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Numerical Modelling of Warkworth Sewage Discharge to Mahurangi Estuary

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Prepared for
Auckland Regional Council

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Executive Summary

The impacts of two discharge options for the Warkworth treated sewage discharge on the concentrations of effluent (%), dissolved inorganic nitrogen (mg/l) and dissolved reactive phosphorus (mg/l) in the Mahurangi estuary are presented. Concentrations were calculated over a tidal cycle using the combined hydrodynamic and transport-dispersion models 3DD and POL3DD developed for the estuary. The discharge options were 1) tidally-staged directly into the estuary and 2) via a wetland to the estuary.

The data are presented graphically for use by managers as:

1. time series plots of surface concentrations at selected sites in the main channel and within oyster farms
2. maps of the effluent plume concentrations throughout the estuary as the plume ebbs and floods with the tide

Data are also summarised in tabular form, and this shows that there are minor differences between the two proposed discharge regimes. There is no best discharge option for the Mahurangi estuary as a whole, because the relative degree of contamination from the two discharge options changes throughout the estuary. The data presented within this report will help to identify areas where one regime provides lower concentrations than the other.

The sewage discharge is a small contributor to estuarine dissolved inorganic nitrogen, but is a significant source of dissolved reactive phosphorus.

INTRODUCTION

NIWA was commissioned by the ARC to develop numerical models of the Mahurangi catchment to enable the ARC to manage the Mahurangi Estuary and its environs in a sustainable manner. Earlier reports give details of the development of both estuary and catchment models (Stroud and Cooper, 1997; Oldman, 1997). These models can now be used as management tools to investigate the effects of changes in catchment use on the Mahurangi Estuary.

This report gives details of the first of these investigations which examines the effects of two different sewage treatment discharge regimes on contamination of the Mahurangi Estuary. This work, while being initiated by the ARC, will be used by Rodney District Council to investigate options for the Warkworth sewage treatment works.

The two options considered are :

- A tidally staged discharge
  - Discharge rate 160 m^3/hour
  - Commencing one hour prior to high tide
  - Continuing for 7.5 hours
  - Using existing outfall
  - Total volume 2400 m^3/day

- A discharge via a wetland : – continuous
  - Discharge rate varies as follows :

Time From High Water	Discharge to Estuary (m^3/hour)
0-1	400
1-2	300
2-7	100

  - Discharge commences at high water
  - Continues for 7 hours
  - Total volume 2400 m^3/day
  - For the first three hours a dilution of effluent of two times is assumed (i.e. discharge concentration to estuary is at 50% of the concentration at the input to the wetland system).

For both scenarios a mean tide with a range of 2.5 metre is assumed and a flow of 1 m^3/s for the Mahurangi River has been used. Figures 1 and 2 give the timings, volumes and dilution of the two discharge options.

For the first model run, the contaminants of interest in the effluent were assumed to be conservative - no decay in concentration with time was applied. This gives a worst case condition for the estimates of contaminant concentrations from the sewage discharge. Model output is given in terms of % effluent. This allows the model output to be used to determine, for example, the concentrations of bacteria in the estuary assuming no die-off due to UV (sunlight) deactivation. An additional model run was carried out for dissolved inorganic nitrogen (DIN) with an applied decay rate. Model output is given in nitrogen concentration (mg/l). This model run gives an indication of the likely concentrations for DIN throughout the estuary which can be attributed to the sewage treatment effluent, and takes into account losses of DIN from processes occurring within the estuary (e.g., denitrification). Further data is presented for predictions of dissolved reactive phosphorus (DRP). Model output is given in phosphorus concentration (mg/l). This data indicates concentrations for DRP throughout the estuary which can be attributed to the sewage treatment effluent.

Figure 3 gives a location map for the estuary while Figure 4 gives the location of the oyster farm lease sites within the estuary.

The model uses a layered Lagrangian method to track particles throughout the estuary (Bell et al. 1997, Oldman 1997). For this report we have used the so-called "fixed surface layer" for presentation of results. This layer represents the top 0-0.2 meters of the water column away from the source, but excludes the "variable" thin surface layer comprising mainly effluent.

RESULTS

PERCENTAGE EFFLUENT : STAGED DISCHARGE

Figure 5a gives the time series plots of percentage effluent concentrations for selected sites within the main channel of the estuary. These show the relative concentrations (in % of initial effluent concentration) as predicted by the model for the "fixed" top layer. It can be seen that by the time the effluent plume has reached Dawsons Creek the percentage of effluent present in the top layer is at a maximum 0.98% of the discharge effluent concentration. This peak occurs at low water. The effluent concentration is never zero at Dawsons Creek i.e. some effluent is present at all states of the tide. As the plume progresses further downstream, further mixing reduces peak effluent concentration. Opposite Cowans Bay (Figure 5b), peak effluent concentrations are 0.40% (again at low water). For 4% of the tidal cycle there is no effluent present in the top layer of the water column. Opposite Dyers Creek (Figure 5c), peak effluent concentrations are 0.23 % (again at low water). For 12% of the tidal cycle there is no effluent present in the top layer of the water column. Opposite Grants Island (Figure 5d), peak effluent concentrations are 0.14% (again at low water). For 8% of the tidal cycle there is no effluent present in the top layer of the water column. By the time the plume has reached Scotts Landing (Figure 5e), peak effluent concentrations are no more than 0.02 % and show little parity with tidal conditions. For 31% of the tidal cycle there is no effluent present in the top layer of the water column. The above information is summarised in Table 1.

Figure 6 gives the time series plots of percentage effluent predicted within the oyster farms shown in Figure 4. No effluent from the sewage treatment works reaches either the Huawai Bay or Te Kapa Inlet oyster farm (Figures 6a,d). For the Puka Puka Inlet oyster farm (Figure 6b), the model predicts that a small amount of effluent (0.03%) reaches the farm just prior to high water. For the Browns Bay oyster farm (Figure 6c), concentrations of 0.11% effluent occur and show no strong tidal signal. Some effluent is present at the site for 57% of the tidal cycle. Effluent at the Cowans Bay oyster farm (Figure 6g), reaches a peak value of 0.87% during the mid-flood tide. Some effluent is present at the site for 81% of the tidal cycle. For the Dyers Creek oyster farms (Figure 6e, f), peak values are 0.65% for the north site and 0.24% for the south site, and are again found on the flooding tide. Some effluent is present at the north site for 76% of the tidal cycle and at the south site for 57% of the tidal cycle. The above information is summarised in Table 1.

Site	Staged discharge				Wetland discharge			
	Peak concentration (%)	1000 fc	Time of peak	Time (%) effluent present	Peak concentration (%)	1000 fc.	Time of peak	Time (%) effluent present
Main Channel								
Dawsons	0.98	9.8	Low water	100	1.1	11	Low water	100
Cowans	0.4	4	Low water	96	0.33	3.3	Low water	100
Dyers	0.23	2.3	Low water	88	0.41	4.1	Low water	100
Grants	0.14	1.4	Low water	92	0.12	1.2	Low water	85
Scotts	0.02	0.2	-	69	0.05	0.5	-	77
Oyster Farms								
Huawai	0	0	-	0	0	0	-	0
Te Kapa	0	0	-	0	0	0	-	0
Puka Puka	0.03	0.3	High water	-	0	0	-	0
Cowans	0.87	8.7	Mid flood	81	1.13	11.3	Mid flood	73
Dyers North	0.65	6.5	Mid flood	76	0.65	6.5	Mid flood	80
Dyers South	0.24	2.4	Mid flood	57	0.22	2.2	Mid flood	65
Browns	0.11	1.1	-	57	0.15	1.5	-	65

Table 1. Comparison of effluent effects at different estuarine sites for staged and wetland discharges. Peak concentrations (%) are given along with the stage of the tide when they occur (time of peak) and the proportion of time (%) when effluent is present.

The predicted movement and characteristics of the plume are depicted in Figures 7a-z at hourly intervals after high water. These show the relative concentrations (in % of initial effluent concentration) as predicted by the model for the "fixed" top layer. (Note that dilution is simply the inverse of relative concentration as a decimal proportion, e.g. a 50% (or 0.50) relative concentration equates to a dilution of 2:1).

At high water (Figure 7a), the plume extends 2.3 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 1.6%. Maximum concentrations occur on the intertidal banks to the south of Duck Creek.

At high water plus one hour (Figure 7b), the plume still extends 2.3 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.0%. Maximum concentrations still occur on the intertidal banks to the south of Duck Creek. A small plume of effluent is evident in Dawsons Creek. This plume occurs because the previous flood tide pushes effluent up into the Dawsons Creek arm. Because the model does not incorporate the freshwater inflows from Dawsons Creek, the plume appears to remain intact and appears not to be flushed out of Dawsons Creek. While the model shows that effluent from the Warkworth sewage treatment works can end up in Dawsons Creek, concentrations presented here should not be relied upon as being realistic. In reality, freshwater inflows flush and dilute effluent in the creek.

At high water plus two hours (Figure 7c), the plume extends 2.5 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.2%. Maximum concentrations occur on the northern intertidal banks to the south of Duck Creek.

At high water plus three hours (Figure 7d), the plume extends 2.8 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.1%. Maximum concentrations now occur in the main channel as the intertidal banks drain, especially nearer the discharge.

At high water plus four hours (Figure 7e), the plume extends 3.5 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 1.7%. Maximum concentrations occur in the main channel.

At high water plus five hours (Figure 7f), the plume extends 4.3 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 1.9%. Maximum concentrations again occur in the main channel.

At high water plus six hours (Figure 7g), the plume extends 6.0 kilometres downstream of the discharge point and, within the core of the plume, has a mean

concentration of 1.8%. Maximum concentrations now occur on the fringes of the intertidal banks.

At low water plus half an hour (Figure 7h), the plume extends 6.5 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.7%. Maximum concentrations now occur in the top part of the estuary near the discharge point. At this stage of the tide, the discharge has been discontinued. However, the discharge within the previous hour has been to very shallow water with low velocities. Hence, initial dilution is at the minimum and results in the highest predicted plume concentrations near the discharge point.

At low water plus one and a half hours (Figure 7i), the plume extends 6.3 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.8%. Maximum concentrations now occur on the fringes of the intertidal banks.

At low water plus two and a half hours (Figure 7j), the plume extends 5.8 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.6%. Maximum concentrations are found in the channel north of Hepburn Creek.

At low water plus three and a half hours (Figure 7k), the plume extends 4.1 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.9%. Maximum concentrations occur evenly throughout the main channel north of Hepburn Creek.

At low water plus four and a half hours (Figure 7l), the plume extends 3.8 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.5%. Maximum concentrations occur on the south intertidal banks to the south of Duck Creek.

At low water plus five and a half hours (Figure 7m), the plume extends 2.4 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.1%. Maximum concentrations still occur on the south intertidal banks to the south of Duck Creek.

Table 2 gives a summary of the above data as well as presenting average, minimum and maximum effluent concentrations for the plume and estuary.

Plots of the plume throughout the following tidal cycle (Figure 7n-6z) are also presented as they are offset relative to high water by half an hour instead of 1 hour as in Figures 7a-7m. Analysis of the concentrations within the plume show no significant picture to that above and so the data are not discussed further.

	Concentration (% effluent) for staged discharge					Concentration (% effluent) for wetland discharge				
Time relative to high water	Mean	Average in plume	Minimum in plume	Maximum in plume	Maximum	Mean	Average in plume	Minimum in plume	Maximum in plume	Maximum
0	0.08	1.6	0.8	2.8	4.5	0.08	2.0	1.4	2.8	8.0
1	0.08	2.0	0.9	2.8	6.3	0.08	1.9	1.0	4.5	6.0
2	0.06	2.2	1.1	3.0	6.5	0.05	2.0	1.0	2.7	3.5
3	0.05	2.1	1.5	3.4	4.0	0.05	1.6	1.1	2.4	3.2
4	0.05	1.7	1.3	2.8	4.2	0.05	1.8	1.1	2.8	4.5
5	0.07	1.9	1.2	3.0	6.5	0.07	2.4	1.7	3.0	5.6
6	0.09	1.8	1.3	2.	5.2	0.08	2.6	1.8	4.4	5.0
7	0.10	2.7	1.5	5.2	4.8	0.11	2.4	1.4	3.7	6.5
8	0.12	2.8	1.7	4.0	6.5	0.12	3.1	2.4	4.2	5.2
9	0.11	2.6	1.8	5.1	6.0	0.11	2.4	1.7	4.8	5.8
10	0.09	2.9	2.3	3.8	5.8	0.09	2.6	1.7	4.1	5.0
11	0.07	2.5	1.7	3.4	4.8	0.07	1.8	1.2	2.8	4.3
12	0.06	2.1	1.7	2.8	3.8	0.06	1.9	1.5	2.7	5.4

Table 2. Effluent concentrations (% effluent) for the staged and wetland discharges. Mean value is the mean over the extent of the plume. Average, minimum and maximum values are for the core of the plume. Maximum is the maximum concentration anywhere in the estuary.

PERCENTAGE EFFLUENT : WETLAND

Figure 8 shows the time series plots of percentage effluent concentrations for selected sites within the main channel of the estuary. It can be seen that by the time the effluent plume has reached Dawsons Creek (Figure 8a), the percentage of effluent present in the top layer of the model (0-0.2m) is at a maximum concentration of 1.1% of the discharge effluent concentration. This peak occurs at low water. The effluent concentration is never zero, i.e., some effluent is present at all stages of the tide. As the plume progresses further downstream, further mixing reduces peak effluent concentration. Opposite Cowans Bay (Figure 7b), peak effluent concentrations are 0.33% (again at low water), and some effluent is present at all stages of the tide. Opposite Dyers Creek (Figure 7c), peak effluent concentrations are 0.41 at low water, and effluent is always present throughout the tide. Opposite Grants Island (Figure 7d), peak effluent concentrations are 0.12% at low water. For 15% of the tidal cycle, there is no effluent present in the top layer of the water column. By the time the plume has reached Scotts Landing (Figure 7e), peak effluent concentrations never exceed 0.05 % and show little parity with tidal conditions. For 23% of the tidal cycle there is no effluent present in the top layer of the water column.

