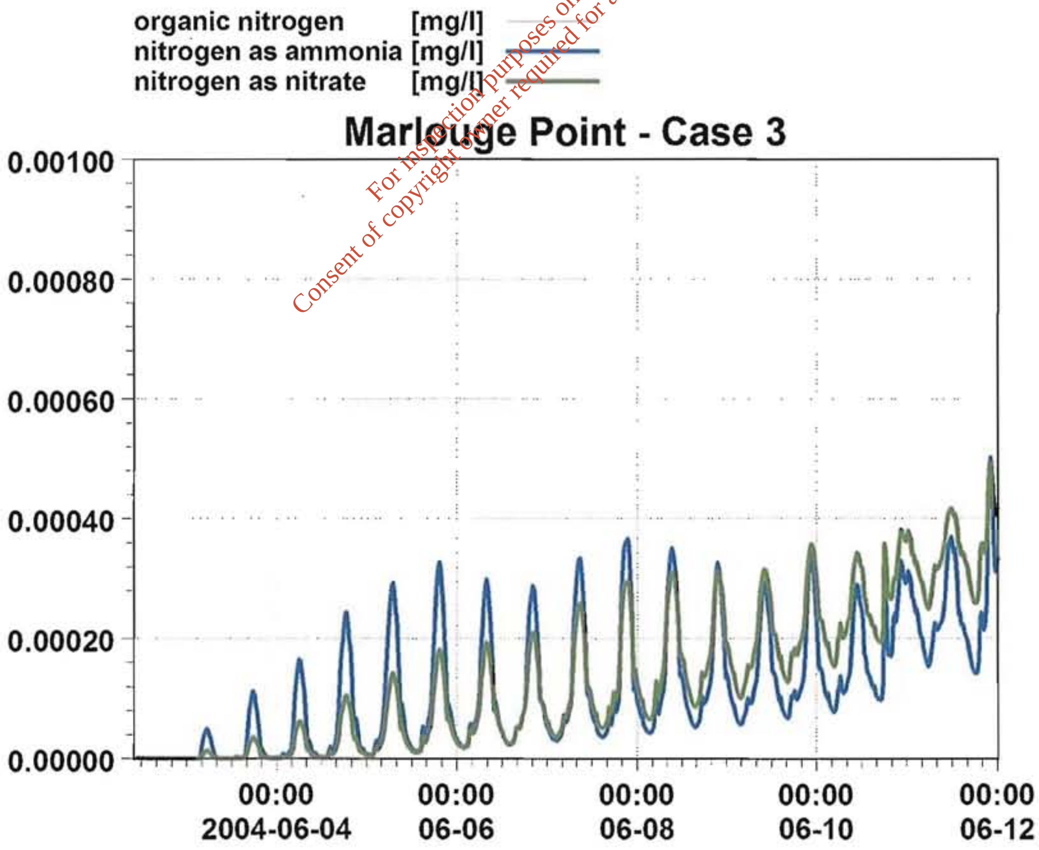


Fig. 6.28 Marlouge Point

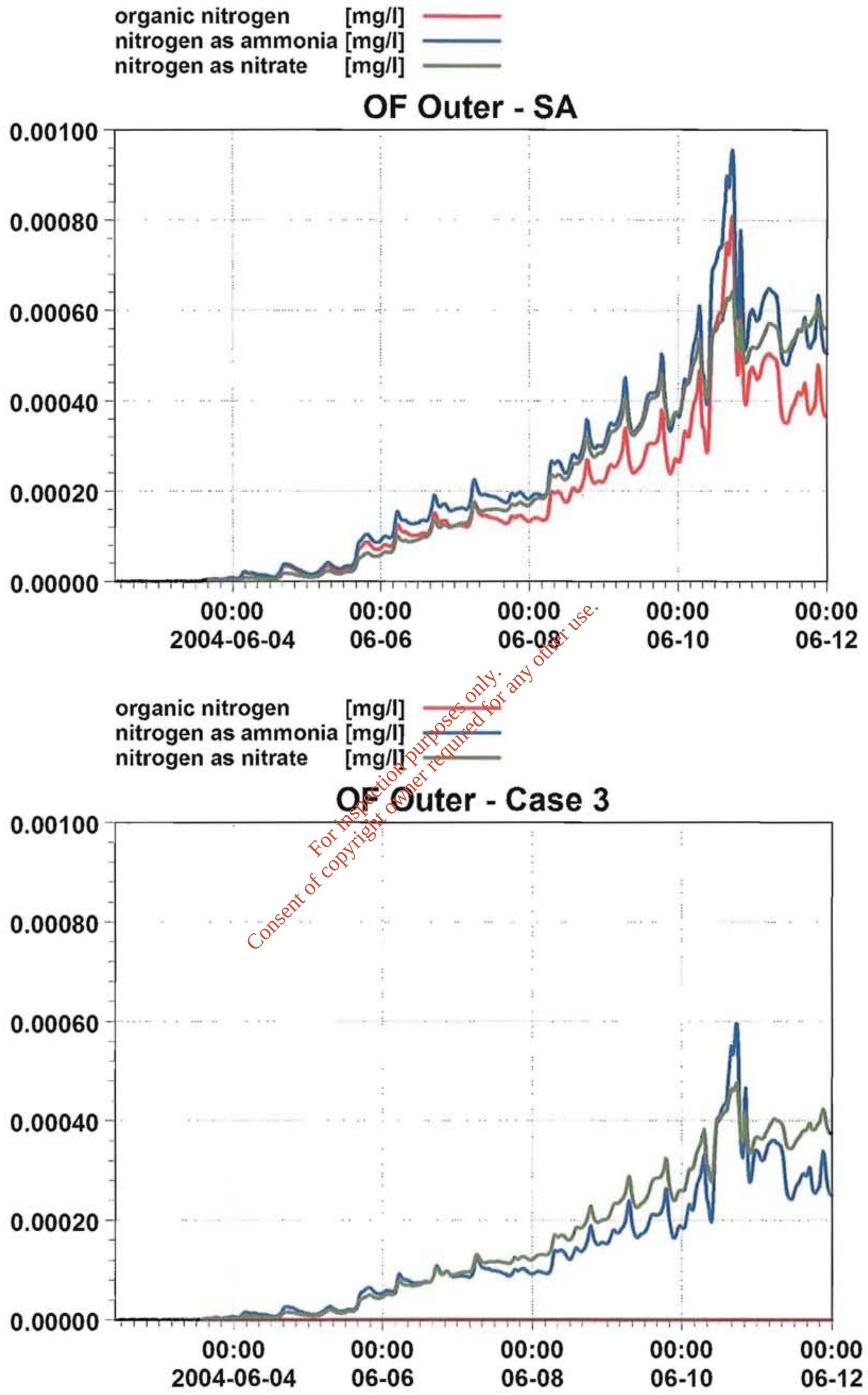


Fig. 6.29 OF – Outer Harbour

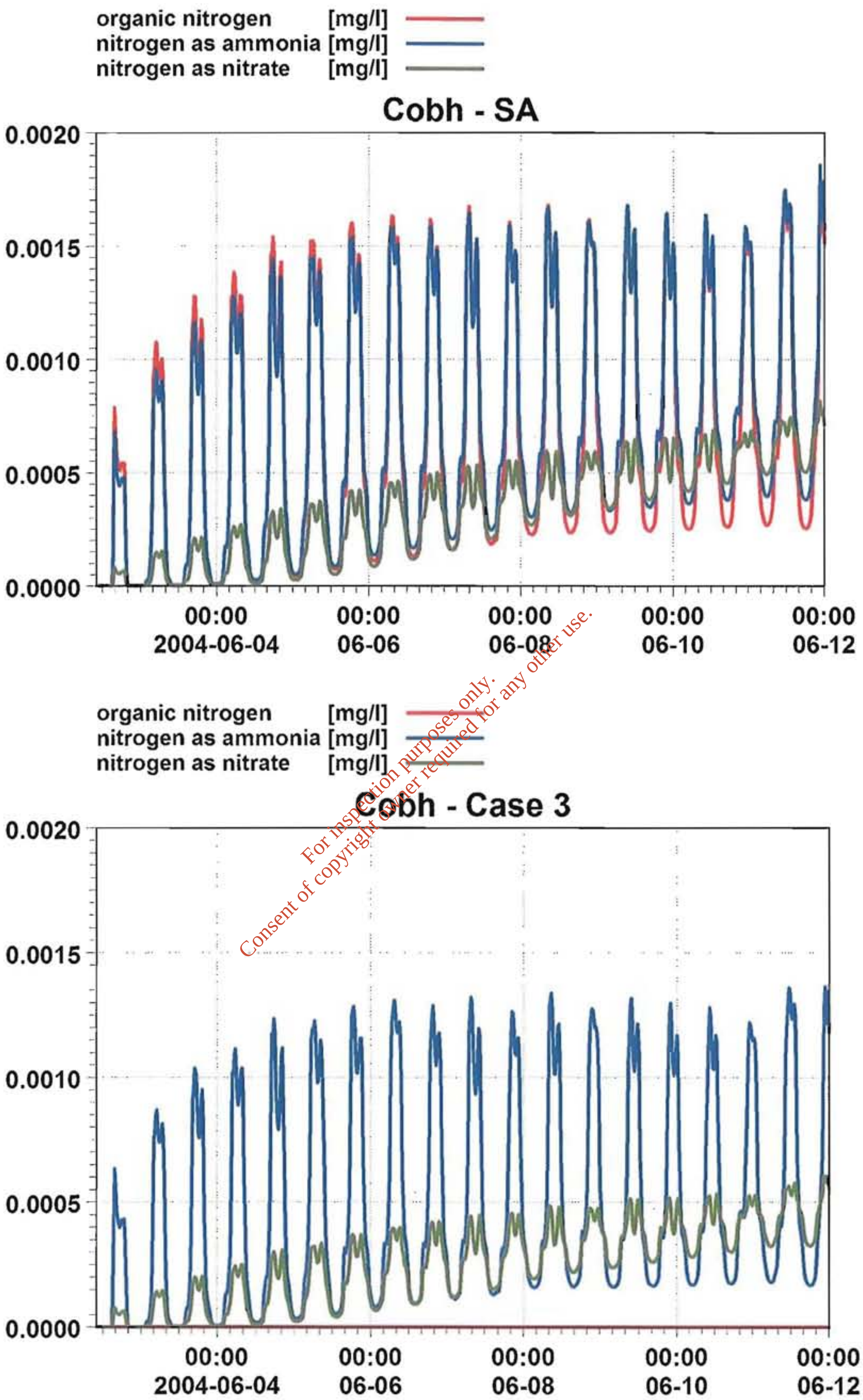
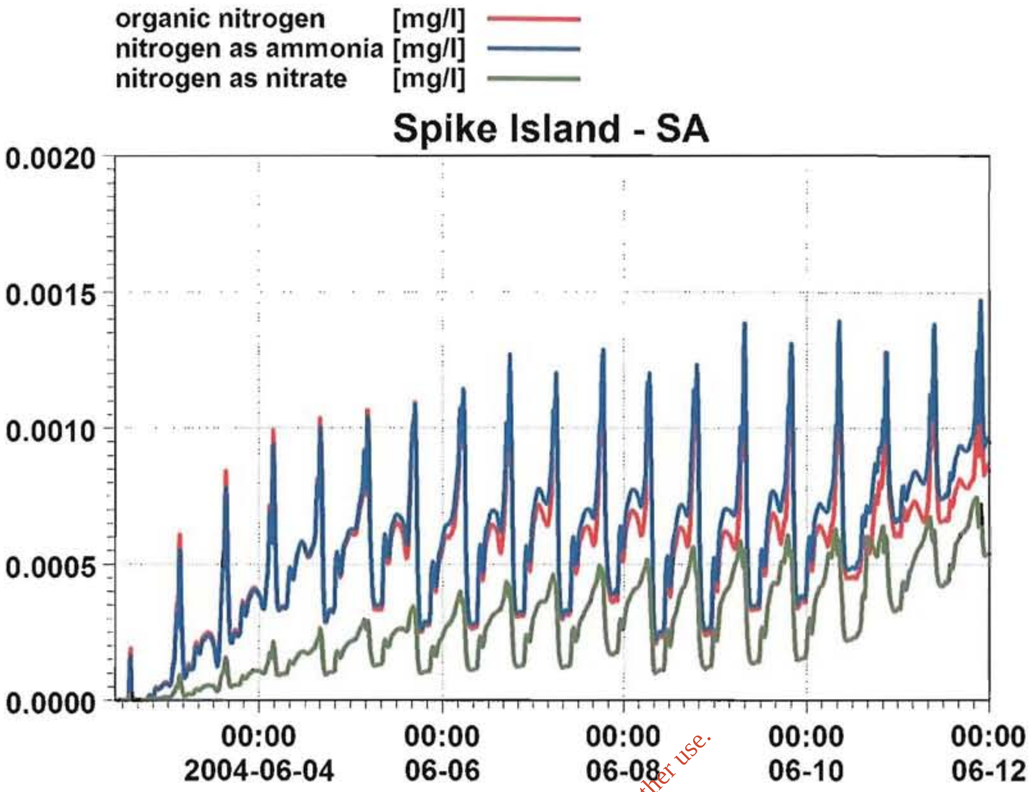

organic nitrogen [mg/l]
nitrogen as ammonia [mg/l]
nitrogen as nitrate [mg/l]
Cobh - SA
0.0020
0.0015
0.0010
0.0005
0.0000
00:00
2004-06-04
00:00
06-06
00:00
06-08
00:00
06-10
00:00
06-12
organic nitrogen [mg/l]
nitrogen as ammonia [mg/l]
nitrogen as nitrate [mg/l]
Cobh - Case 3
0.0020
0.0015
0.0010
0.0005
0.0000
00:00
2004-06-04
00:00
06-06
00:00
06-08
00:00
06-10
00:00
06-12

Fig. 6.30 Cobh



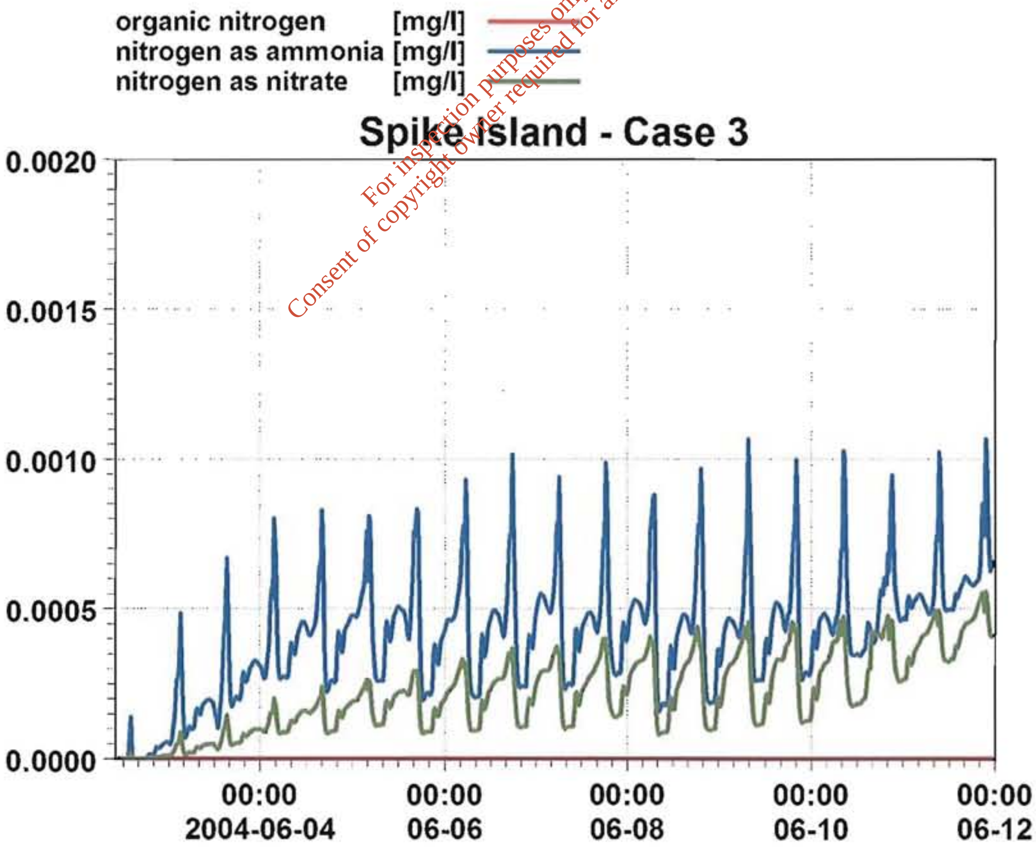
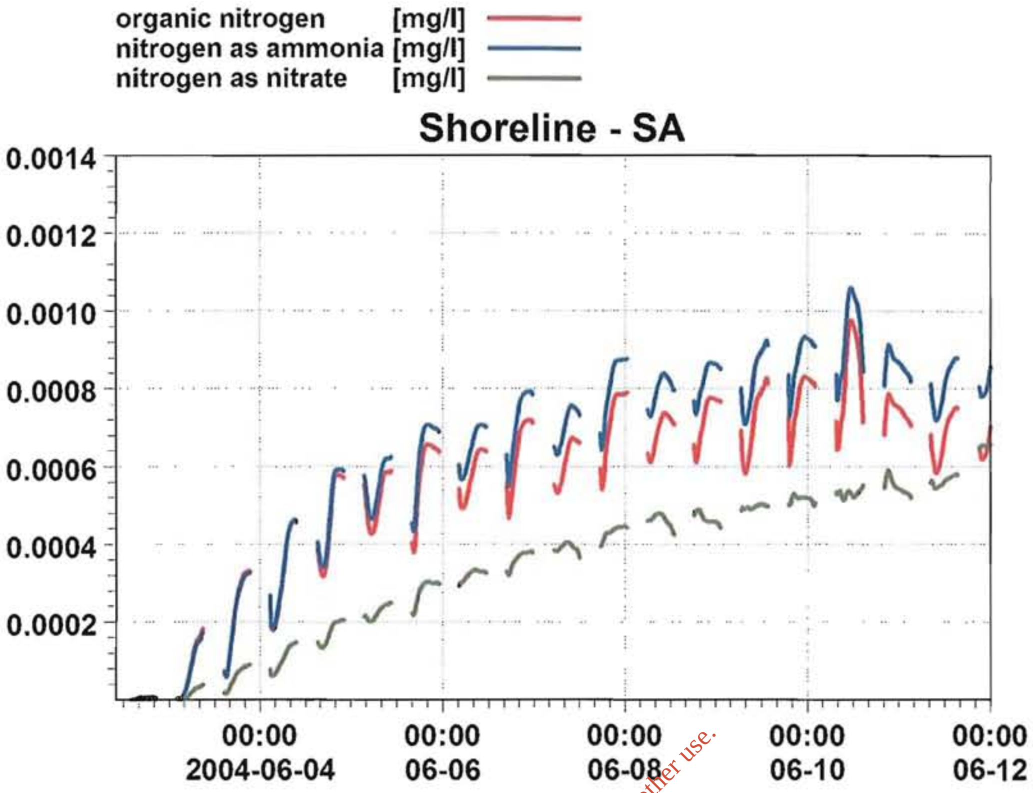