Figure 9 gives the time series plots of percentage effluent within the oyster farms shown in Figure 4. No effluent from the sewage treatment works reaches the Huawai Bay, Te Kapa Inlet or Puka Puka Inlet oyster farms (Figure 8a,b,d). For the Browns Bay oyster farm (Figure 8c), concentrations of 0.15% effluent occur, and show no strong tidal signal. Some effluent is present at the site for 65% of the tidal cycle. For the Dyers Creek oyster farms (Figure 8e,f), peak values are 0.65% for the north site and 0.22% for the south site and occur on the flooding tide. Some effluent is present at the north site for 80% of the tidal cycle and at the south site for 65% of the tidal cycle. Effluent at the Cowans Bay oyster farm (Figure 8g), reaches a peak value of 1.13% during the mid-flood tide. Some effluent is present at this site for 73% of the tidal cycle.

The predicted movement and characteristics of the plume are depicted in Figures 10a-z at hourly intervals after high water. These show the relative concentrations (in % of initial effluent concentration) as predicted by the model for the "fixed" top layer

At high water (Figure 10a), the plume extends 2.4 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.0% . Maximum concentrations occur on the intertidal banks to the south of Duck Creek.

At high water plus one hour (Figure 10b), the plume extends 2.6 kilometres downstream of the discharge point and, within the core of the plume, has a mean

concentration of 1.9%. Maximum concentrations occur on the northern intertidal banks to the south of Duck Creek.

At high water plus two hours (Figure 10c), the plume extends 2.7 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.0%. Concentrations are relatively uniform over the plume.

At high water plus three hours (Figure 10d), the plume extends 2.8 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 1.6%. Maximum concentrations occur mainly in the main channel as the intertidal banks drain.

At high water plus four hours (Figure 10e), the plume extends 3.5 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 1.8%. Maximum concentrations now occur on the fringes of the intertidal banks.

At high water plus five hours (Figure 10f), the plume extends 4.2 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.4%. Maximum concentrations are found in the main channel.

At high water plus six hours (Figure 10g), the plume extends 6.5 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.6%. Maximum concentrations occur in the upper part of the plume in the main channel.

At low water plus half an hour (Figure 10h), the plume extends 6.8 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.4%. Maximum concentrations are found on the fringes of the intertidal banks in the upper part of the plume in the main channel.

At low water plus one and a half hours (Figure 10i), the plume extends 6.5 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 3.1%. Maximum concentrations still occur on the fringes of the intertidal banks in the upper part of the plume in the main channel.

At low water plus two and a half hours (Figure 10j), the plume extends 5.7 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 2.4%. Maximum concentrations occur on the fringes of the intertidal banks.

At low water plus three and a half hours (Figure 10k), the plume extends 4.6 kilometres downstream of the discharge point and, within the core of the plume, has a

mean concentration of 2.6%. At this and the next two hours, maximum concentrations occur on the intertidal banks to the south of Duck Creek.

At low water plus four and a half hours (Figure 10l), the plume extends 3.8 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 1.8%.

At low water plus five and a half hours (Figure 10m), the plume extends 2.4 kilometres downstream of the discharge point and, within the core of the plume, has a mean concentration of 1.9%.

Table 2 gives a summary of the above data as well as presenting average, minimum and maximum effluent concentrations for the plume and estuary.

Plots of the plume throughout the following tidal cycle (Figure 10n-10z) are also presented, because they are offset relative to high water by half an hour instead of 1 hour as in figures (10a-10m). Analysis of the concentrations within the plume show no significant picture to that above and so the data are not discussed further.

NUTRIENT CONTRIBUTIONS FROM SEWAGE

In addition to investigating the effect of the two discharge regimes on effluent concentrations within the estuary the model was used to determine the concentrations of nutrients within the estuary.

The ARC monitors the estuary on a regular basis for nutrient concentrations at various sites around the estuary (ARC 1993). The mean dissolved inorganic nitrogen (DIN) concentration for the sewage treatment works discharge is 10.6 mg/l and for dissolved inorganic phosphorus (DRP) it is 6.0 mg/l. The mean discharge volume per day is 660 m^3, so that, on average, the sewage treatment works contributes 2400 kg N/annum and 1450 kg P/annum to the Mahurangi Estuary. By comparison, the input to the Mahurangi Estuary from the Mahurangi River can be calculated from the monitoring data from the College site. Specific yields calculated from this data (Stroud and Cooper 1997 - Table 5) were applied to the total Mahurangi River catchment area of 54 km^2, which yields 24192 kg N/annum for DIN and 1409 kg P/annum for DRP. Stroud and Cooper (1997) also estimate the total point source loadings to waterways within the total Mahurangi Estuary catchment (their Table 2). These are 7788 kg N/annum for DIN and 1880 kg P/annum for the DRP. Therefore the sewage treatment works is a major component of point source discharges within the catchment, and a major contributer of DRP to the upper estuary. However, it is a minor contributer to the annual land-based input of DIN to the upper estuary.

Predictions of estuary DIN and DRP concentrations, which are solely derived from the sewage treatment works, were made with the model. Other sources of DIN and DRP (e.g., from catchment runoff, sea water) were not included in these computations. For DIN, we assumed an effluent concentration of 10 mg/l and non-conservative behaviour, where DIN is lost by plant uptake and denitrification, by incorporating a decay rate of 25 days. This decay rate is the slower of the two values reported in Black et al. (1995) for the Manukau Harbour. For DRP, we assumed conservative behaviour with an effluent concentration of 6 mg/l.

NITROGEN

Figure 11 and 12 shows the time series plots of DIN concentrations for the staged discharge at selected sites within the main channel and oyster farms of the estuary. Fig 13 (a-z) maps the concentration of DIN in the plume and estuary over a tidal cycle. These predictions are made assuming that the sewage discharge is the sole source of DIN. Figures 14-16 show the equivalent situation for the wetland discharge.

The relative importance of the sewage discharge to DIN nutrient status of the estuary can be assessed by comparing predicted and measured concentrations. Some of the

selected sites in Figures 11 and 14 are close to ARC monitoring sites (Auckland Regional Council 1993). This data is summarised in Appendix 1, and is used for the comparison. These comparisons are:

- Cement Wharf (Figure 11a And 14a) with ARC site 12
- 100m south of Duck Creek (Fig 11b And 14 b) with ARC site 15
- Dawsons Creek (Figure 11c And 14c) with ARC site 23
- Dyers Creek (Figure 11e and 14e) with ARC site 29
- Grants Island (Figure 11f And 14f) with ARC site 31

The range of predicted concentrations are always less than observed concentrations. These comparisons demonstrate that the sewage discharge makes a relatively small contribution to the DIN concentrations in the estuary.

The difference between the stage and wetland discharges on DIN concentrations are summarised in Table 3 and 4, which summarise information from Figures 11-16. Overall, there is not a great deal of difference in the two discharges.

A complete set of plots of the plume concentrations (Figures 13 and 16) are provided so that the concentrations of DIN contributed from the sewage can be estimated for any site in the harbour.

	Staged discharge			Wetland discharge		
Site	Peak concentration (mg/l)	Time of peak	Time (%) effluent DIN present	Peak concentration (mg/l)	Time of peak	Time (%) effluent DIN present
Main Channel						
Dawsons	0.054	Low water	96	0.059	Low water	100
Cowans	0.018	Low water	81	0.022	Low water	85
Dyers	0.018	Low water	85	0.016	Low water	73
Grants	0.008	Low water	89	0.012	Low water	69
Scotts	0.0025	-	69	<0.001	-	46
Oyster Farms						
Huawai	0	-	0	0	-	0
Te Kapa	0	-	0	0	-	0
Puka Puka	0	-	-	0	-	0
Cowans	0.052	Mid flood	46	0.057	Mid flood	69
Dyers North	0.041	Mid flood	53	0.024	Mid flood	42
Dyers South	0.024	Mid flood	31	0.011	Mid flood	57
Browns	0.007	-	23	0.006	-	19

Table 3. Comparison of dissolved inorganic nitrogen (DIN) concentrations at different estuarine sites for staged and wetland discharges. Peak concentrations (mg/l) are given along with the stage of the tide when they occur (time of peak) and the proportion of time when effluent-derived DIN is present.

	Concentration (mg/l Nitrogen) for staged discharge					Concentration (mg/l Nitrogen) for wetland discharge				
Time relative to high water	Mean	Average in plume	Minimum in plume	Maximum in plume	Maximum	Mean	Average in plume	Minimum in plume	Maximum in plume	Maximum
0	0.030	0.100	0.044	0.179	0.280	0.050	0.129	0.099	0.165	0.500
1	0.050	0.117	0.050	0.202	0.480	0.050	0.138	0.074	0.208	0.670
2	0.050	0.138	0.081	0.194	0.550	0.040	0.152	0.106	0.210	0.320
3	0.040	0.155	0.056	0.270	0.270	0.050	0.152	0.093	0.223	0.250
4	0.040	0.098	0.044	0.164	0.380	0.040	0.141	0.083	0.239	0.320
5	0.050	0.118	0.078	0.158	0.320	0.050	0.128	0.096	0.199	0.380
6	0.060	0.163	0.113	0.221	0.380	0.060	0.263	0.160	0.531	0.340
7	0.070	0.159	0.111	0.214	0.480	0.070	0.291	0.171	0.443	0.530
8	0.080	0.241	0.124	0.443	0.520	0.090	0.212	0.129	0.387	0.380
9	0.070	0.227	0.129	0.312	0.380	0.070	0.179	0.165	0.200	0.420
10	0.060	0.180	0.141	0.310	0.530	0.060	0.155	0.055	0.283	0.350
11	0.040	0.173	0.081	0.266	0.400	0.050	0.128	0.055	0.229	0.250
12	0.040	0.122	0.041	0.197	0.300	0.040	0.117	0.042	0.186	0.380

Table 4. Dissolved inorganic nitrogen (DIN) concentrations (mg/l) for the staged and wetland discharges. Mean value is the mean over the extent of the plume. Average, minimum and maximum values are for the core of the plume. Maximum is the maximum concentration anywhere in the estuary.

PHOSPHORUS

Figure 17 and 18 shows the time series plots of DRP concentrations for the staged discharge at selected sites within the main channel and oyster farms of the estuary. Fig 19 (a-z) maps the concentration of DRP in the plume and estuary over a tidal cycle. These predictions are made assuming that the sewage discharge is the sole source of DRP. Figures 20-22 show the equivalent situation for the wetland discharge.

The relative importance of the sewage discharge to phosphorus nutrient status of the estuary can be assessed by comparing predicted and measured concentrations. The Auckland Regional Council (1993) only report data for the lower estuary. This data is summarised in Appendix 1, and is used for the comparison. These comparisons that can be made are:

- Dyers Creek (Figure 11e and 14e) with ARC site 29
- Grants Island (Figure 11f And 14f) with ARC site 31

The range of predicted concentrations are similar to observed concentrations which suggests that the sewage discharge makes a significant contribution to the DRP concentrations in the estuary. However, this conclusion would be more robust if comparisons could be made in the upper estuary, as was done for DIN. Measured concentrations of DRP in the upper estuary do not seem to be available (Auckland Regional Council 1993).

The difference between the stage and wetland discharges are summarised in Table 3 and 4, which summarise information from Figures 17-22. Overall, as expected from earlier discussion, there is not a great deal of difference in the two discharges.

A complete set of plots of the plume concentrations (Figure 19 and 22) are provided, so that the concentrations of DRP contributed from the sewage can be estimated for any site in the estuary.

	Staged discharge			Wetland discharge		
Site	Peak concentration (mg/l)	Time of peak	Time (%) effluent DRP present	Peak concentration (mg/l)	Time of peak	Time (%) effluent DRP present
Main Channel						
Dawsons	0.059	Low water	100	0.068	Low water	100
Cowans	0.024	Low water	96	0.02	Low water	100
Dyers	0.014	Low water	88	0.025	Low water	100
Grants	0.009	Low water	92	0.007	Low water	85
Scotts	0.001	-	69	0.003	-	77
Oyster Farms						
Huawai	0	-	0	0	-	0
Te Kapa	0	-	0	0	-	0
Puka Puka	0.002	High water	-	0	-	0
Cowans	0.052	Mid flood	81	0.064	Mid flood	73
Dyers North	0.039	Mid flood	76	0.039	Mid flood	80
Dyers South	0.014	Mid flood	57	0.014	Mid flood	65
Browns	0.11	-	57	0.009	-	65

Table 5. Comparison of dissolved reactive phosphorus (DRP) concentrations at different estuarine sites for staged and wetland discharges. Peak concentrations (mg/l) are given along with the stage of the tide when they occur (time of peak) and the proportion of time when effluent-derived DRP is present.

	Concentration (mg/l Phosphorus) for staged discharge					Concentration (mg/l Phosphorus) for wetland discharge				
Time relative to high water	Mean	Average in plume	Minimum in plume	Maximum in plume	Maximum	Mean	Average in plume	Minimum in plume	Maximum in plume	Maximum
0	0.005	0.096	0.048	0.168	0.027	0.005	0.120	0.084	0.168	0.480
1	0.005	0.120	0.054	0.168	0.378	0.005	0.114	0.060	0.270	0.360
2	0.004	0.132	0.066	0.180	0.390	0.003	0.120	0.060	0.162	0.210
3	0.003	0.126	0.090	0.204	0.240	0.003	0.096	0.066	0.144	0.192
4	0.003	0.102	0.078	0.168	0.252	0.003	0.108	0.066	0.168	0.270
5	0.004	0.114	0.072	0.180	0.390	0.004	0.144	0.102	0.180	0.336
6	0.005	0.108	0.078	0.120	0.312	0.005	0.156	0.108	0.264	0.300
7	0.006	0.162	0.090	0.312	0.288	0.007	0.144	0.084	0.222	0.390
8	0.007	0.168	0.102	0.240	0.390	0.007	0.186	0.144	0.252	0.312
9	0.007	0.156	0.108	0.306	0.360	0.007	0.144	0.102	0.288	0.348
10	0.005	0.174	0.138	0.228	0.348	0.005	0.156	0.102	0.246	0.300
11	0.004	0.150	0.102	0.204	0.288	0.004	0.108	0.072	0.168	0.258
12	0.004	0.126	0.102	0.168	0.228	0.004	0.114	0.090	0.162	0.324

Table 6. Dissolved reactive phosphorus (DRP) concentrations (mg/l) for the staged and wetland discharges. Mean value is the mean over the extent of the plume. Average, minimum and maximum values are for the core of the plume. Maximum is the maximum concentration anywhere in the estuary.