Fig. 6.31 Spike Island



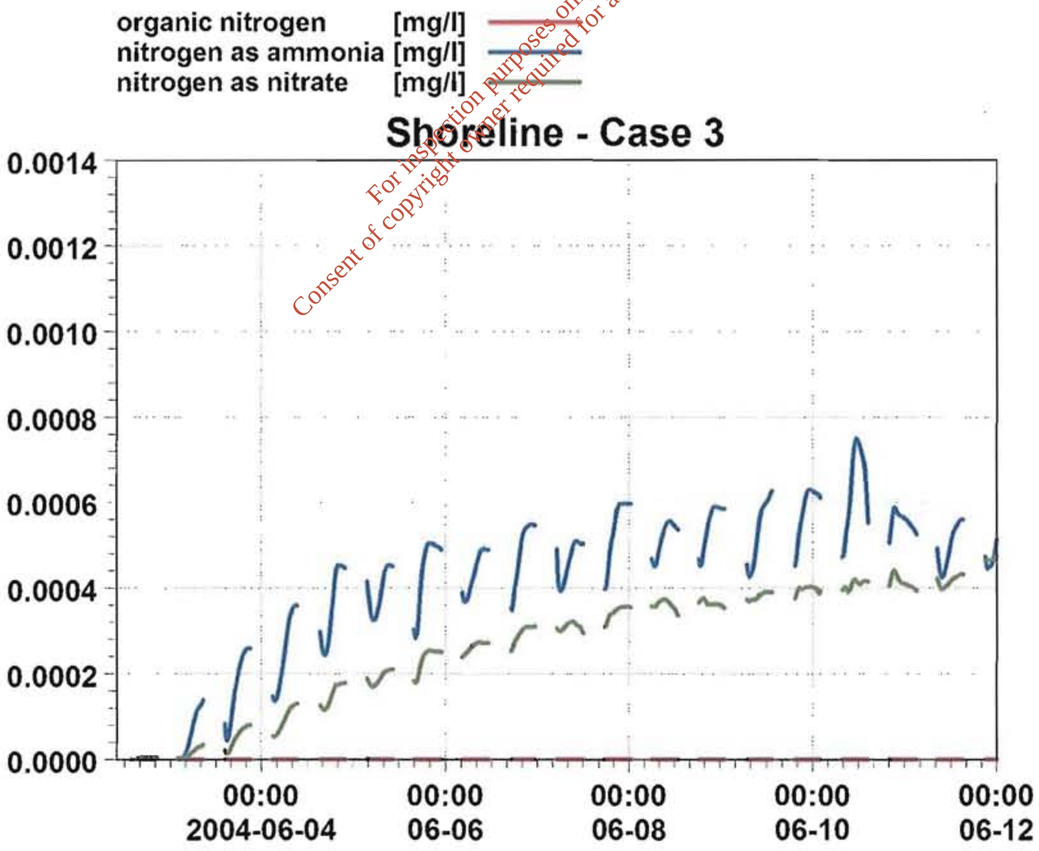


Fig. 6.32 Shoreline

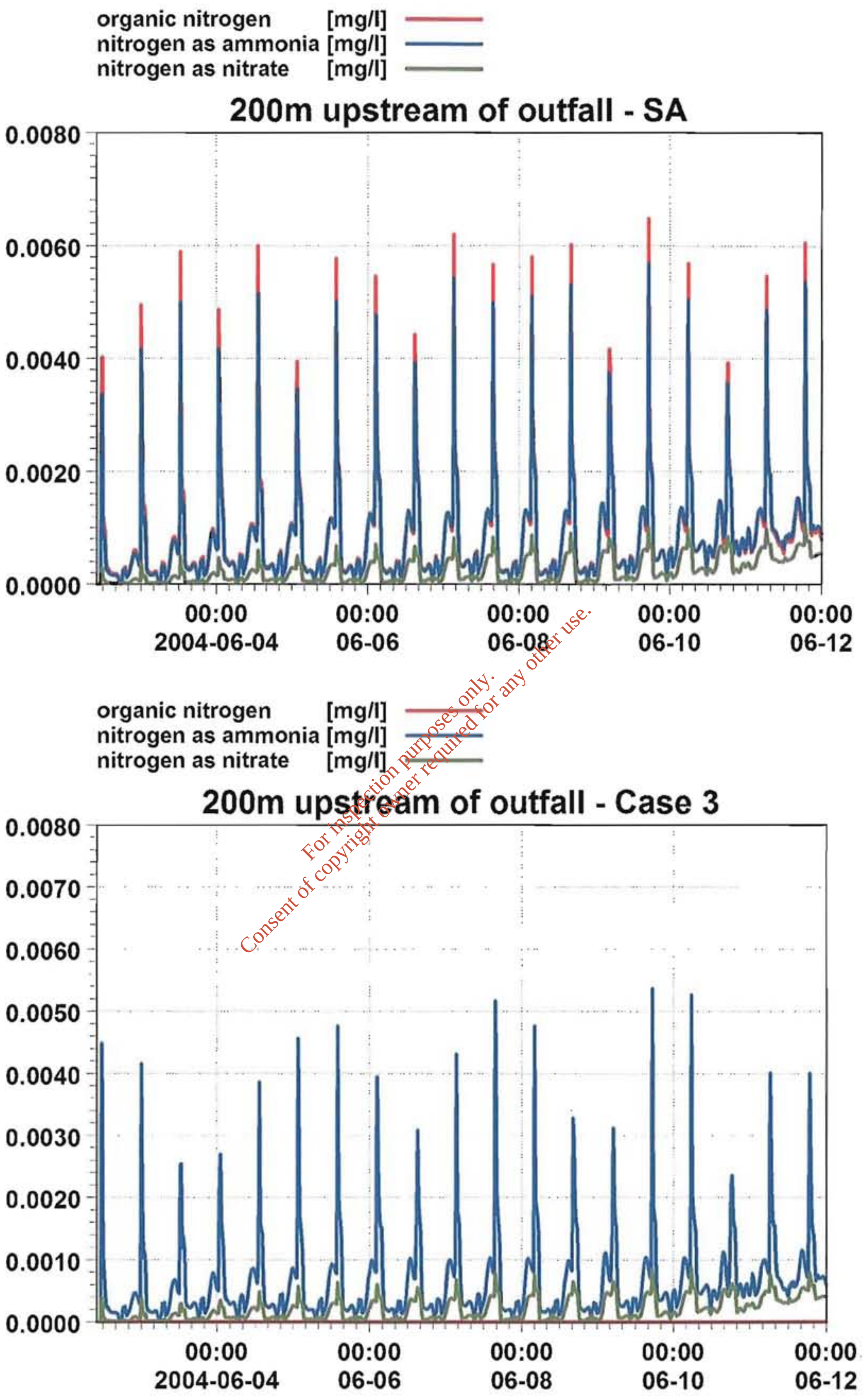


Fig. 6.33 200m upstream of outfall

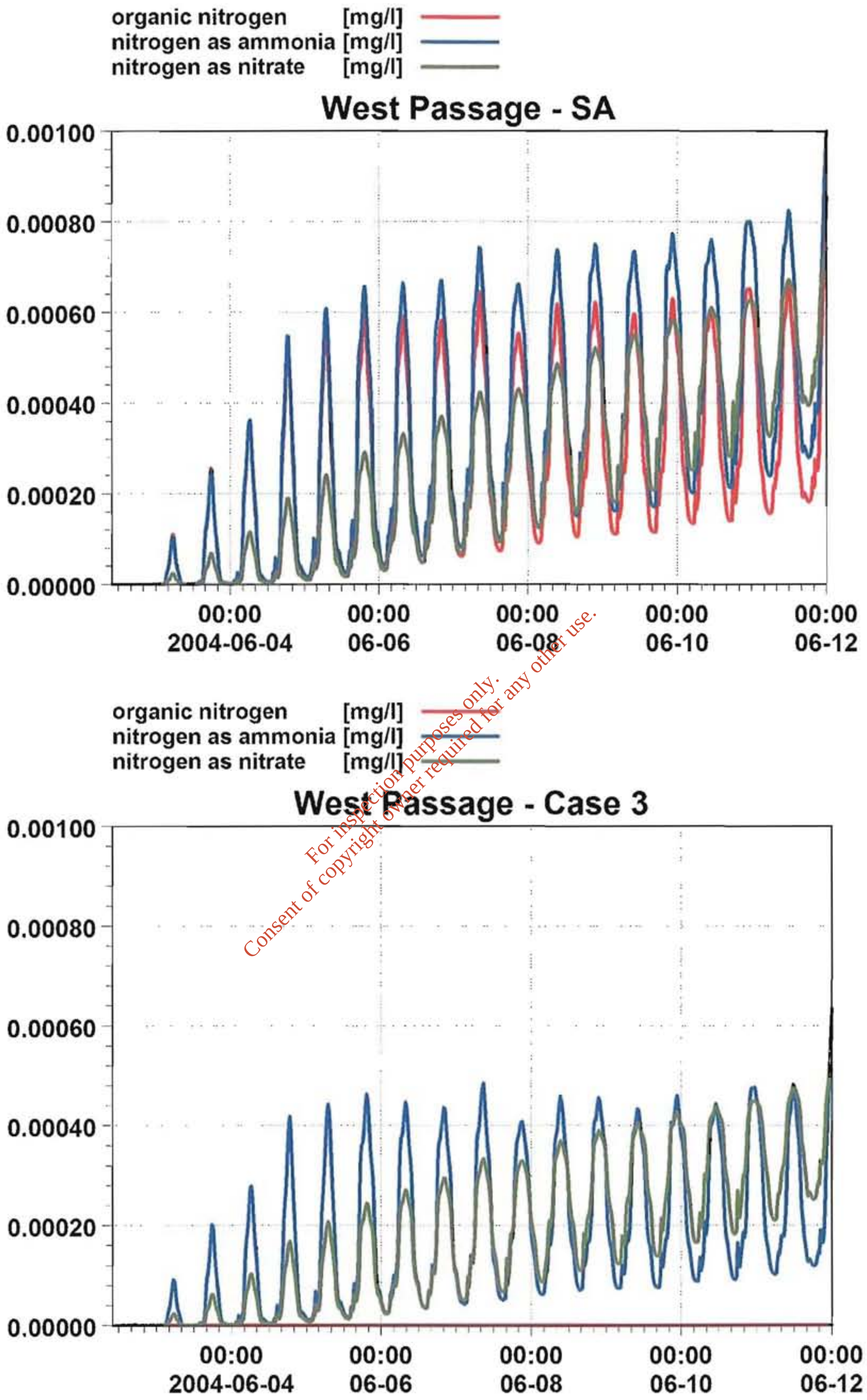


Fig. 6.34 West Passage

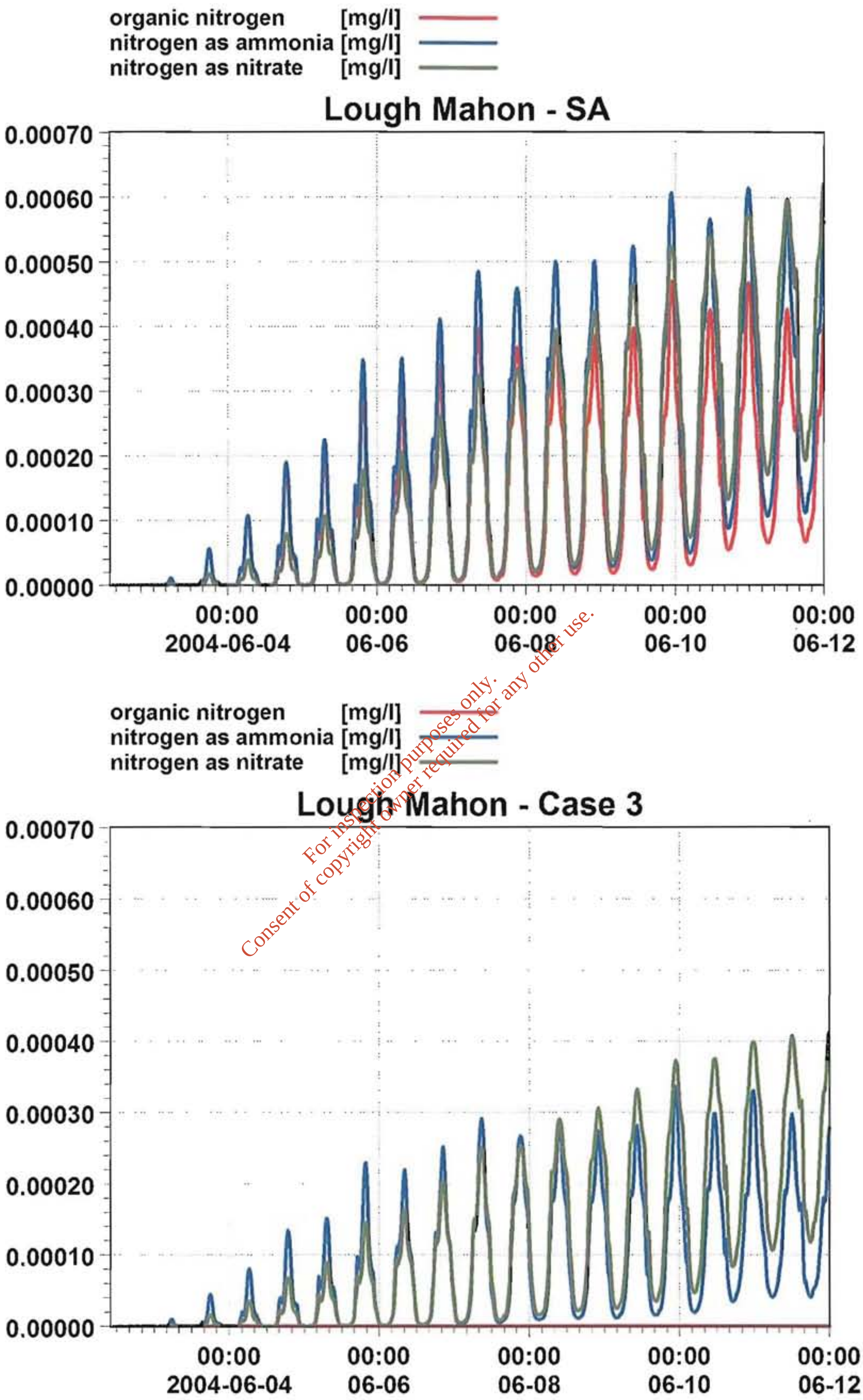


Fig. 6.35 Lough Mahon

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.

Chapter 7 Discussion and Conclusion

7.1 Discussion

The lead author of this report was commissioned by Mott MacDonald Pettit (MMP) to undertake a detailed Environmental Impact Assessment of the likely relative improvement in water quality as a result of the proposed Lower Harbour Main Drainage Scheme. At present the towns of Cobh, Passage West, Monkstown, Glenbrook, Ringaskiddy, Crosshaven and Carrigaline all discharge untreated sewage into Cork Harbour. The proposed scheme will collect this waste and treat it to a secondary standard at a new wastewater treatment plant near Carrigaline. The treated effluent will be discharged through the existing Carrigaline/Crosshaven outfall near Dognose Bank. In spite of increasing population a marked improvement in quality is to be expected for two reasons: (a) the reduction in pollutant load due to the treatment plant, and (b) the increased dilution available downriver when the treated effluent is discharged just inside the mouth of the Outer Harbour. This study quantifies the improvement.

A computer model, called the 'OH_2' model covering an area from the Old Head of Kinsale to the Waterworks weir in Cork City was developed. The calibration of this model was based on that of a similar, but smaller, model of Cork Harbour (the 'RP_2' model) which covers an area from Roches Point to the Waterworks weir. The water level validation of the OH_2 model showed that it is capable of reproducing the tides in Cork Harbour with an acceptable error (<25cm).

The OH_2 model has been used to simulate the discharge, transport and decay of three separate micro-organisms present in sewage from the relevant outfalls:

1. **Faecal coliform bacteria -** The number of faecal coliforms per 100ml is a recognised standard in the relevant EU Directives. The I (mandatory) and G (guide) values for the Bathing Water Directive are, for faecal coliforms, 2000 counts per 100ml and 100 counts per 100ml respectively. The G (guideline) values for the Shellfish Waters

Directive are, for faecal coliforms, less than 300 counts per 100ml in the *shellfish flesh and intervalvular liquid.*

2. **Norovirus** - The *Norovirus* or "Winter Vomiting bug" is the primary pathogen in outbreaks of gastroenteritis following consumption of raw oysters. There is no standard for seawater at present due to the difficulty of measuring its concentration.
3. **Simple Nitrogen Cascade** - The forcing exerted on the Harbour ecosystem by organic nitrogen, nitrate and ammonia is examined using a simplified nitrogen cascade model.

In order to illustrate the overall benefit of the proposed scheme a detailed comparison was made between the case where untreated waste is being discharged from all of the relevant outfalls in 2010 (**CASE 2** in this report) and the case where treated waste is being discharged from the single Carrigaline/Crosshaven outfall near Dognose Bank in 2010 (**CASE 3** in this report).

The OH_2 model has a number of inherent assumptions:

- Bacteria, nitrogen, and *Norovirus* are neutrally buoyant.
- Adsorption onto sediment is not modelled.
- Density gradients and stratification due to variations in salinity are excluded.

In this study we have not considered the discharges of treated effluent from Carrigrennan, Midleton or Cloyne or the untreated discharges from the outfalls serving the towns on the eastern side of the harbour. Neither have we considered the intermittent discharge of storm overflows during heavy rainstorms and/or large infiltration of groundwater into sewers. Once secondary treatment has been introduced everywhere, these episodic discharges become important. Therefore, the results are not representative of the absolute water quality in the harbour and surrounding waters. They show the improvement to be expected from the proposed treatment plant.

We have examined the measurements of background concentrations of coliforms and nitrogen from the harbour. There are no measurements of

Norovirus in water anywhere in the world. The sampling error and the spatio-temporal variability of coliforms and nitrogen throughout the harbour make any estimate of the background concentrations very uncertain. Consequently, in our view, it is sufficient to model the improvement in concentrations due to the proposed treatment plant and outfall.

It is possible to model the background concentrations but this would require substantially more resources and time than were available for this comparative study.

The results of the three modelled micro-organisms are discussed in the following sections.

7.2 Faecal Coliform Results

The OH_2 model results showed that the proposed treatment plant will reduce the number of faecal coliforms in Cork Harbour and the waters outside Roches Point. This will lead to a considerable improvement in water quality.

The maximum number of faecal coliforms attained at each grid point of the model for Case 2 with repeating spring tides ranged from 2 to 1500 faecal coliforms per 100ml across the harbour. This range ignores the extremely high concentrations in the immediate vicinity of each individual outfall. The equivalent range with the proposed treatment plant in operation, Case 3, is from 2 to 400 faecal coliforms per 100ml. This represents a significant improvement in water quality. The results of the repeating neap tides were similar.

When the average number of faecal coliforms at each grid point were compared it was found that the range was reduced from 2 - 140 per 100ml for CASE 2 to 2 – 40 per 100ml for Case 3.

The reduction in the number of faecal coliforms was quantified by expressing the maximum concentrations attained at each grid point with the treatment plant in place as a percentage of the maximum concentrations attained at each grid point without any treatment in place. It was found that the percentage relative reduction varied across the harbour. For Lough Mahon, the Inner harbour, the East and West Passages as well as the area around Ringaskiddy the maximum concentrations with the treatment plant in place were less than 5% of the maximum concentrations with no treatment i.e. there is at least a 95% relative reduction in indicator organisms for these areas. For the rest of the harbour and the area outside Roches Point they were less than 20% i.e. there is at least an 80% relative reduction in indicator organisms for these areas.

When the averages in concentration were compared the same pattern emerged. There was a substantial relative improvement (at least 95% relative reduction) for Lough Mahon, the inner harbour and the East and West passages. For the outer harbour the relative improvement was less (at least 80% relative reduction).

This percentage relative reduction is one of the main findings of our report. The proposed treatment plant will significantly reduce the number of indicator organisms in the upper harbour area. It will also reduce the number of indicator organisms in the outer harbour area and outside the harbour mouth but to a lesser degree.

Time series of faecal coliform concentration were also presented for 15 points of special interest. The improvement in water quality was observed from these graphs by plotting the time series for Case 2 and Case 3 together. The concentrations for 2030 were not presented as they are simply equivalent to the plots for Case 3 multiplied by 1.431.

A sensitivity analysis was carried out on the release of treated waste from the proposed scheme with the 2010 population (**Case 3**). It was found that the maximum number of faecal coliforms may increase by as much as 30 – 40 per 100ml, in certain areas of the outer harbour, when they decay with a T90 of 24 hours and not 12 hours. It was also found that the maximum number of faecal coliforms may increase by as much as 40 – 60 per 100ml, in certain areas of the outer harbour, with adverse wind conditions.

We have assumed that there are $1.0*10^7$ faecal coliforms present in every 100ml of untreated sewage. We have also assumed that the proposed wastewater treatment plant will remove 90% of the organic matter such that there are $1.0*10^6$ faecal coliforms present in every 100ml of treated effluent. Both of these assumptions are conservative. In a similar study to this for a proposed wastewater treatment plant at Spiddle, Co. Galway[44] it was assumed that there were $2.2*10^5$ faecal coliforms per 100ml of treated effluent. Our assumption is 4.5 times greater than this. There was no comment in this report on the assumed removal efficiency of the wastewater treatment plant.

The 90% removal assumption of organic matter is also conservative. Over the course of the authors' previous *Norovirus* study data from the waste water treatment plant at Midleton was obtained from Cork County Council[45]. This data suggested that over 98% of indicator bacteria are removed in the secondary treatment plant at Midleton. Based on our assumption of $1.0*10^7$ faecal coliforms present in every 100ml of untreated sewage a 98% removal efficiency leads to $2.0*10^5$ faecal coliforms per 100ml of treated effluent (a figure similar to the Spiddle study). This figure is 5 times less than the value we used ($1.0*10^6$) in Chapter 4.

The principle of superposition allows us to rescale our results based on an assumed 98% removal rate of organic matter. The maximum concentrations for this rescaled case (i.e. Case 3 rescaled from 90% removal efficiency to 98% removal efficiency) may then be expressed as a percentage of the maximum concentrations of Case 2 (all the relevant towns discharging untreated waste). We can see from Fig. 7.1 that the maximum concentrations with the proposed treatment plant operating at 98% removal efficiency are less than 1% of the maximum concentrations with no treatment for the Inner harbour area. This is equivalent to a 99% removal of indicator bacteria. This exceeds the removal efficiency of the treatment plant because the number of outfalls will be reduced. All waste will be collected from these areas, treated and then discharged at a single point (the existing outfall from Carrigaline/Crosshaven near Dognose Bank)

For the outer harbour they are less than 4% i.e. there is a 96% removal of indicator bacteria.

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[44] AQUA-FACT, Hydrographic Survey and Water Quality Model, Spiddle, Co. Galway, 2005

[45] Personal communication with Cork County Council

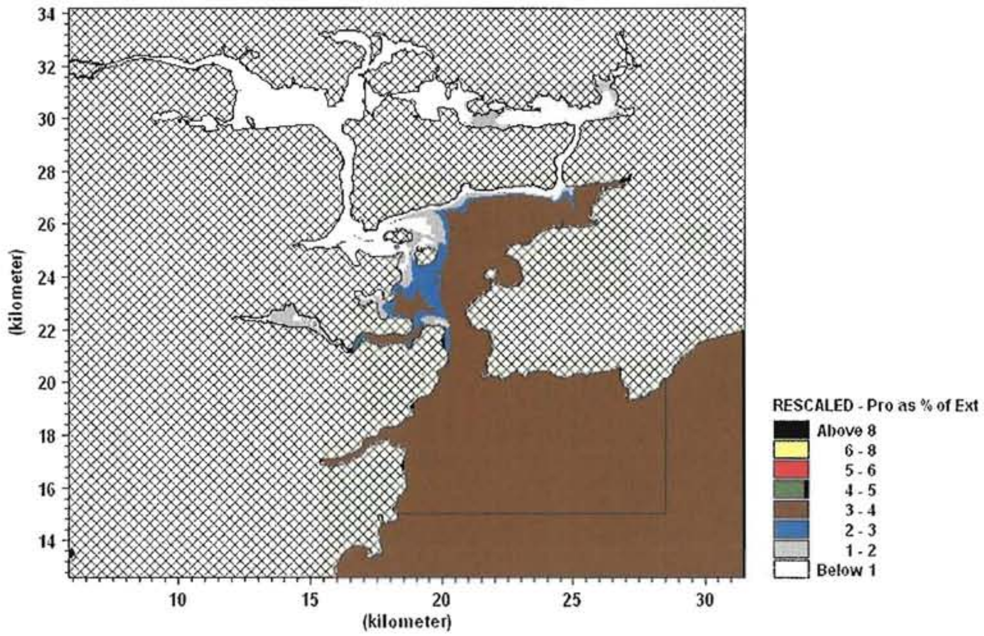


Fig. 7.1 The maximum concentrations from the proposed treatment (98% removal efficiency) as a percentage of the maximum concentrations with no treatment from the relevant towns.

The predicted concentrations of faecal coliforms are compared with the regulatory requirements in the 2 relevant EU Directives listed below.

The directives of interest are:

- Bathing Water Directive (76/160/EEC)
- Shellfish Waters Directive (79/923/EEC)

The I (mandatory) and G (guide) values for the Bathing Water Directive are, for faecal coliforms, 2000 counts per 100ml and 100 counts per 100ml respectively. From the results presented in Chapter 4 we may conclude that the contribution from the proposed treatment plant is several orders of magnitude less than these requirements far the bathing areas.

The G (guideline) values for the Shellfish Waters Directive are, for faecal coliforms, less than 300 counts per 100ml in the shellfish flesh and intervalvular liquid. We can see from the results presented in Chapter 4 that the contribution from the proposed treatment plant is several orders of magnitude less than these requirements.

7.3 Norovirus Results

The *Norovirus* was included as part of this study in order to determine the impact of the proposed treatment plant on the oyster farms and recreational areas present in the harbour. It was found that with the proposed scheme in place, the number of *Norovirus* in Cork Harbour and the surrounding waters will be reduced leading to a considerable improvement in water quality. The results of the model indicate a 90 – 95% relative reduction in the maximum number of *Norovirus* near the oyster farm with the introduction of the proposed treatment plant.

The maximum number of *Norovirus* reached at each grid point for the untreated waste simulation (Case 2) ranged from 2 to 18,000 *Norovirus* per cubic metre. This range ignores the extremely high concentrations in the immediate vicinity of each individual outfall. The equivalent range with the proposed treatment plant in operation (Case 3) is from 2 to 2,000 *Norovirus* per cubic metre indicating an improvement in water quality.

The reduction in the number of *Norovirus* was quantified by dividing the maximum values for the treated waste situation (Case 3) by the maximum values for the untreated waste situation (Case 2) and multiplying the answer by 100. This expressed the maximum concentrations with the treatment plant in place as a percentage of the maximum concentrations without any treatment. It was found that the percentage relative reduction varied across the harbour. For Lough Mahon, the Inner harbour, the East and West Passages as well as the area around Ringaskiddy the maximum concentrations with the treatment plant in place were less than 10% of the maximum concentrations with no treatment i.e. there was a 90% relative reduction in the maximum concentrations of *Norovirus* in this region.

For the rest of the harbour and the area outside Roches Point they were less than 20% i.e. there was an 80% relative reduction in the maximum concentrations of *Norovirus* in this area.

Time series of *Norovirus* concentration were also presented for 15 points of special interest. The improvement in water quality was observed from these graphs by plotting the time series for Case 2 and Case 3 together. The *Norovirus* plots for 2030 were not presented as they are simply equivalent to the plots for Case 3 multiplied by 1.431.

Regulatory requirements on concentrations of *Norovirus* are not included in any of the EU Directives on water quality.

7.4 Nitrogen Results

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 scheme 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. The effect is with respect to an unaltered background concentration of each species of nitrogen.

The results reported were estimates of the change in forcing, expressed as changes in the concentrations of the three species of nitrogen, due to the proposed scheme. They are estimates of relative changes compared to the background concentrations of nitrogen. We have left the judgement of the wider consequences of these relative changes in nutrient forcing to the marine ecologists advising the project.

The time series presented in chapter 6 showed a marked reduction in concentrations of ammonia and nitrate in all of the fifteen points of special interest to the project compared to the unspecified background following the 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 spatially varying maps of concentration showed 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.

7.5 Discussion of results inside and outside the mouth

A large area outside the mouth between Ballycotton and Oysterhaven gradually accumulates material discharged from the Outer Harbour on successive ebb tides. During all tides we have simulated, a large anticlockwise eddy forms immediately outside the mouth during the ebb. It is fed from the western side of the Outer Harbour. When the tide turns all the simulations show the tide running initially on the eastern side of the mouth and in many cases this feeds water of oceanic quality into the Outer Harbour improving its quality. This appears to be associated with a weak residual current along the coast to the southwest for the period we have chosen to simulate with the model (June 2004). Data from moored *in situ* devices would confirm this. This is extremely expensive and difficult to do. There are also several smaller eddies on the eastern side of the mouth during the flood tide as it enters the harbour.

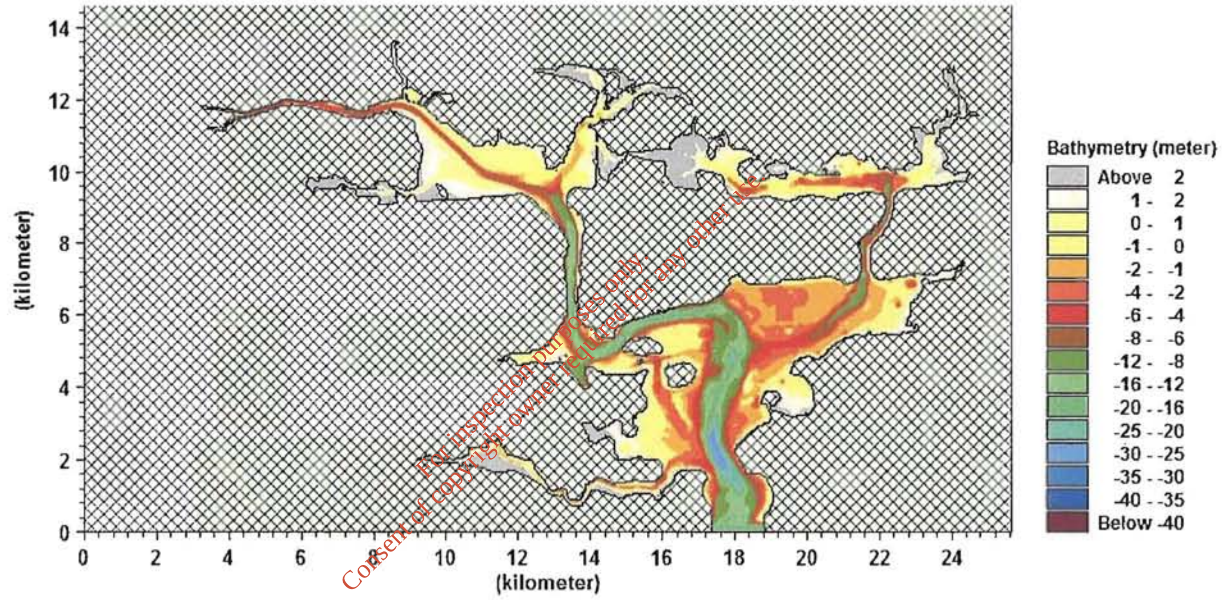
Consequently, we are unable to indicate with confidence and precision what effect the proposed scheme will have on the concentrations of coliforms and *Norovirus* in the coastal waters between Ballycotton and Oysterhaven. However the model shows a reduction in concentration.

Appendix A Calibration of the RP_2 model

The calibration and validation of the RP_2 model is described in this Appendix. The parameters from the calibrated RP_2 model (run with recorded data) have been exported and used in the OH_2 model (run with Proudman data).

A.1 Development of the RP_2 model

The Roches Point_2 (RP_2) model has two separate grids each of varying resolution (see below). The outer grid has a grid spacing of 30m and covers the outer harbour. The narrow Belvelly channel is resolved with a 10m resolution.

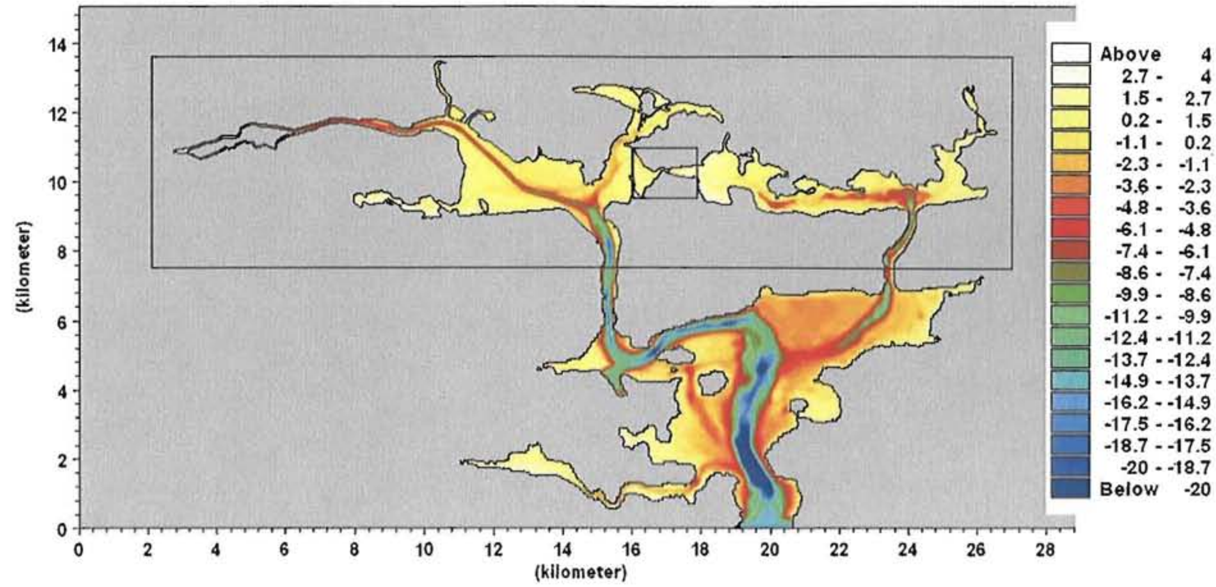


Layout of the RP_2 model. The resolution of the 2 nested grids are 30m and 10m

A.2 Calibration of the RP_2 model

Previous RP model

The calibration of the RP_2 model is based on the calibration of a similar model in the authors' previous work. This model, named the RP model, covers the same area as the RP_2 model but is resolved with 3 separate nested grids each with a different resolution (see next page).



RP model bathymetry plot from the previous study by the authors'. 3 nested grids of varying resolution (54m, 18m & 6m) are used in this model.

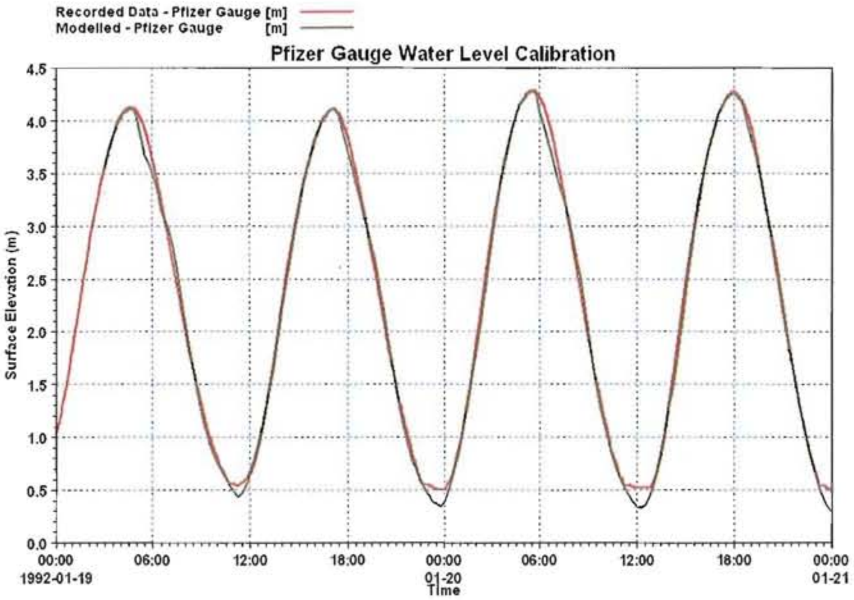
The calibration and validation of the RP_2 model is very similar to that of the RP model.

Calibration Period

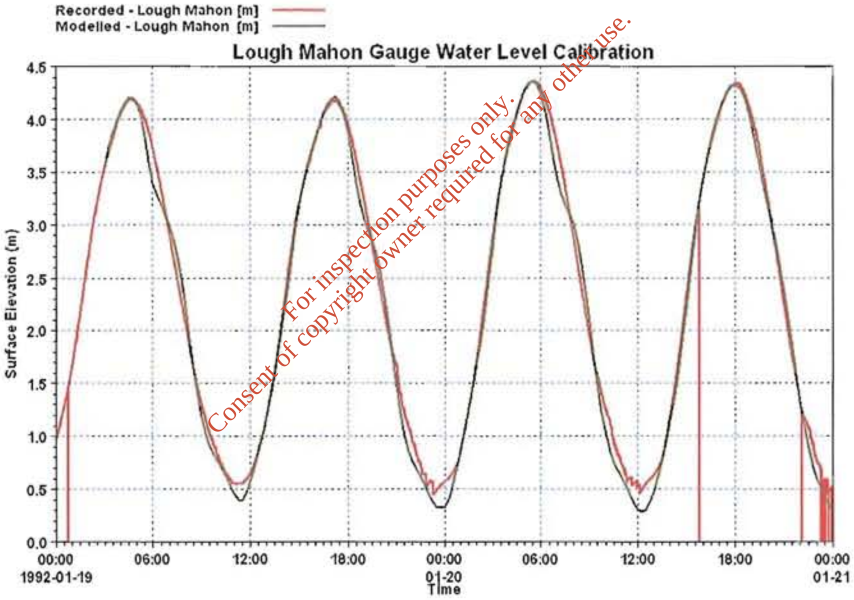
The model was calibrated and validated using the data from the 1992 survey by Irish Hydrodata. As discussed in chapter 2 six automatic water level recorders were deployed at sites in the Inner and Outer harbour on three separate occasions in December 1991 and January/February 1992, as well as two current speed and direction recorders. Data from the Fort Camden gauge was used to drive the hydrodynamics of the RP_2 model by acting as the boundary condition at Roches Point. Data from the Pfizer (water level), Lough Mahon (water level and current speed/direction), Belvelly (water level) and Spit Bank (current speed/direction) gauges were used to calibrate and validate the hydrodynamic model.

Water Level Calibration Plots

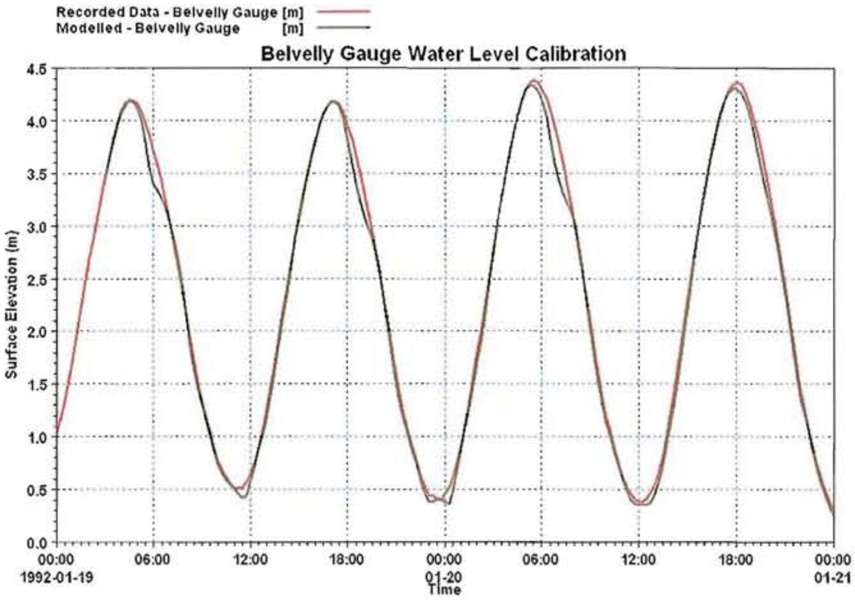
The water level calibration plots are shown below. The modelled data is plotted with a green line while the recorded is shown with a red line. We can see from the figures that there is a very good match between the recorded and modelled data for all three gauges.



Pfizer Gauge Calibration Plot



Lough Mahon Gauge Calibration Plot



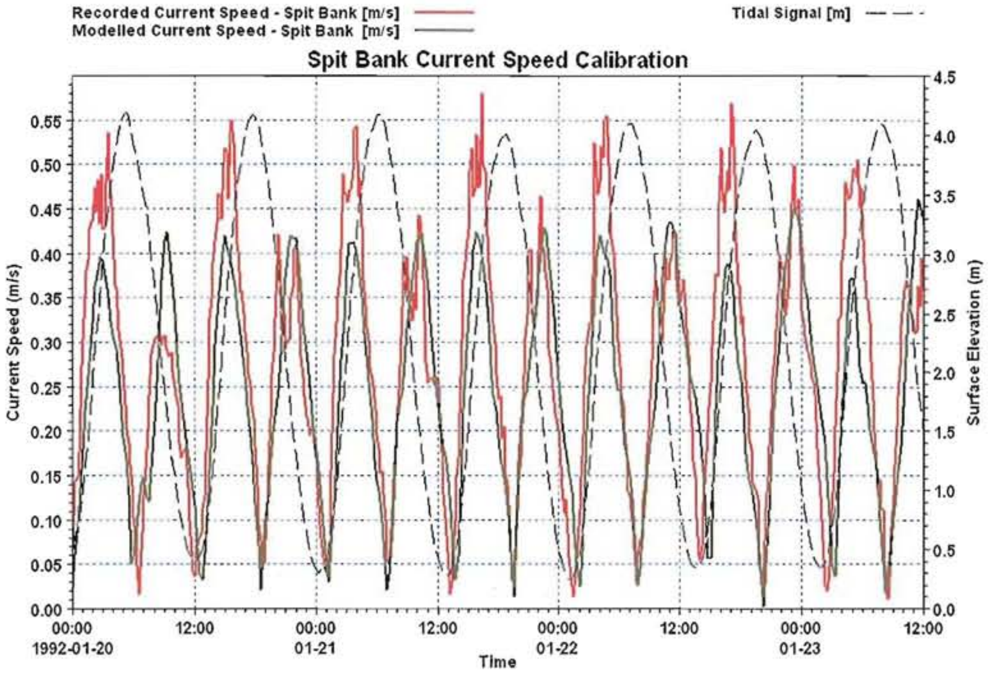
Belvelly Gauge Calibration Plot

From these figures we can conclude that the RP_2 model can reproduce the observed tides in Cork Harbour.

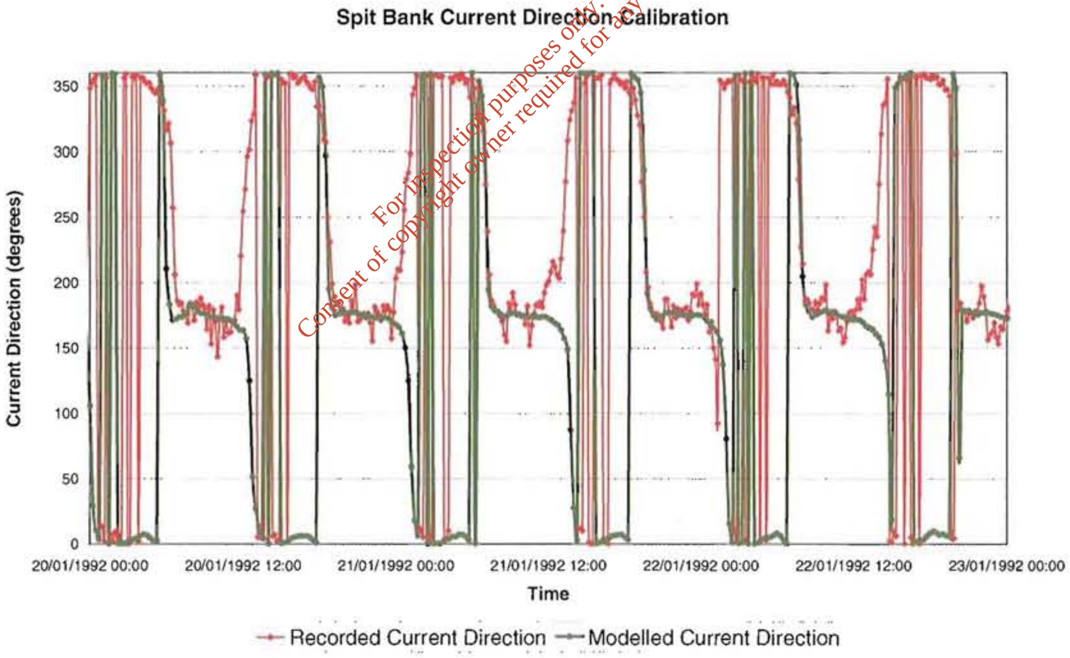
Current Speed and Direction Calibration Plots

The current speed and direction calibration plots are presented in the following set of figures. We can see from the figures that there is an excellent match between the modelled and the measured data for the Spit Bank gauge in the outer harbour. The current speeds on the ebb tide for this gauge are very well matched with the modelled data. There is slight underestimation on the flood tide (0.1 – 0.15m/s). The time at which slack water occurs is also in very good agreement in both the model and the data.

We can also see that there is a very good agreement between the measured and modelled current direction for this the Spit Bank as well.



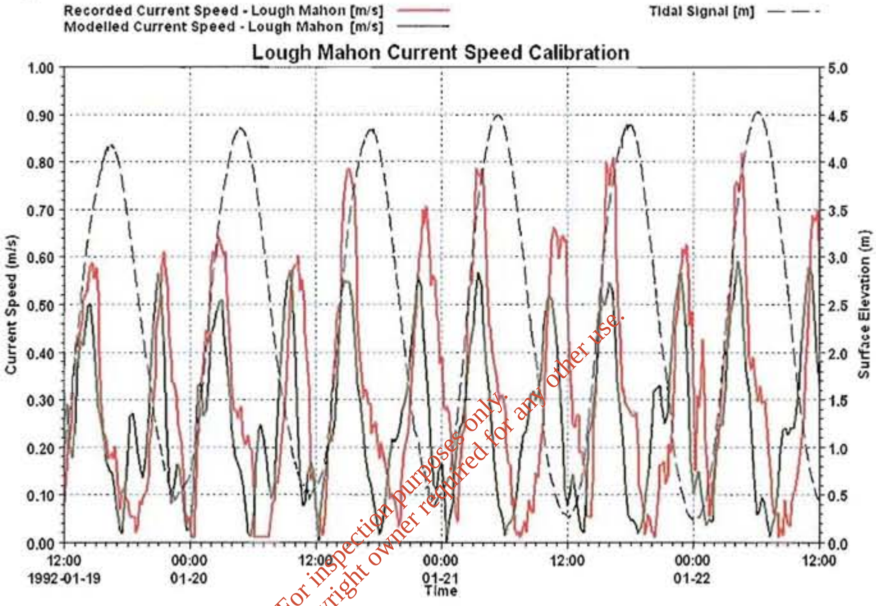
Spit Bank Current Speed Calibration



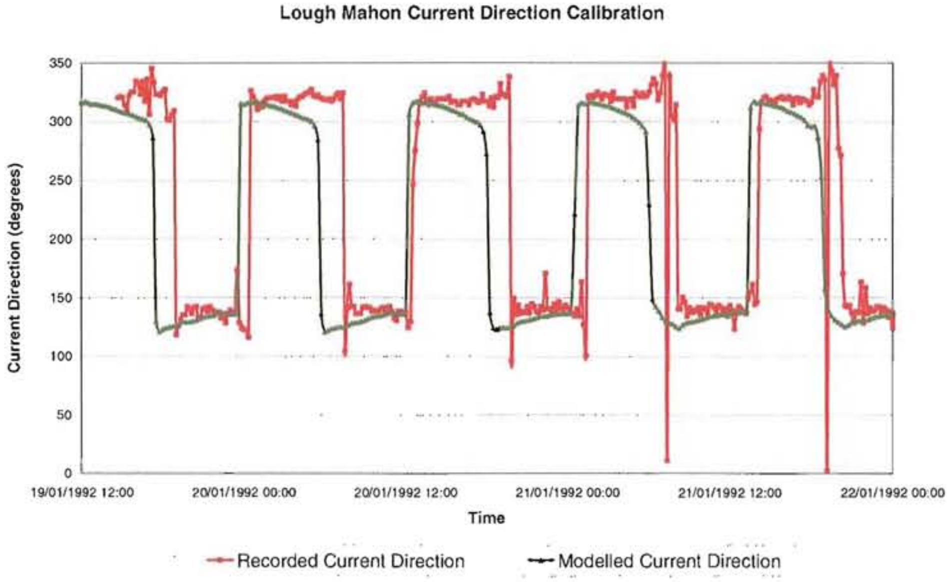
Spit Bank Current Direction Calibration

The current speed and direction calibration plots for the gauge in Lough Mahon are now presented. We can see from the figures that there is a slight underestimation of the current speed on both the flood and ebb tides. We can see that the difference is not consistent for the different tides. It varies from 0.05 to 0.25m/s. The general directions on the flood and ebb tides of the model are in agreement with the measured but there is a slight variation in the timing of the turning of the tide when it switches from ebb to flood.