DISCUSSION

The two discharge regimes produce different effluent concentrations at different sites throughout the Mahurangi Estuary. For example within the main channel at Dawson Creek the staged discharge gives a lower peak (and mean) effluent concentration (Figures 5a, 8a) compared to the wetland discharge. However, opposite Grants Island the reverse is true (Figure 5d, 8d). Likewise, within the core of the plume, at times one discharge regime produces higher concentrations than the other, while at other times, the reverse is true (Table 1-6). Similarly, for the oyster farm sites, some receive higher effluent concentrations under the staged discharge regime than the wetland discharge regime (Cowans Bay - Figures 6g, 9g), while others receive lower effluent concentrations under the staged discharge regime than the wetland discharge regime (Dyers Creek South - Figures 6e, 9e). The oyster farm at the north of Dyers creek receives similar quantities of effluent from both discharge regimes.

DIN concentration within the main channel are very similar for the two discharge regimes (Figures 11 and 14). Here the loss of nitrogen, effectively "smoothes" the differences between the two discharge regimes. Similarly, within the oyster farm sites, there are similar concentration values for the different discharge regimes. However there are subtleties within the time series plots. For example, at the northern Dyers Creek site, average concentrations are very similar, but the peak value for the staged discharge is higher compared to the wetland discharge (0.041 mg/l compared to 0.024 mg/l). Lower nitrogen concentrations occur on the ebbing tide compared to the flooding tide.

Data from the main channel sites should be used to give an indication of the worst case effluent concentrations that could be encountered on inter-tidal areas outside the main channels. This would happen if wind conditions were such that the plume arrived "intact" at a channel site and was then displaced onto the adjoining inter-tidal areas.

Clearly, there is no best discharge option in terms of the Mahurangi Estuary as a whole. The data presented within this report will help to identify areas where one regime provides lower concentrations than the other.

REFERENCES

Auckland Regional Council (1993) "Review of Mahurangi Catchment, Estuary and Harbour Water Quality" ARC Technical Publication Number 27.

Bell, R.G.; Oldman, J.W.; Black, K.P.; Gorman, R. (1996) "Challenges encountered modelling shoreline discharge from Mangere wastewater treatment plant" New Zealand water and wastes association 1996 annual conference proceedings.

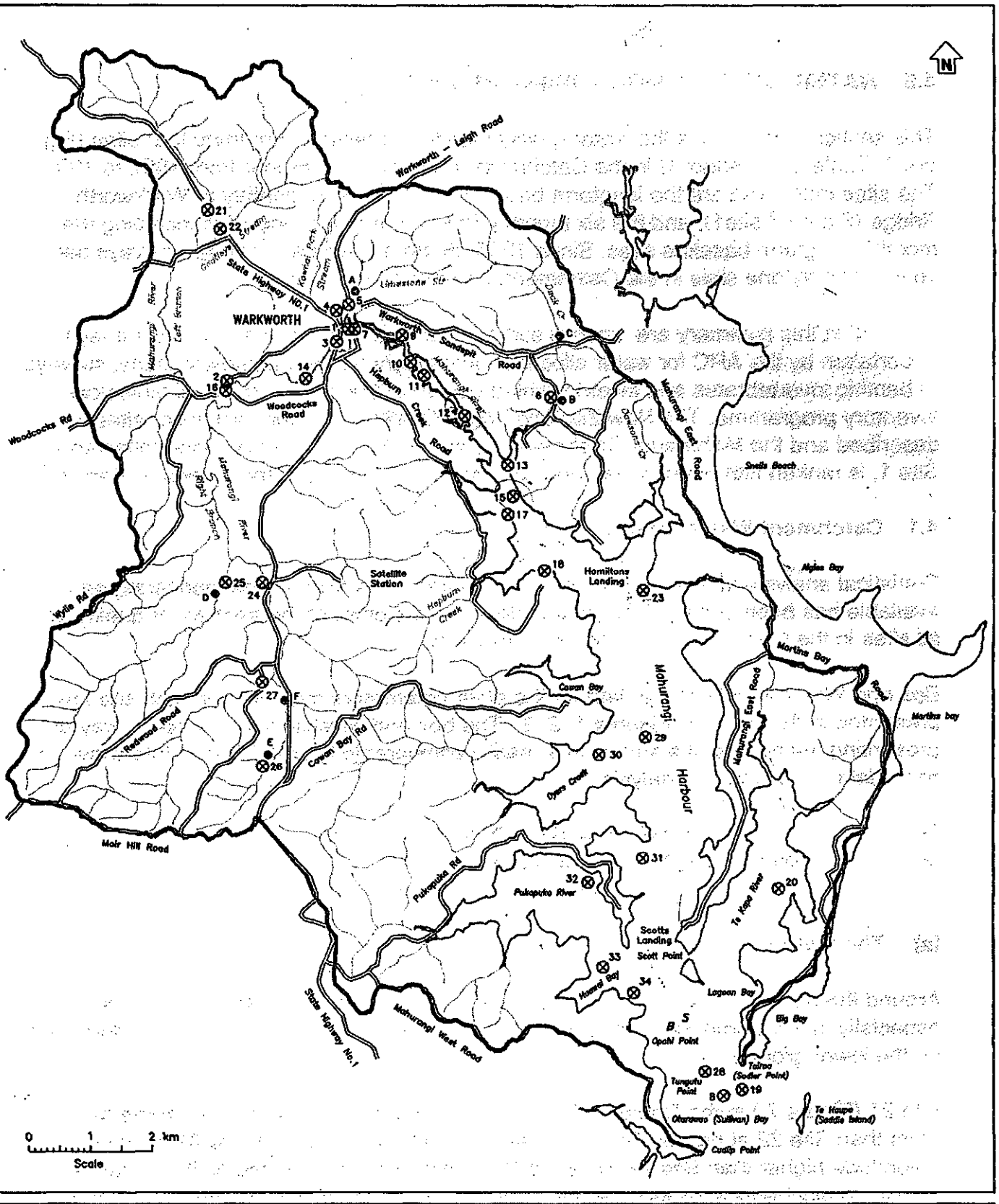
Black, K.P.; Bell, R.G.; Oldman, J.W.; Gorman, R.; Oulton, D. (1995) "Numerical modelling of a future diffuse shoreline discharge option for the Mangere wastewater treatment plant" NIWA Consultancy Report WSL60203/1.

Oldman, J.W.; Black, K.P.; (1997) "Mahurangi estuary numerical modelling" NIWA Consultancy Report ARC60208/1.

Stroud, M.J.; Cooper, A.B. (1997) "Modelling loads to the Mahurangi Estuary" NIWA Consultancy Report ARC60211.

APPENDIX 1

Relevant maps, tables and figures for Auckland Regional Council (1993) on water quality monitoring data for the Mahurangi Harbour.



MAHURANGI CATCHMENT AND HARBOUR

WATER QUALITY MONITORING SITES

BOUNDARY OF STUDY AREA

ROAD

99 WATER QUALITY MONITORING SITES

RIVER

A BENTHIC INVERTEBRATES AND ELECTRIC FISHING SITES

S/B SALINE OR BIOMONITORING SITE

FIGURE 7

Produced by Environment and Planning Division
Auckland Regional Council

WOMAHUB

APPENDIX 1

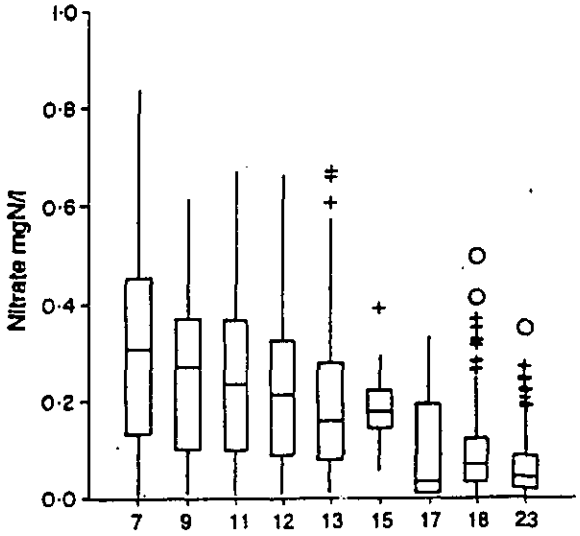
TABLE 3

WATER QUALITY MONITORING SITES

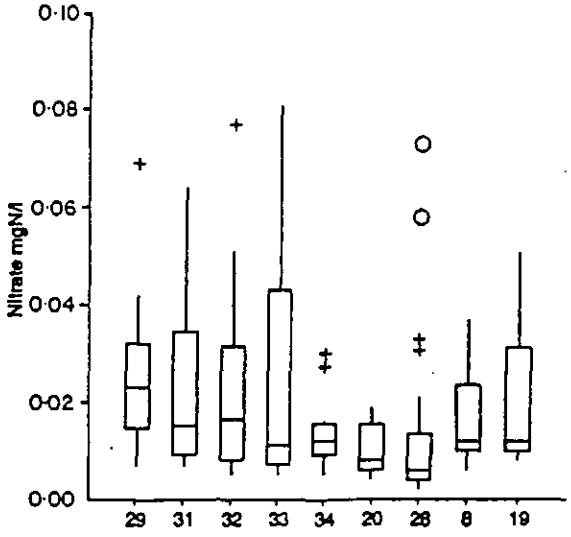
NO.	LOCATION	MAP REF
1	Mahurangi River/Warkworth Bridge	R09 596,324
2	Mahurangi River/L Branch at Falls Rd	R09 576,315
3	Mahurangi River/Water supply intake jetty	R09 594,322
4	Kowhai Park St at campsite bridge	R09 594,327
5	Limeworks St at Sandspit Rd	R09 596,328
6	Duck Creek at Hamilton Rd	R09 629,313
7	Town Basin	R09 597,324
8	Mouth of Mahurangi off Sadler and Tungutu	R09 657,199
9	U/S of S.T.P. outfall	R09 605,323
10	S.T.P. Pebble filter discharge	R09 606,319
11	D/S of septic tank outfall	R09 608,317
12	Jetty D/S of cement works	R09 615,310
13	Mahurangi River off Duck Creek	R09 622,302
14	Recorder site	R09 589,316
15	D/S off Duck Creek	R09 623,297
16	Mahurangi River/R. branch at Woodcocks Rd	R09 576,314
17	Mahurangi River D/S of Vialls Landing and S.T.P.	R09 622,294
18	S.H. Beacon/Estuary month (Hepburn Creek)	R09 628,285
19	Mahurangi Heads	R10 660,200
20	Te Kapa Inlet	R10,666,233
21	Mahurangi/Dome Valley	R09 573,343
22	Mahurangi/Mission Creek	R09 575,340
23	Dawsons Creek mouth	R09 644,281
24	Mahurangi/Perry Road	R09 582,283
25	Mahurangi/Stillwater farm	R09 576,283
26	Mahurangi/Pohuehue Stream	R09 582,253
27	Mahurangi/Mahurangi Road	R09 582,267
28	Mahurangi Harbour at Heads	R09 654,203
29	D/S of Bradley Pt/At mouth of Dyers Creek	R09 645,258
30	Inshore Dyers Creek	R09 637,255
31	Brownes Bay	R09 644,238
32	Pukapuka Inlet U/S of Oaua Point	R09 635,234
33	Huawai Bay	R09 637,220
34	Jamieson Bay	R09 642,216
A	Limeworks Stream	R09 597,330
B	Duck Creek	R09 631,313
C	Adj to Warkworth-Sandspit Rd	R09 630,323
D	Stillwater Farm	R09 574,281
E	Pohuehue Catchment-Electric Fishing	R09 583,255
F	Pohuehue Catchment-Benthic Invertebrates	R09 585,264

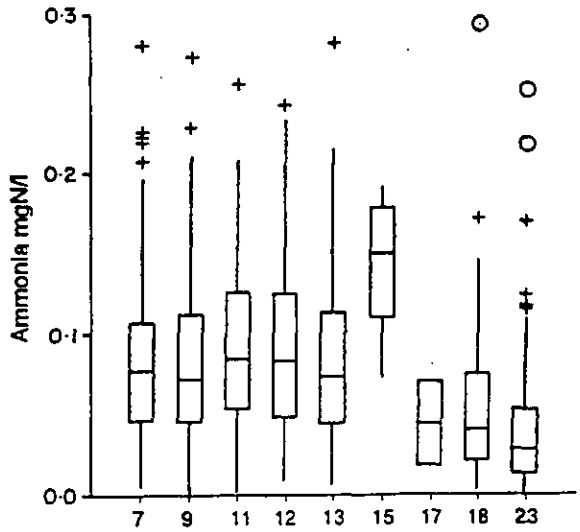
Results from water quality monitoring

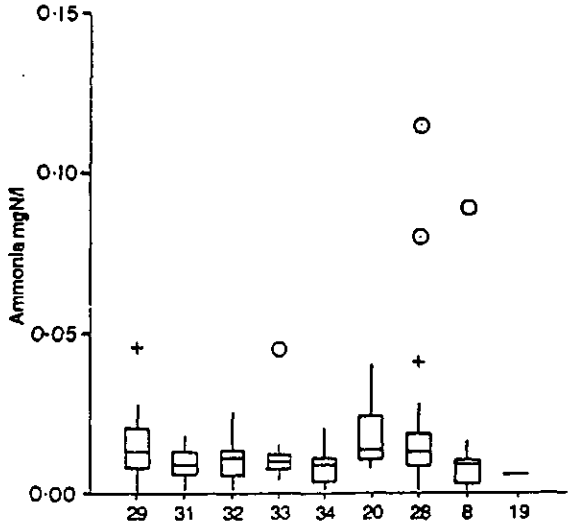
Upper Estuary monitoring sites

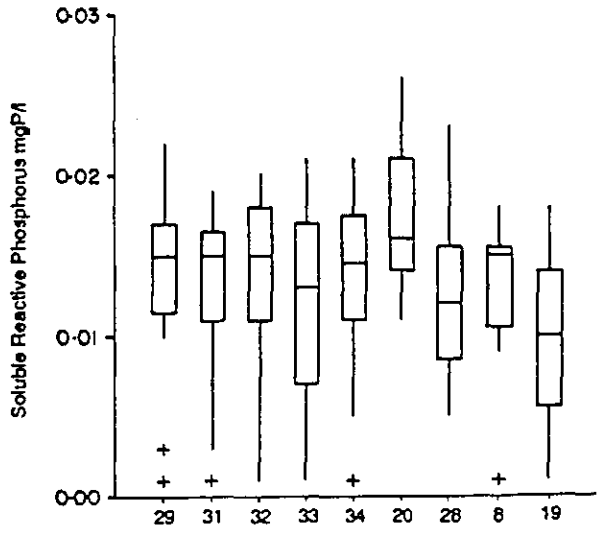


Lower Estuary monitoring sites









APPENDIX 2: FIGURES

Figure 1. Input data for the staged discharge. Discharge volume 160 cubic metres per hour. Commencing one hour before high water and continuing for 7.5 hours

Figure 2. Input data for the wetland discharge. Dilution of effluent through wetland system assumed to be 50% during first 3 hours of tide. Discharge volume varies throughout the tide starting at high water continuing for 7 hours

Figure 3. Mahurangi Estuary location map

Figure 4. Mahurangi Estuary bathymetry and location of oyster farms.