The gauge in Lough Mahon is located in the centre of the Lough at the point where the shallow mudflat meets the dredged channel. The flow here is quite complicated with strong localised, subgrid hydrodynamics. Capturing this is quite difficult because the modelled currents are averaged over a 30m grid cell. The calibration is well within an acceptable limit of error.



Lough Mahon Current Speed Calibration



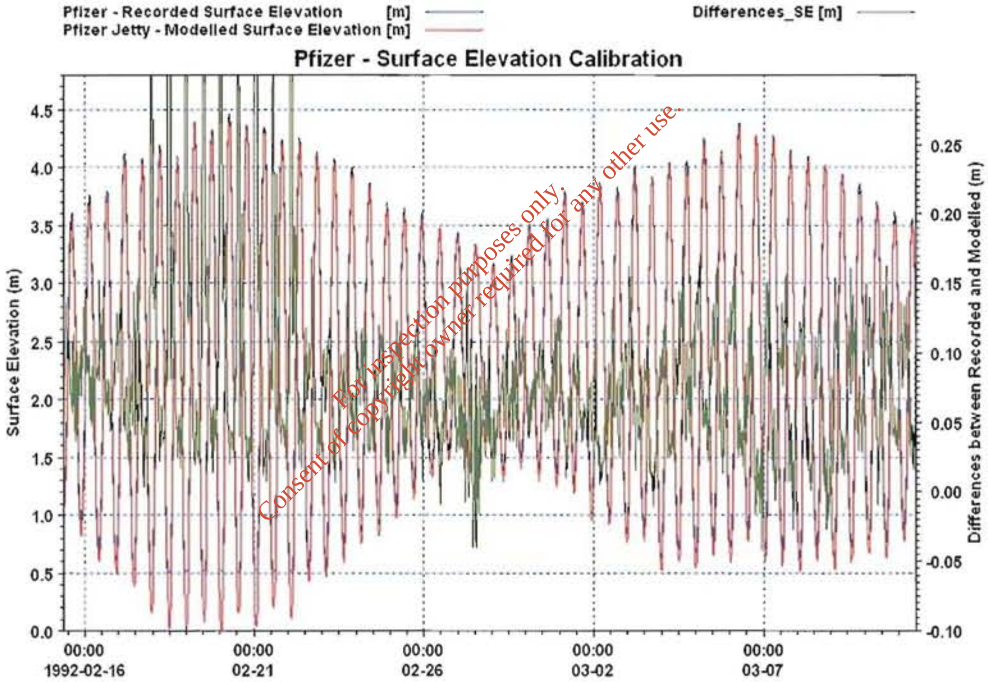
Lough Mahon Current Direction Calibration

A.3 Water Level Validation Plots

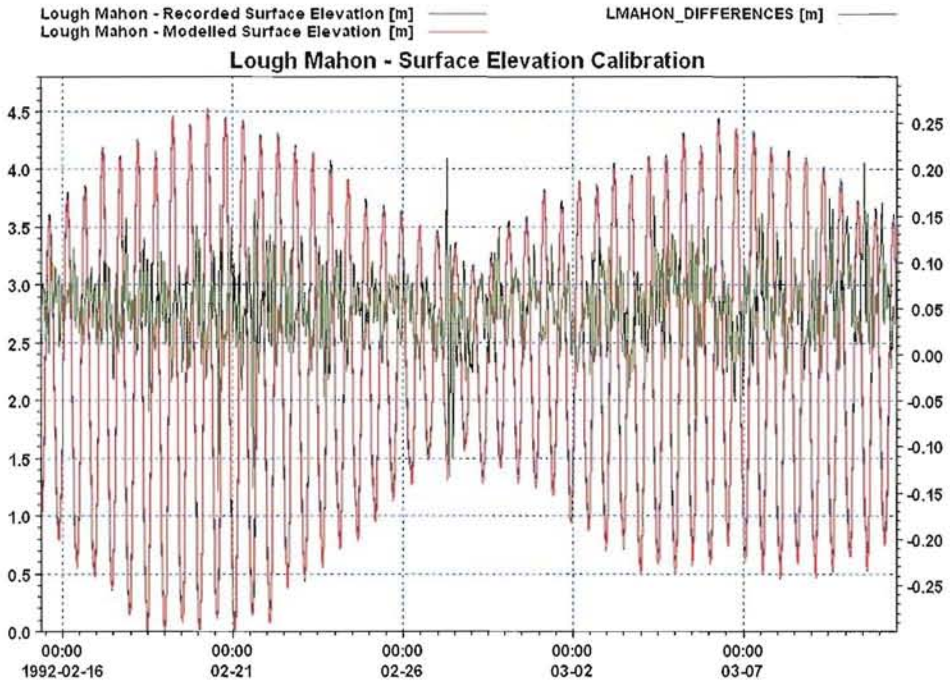
The water level validation plots are presented in this section. The recorded data is plotted with a blue line while the modelled data is shown with a red one. The difference between the modelled and the measured, the error, is plotted on the secondary axis on the left-hand-side with a green line. The scaling on this secondary axis varies slightly for each plot.

We can see from the figure below that there is a very close agreement for the Pfizer gauge. The error varies between 5 and 15cm.

The validation for the gauge in Lough Mahon is presented on the following page. Again we can see that the error is between 5 and 15 cm.

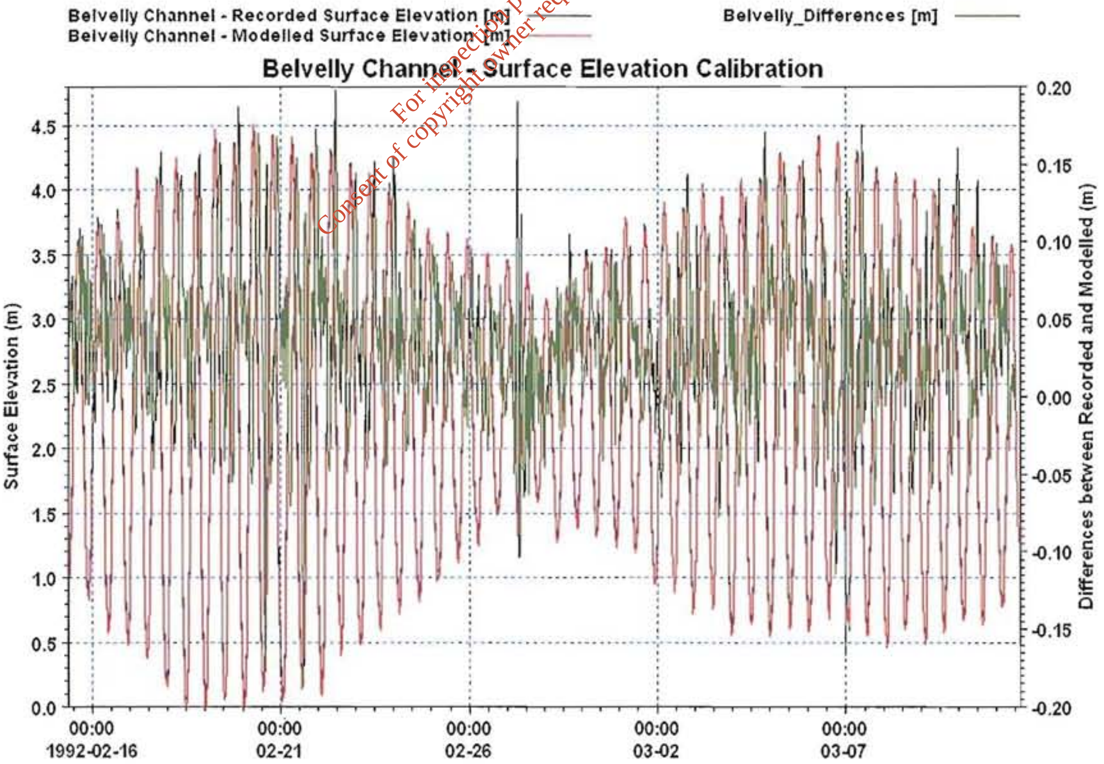


Pfizer Gauge Water Level Validation



Lough Mahon Gauge Validation

The validation for the Belvelly gauge is presented below. We can see that the error is between 5 and 18 cm.



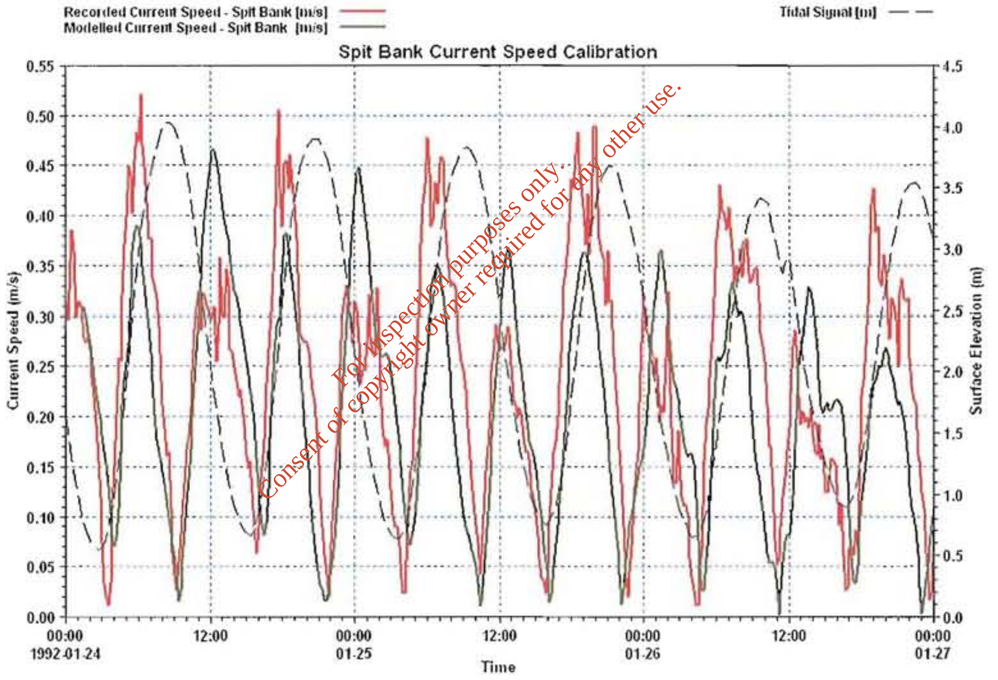
Belvelly Gauge Validation

A.4 Current Speed and Direction Validation

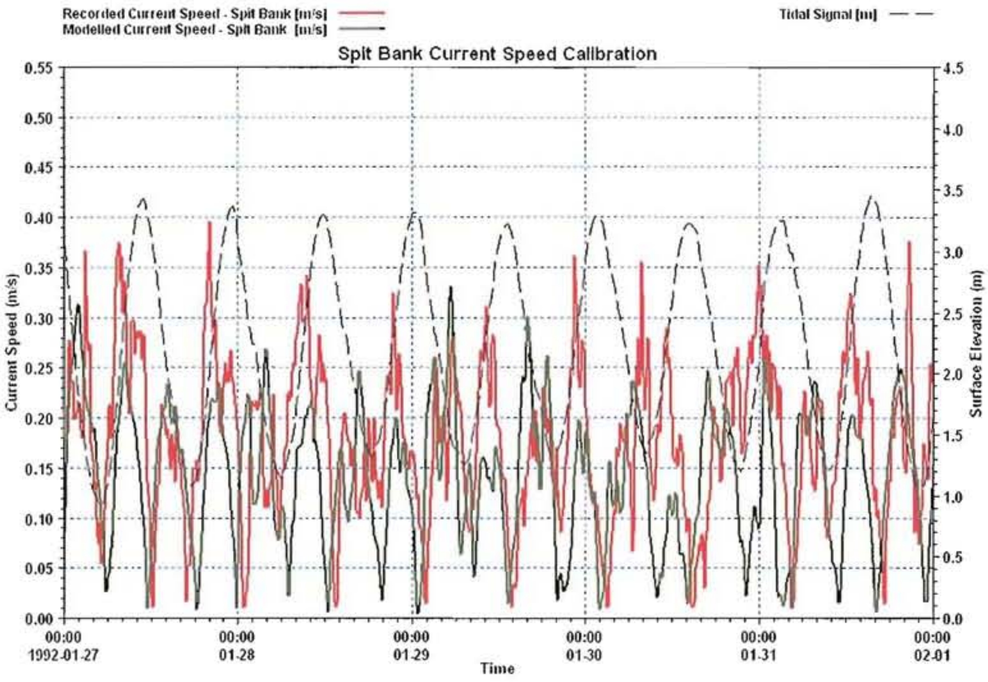
The current speed and direction validation for the Spit Bank are presented in the following 8 figures. The validation covers a 2-week period. We can see from the plots that overall a very good agreement between the datasets is achieved with the RP model. For the first 8 days, covering neap tide, the maximum current speeds are underestimated for the flood and ebb tides. As the neap cycle moves to spring, the difference between the datasets decreases.

The current direction validation follows a similar pattern. Overall it can be stated that there is a very good match between the modelled and measured datasets.

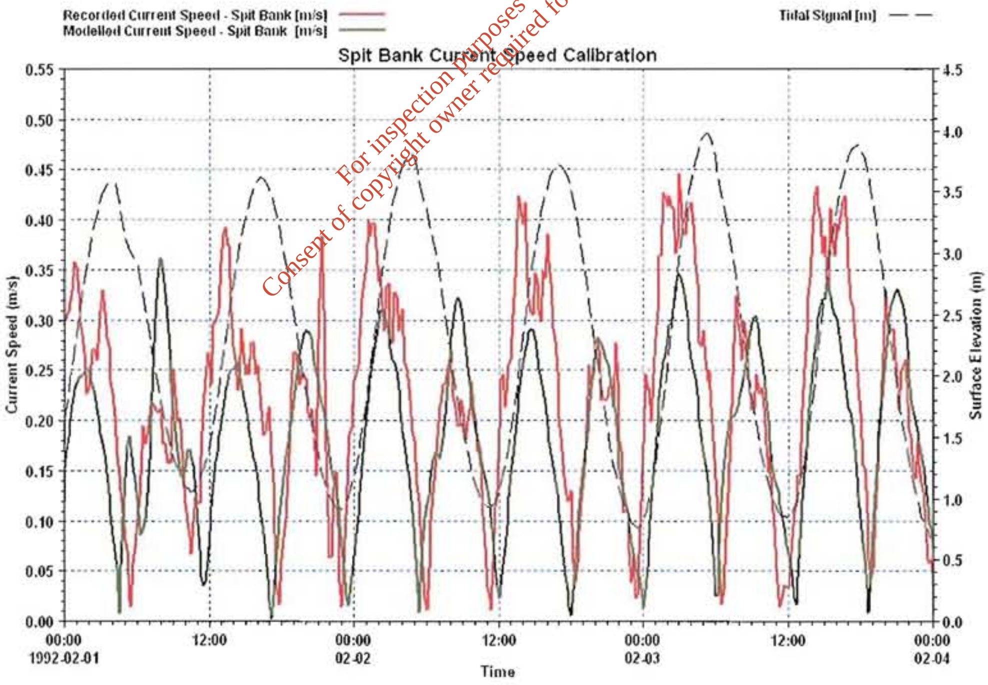
Spit Bank



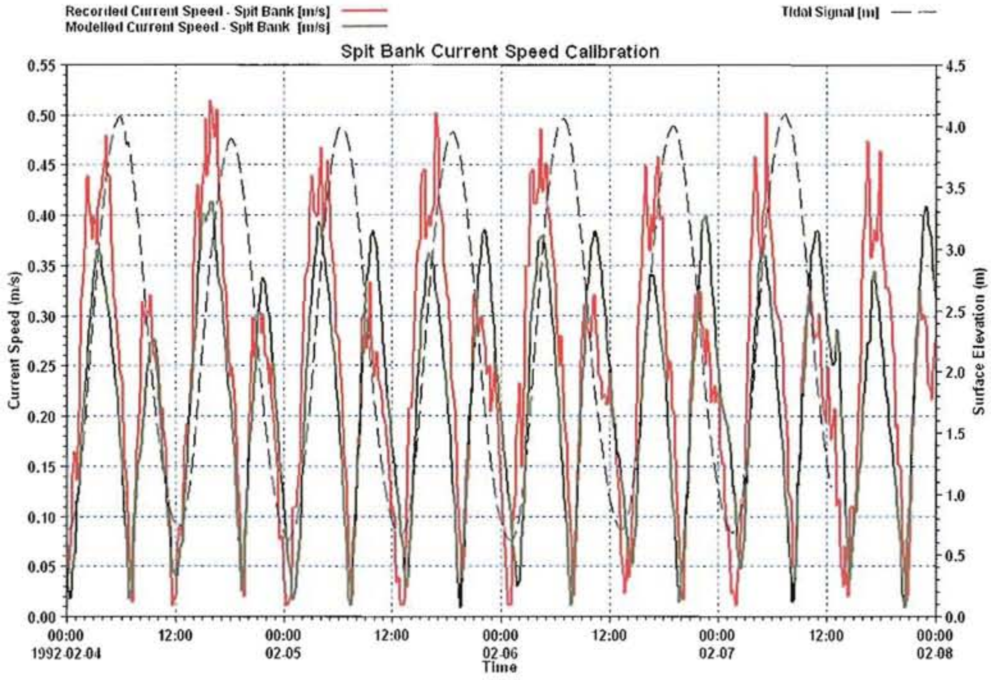
Spit Bank Current Speed Validation



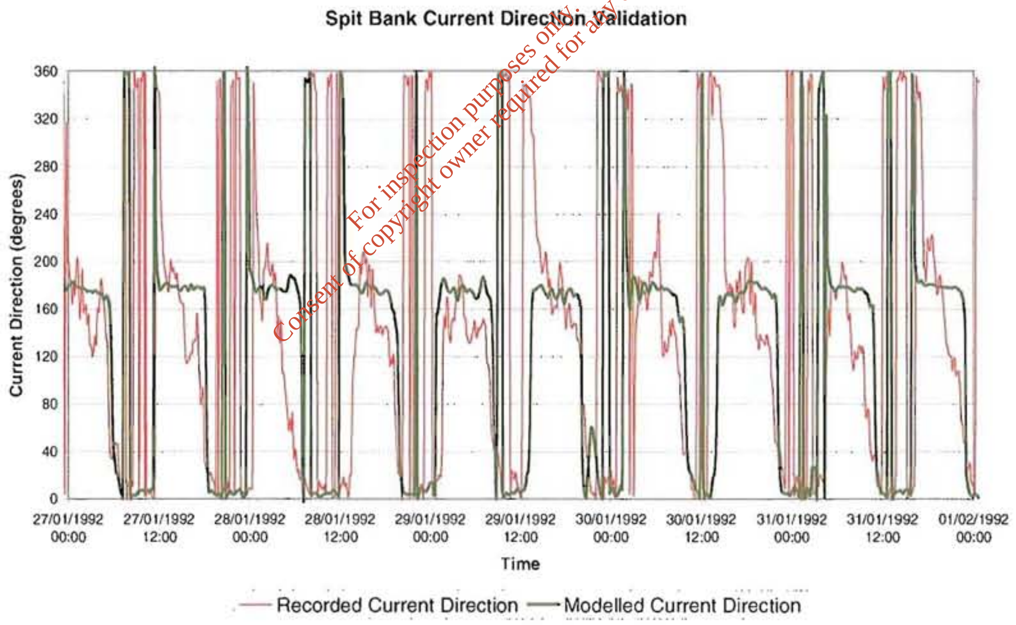
Spit Bank Current Speed Validation



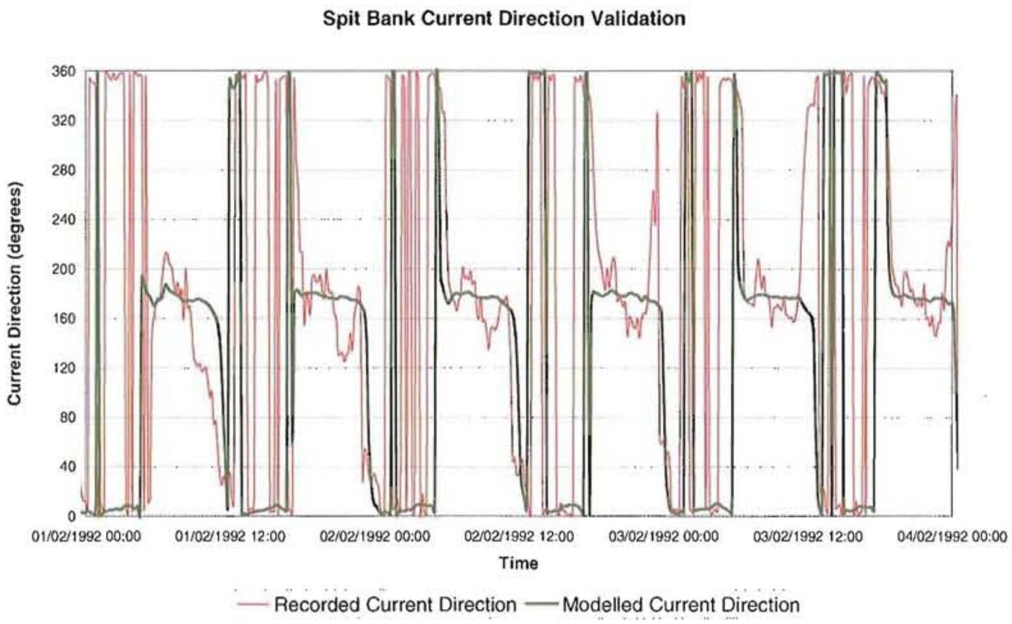
Spit Bank Current Speed Validation



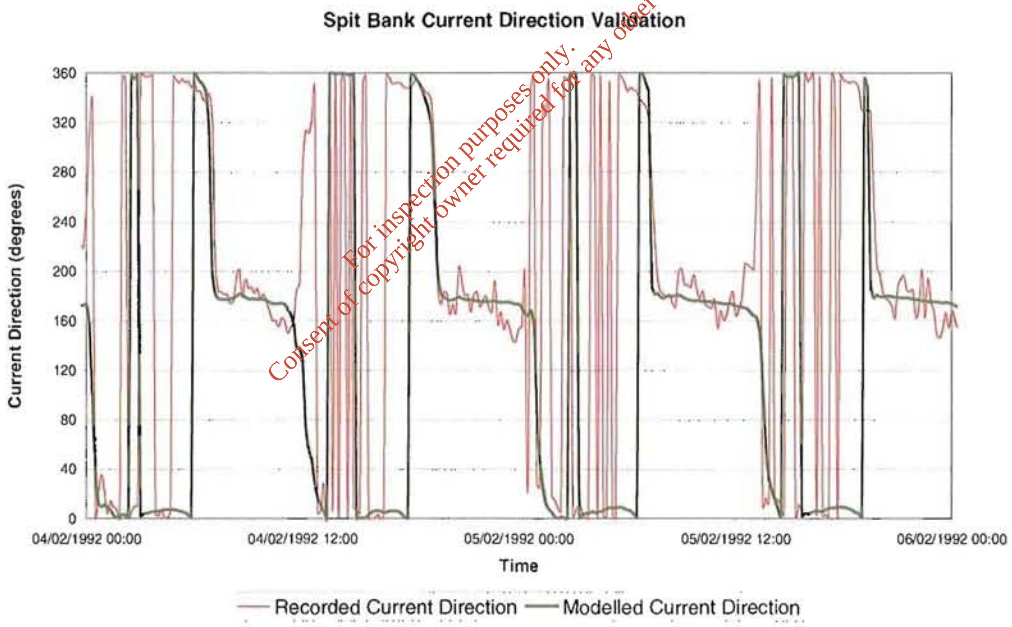
Spit Bank Current Speed Validation



Spit Bank Current Direction Calibration



Spit Bank Current Direction Calibration



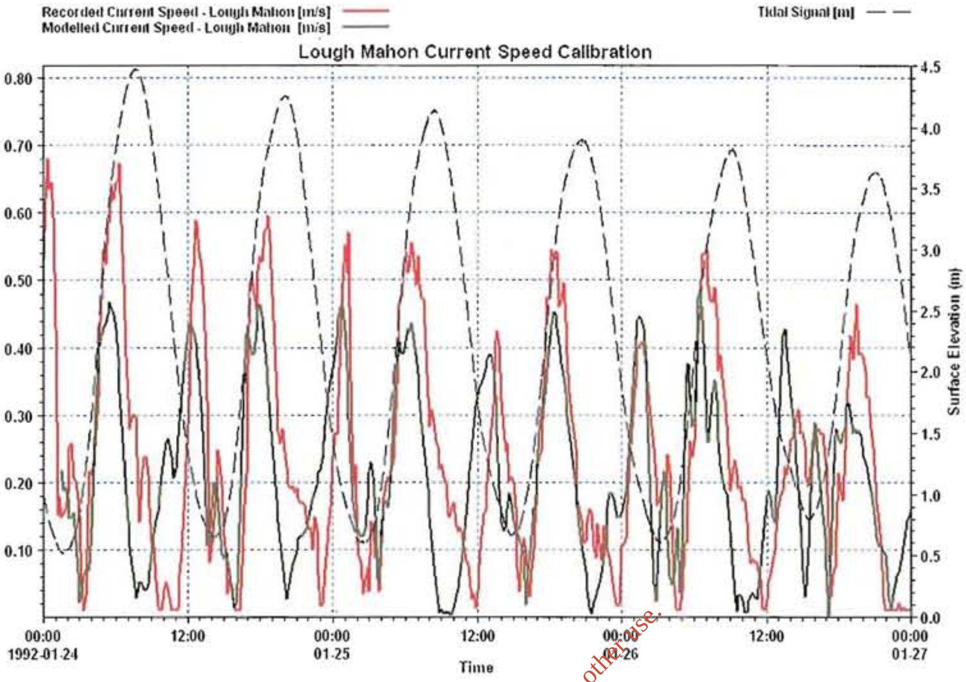
Spit Bank Current Direction Calibration

Lough Mahon Current Speed and Direction Validation

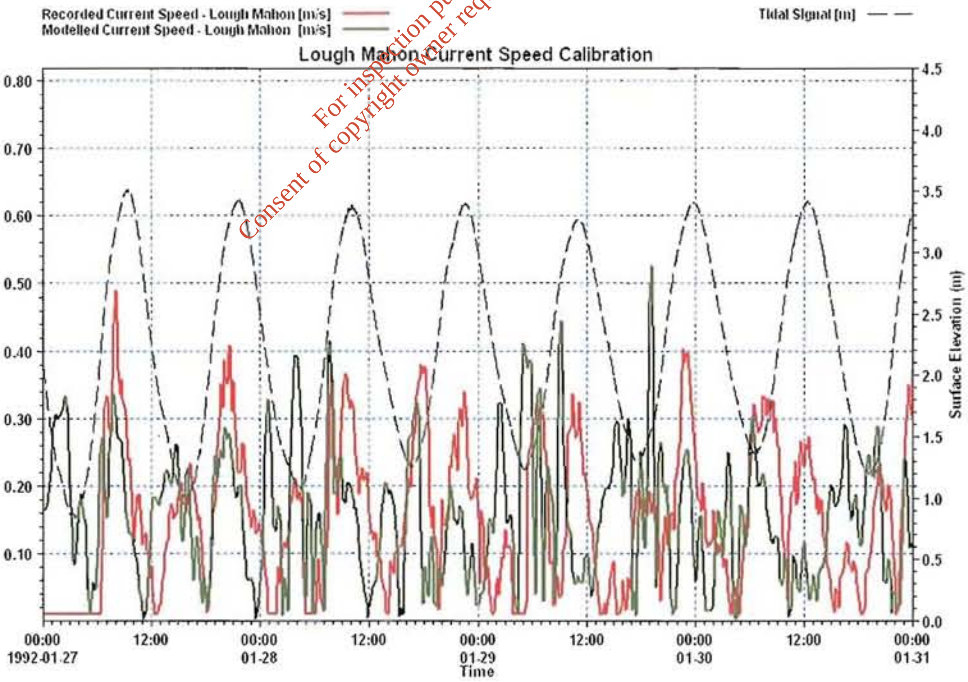
The current speed and direction validation for the Lough Mahon gauge are presented in the following 8 figures. The validation covers a 2-week period.

We can see that the difference between the modelled and measured current speeds is very good for some periods while less good for others

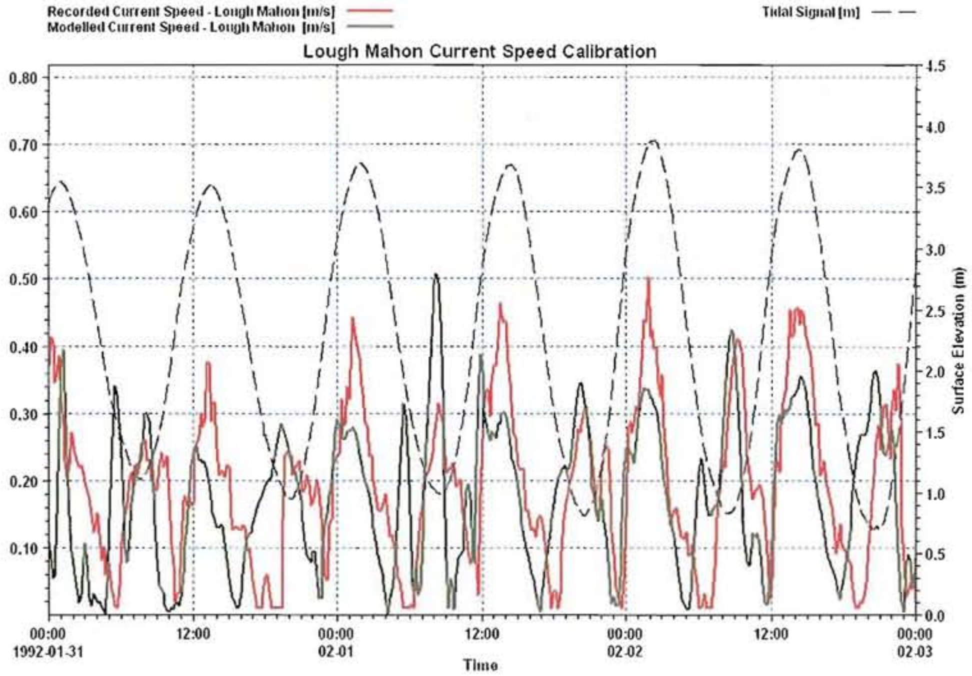
Overall however we can state that there is a very good agreement between the modelled and measured datasets for Lough Mahon.



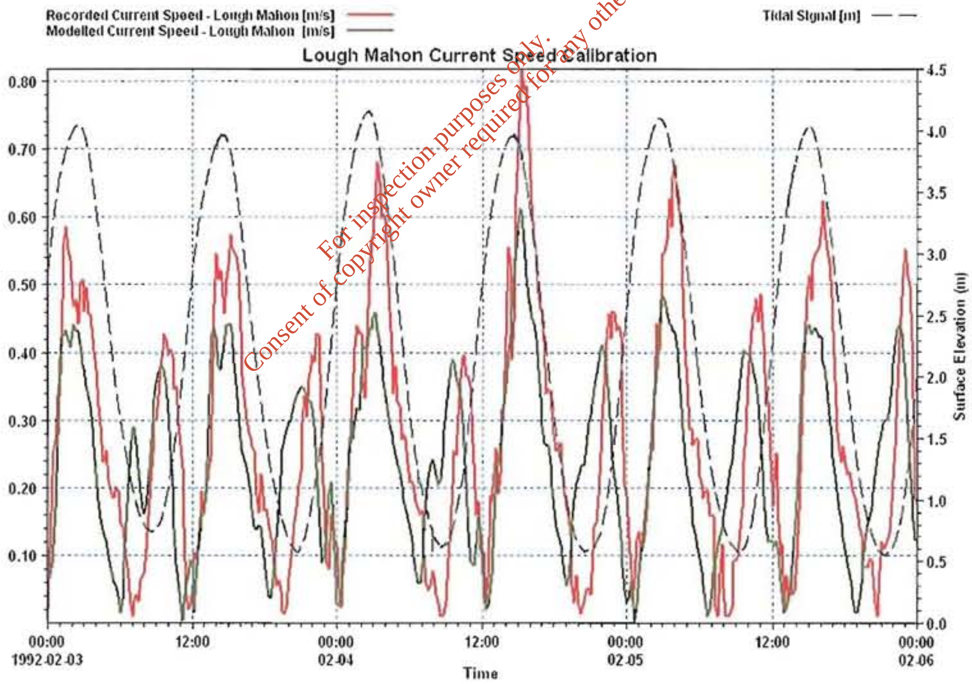
Lough Mahon Current Speed Validation



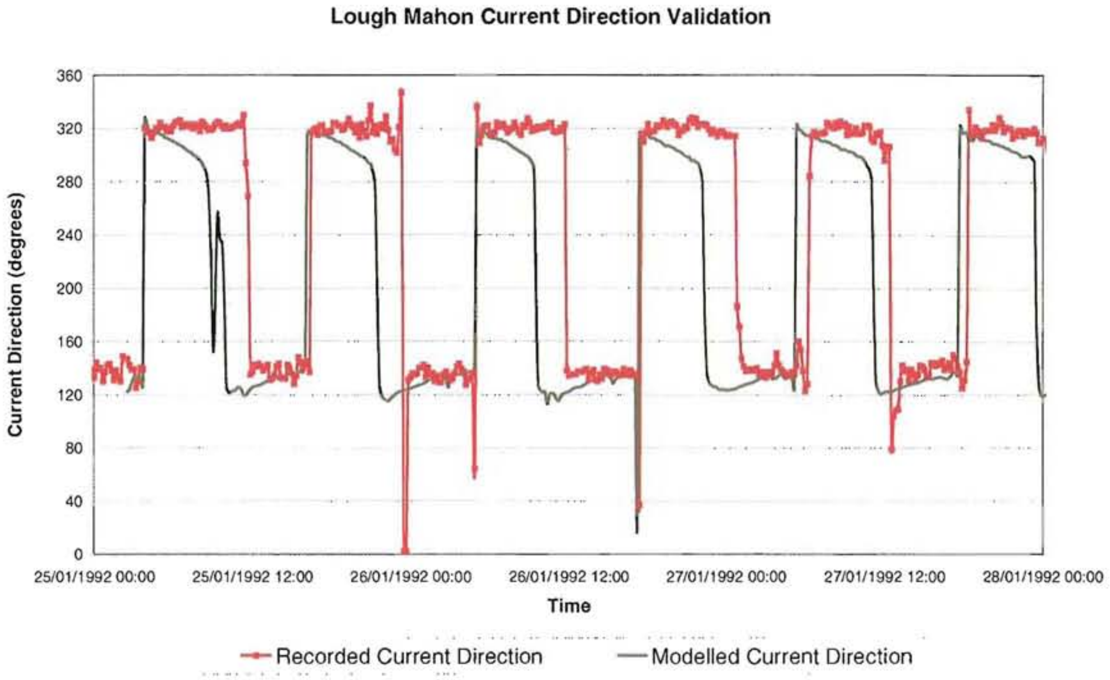
Lough Mahon Current Speed Validation



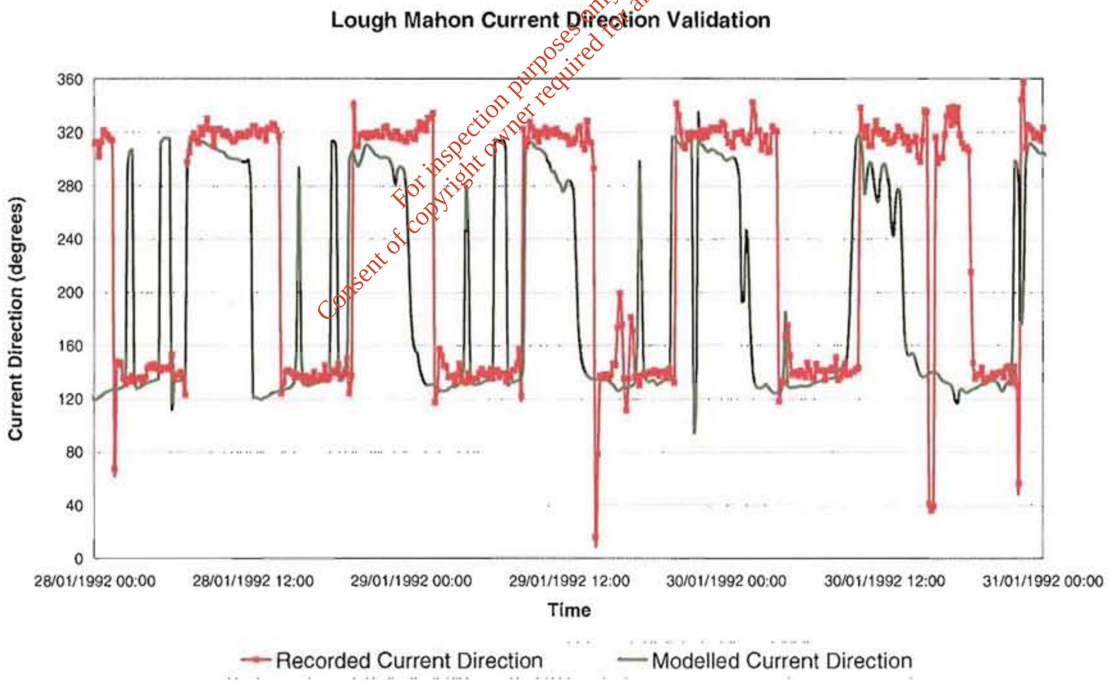
Lough Mahon Current Speed Validation



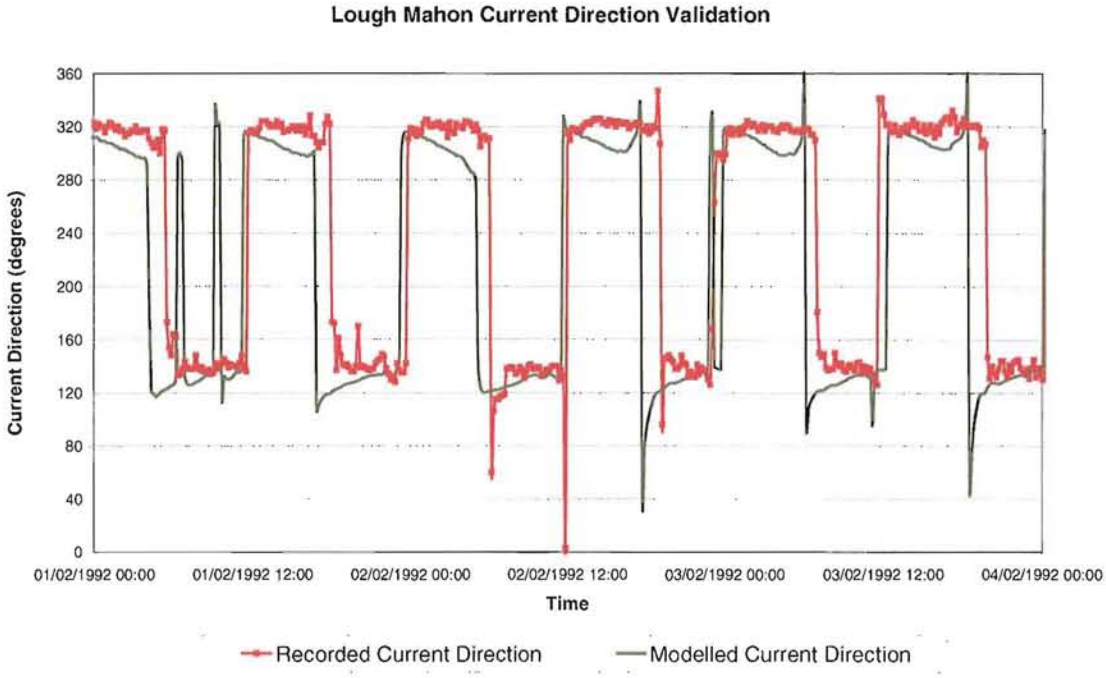
Lough Mahon Current Speed Validation



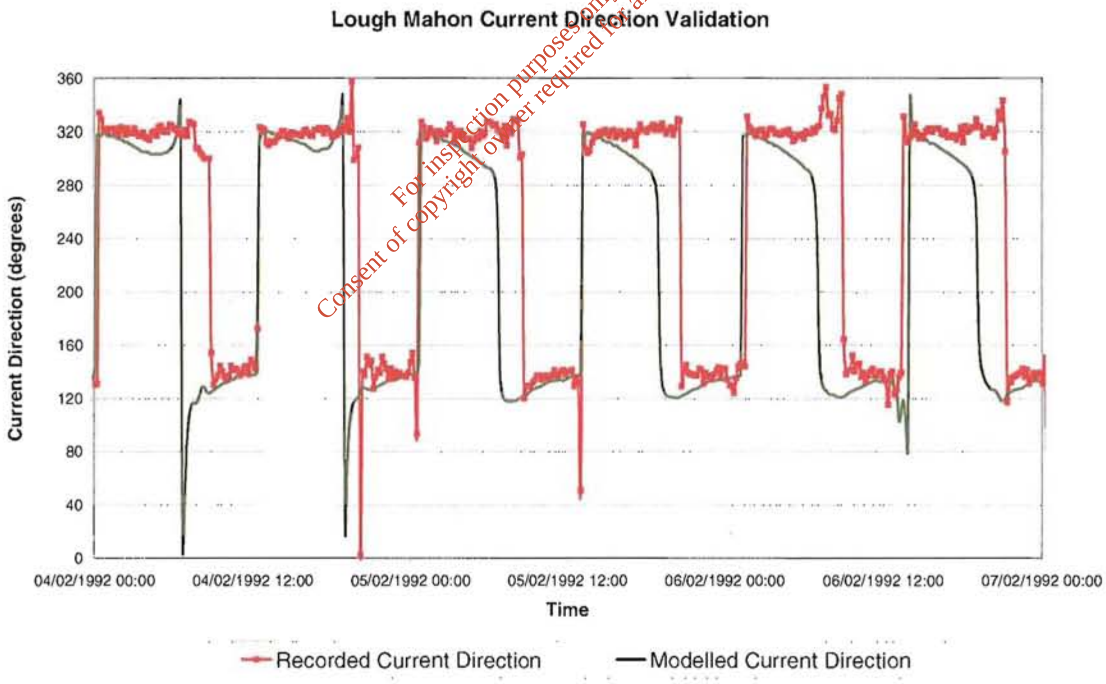
Lough Mahon Current Direction Validation



Lough Mahon Current Direction Validation



Lough Mahon Current Direction Validation



Lough Mahon Current Direction Validation

A.5 Conclusions

The RP_2 model has been calibrated and validated against water levels for a number of locations in the harbour. Water levels recorded at the Pfizer gauge, Lough Mahon and the North Channel near the oyster farm are all in very good agreement with the model. There is a slight error at high and low water which varies between 10cm and 15cm. This is well within an acceptable limit of error.