Figure 5. Time series of percent effluent for Staged discharge to Mahurangi River for selected sites in the main channel

Figure 6. Percent effluent concentrations for Staged discharge to Mahurangi River. Spatial average for oyster farms at sites as indicated

Figure 7a. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7b. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus one hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7c. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus two hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7d. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus three hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7e. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus four hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7f. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus five hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7g. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus six hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7h. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus half an hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7i. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus one and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7j. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus two and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7k. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus three and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7l. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus four and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7m. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus five and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7n. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus half an hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7o. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus one and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7p. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus two and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7q. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus three and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7r. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus four and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7s. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus five and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7t. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7u. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus one hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7v. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus two hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7w. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus three hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7x. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus four hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7y. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus five hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 7z. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 8. Time series of percent effluent for Wetland discharge to Mahurangi River for selected sites in the main channel

Figure 9. Percent effluent concentrations for Wetland discharge to Mahurangi River. Spatial average for oyster farms at sites as indicated

Figure 10a. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10b. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus one hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10c. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus two hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10d. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus three hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10e. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus four hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10f. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus five hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10g. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus six hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10h. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus half an hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10i. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus one and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10j. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus two and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10k. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus three and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10l. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus four and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10m. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus five and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10n. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus half an hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10o. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus one and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10p. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus two and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10q. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus three and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10r. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus four and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10s. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus five and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10t. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10u. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus one hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10v. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus two hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10w. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus three hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10x. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus four hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10y. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus five hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 10z. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

Figure 11. . Time series of Nitrogen concentration (mg/l) for Staged discharge to Mahurangi River for selected sites in the main channel

Figure 12. Nitrogen concentration (mg/l) for Staged discharge to Mahurangi River. Spatial average for oyster farms at sites as indicated

Figure 13a. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13b. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13c. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13d. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13e. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13f. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13g. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus six hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13h. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus half an hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13i. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13j. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13k. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13l. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13m. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13n. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus half an hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13o. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13p. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13q. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13r. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13s. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13t. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13u. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13v. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13w. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13x. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13y. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 13z. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 14. Time series of Nitrogen concentration (mg/l) for Wetland discharge to Mahurangi River for selected sites in the main channel

Figure 15. Nitrogen concentration (mg/l) for Wetland discharge to Mahurangi River. Spatial average for oyster farms at sites as indicated

Figure 16a. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16b. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16c. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16d. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16e. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16f. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16g. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus six hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16h. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus half an hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16i. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16j. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16k. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16l. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16m. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16n. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus half an hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16o. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16p. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16q. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16r. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16s. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16t. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16u. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16v. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16w. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16x. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16y. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 16z. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 17. Time series of Phosphorus concentration (mg/l) for Staged discharge to Mahurangi River for selected sites in the main channel

Figure 18. Phosphorus concentration (mg/l) for Staged discharge to Mahurangi River. Spatial average for oyster farms at sites as indicated

Figure 19a. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19b. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19c. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19d. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19e. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19f. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19g. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus six hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19h. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus half an hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19i. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19j. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19k. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19l. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19m. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19n. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus half an hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19o. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19p. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19q. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19r. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19s. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19t. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19u. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19v. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19w. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19x. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19y. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 19z. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 20. Time series of Phosphorus concentration (mg/l) for Wetland discharge to Mahurangi River for selected sites in the main channel

Figure 21. Phosphorus concentration (mg/l) for Wetland discharge to Mahurangi River. Spatial average for oyster farms at sites as indicated

Figure 22a. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22b. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22c. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22d. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22e. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22f. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22g. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus six hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22h. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus half an hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22i. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22j. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22k. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22l. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22m. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22n. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus half an hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22o. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22p. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22q. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22r. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22s. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22t. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22u. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22v. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22w. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22x. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22y. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

Figure 22z. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

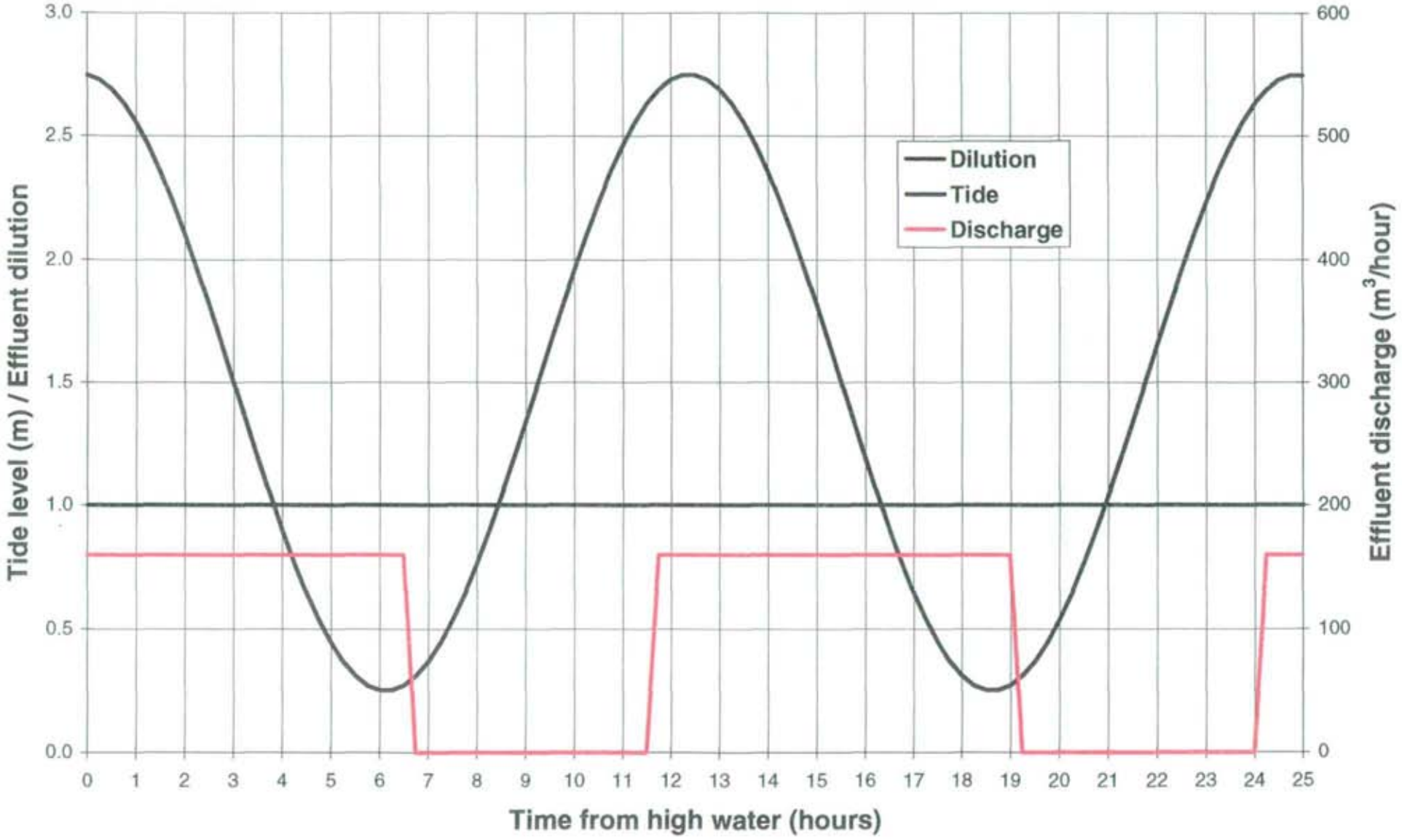


Figure 1. Input data for the staged discharge. Discharge volume 160 cubic metres per hour. Commencing one hour before high water and continuing for 7.5 hours

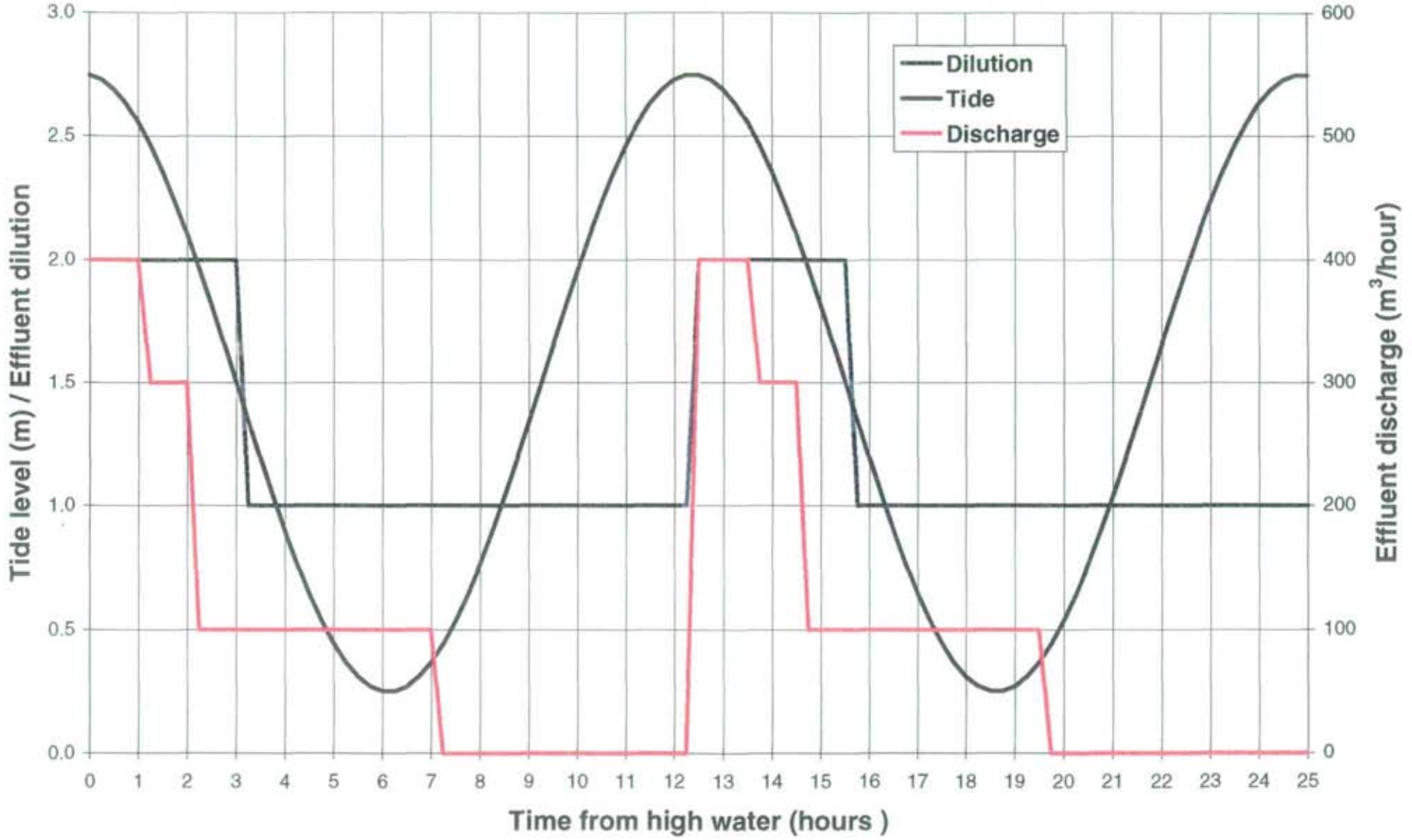


Figure 2. Input data for the wetland discharge. Dilution of effluent through wetland system assumed to be 50% during first 3 hours of tide. Discharge volume varies throughout the tide starting at high water continuing for 7 hours