The RP model has been calibrated and validated against current speed and directions for a number of locations in the harbour. Current readings from the Spit Bank in the outer harbour, Lough Mahon and the Belvelly Channel all compare very well with the output from the model. The calibration in Lough Mahon for neap tides is not as good as for Spring tides. The error is however well within an acceptable limit as velocities in a two-dimensional hydrodynamic model are averaged over the grid cell. For Lough Mahon this is 18m. Strong localised (i.e. less than 18m), subgrid scale hydrodynamics cannot be resolved.

Overall we can state that there is very good agreement between the RP model and the recorded datasets.

Appendix 4A

Geophysical Survey

Mott MacDonald

Cork Lower Harbour Main Drainage Scheme
Water Treatment Plant, Shanbally, County Cork

Geophysical Survey

Report Status: Draft

MGX Project Number: 5213

MGX File Reference: 5213d_005.doc

14th November 2007

Confidential Report To:

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Minerex Geophysics Limited

Geophysical Services

EXECUTIVE SUMMARY

1. Minerex Geophysics Ltd. (MGX) carried out a geophysical survey consisting of EM31 Ground Conductivity, 2D-Resistivity and Seismic Refraction measurements for a proposed water treatment works development at a Cork County Council site in Shanbally, Co. Cork.
2. The main objectives of the survey were to determine ground conditions, the depth to rock, the existence of karst features and to reduce the risk of encountering difficult subsurface conditions and possible subsidence for proposed developments on the site.
3. The results of the geophysical survey show a thick overburden and possible fractured rock layer overlying clean strong limestone at a depth between 8 and in excess of 20m below ground level. Where the top of strong bedrock is approx. 20m and more deep it is at the penetration limit of the seismic setup.
4. The data describes a four layer earth model. The top three layers represent a transition from topsoil to stiff to very dense overburden and possible broken/fractured mudstone to clean limestone. The limestone bedrock has a typical depth of > 20m below ground level.
5. Overburden conductivities are quite low (unless influenced by metal objects) and indicate gravelly soil and sub soil types. There are no indications for soft ground layers on the site.
6. The overburden is interpreted as gravelly clay, sand and gravel and is expected to be well drained.
7. The shallowest rock is in the SE corner of the site (at R1) and the rock head dips to the north at the centre of the profile R1.
8. Generally the top of rock is so deep that no indicating for karstification of the bedrock can be found.
9. In the south east corner of the site where limestone bedrock is interpreted a 25m wide zone of possible faulting, fracturing or karstification is present and a borehole is recommended at this location.
10. Borehole locations for a possible drilling programme are recommended to further investigate areas of possible thickening of the overburden and shallowing bedrock as they may be related to the proposed constructions on the site.

CONTENTS

List of Tables, Maps and Figures:

Title	**Pages**	**Document Reference**
Table 1: Geophysical Survey Locations	In text	In text
Table 2: Summary of Results and Interpretation	In text	In text
Map 1: Location Map of Geophysical Survey	1 x A3	5213d_Maps.dwg
Map 2: EM31 Ground Conductivity Contour Map	1 x A3	5213d_Maps.dwg
Figure 1: Results and Interpretation of 2D-Resistivity & Seismic Profiles R1 – R3	1 x A3	5213d_Figs.dwg
Figure 2: Results and Interpretation of 2D-Resistivity & Seismic Profiles R4 – R6	1 x A3	5213d_Figs.dwg
Figure 3: Results and Interpretation of 2D-Resistivity & Seismic Profiles R7 – R8	1 x A3	5213d_Figs.dwg

1. INTRODUCTION

1.1 Background

Minerex Geophysics Ltd. (MGX) carried out a geophysical survey for a proposed development by Cork County Council at a site in Shanbally, Co. Cork. The survey consisted of mapping the site with EM31 Ground Conductivity Measurements followed by 2D-Resistivity and Seismic Refraction Profiles.

1.2 Objectives

The main objectives of the geophysical survey were:

- To determine the ground conditions under the site
- To determine the depth to rock
- To estimate the strength/stiffness/quality of overburden and rock
- To detect lateral changes within the geological layers
- To determine the presence of possible faults, fracture zones and karstified rock
- To reduce the risk of encountering difficult subsurface conditions during construction
- To reduce the risk of possible subsidence of future buildings and structures

1.3 Site Description

The site has a size of approximately 12 ha and consists of two open fields of pastureland. There is an elevation difference of about 2m from the northern to southern side of the site. An ESB station lies 200m to the west of the area and a number of pylons and high powered overhead cables are present. There is a BGE installation in the southwest. Underground pipelines (possible foul sewer and surface water drain) run west – east across the southern part of the site.

1.4 Geology

The site is underlain by Carboniferous lithologies, Waulsortian limestones and rocks of the latest Devonian and Carboniferous Cork Group, the Kinsale Formation. The Waulsortian Limestones consist of massive unbedded fine grained limestone. To the north near Cloyne the Waulsortian is known to be over 400m thick. The Kinsale Formation consists of grey mudstone with sandstone. South Cork consists of a series of west – east trending synclines and anticlines. The site lies between the Ringaskiddy Anticline and the more southerly Church Bay Anticline. These fold belts are cross-cut by a series of NNW – SSE trending faults (GSI, 1995).

1.5 Report

This report includes the draft results and interpretation of the geophysical survey. Maps, figures and tables are included to illustrate the survey and the results. More detailed descriptions of geophysical methods and measurements can be found in GSEG (2002), Milsom (1989) and Reynolds (1997).

The client provided a digital map of the site and ground investigation data from boreholes and trial pits in an area just north of the survey site. The map was used as the background for the maps in this report.

The interpretative nature and the non-intrusive survey methods must be taken into account when considering the results of this survey and Minerex Geophysics Limited, while using appropriate practice to execute, interpret and present the data give no guarantees in relation to the existing subsurface.

2. GEOPHYSICAL SURVEY

2.1 Methodology

The methodology consisted of using EM31 Ground Conductivity measurements to map the whole accessible area within the site. The results were reviewed and followed by 2D-Resistivity profiles and seismic refraction profiles.

The conductivity survey was carried out on lines nominally 10 m apart using a Geonics EM31. Along each line a reading of ground conductivity was taken every second, thereby resulting in a survey grid of about 10 x 2 m. Base station readings were taken and no instrument drift was noted. The ground conductivity contour map is shown on Map 2. The locations were measured with a DGPS system attached to the EM31 and all data was jointly stored in a data logger for later office based processing and analysis.

The 2D-Resistivity profiles were located to give good coverage of the site. The specifications for the 2D-Resistivity survey were: Multi-electrode switching system Tigre Resistivity Meter, laptop computer, power supply, 32 electrodes under computer control per array, 5 m electrode spacing, profile length of 155m, Imager 5 cable, stainless steel electrodes, contact resistances < 2000 Ωm, Wenner electrode configuration and 3 cycles per reading to reduce background noise. A total of 8 locations were surveyed (R1 – R8, see Map1).

Along each 2D-Resistivity profile a seismic profile with 12 geophones and 5 m geophone spacing, resulting in a profile length of 55m, was surveyed. The recording equipment was 6 DMT Summit 2in1 remote units with 10 Hz vertical geophones. The seismic energy source was a hammer and plate. A zero delay trigger was used to start the recording.

The resolution of the geophysical methods used depends on a large number of factors, but the following can be used to estimate the performance and detection ability of layers and features:

The EM31 method determines bulk ground conductivities to an approximate depth of 6m below ground level.

2D-Resistivity profiles determine the subsurface resistivity on a cross section. With a five meter electrode spacing and profile length of 155m as used in this project it is possible to detect lateral changes with an extent of 3-5 m and more and get depth penetration of 30m.

Seismic Refraction generally determines the depth to layers where the compaction/strength/rock quality changes with an accuracy of 10 – 20% of depth to that layer. The depth of penetration for the setup used on this site is approx. 20m.

The field observers ensured that good data quality was gathered and recognised on site if sudden changes in ground conditions occurred.

2.2 Site Work

The geophysical survey was carried out between the 5th and 7th of November 2007 in good weather conditions. The locations are indicated on the following table.

Table 1: Geophysical Survey Locations.

Profile Name	ING Northing Start	ING Easting Start	ING Northing End	ING Easting End
R1	175299	63630	175313	63784
R2	175140	63709	175295	63704
R3	175003	63853	175157	63838
R4	175092	63637	175122	63789
R5	175003	63723	175034	63875
R6	174856	63706	175007	63672
R7	174870	63645	174899	63797
R8	174916	63782	175068	63754
S1	175305	63679	175310	63734
S2	175200	63706	175255	63704
S3	175080	63843	175134	63839
S4	175103	63686	175114	63740
S5	175014	63772	175025	63826
S6	174905	63694	174958	63682
S7	174881	63694	174891	63748
S8	174965	63772	175019	63762

3. RESULTS AND INTERPRETATION

The interpretation of geophysical data was carried out utilising the known response of geophysical measurements, typical physical parameters for subsurface features that may underlay the site and the experience of the authors.

3.1 EM31 Ground Conductivity

The EM31 ground conductivity values were merged into one data file and contoured and gridded with the SURFER contouring package. The colour contour map with ground conductivities is displayed on Map 2 overlaid over the site base map. The contours are created by gridding and interpolation and care must be taken when using the data. The values in milliSiemens/metre (mS/m) are colour coded and the colour scale is shown on the map.

Low (blue contours) conductivities would indicate shallow bedrock and higher (green to red contours) conductivities would indicate deeper bedrock and thicker overburden. Very high conductivities (orange) indicate noise from man made metal objects. High interference occurs along the route of the pipelines in the south of the area as indicated by the long linear and bulls eye anomalies. The pipelines show as a different pattern in the EM31 data as the walking direction differed between the two fields. In some parts of the site small scale interference from a number of fences can be seen in the conductivity data. Such anomalies are seen close to the north – south field boundary running down the middle of the site and also in the western field boundary.

The ground conductivity values are generally quite small (where not disturbed by metal objects). This would indicate soils and subsoil with a gravelly nature. The range of values would indicate gravely clay and sand and gravel. The values would also indicate a well drained overburden. The conductivities do not show strong geological anomalies within the depth range of 6m. More detail within the overburden will be shown below by the other methods.

3.2 2D-Resistivity and Seismic Refraction

The 2D-Resistivity data was inverted with the RES2DINV inversion package. The programme uses a smoothness constrained least-squares inversion method to produce a 2D model of the subsurface model resistivities from the recorded apparent resistivity values. Three variations of the least squares method are available but it was determined that for this project the Jacobian Matrix would be recalculated for the first two iterations then a Quasi-Newton approximation would be used for subsequent iterations. This is deemed sufficient for this project as the largest changes in the Jacobian matrix normally occur in the early iterations, where a more robust Gauss – Newton method was used, and as large resistivity contrasts over small areas are not significant here. Each dataset was inverted using five iterations resulting in a maximum RMS error of < 2.5%. The resulting models are displayed as colour contoured sections in Figures 1 - 3 (left hand section) in the report. Interpretations of the data are shown on the right hand sections in Figures 1 - 3. The colour scale is the same for all profiles.

The seismic refraction data was processed with the SEISIMAGER software package to give a layered model of the subsurface. The number of layers has been determined by analysing the seismic traces and 4 layers were used in the models. All seismic profiles have been ray-traced, and residual deviations of typically 0.6 to 2.8 msec RMS have been obtained for each profile. The resulting layer boundaries are shown as thick lines on the cross sections (Fig. 1 – 3).

The interpretations for the site were based on all available geophysical data and supplied ground investigation data for a nearby site. The layer boundaries were determined by the seismic velocities and interpretation of lateral variation within the layers was based on the 2D-Resistivity datasets.

Table 2 summarises the interpretation of the geophysical data. The compaction/strength/rock quality has been estimated from the seismic velocity. An estimation of the excavatability for the bedrock has been made according to the caterpillar chart published in Reynolds (1997). A full estimation of excavatability should take borehole data and core descriptions into account.

Table 2: Summary of Results and Interpretation

Layer	**General Seismic Velocity Range (km/sec)**	**General Resistivity Range (Ohmm)**	**Compaction/ Strength/ Rock Quality**	**Interpretation**	**Estimated Excavation Method**
1	0.3	any	Loose/Soft	**Overburden/Topsoil**	Diggable
2a	0.9	< 566	Loose/Soft	**Gravelly Clay Overburden**	Diggable
2b	0.9	> 566	Loose	**Sand and Gravel Overburden**	Diggable
3a	1.9 – 2.0	< 566	Stiff – Very Stiff	**Gravelly Clay** (Or Fractured Rock/Mudstone)	Diggable
3b	1.9 – 2.0	> 566	Very Dense	**Sand and Gravel** (Or fractured Rock/Limestone)	Diggable
4	2.7 – 2.8	> 400	Good Rock	**Clean Limestone**	Breaking/Blasting

3.3 Summary Interpretation

The combined geophysical datasets collected at Shanbally describe a four layered earth model below the site with very thick overburden overlying clean limestone and mudstone bedrock lithologies. Layer 1 consists of a thin loose/soft overburden/topsoil deposit which is no more than about 3m thick.

Layer 2, which is < 3m - ~22m thick, has seismic velocities of 0.9 Km/S and is interpreted as overburden rather than rock. This layer has a very wide range of model resistivity values, 200 Ωm - > 1600 Ωm, and this variation is used to subdivide the layer into two. Layer 2a which has resistivity values < 566 Ωm is described as a gravelly clay. Resistivity values between 200 and 566 Ohmm are typical for gravelly clay. There are no model resistivity values less than 200 Ohmm recorded under the site. Such smaller values would be typical for soft clay and cohesive soils with high water content. Therefore it is concluded that there are no soft clays or organic mud in the overburden layer under the site. No soft ground conditions are likely to exist under the site. Layer 2b has model resistivity values > 566 Ωm, suggesting a decrease in clay content and an increase in sand and gravel. Within this layer there are pockets of very high values > 1131 Ωm. It is likely that these areas, mainly found in the eastern part of the site, are unsaturated sand and gravel deposits. These areas are seen at the north end of profile R1, the eastern end of R2 and R3 and centred around 60m on R4 (Figures 1 & 2). In the east of the site, at a distance of ~ 40 m – 80 m on R1, very high resistivity values suggest the gravel here may be rock derived in nature. It is possible that weathering, fracturing and breaking of the bedrock created a gravel deposit close to the surface and at the top of the strong rock.

The boundary between Layer 2 and Layer 3 is at a maximum depth of ~ 24m. It is important to note that given such significant depth values an accurate depth estimation of the deeper boundaries is difficult with small scale seismic refraction methodologies. Layer 3 has a significant seismic velocity of 1.9 – 2.0 Km/s and is therefore described as a very dense/very stiff lithology. This layer is also subdivided based on model resistivity values and is similar to layer 2 but is more indurated. It has a thickness range of < 2.0m - ~15m and reaches its maximum in the far west. It is likely this layer is made up of gravelly clay and sand and gravel deposits but given the determined velocity it may in places be a fractured or broken mudstone or limestone.

Layer 4 which has high seismic velocities and model resistivity values is a clean limestone. The top of this layer is at depths > 8m but is normally > 20m. In the SE corner of the site the rock is shallowest with values of 8m at the start of S1. Generally the strong rock is deep and at the depth penetration limit of the seismic refraction setup.

In addition to the above descriptions it should be noted that strong lateral variation in the model resistivity values on Profile R1 (see Figure 1) at depths of over 15 – 20 m may be due to faulting or fracturing of the rock. It is also possible that this zone represents karstification of the Waulsortian Limestone.

4. Conclusions and Recommendations

The following conclusions and recommendations are made:

- A geophysical survey consisting of EM31 Ground Conductivity, 2D-Resistivity and Seismic Refraction measurements was undertaken at the site of a proposed water treatment works at a site in Shanbally County Cork.

- The results of each of the geophysical methodologies indicated thick overburden overlying limestone and mudstone geology at a depth of 20m and more below ground level.

- The data describes a four layer earth model. Layer 1 is about 3m thick and is overburden and topsoil.

- Layer 2 is 3 – 22m of thick overburden. This layer shows significant lateral variation and consists mainly of gravelly clay (low resistivities) and sand and gravel (high resistivities). In places, particularly in the east, the gravels are likely unsaturated to depths of 10 – 15m bgl.

- Layer 3 is subdivided into stiff – very stiff gravelly clay and very dense sand and gravel. This layer is more consolidated than layer 2 and may in places contain fractured mudstone or limestone. This layer is ~2m - ~15m thick.

- Layer 4 is a clean limestone and has a depth which is normally 20m b.g.l. This layer is shallowest in the southeast corner of the site with a depth to the top of rock of 8m.

- In the east of the area there is a small area at the centre of R1 which may represent faulting/fracturing of the rock or karstification of the limestone (see Figure 1).

- In general ground conductivities are low and resistivities are larger than 200Ohmm. This would indicate gravelly and very gravelly clay as well as Sand and Gravel. This overburden type would provide for good drainage on the site and would indicate an absence of ground water to within 10 – 15 m under the site.

- For a possible drilling programme a number of boreholes are recommended at the following locations (Map 1). These target possible thickening of the overburden and areas of shallower bedrock. These should be considered based on the design of proposed constructions:

Borehole Number	ING Northing Coordinate	ING Easting Coordinate
BH1	175304	63689
BH2	175309	63723
BH3	175136	63840
BH4	175105	63707
BH5	174930	63689
BH6	174884	63719

5. REFERENCES

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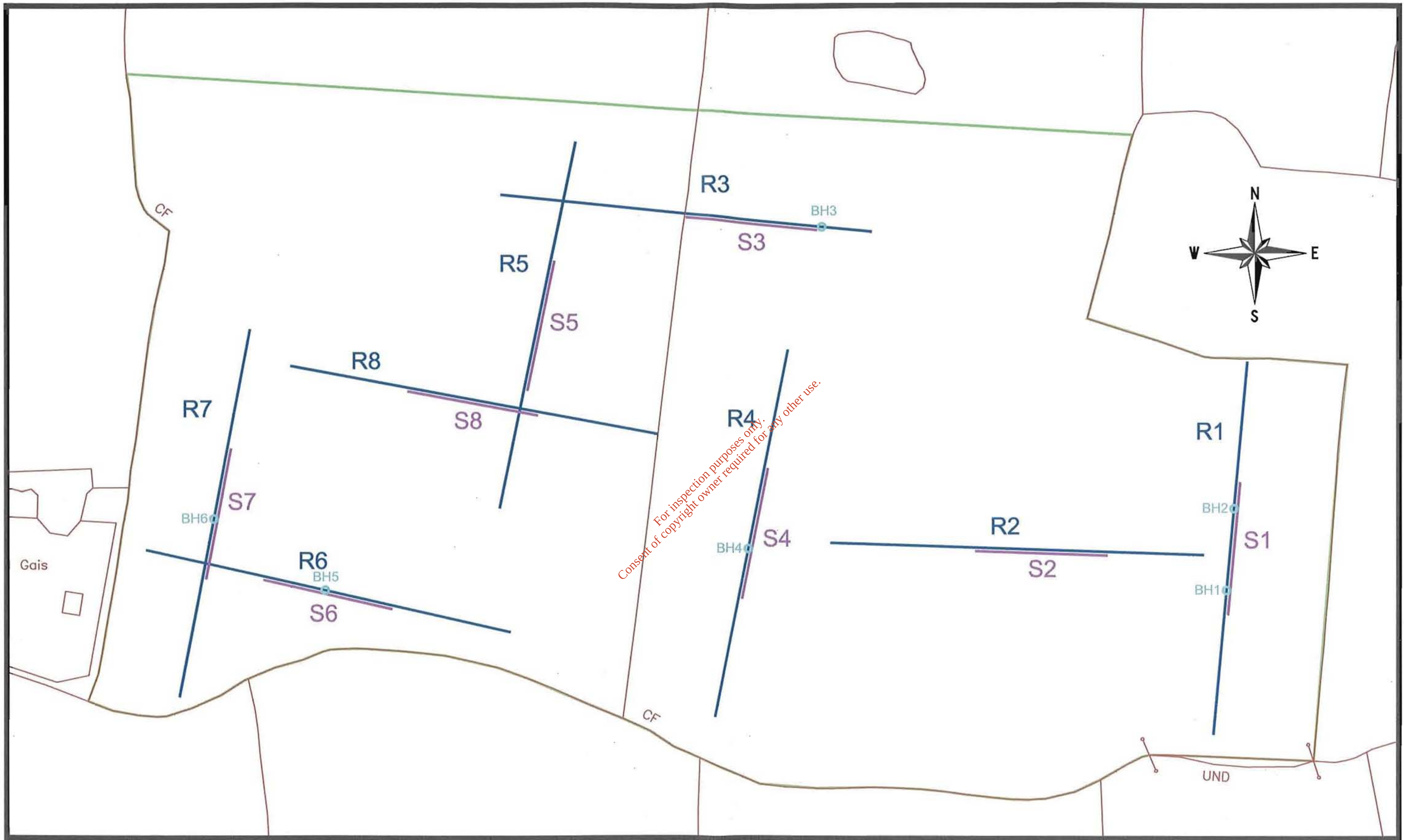

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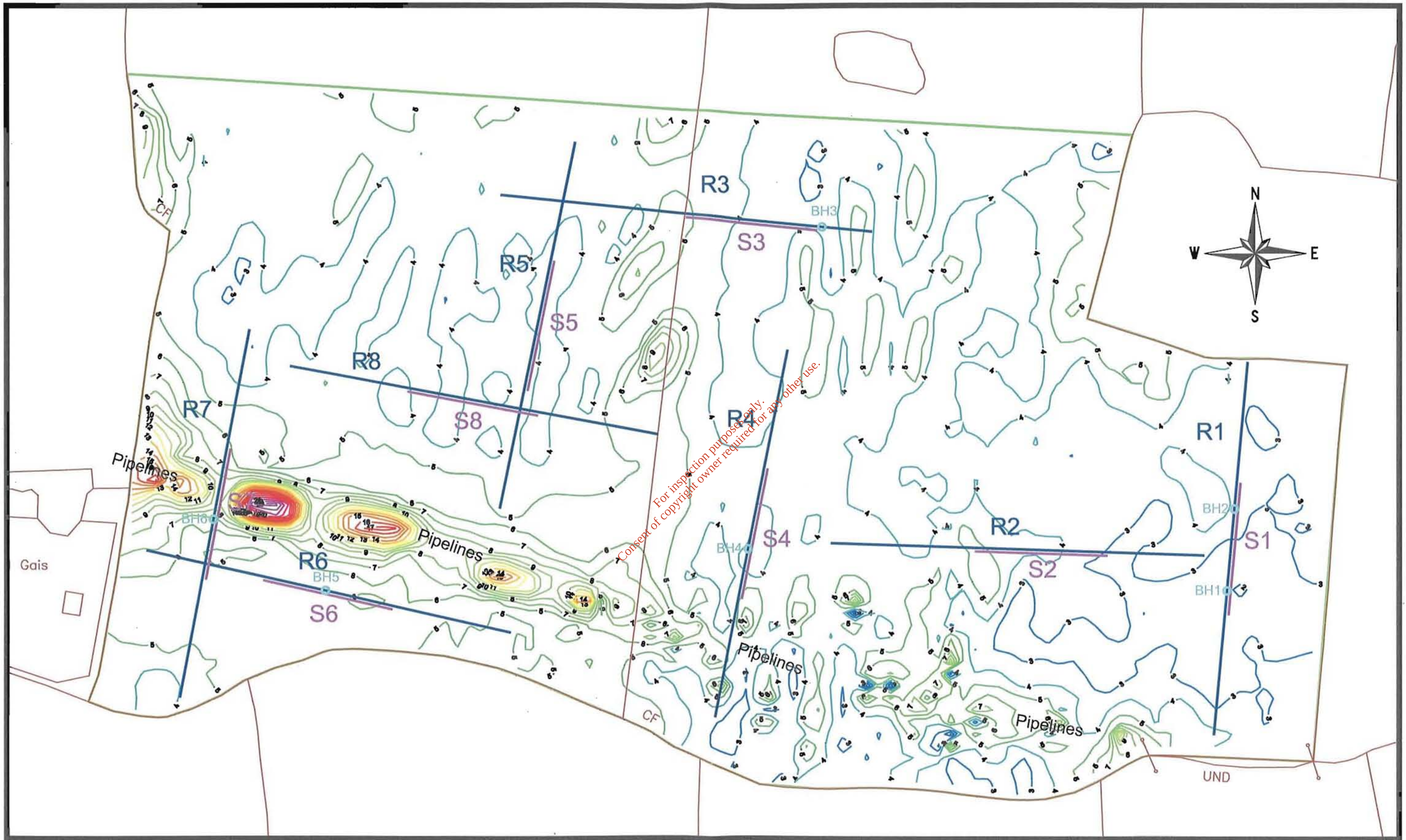
CLIENT	Mott MacDonald Pettit Cork County Council
PROJECT	Water Treatment Plant, Shanbally, Co. Cork, Geophysical Survey
TITLE	Map 1: Location Map of Geophysical Survey

SCALE:	1:1500 at A3
PROJECT:	5213
DRAWN:	TL
DATE:	13/11/07
MGX FILE:	5213d_Maps.dwg
STATUS:	Draft

LEGEND: (Refer to Report)

▱	Site and EM31 Survey Boundary
—	2D-Resistivity Profile
—	Seismic Profile
BH1 ○	Proposed Borehole Location



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CLIENT Mott MacDonald Pettit
Cork County Council

PROJECT Water Treatment Plant, Shanbally,
Co. Cork, Geophysical Survey

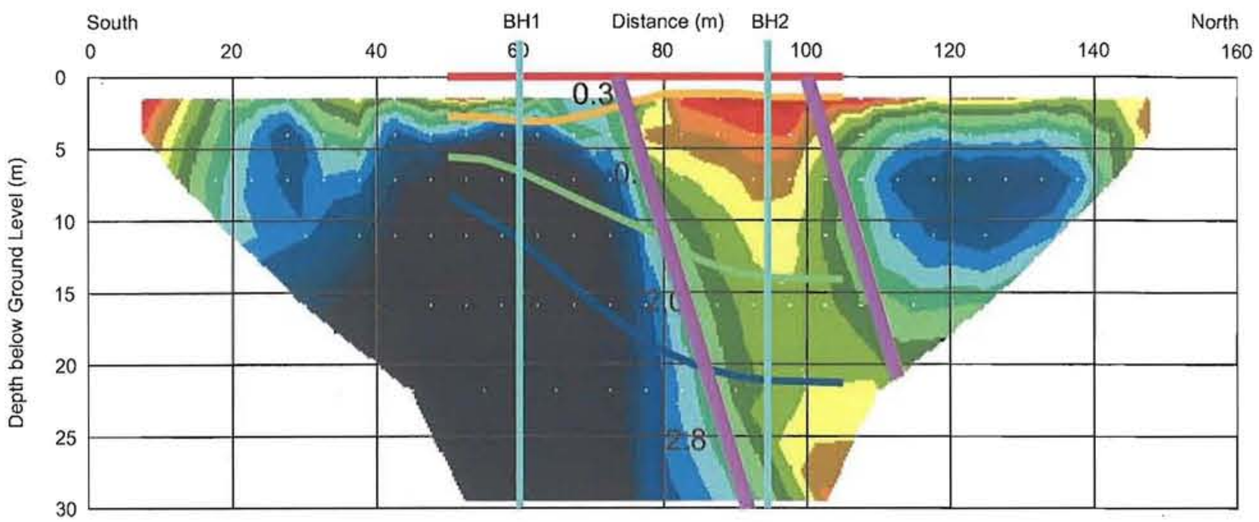
TITLE Map 2: EM31 Ground Conductivity
Contour Map

SCALE: 1:1500 at A3
PROJECT: 5213
DRAWN: TL
DATE: 13/11/07
MGX FILE: 5213d_Maps.dwg
STATUS: Draft

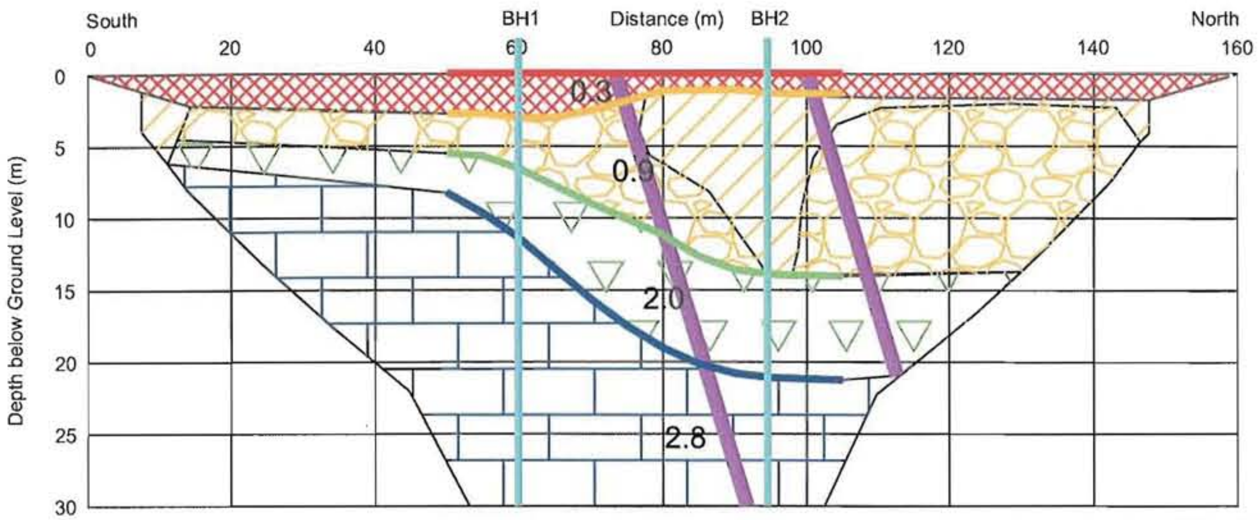
LEGEND: (Refer to Report)

Site and EM31 Survey Boundary
2D-Resistivity Profile
Seismic Profile
Colour Contours show conductivities in mS/m
BH1 ○ Proposed Borehole Location

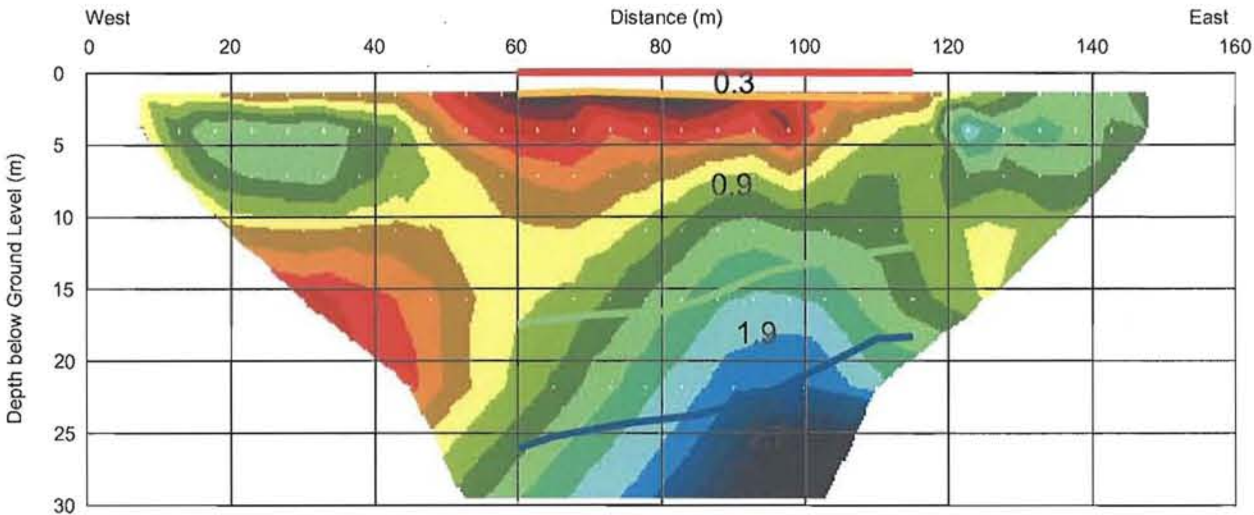
2D-Resistivity Profile R1 Model



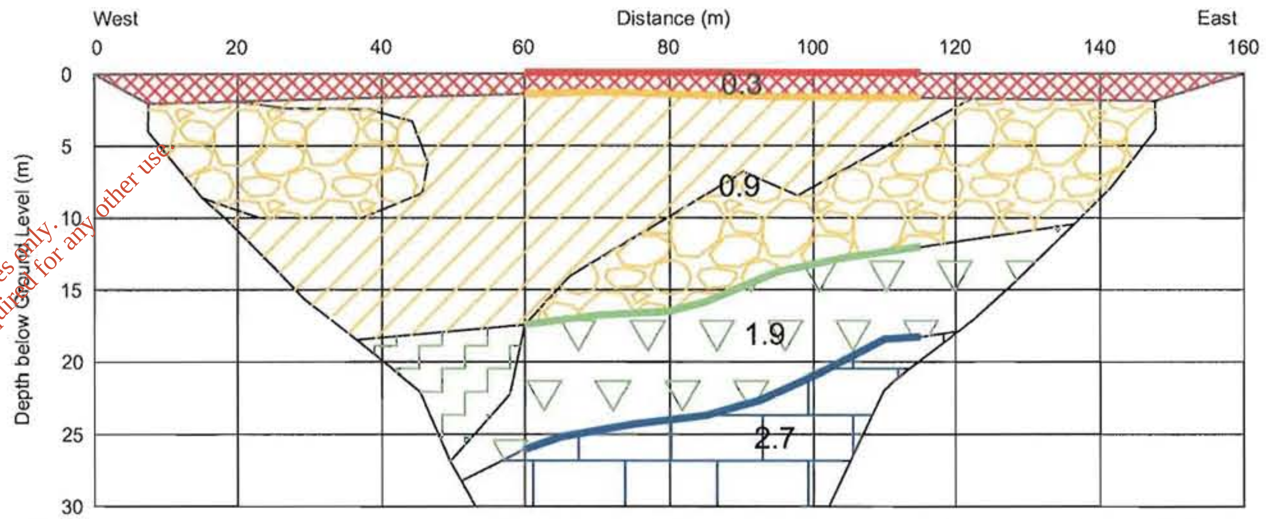
2D-Resistivity Profile R1 Interpretation



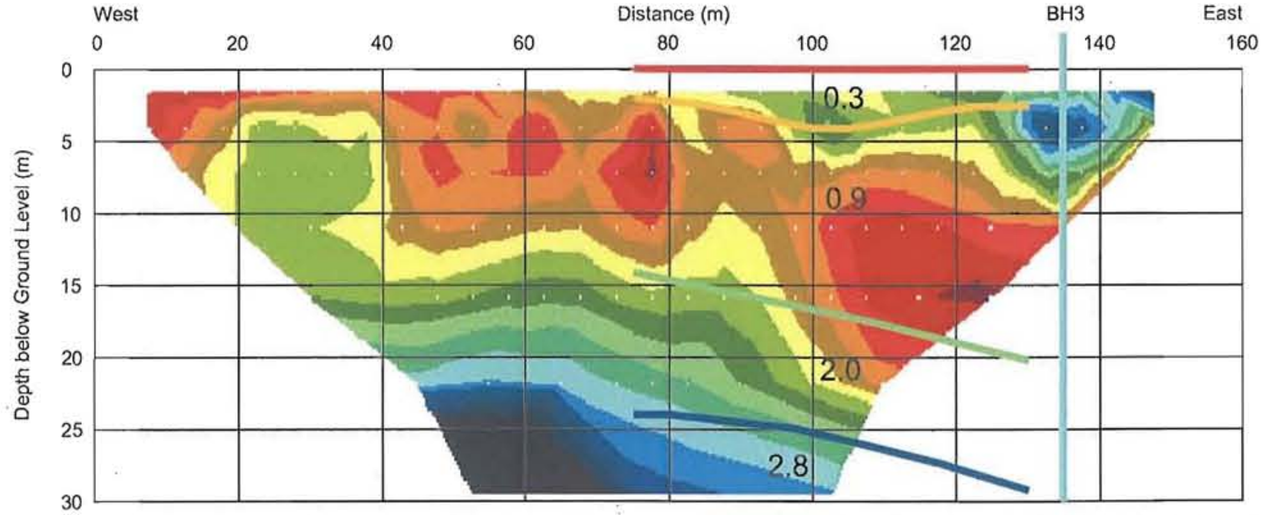
2D-Resistivity Profile R2 Model



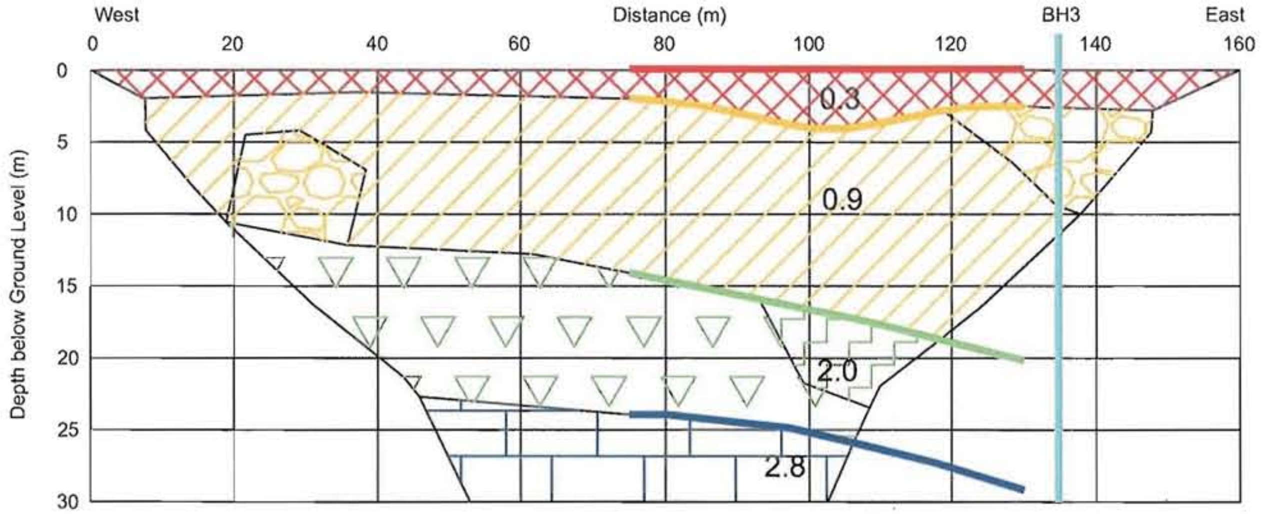
2D-Resistivity Profile R2 Interpretation



2D-Resistivity Profile R3 Model



2D-Resistivity Profile R3 Interpretation



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CLIENT Mott MacDonald Pettit
Cork County Council

PROJECT Water Treatment Plant, Shanbally, Co. Cork
Geophysical Survey

TITLE Figure 1: Results and Interpretation of
2D-Resistivity & Seismic Profiles R1 - R3

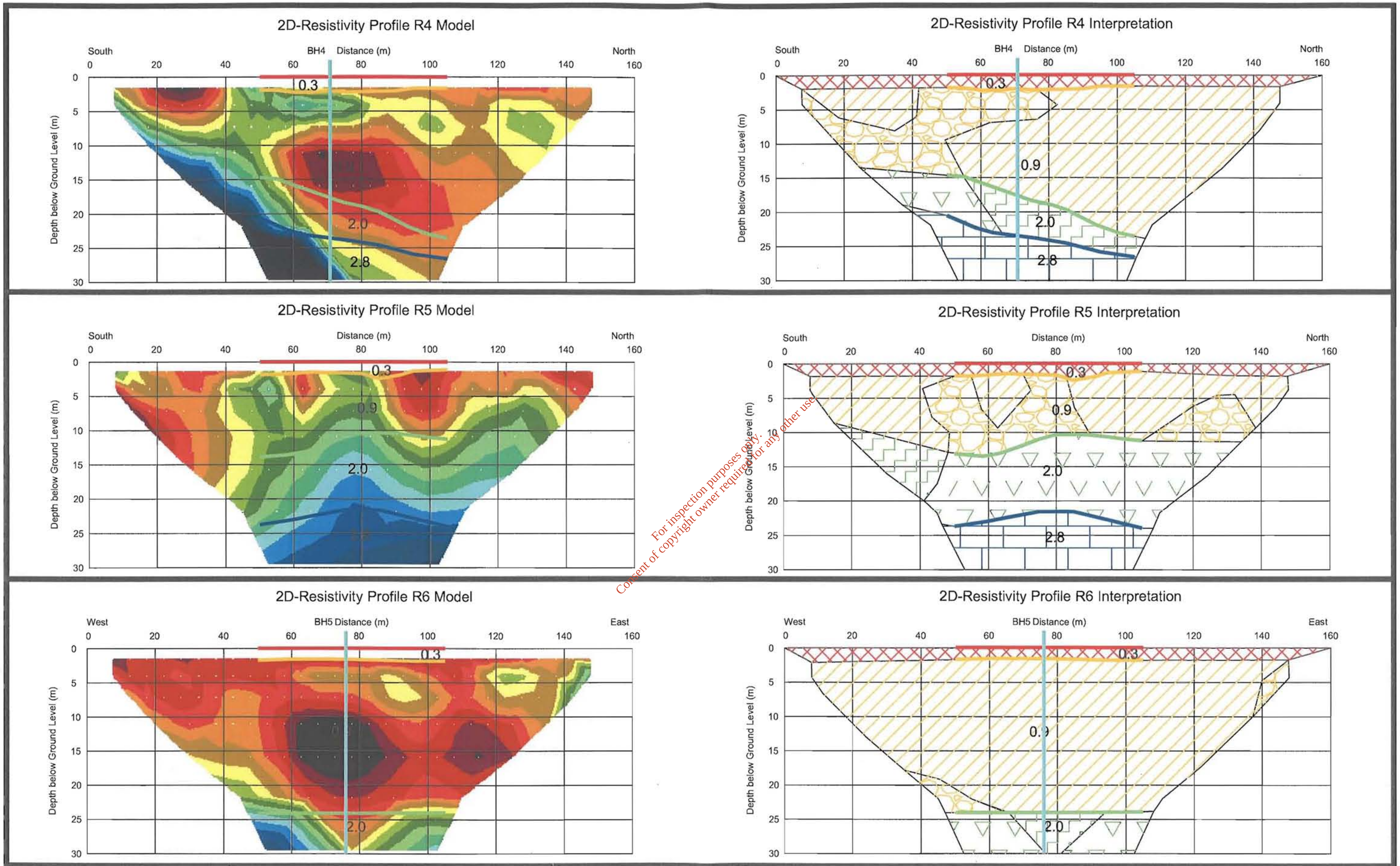
SCALE: NTS, 2 x VE
PROJECT: 5213
DRAWN: TL
DATE: 13/11/07
MGX FILE: 5213d_Figs.dwg
STATUS: Draft

LEGEND: Integrated Interpretation

- 🟥 Top of Layer 1 from Seismic Data
- 🟨 Top of Layer 2 from Seismic Data
- 🟩 Top of Layer 3 from Seismic Data
- 🟦 Top of Layer 4 from Seismic Data
- 0.9 Seismic Velocity in Km/S
- 1 - Overburden/Soil
- 2A - Gravelly Clay
- 2B - Sand and Gravel
- 3A - Stiff -Very Stiff Gravelly Clay or Fractured Mudstone
- 3B - Very Dense Sand and Gravel or Fractured Limestone
- 4 - Clean Limestone
- Possible Fault, Fracture or Karst Zone
- BH1 Recommended Borehole Location

Model Resistivities Ohm.m

200 283 400 566 800 1131 1600 2263



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CLIENT: Mott MacDonald Pettit
Cork County Council

PROJECT: Water Treatment Plant, Shanbally, Co. Cork
Geophysical Survey

TITLE: Figure 2: Results and Interpretation of
2D-Resistivity & Seismic Profiles R4 - R6

SCALE: NTS, 2 x VE
PROJECT: 5213
DRAWN: TL
DATE: 13/11/07
MGX FILE: 5213d_Figs.dwg
STATUS: Draft