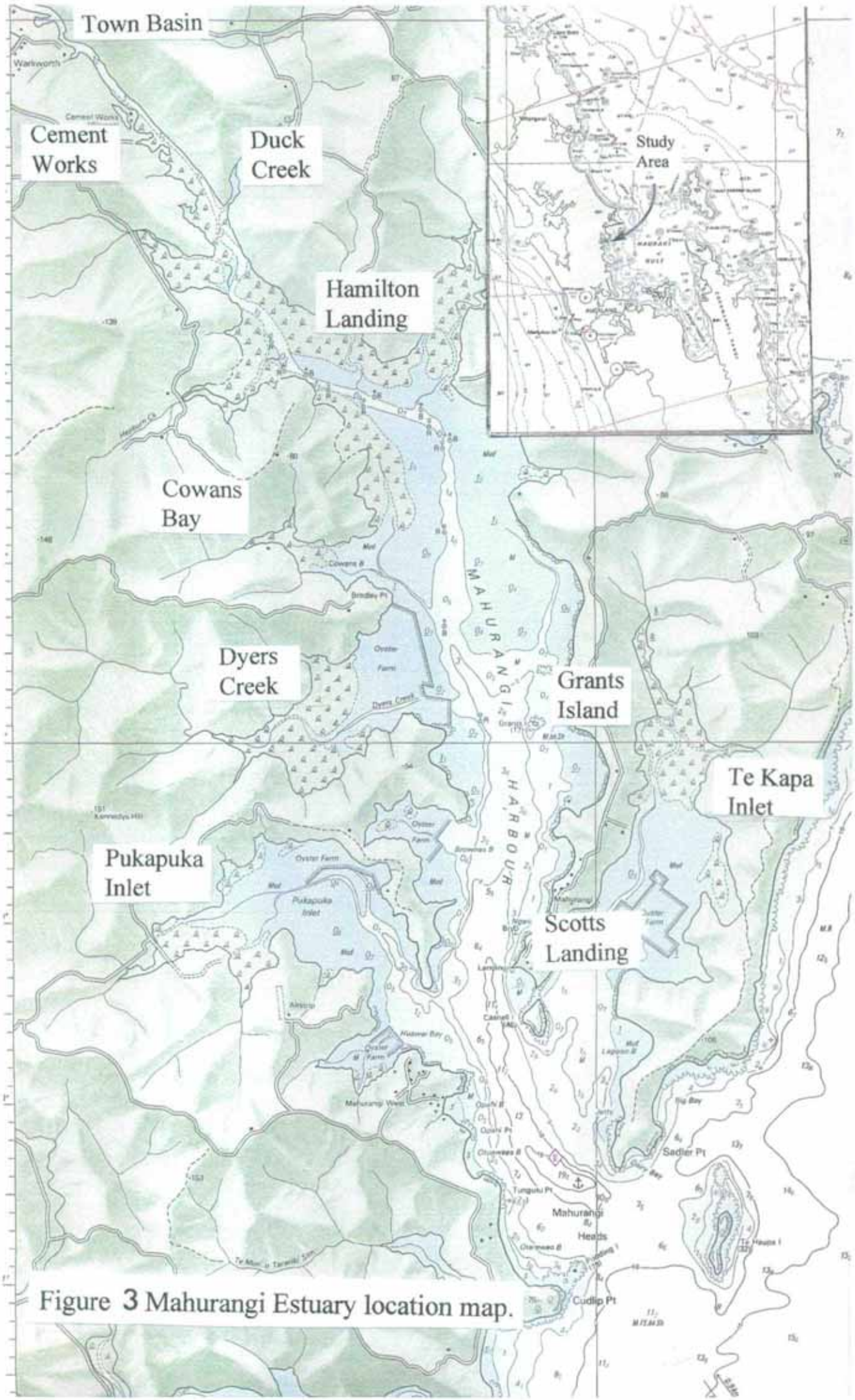


Figure 3 Mahurangi Estuary location map.

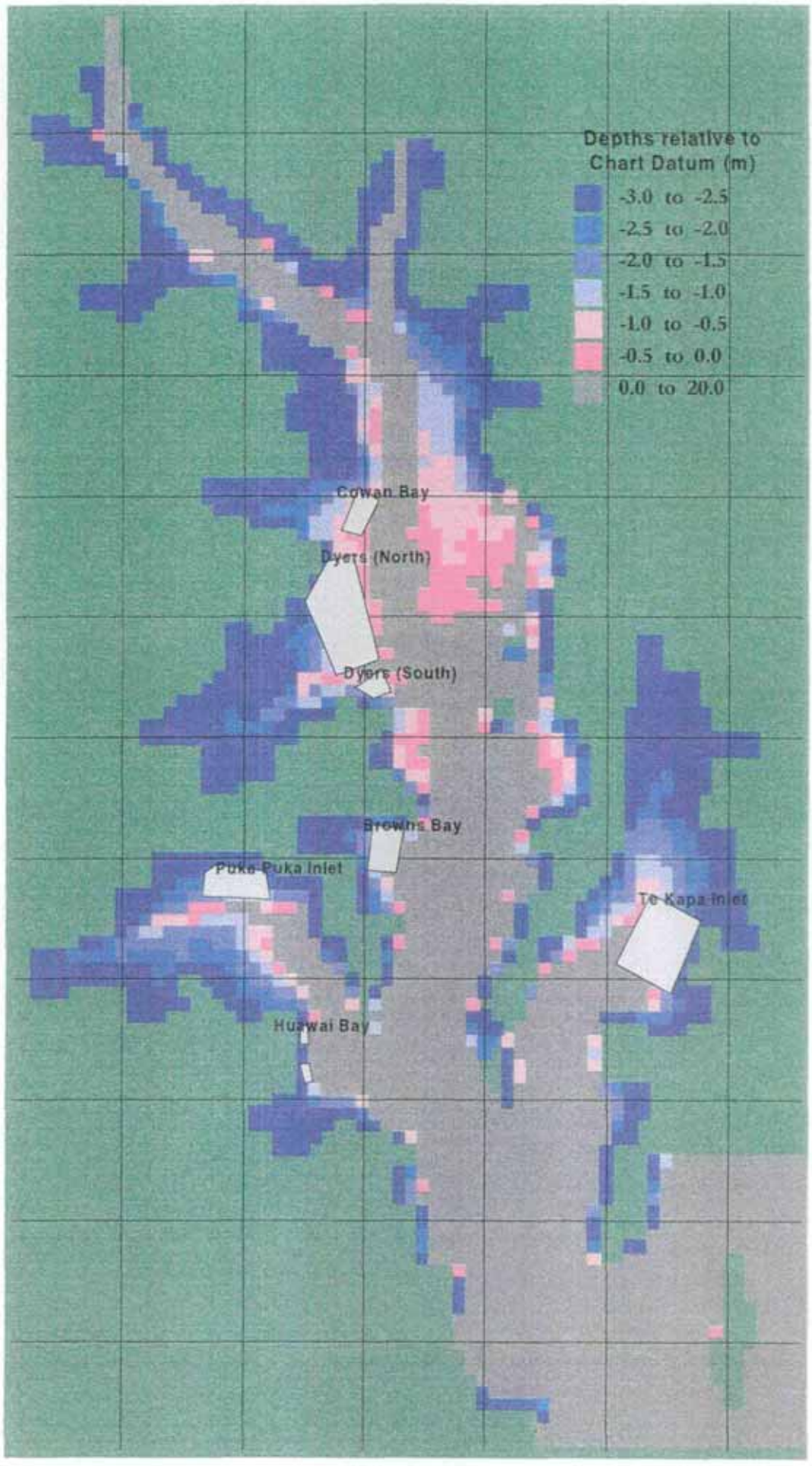


Fig 4. Mahurangi Estuary bathymetry and location of oyster farms.

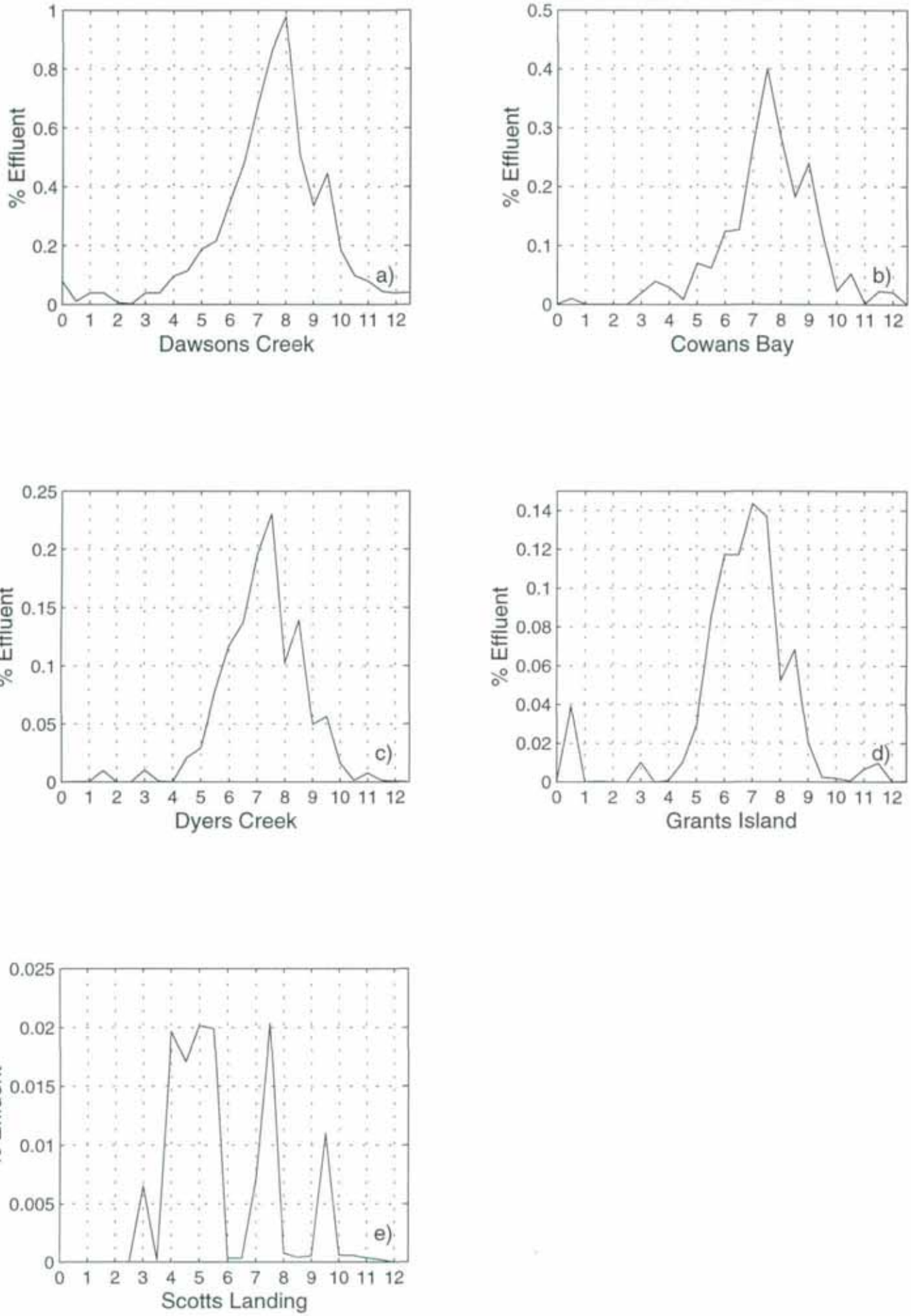


Figure 5: Time series of percent effluent for Staged discharge to Mahurangi River for selected sites in the main channel

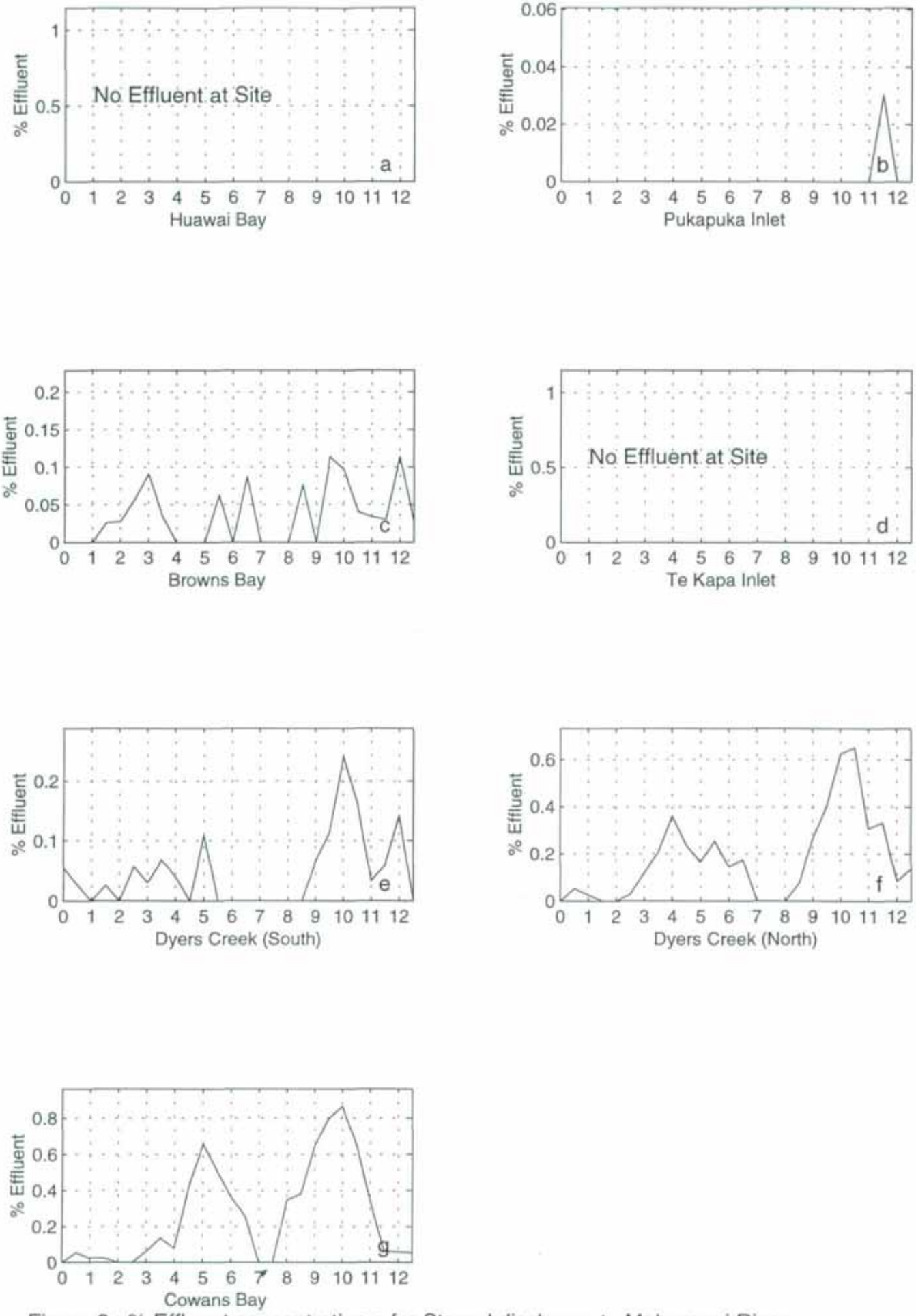


Figure 6 : % Effluent concentrations for Staged discharge to Mahurangi River. Spatial average for oyster farms at sites as indicated