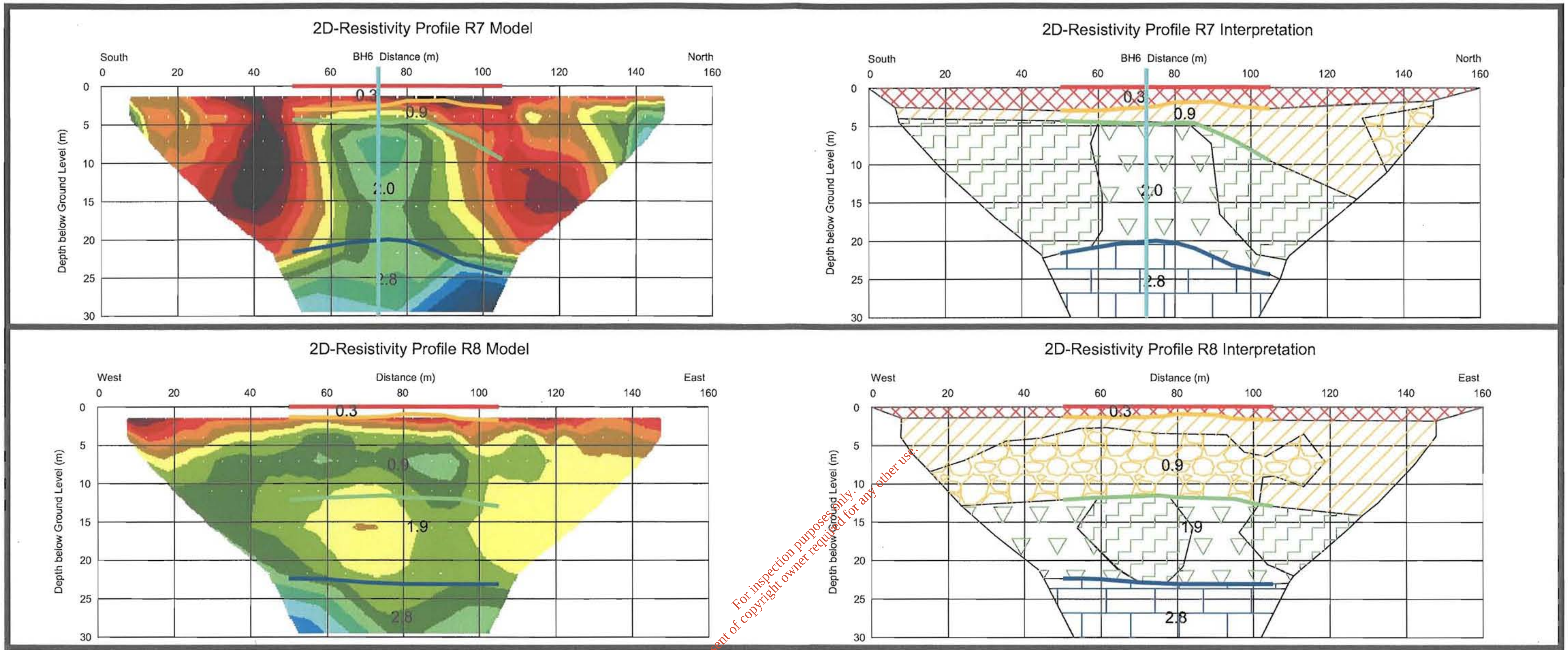
LEGEND: Integrated Interpretation

— Top of Layer 1 from Seismic Data
— Top of Layer 2 from Seismic Data
— Top of Layer 3 from Seismic Data
— Top of Layer 4 from Seismic Data
0.9 Seismic Velocity in Km/S

▨ 1 - Overburden/Soil
▨ 2A - Gravelly Clay
▨ 2B - Sand and Gravel
▨ 3A - Stiff -Very Stiff Gravelly Clay or Fractured Mudstone
▨ 3B - Very Dense Sand and Gravel or Fractured Limestone
▨ 4 - Clean Limestone
| Possible Fault, Fracture or Karst Zone
BH1 | Recommended Borehole Location

Model Resistivities Ohm.m

200 283 400 566 800 1131 1600 2263



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CLIENT Mott MacDonald Pettit
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PROJECT Water Treatment Plant, Shanbally, Co. Cork
Geophysical Survey

TITLE Figure 3: Results and Interpretation of 2D-Resistivity & Seismic Profiles R7 - R8

SCALE: NTS, 2 x VE
PROJECT: 5213
DRAWN: TL
DATE: 13/11/07
MGX FILE: 5213d_Figs.dwg
STATUS: Draft

LEGEND: Integrated Interpretation

- 🟥 Top of Layer 1 from Seismic Data
- 🟧 Top of Layer 2 from Seismic Data
- 🟩 Top of Layer 3 from Seismic Data
- 🟦 Top of Layer 4 from Seismic Data
- 0.9 Seismic Velocity in Km/S
- ▨ 1 - Overburden/Soil
- ▨ 2A - Gravelly Clay
- ▨ 2B - Sand and Gravel
- ▨ 3A - Stiff -Very Stiff Gravelly Clay or Fractured Mudstone
- ▽ 3B - Very Dense Sand and Gravel or Fractured Limestone
- ▦ 4 - Clean Limestone
- | Possible Fault, Fracture or Karst Zone
- BH1 | Recommended Borehole Location

Model Resistivities Ohm.m

200 283 400 566 800 1131 1600 2263

Appendix 4B

Bedrock Geology Summary

GEOLOGY OF SOUTH CORK

A GEOLOGICAL DESCRIPTION OF SOUTH CORK
AND ADJOINING PARTS OF WATERFORD
TO ACCOMPANY THE BEDROCK GEOLOGY
1:100,000 SCALE MAP SERIES, SHEET 25, SOUTH CORK.

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Published under the authority of the
Director of the Geological Survey of Ireland.

The lack of heterolithic lithologies and bipolar current structures suggest that the environment was fluviatile. The succession is interpreted to be the deposit of meandering rivers with **levees** in a coastal plain environment. There is a total absence of marine faunas.

THE DEVONIAN STRATIGRAPHY IN THE CENTRAL AND EASTERN PART OF THE MUNSTER BASIN

Apart from the Gortanimill Fm. which extends into East Cork (to the south of Ballynoe at grid ref. 19500 08700), no other formations recognised in West Cork have been mapped. In general, only the higher parts of the Old Red Sandstone facies are exposed in East Cork.

Ballytrasna Formation

The type section of the Ballytrasna Formation (MacCarthy *et al.* 1978, here raised to formation status) is at Ballytrasna near Ballycotton (grid ref. 19830 06320). The thickness ranges from 360m up to 1500m. In the type area some 90% of the formation is composed of dusky-red mudstone while the remainder comprises pale-red fine-medium grained sandstone. The sandstones are occasionally large scale trough cross-laminated with planar or irregular lower surfaces (MacCarthy *et al.* 1978). Correlation of the Ballytrasna Formation with the Caha Mountain, Gun Point and Castlehaven Formations on broad lithological grounds is possible.

The Gyleen Formation

The Gyleen Formation (Gyleen Member, MacCarthy 1974; raised to formation status by Sleeman 1991) is characterised by alternating mudstones and sandstones. The type section is situated to the northwest of Cotters Point (grid ref. 18480 06030).

At the type section the Gyleen Formation comprises about 20% of medium-grained sandstone with large and small-scale cross lamination and about 80% mudstones. Fining up sequences are characteristic throughout the formation. Intraformational breccias, where present, occur in the basal parts of the sandstone units (MacCarthy *et al.* 1978).

The formation shows various colours from green to grey and purple but there is a general decrease of the purple colouration in relation to the underlying units. The base of the formation is at the lowermost thick (greater than 1.5m) sandstone unit, the top at the incoming of the first heterolithic sediments. Stratigraphically it has a similar transitional position as the Toe Head Formation further to the southwest.

Ballyknock Member

The type section is north west of Cotters Point, Co. Cork(grid Ref: 18500 06020). The member varies from 0-365m thick and comprises rapidly alternating thin green siltstone and sandstones with red mudstones. Thick fining upwards sequences, as found in the rest of the Gyleen Formation are rare. The red mudstones (2-30m thick) occur as sheets separated by thin red sandstones. The green siltstones and sandstones (2-20m thick) contain ubiquitous small-scale cross- lamination. About 50% of these sandstones are cross-stratified and arranged in lenticular units. Thin pale green and grey mudstones occur towards the top of the member (MacCarthy *et al.* 1978).

Ballyquinn Member

The type section is in the cliffs at Ballyquinn, Co. Waterford (grid Ref: 22130 08020) where it is approximately 390m thick. The base of the member is transitional from the Ballytrasna Formation and the top passes up transitionall to the Ardmore Member. The member comprises, alternating thick, grey and red medium-grained sandstones with thick red mudstones. The sandstones erosively cut into earlier mudstones and are large-scale, tabular and trough cross-stratified and parallel laminated. They frequently show **epsilon cross-stratification** and **fining upwards cycles**. Intraformational mudstone-flake conglomerates occur at several levels (MacCarthy *et al.* 1978).

Ardmore Member

The type section is located on the coast to the north of Ardmore Village, Co.Waterford (grid Ref: 21970 07740) where it is approximately 107-154m thick. It overlies the Ballyquinn Member conformably and passes up to the Castle Slate Member of the Kinsale Formation at the type section. The member is distinguished by regular alternations of grey and pale red sandstones (2-9m thick) (38%), with grey-yellow siltstones up to 6m thick (62%) (MacCarthy *et al.* 1978). Red beds are isolated and discontinuous where present.

The formations of the Cork Group are defined at the Old Head of Kinsale where they form a sequence more than 2km thick (Naylor 1966; Naylor *et al.* 1985; Kuijpers 1972). This Old Head sequence compares with a thickness near the geographical centre of the South Munster Basin (George *et al.* 1976) of 2.5km recorded in the Ringabella area (Naylor 1969). Further to the north, however, in Cork Harbour, the succession thins markedly (Sleeman et al 1978; Naylor *et al.* 1989) as the North Munster shelf is reached[6]. Further northeast at Ardmore, in County Waterford, the Cork Group is only represented by the 8m thick (MacCarthy et al 1978) Castle Slate Member of the Kinsale Formation.

OLD HEAD SANDSTONE FORMATION

The Old Head Sandstone Formation comprises a thick succession of grey sandstones and heterolithic bedded sandstones and mudstones. The type section is at the Old Head of Kinsale where the sequence has been divided into two members, the Bream Rock Member (550m thick) and the overlying Holeopen Bay Member (290m thick) (Naylor 1966; Kuijpers 1972). Individual members within the formation have generally only been recognised on well exposed coastal sections, so these are not distinguished separately on this mapsheet. The base of the formation is not seen at the type section, but where it can be seen (e.g. Curraghbinny to the north of Crosshaven), it is generally taken "at the entry of significant amounts of lens bedding and flaser bedding into the sequence" (Naylor 1975; Sleeman *et al.* 1978).

The lowest 60m of the Bream Rock Member are mud dominant and bioturbated heterolithic beds (Kuijpers 1972). Above this the heterolithic beds are less bioturbated and the sand dominant heterolithic beds are more common though still subordinate. From 170m above the lowest bed, sand dominant heterolithics predominate. From 355m - 410m above the base the section is inaccessible, but above this sandstone facies constitutes 40% of the succession and the remainder are sand dominant heterolithics (Kuijpers 1972).

The lowest 100m of the Holeopen Bay Member is dominated by sandstone facies. In the remainder of the member, sandstone bodies and mudstone complexes are both common whereas heterolithic facies rocks are less common (Kuijpers 1972).

Kuijpers (1972) interprets the Old Head Sandstone Formation as a tidally influenced depositional environment. The base of the Bream Rock Formation he interprets partly as intertidal mudflat deposits while the remainder of the member is considered to represent a sub tidal environment governed by low energy tidal currents. The Holeopen Bay Member Kuijpers interprets as a tidally influenced environment in which high energy tidal currents prevailed with some strata presumably deposited in a shallow lagoon or (interdistributary) bay lacking evidence of appreciable tidal current action.

The formation is well exposed (in part) at Coolmain (southwest of Ballinspittle) and further west at Seven Heads where Naylor (1964) recognised both the Bream Rock and Holeopen Bay Members. Here the succession is thinner (450m - Kuijpers 1972).Eastwards the formation is well exposed along the coastline from the Old Head of Kinsale, through Reanies Bay, Flat Head to Man of War Cove and Carrigada Bay and on to Cork Harbour (Naylor and Higgs 1980). In the latter area it is well exposed north of Roches Point at Whitebay (MacCarthy *et al.* 1978 - as the Coomhola Formation, Whitebay and Glanagow Members) and is also well exposed at Curraghbinny, Ringaskiddy, Cuskinny (Grid. Ref. 18097 06657) and Marino Point (Grid. Ref. 17716 06955) (Sleeman *et al.* 1978). The latter exposures in Cork Harbour are much thinner (92m - 42m) than further south into the main basin (Sleeman *et al.* 1978).

Inland, the formation is generally rather poorly exposed. Further thinning has been demonstrated northwards (Sleeman *et al.* 1978, Sleeman 1991) into the Cork Syncline where a 10m thick exposure can be seen at the entrance to St. Joseph's Hospital (grid ref: 16295 07201), beyond Sundays Wells, Cork City (MacCarthy 1987). East of Midleton the formation feathers out and is replaced **diachronously** by the topmost red beds of the Gyleen Formation (Sleeman 1991). The formation is also well exposed in Killeady Quarry (Crossbarry, north of Inishannon, grid ref: 15675 06170), where the apparent outcrop width is increased by subsidiary folding (Sleeman 1991).

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[6] The top of the "Old Red Sandstone facies", on which the Cork Group rests conformably, is, however, diachronous. This has been demonstrated within the confines of this map sheet (Sleeman et al 1978).

The age of the formation, based on miospores is summarised by Higgs *et al.* (1988) who show that the formation encompases the LL, LE and LN miospore Biozones and is thus of Strunian age. The northward thinning of the formation is paralleled by the later age of the base of the formation demonstrated by the presence of LN Biozone miospores at or near the base of the formation at various localities between North Ringabella and Marino Point (Higgs 1975; Higgs *et al.* 1988; Sleeman *et al.* 1978).

KINSALE FORMATION

The Kinsale Formation, 762m thick at the Old Head of Kinsale (Naylor 1966), is defined, overall, as a mud-dominant succession. The formation is divided into three members on the Old Head: the Castle Slate, Narrow Cove and Pig's Cove Members (Naylor 1966; see also Naylor *et al.* 1977). They are not always shown separately on the mapsheet because inland, west of Kinsale, it has not yet proved possible to map them out in detail, for the most part. The individual members however are mapped out in the Cork City and Harbour district as shown here and on the recent Geological Survey 1:25,000 maps (Sleeman 1991). Approximately east and north of Belgooly and the Carrigada Fault, the overall mud dominant but sandy Narrow Cove Member, is represented by the sand dominant Cuskinny Member (MacCarthy *et al.* 1978; *Sleeman 1987*).

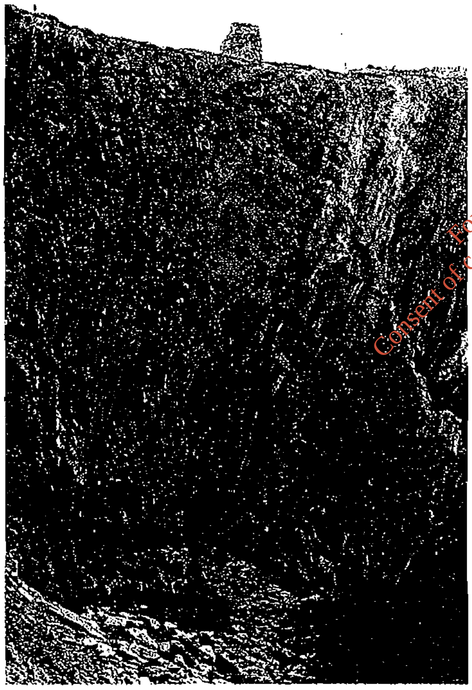

Plate 3. The topmost beds of the Uppermost Devonian Old Head Sandstone Formation on the right pass up to the dark-grey mudstones of the Carboniferous Kinsale Formation (Castle Slate Member) at the Old Head of Kinsale. This locality is the Courceyan Stratotype and approximates to the international Devonian-Carboniferous boundary (photo. by A.G.Sleeman).

The Old Head of Kinsale is the stratotype for the base of the Courceyan Stage, the lowest of six regional stages in the Dinantian proposed for Great Britain and Ireland (George *et al.* 1976). It is named after the local Barony of de Courceys. The base of the stage corresponds to the Old Head Sandstone/ Kinsale Formation boundary located in Holeopen Bay West (plate 3). The base of the Courceyan Stage corresponds with the boundary between the LN and VI miospore Zones, (Clayton *et al.* 1974; George *et al.* 1976), which, in the absence of **goniatites** of the *Gattendorfia subinvoluta* Zone of Germany, approximates to the Devonian/ Carboniferous boundary.

The formation spans the VI, HD and BP miospore Biozones. Higgs *et al.* (1988) summarise the available data for localities within the mapsheet. The Castle Slate Member contains miospores of the VI Biozone. The Narrow Cove and Cuskinny Members contain VI Biozone miospores near the base but most of the sequence is in the HD Biozone. The base of the Pig's Cove Member contains upper HD biozone miospores and the top generally contains BP miospores[7]. These miospores show that the formation is of earliest to mid Courceyan age (Tn1b - Tn2b/c in Belgian terms).

Other stratigraphically useful fossils are scarce. Matthews and Naylor (1973), however, have recorded **conodonts** from the Castle Slate Member at the Old Head and Matthews (1983), has recorded an interesting goniatite fauna from the same member at Nohaval Cove (east of Kinsale).

Castle Slate Member

The Castle Slate Member, as defined in Holeopen Bay West, is 61.5m thick. The base of the member

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[7] At one locality PC Biozone miospores were obtained from the topmost few metres suggesting that elsewhere the top of the member was eroded before deposition of the overlying Courtmacsherry Formation.

is the base of the Courceyan Stage as described above. The member consists of uniform, dark-grey, well cleaved massive mudstones (Naylor 1966) and is in marked contrast to the sandstones of the underlying Old Head Formation. Phosphatic **cryptocrystalline** quartz nodules are common, and especially near the base of the member, comminuted crinoid debris is found, sometimes in bioclastic lenses which also contain **ostracods** and small indeterminate bivalves (Naylor 1966).

The member is an excellent marker horizon across the whole South Munster Basin. It is found as far west as the Beara Peninsula (Gardiner and Horne 1976) and as far east as Ardmore (MacCarthy *et al.* 1978; Clayton *et al.* 1982). Within the area of Sheet 25 it can be seen in many other coastal sites including Dunnycove Bay (Galley Head), Lions Cove (Dunworly Bay) (Graham and Reilly 1976; Naylor and Reilly 1981, MacCarthy 1987), Nohaval Cove and Flat Head (Naylor and Higgs 1980), Ringabella Bay (Naylor 1969), Curraghbinny, Marino Point and Cuskinny, (Sleeman *et al.* 1978; MacCarthy *et al.* 1978), Whitebay, Inch, Ballycotton and Knockadoon (MacCarthy *et al.* 1978).

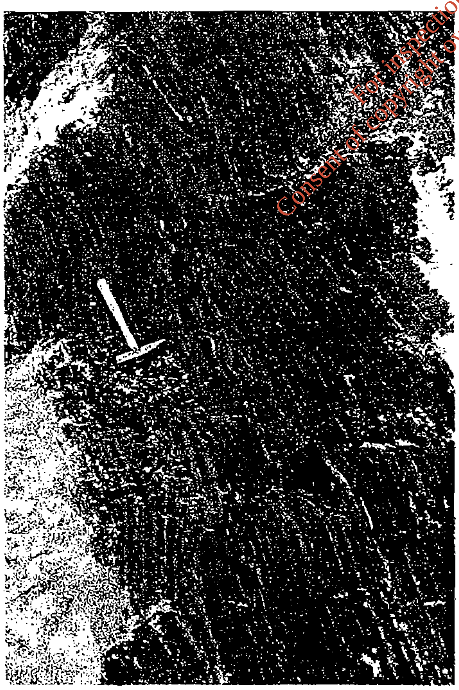

Plate 4. Vertically bedded sand-lensed (linsen) and sand-streaked mudstones of the Courceyan (Lower Carboniferous) Kinsale Formation (Narrow Cove Member) at Duneen Bay near Clonakilty (photo by A.G. Sleeman).

The member is found in many stream sections and quarries inland (the latter often worked in the past for roofing slate), but is difficult to map inland west of Belgooly.

The base of the member represents a sudden but slight deepening of the sea (Naylor *et al.* 1983), immediately succeeding the topmost sandstones of the Old Head Formation which, in some places, are probably shore face deposits (Graham 1975a).

Narrow Cove Member

The type section at Narrow Cove, on the west coast of the Old Head is 303m thick (Naylor 1966). The dominant lithology is sand-lensed (linsen) mudstone (plate 4); although a wide range of lithologies are found including parallel and cross-bedded sandstone, flaser-bedded sandstones and laminated mudstones. There is a general increase in the proportion of sand up sequence so that the top few metres are sand-dominant (Naylor 1966).

The member is well exposed between the Old Head of Kinsale and Kinsale Harbour (de Raaf *et al.* 1977; Naylor and Higgs 1980). Further east the cliff sections are inaccessible. Westwards, there is a good section at Dunworly Bay (Graham and Reilly 1976) and the member thins towards Galley Head (Keegan 1977). Inland it is exposed along the Cork - Bandon road west of Inishannon, where it is very sandy. However, at present it has not been mapped out inland west of Belgooly.

The member, while mudstone dominant, is relatively sandy. The proportion of sandstone gradually increases north and east from the Old Head until north of the Carrigada Fault at Robert's Cove (Robert's Cove Sandstone Formation of Naylor 1969) its equivalent is sandstone dominant (Van Gelder and Clayton 1978). In consequence Sleeman (1987) proposed that the name Cuskinny Member (MacCarthy *et al.* 1978) should be used north of the Carrigada Fault.

De Raaf *et al* . (1977) concluded that the depositional environment was a muddy shallow marine platform on which sandy shoals were formed under the influence of wave action and, overall, represents a regressive phase.

Cuskinny Member

The Cuskinny Member (MacCarthy *et al.* 1978) is the lateral equivalent of the Narrow Cove Member, north and east of the Carrigada Fault (Sleeman 1987). The type section at Cuskinny, east of Cobh (Grid. Ref. 18097 06651), is more than 235m thick