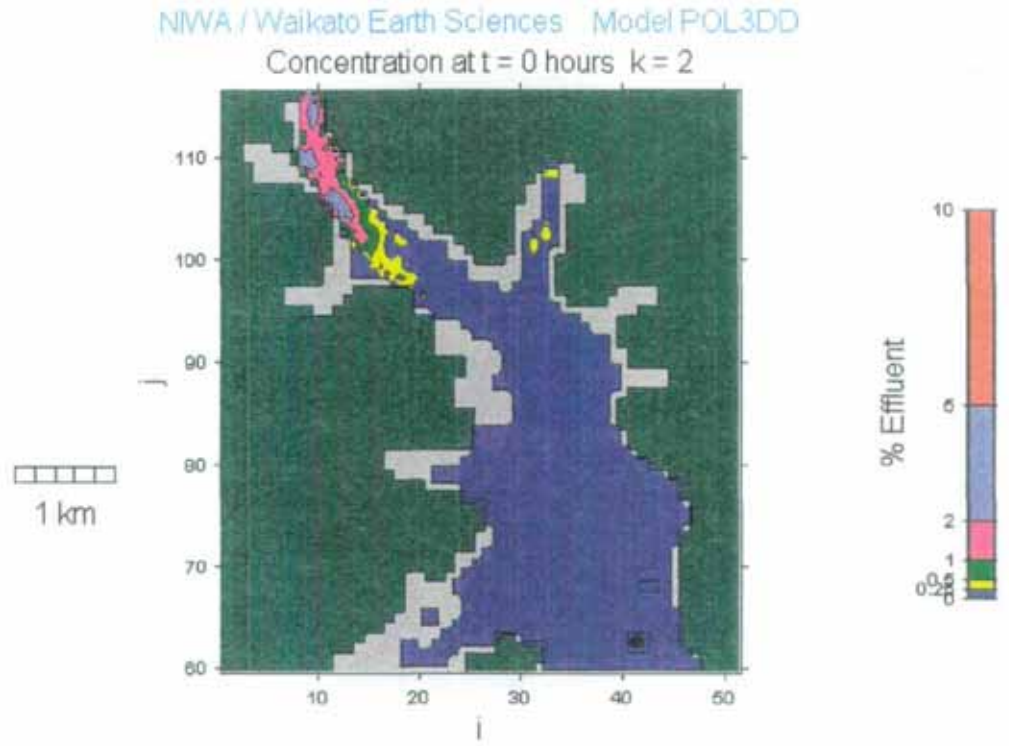


Figure 7a. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

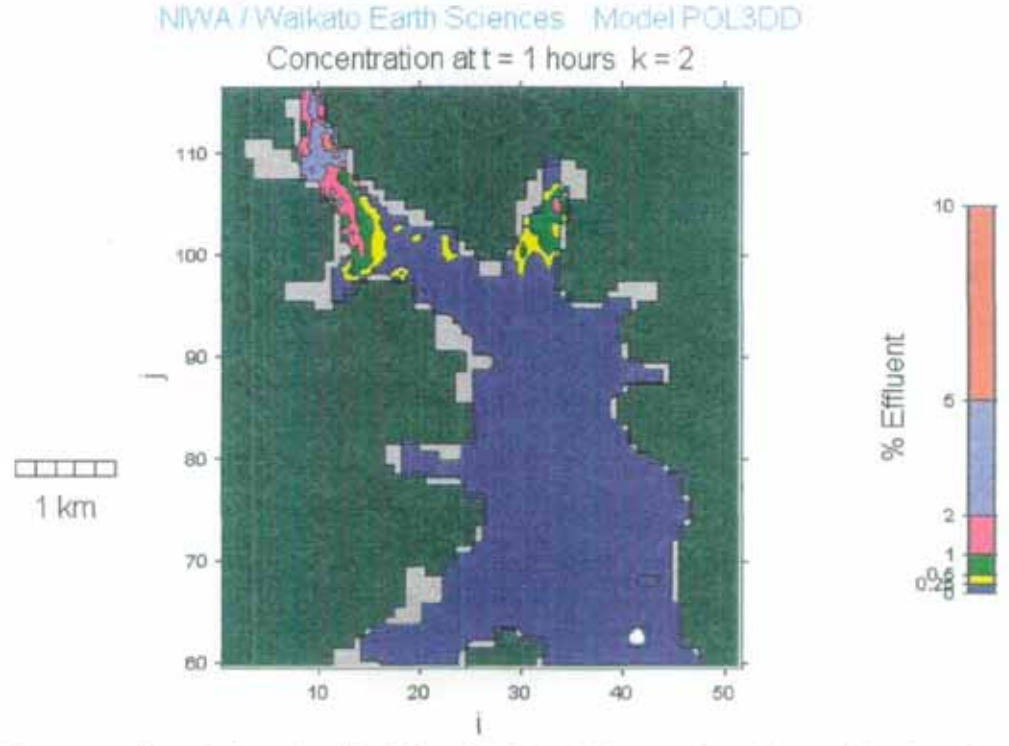


Figure 7b. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus one hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

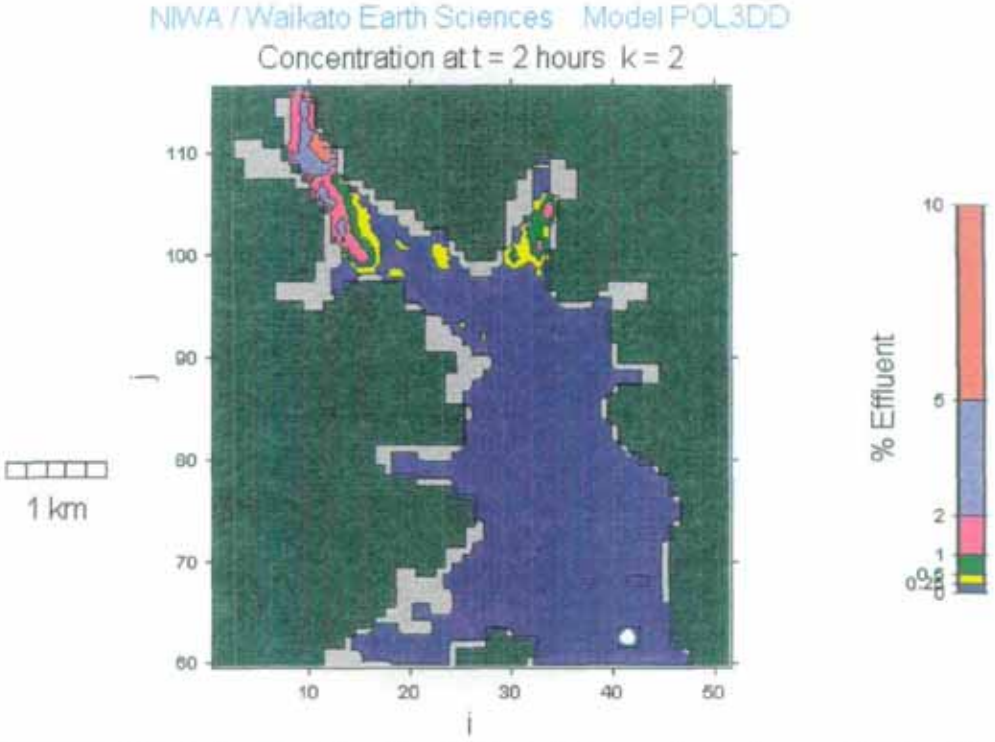


Figure 7c. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus two hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

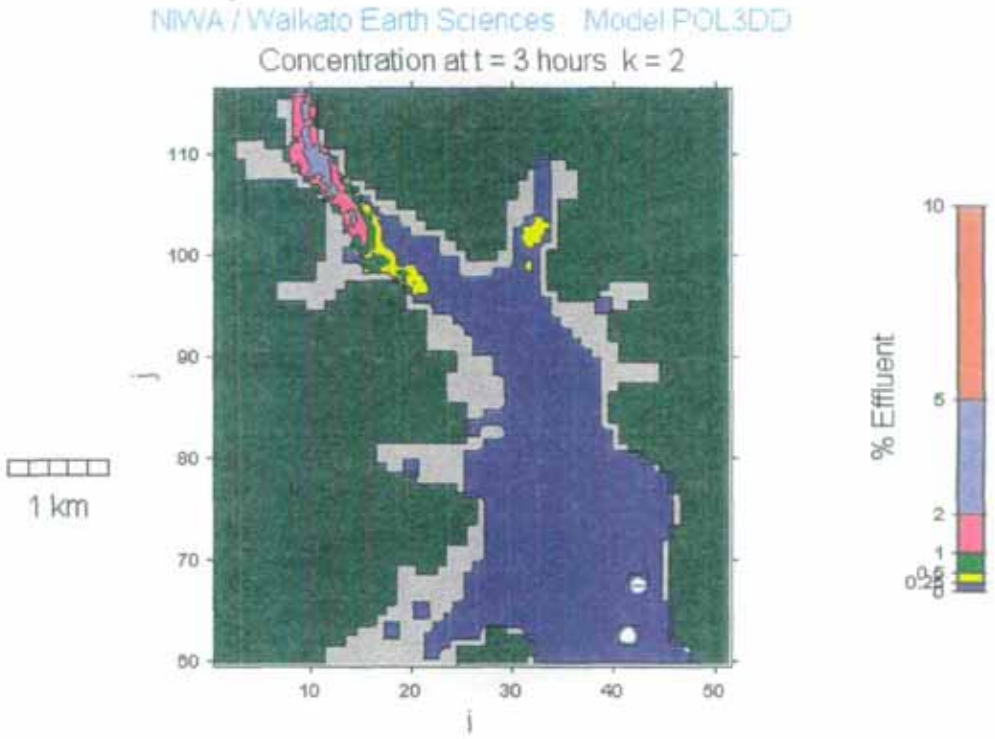


Figure 7d. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus three hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

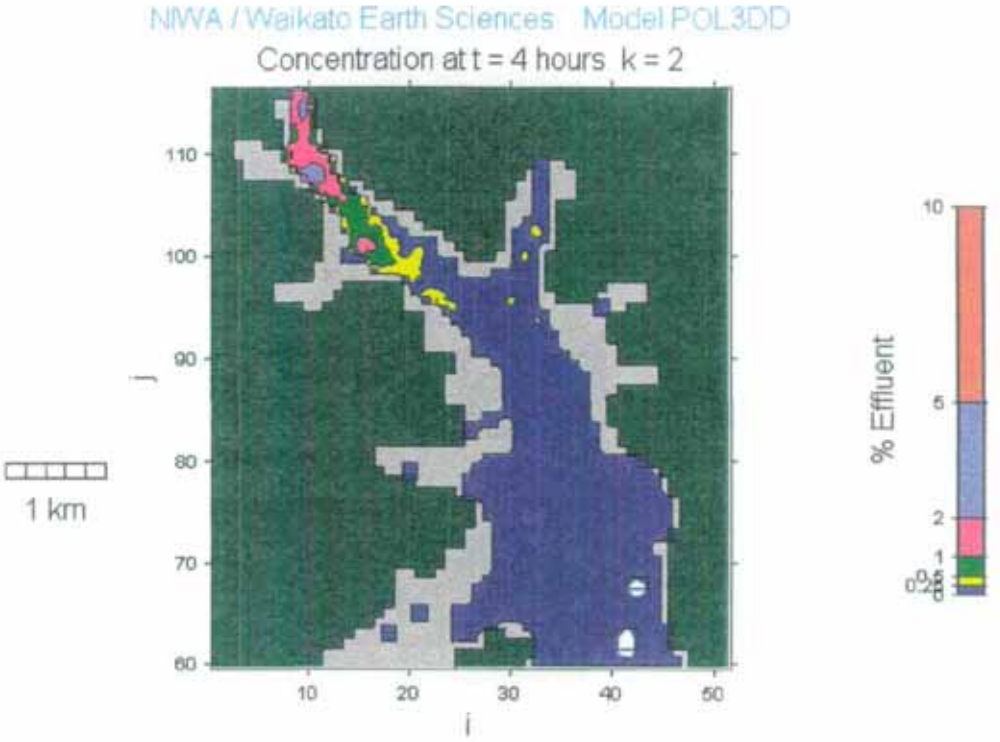


Figure 7e. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus four hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

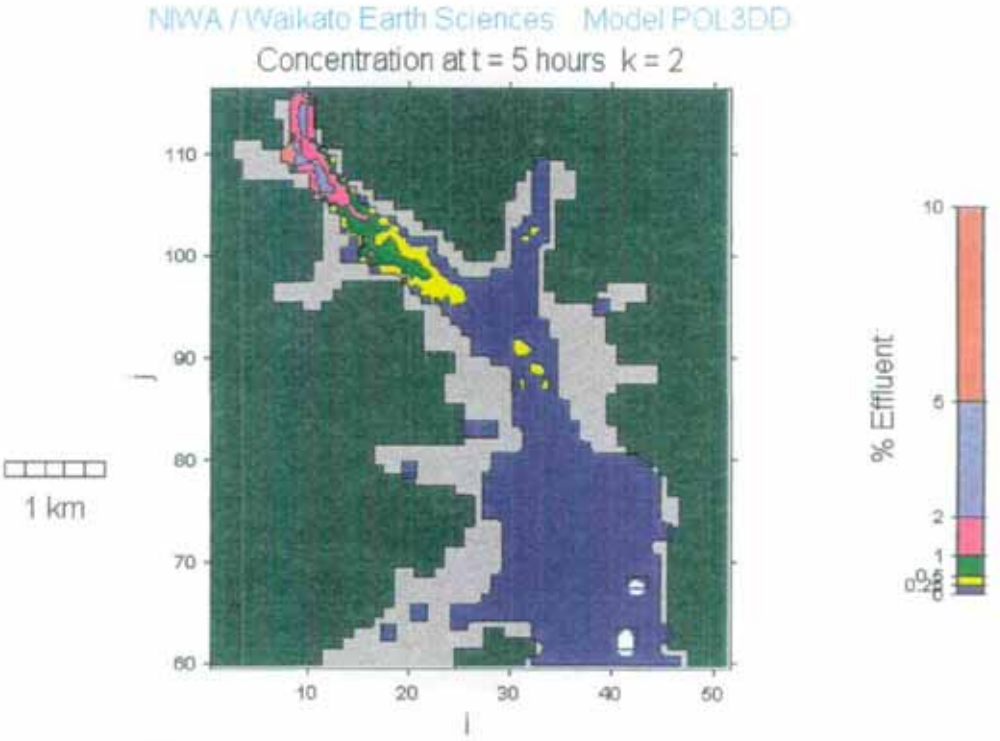


Figure 7f. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus five hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

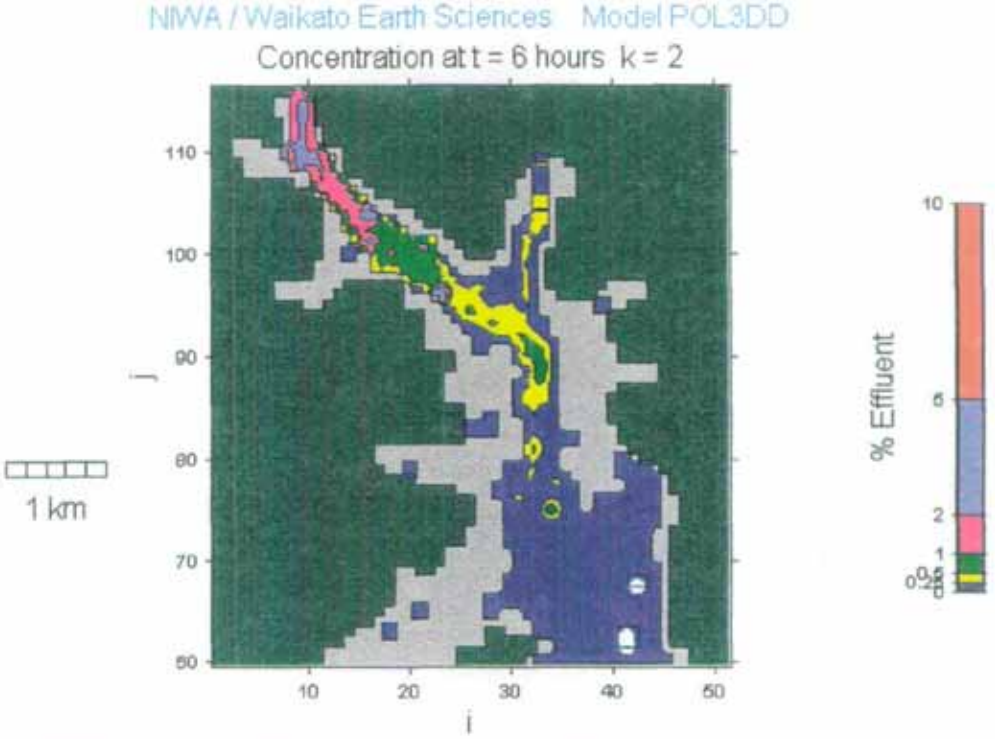


Figure 7g. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus six hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

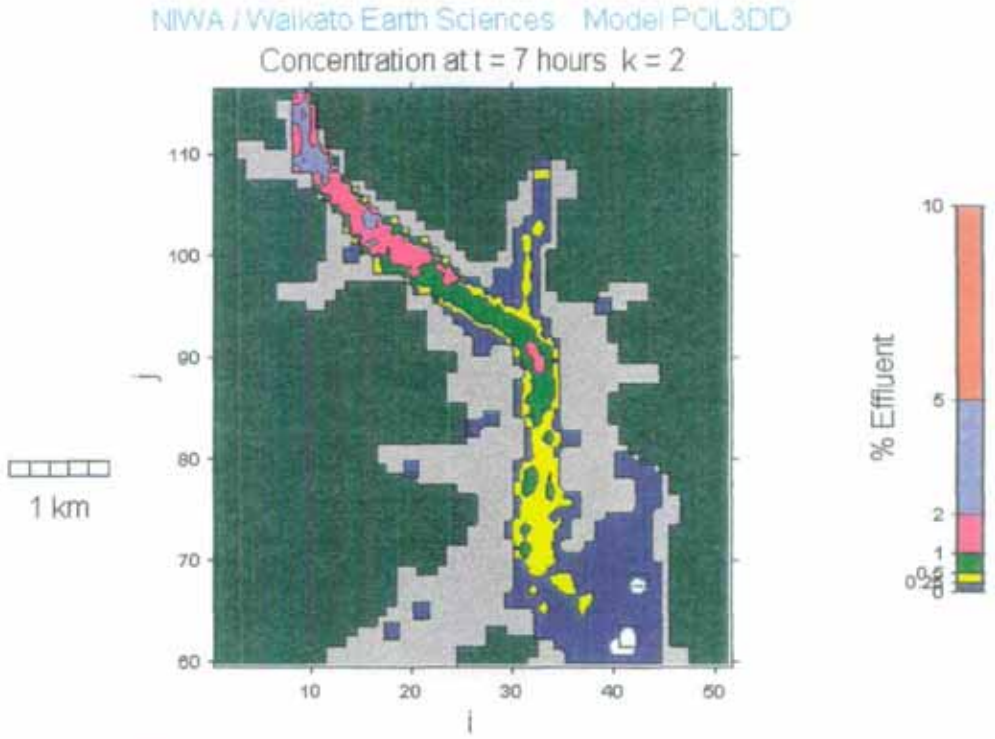


Figure 7h. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus half an hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

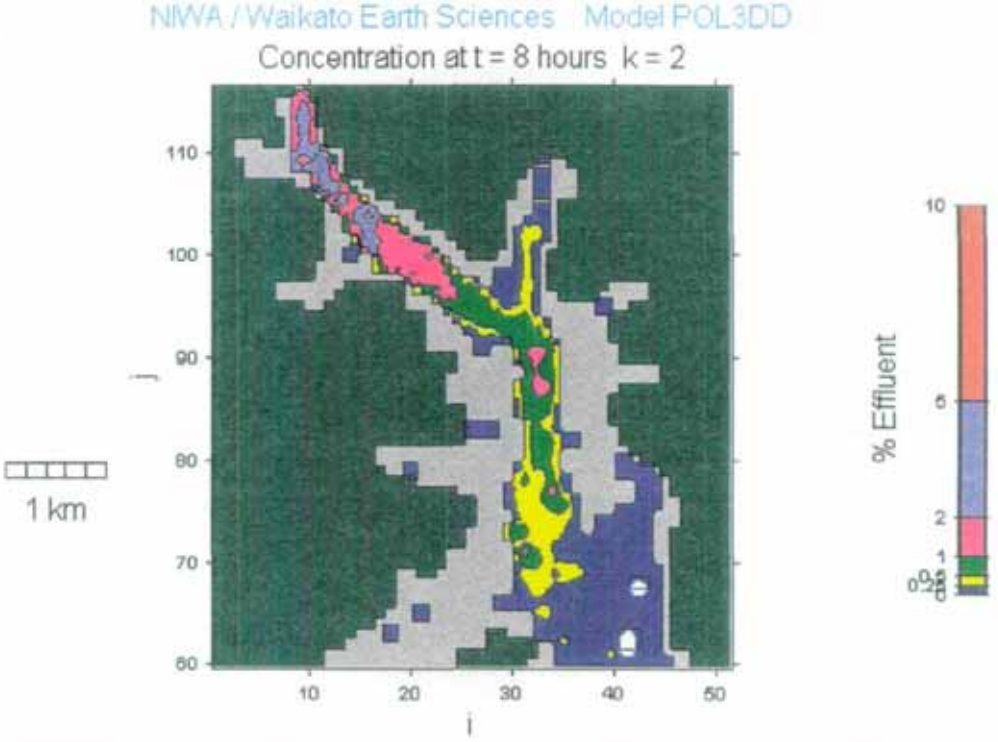


Figure 7i. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus one and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

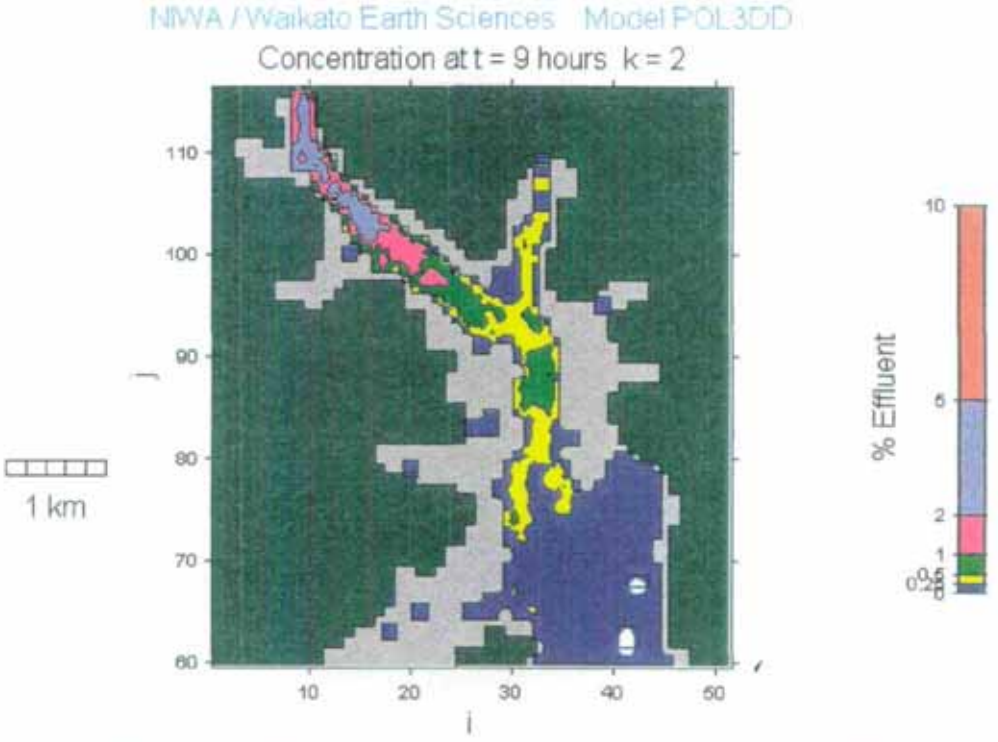


Figure 7j. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus two and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

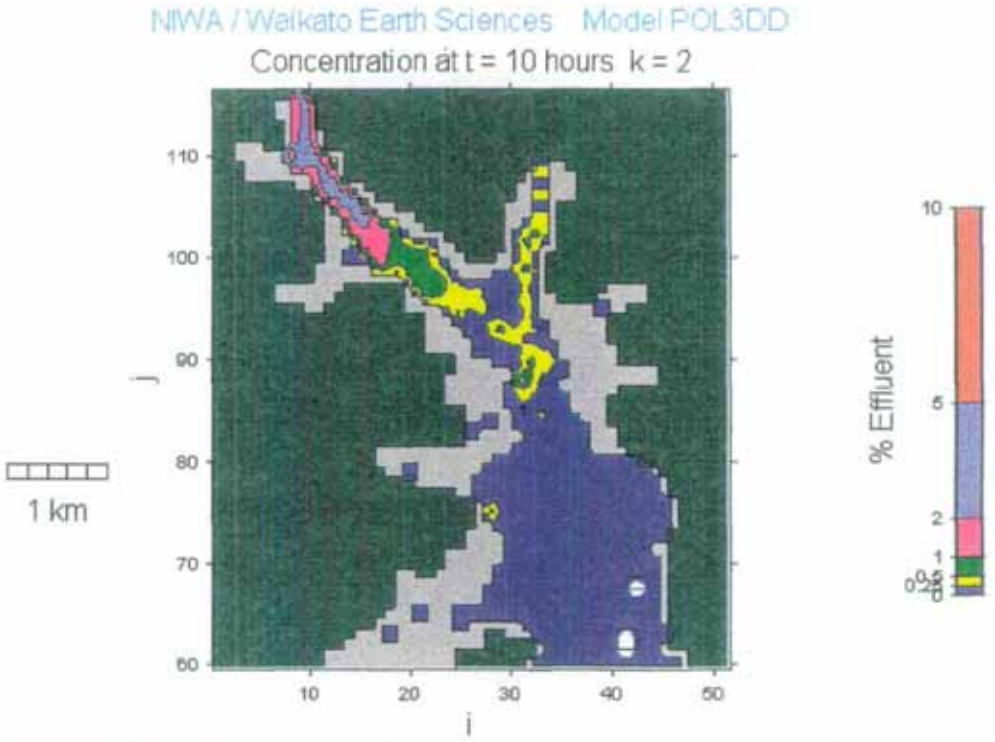


Figure 7k. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus three and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

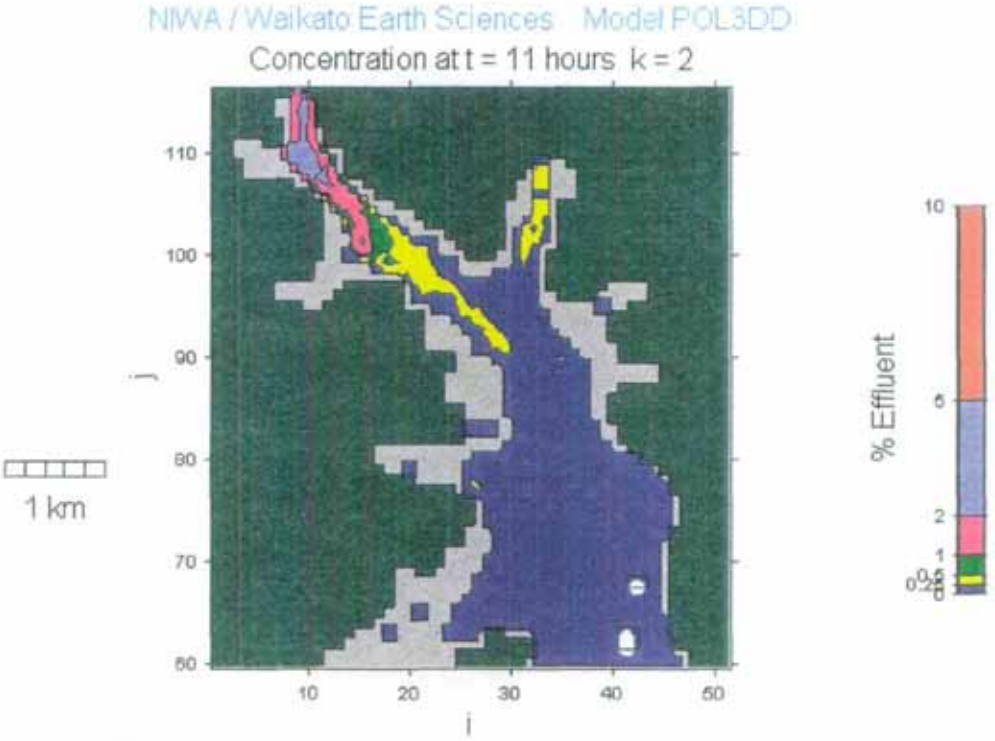


Figure 7l. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus four and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

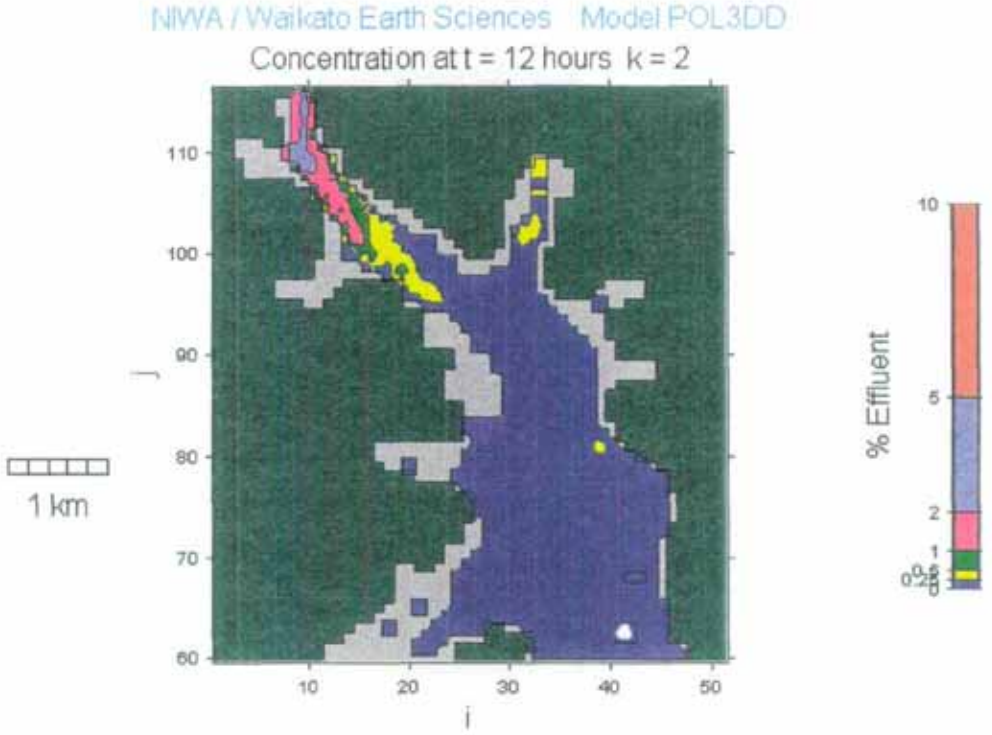


Figure 7m. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus five and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

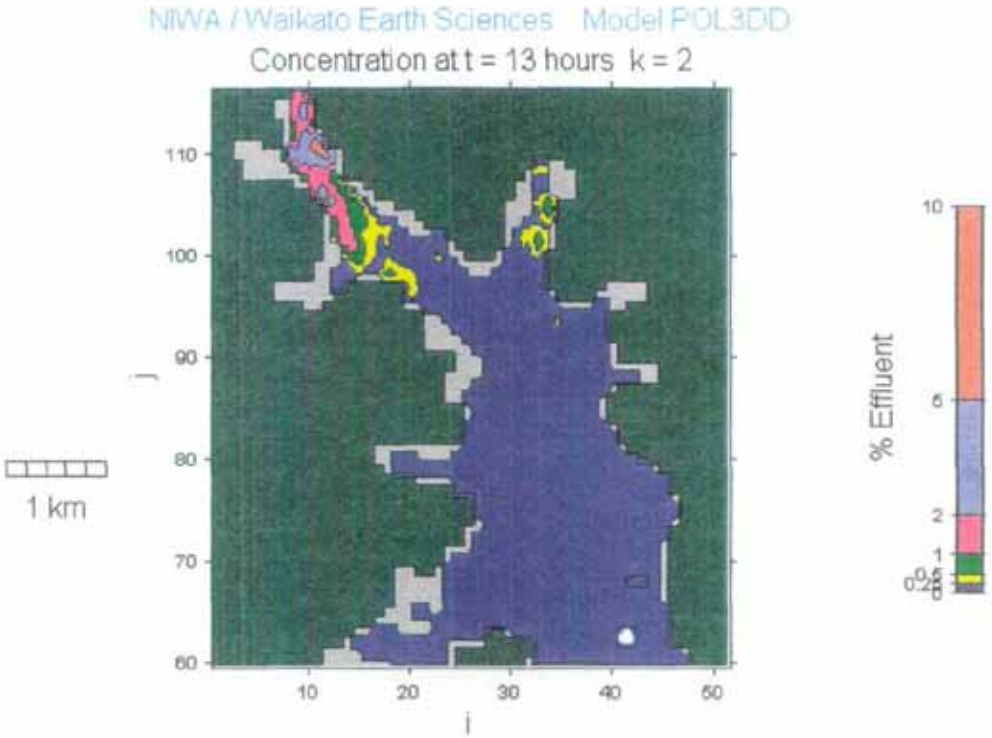


Figure 7n. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus half an hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

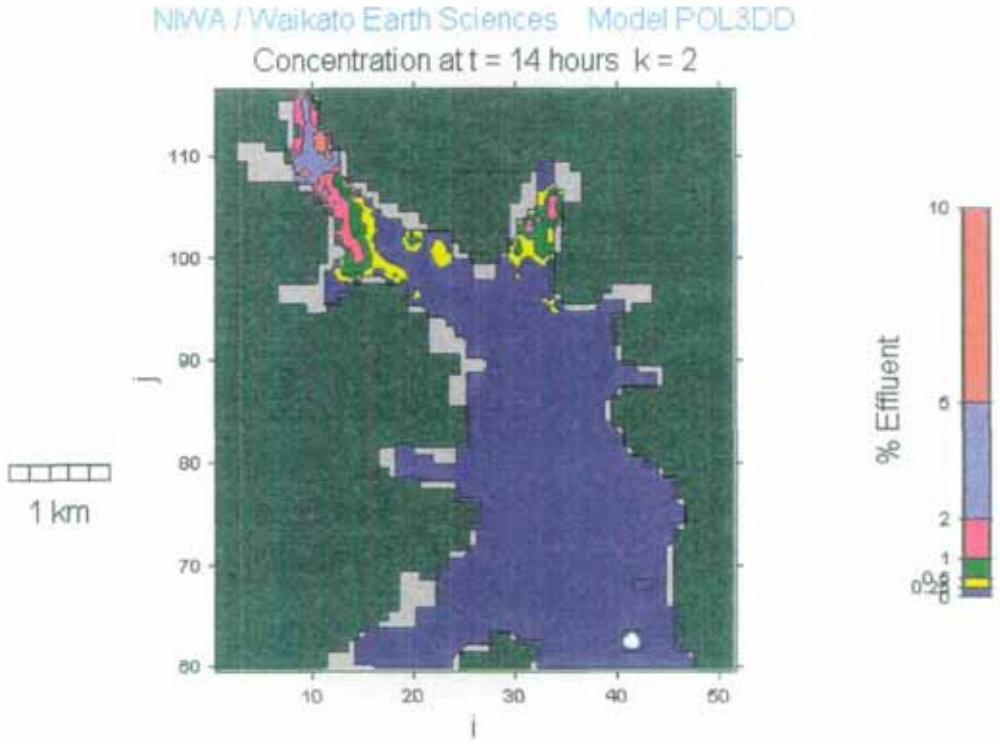


Figure 7o. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus one and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

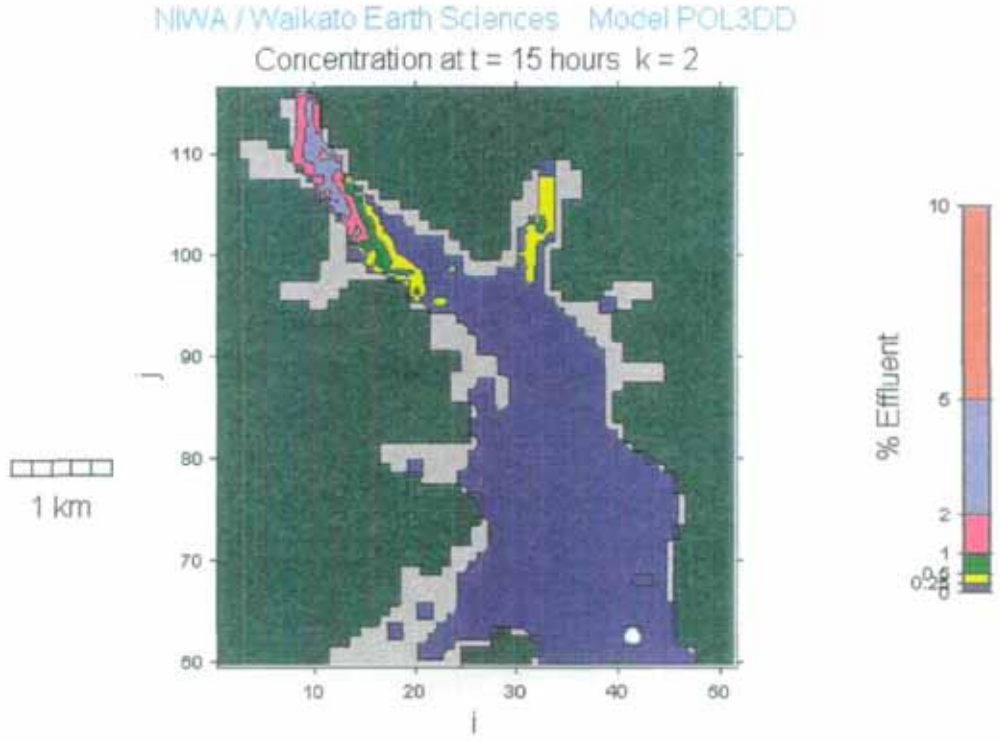


Figure 7p. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus two and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

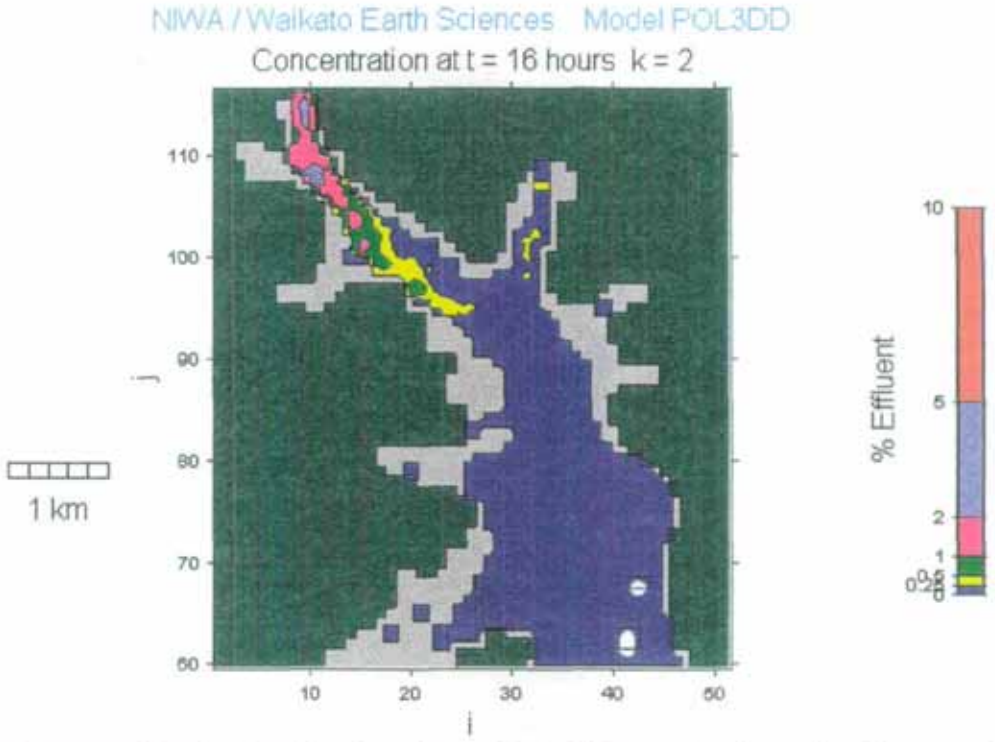


Figure 7q. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus three and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

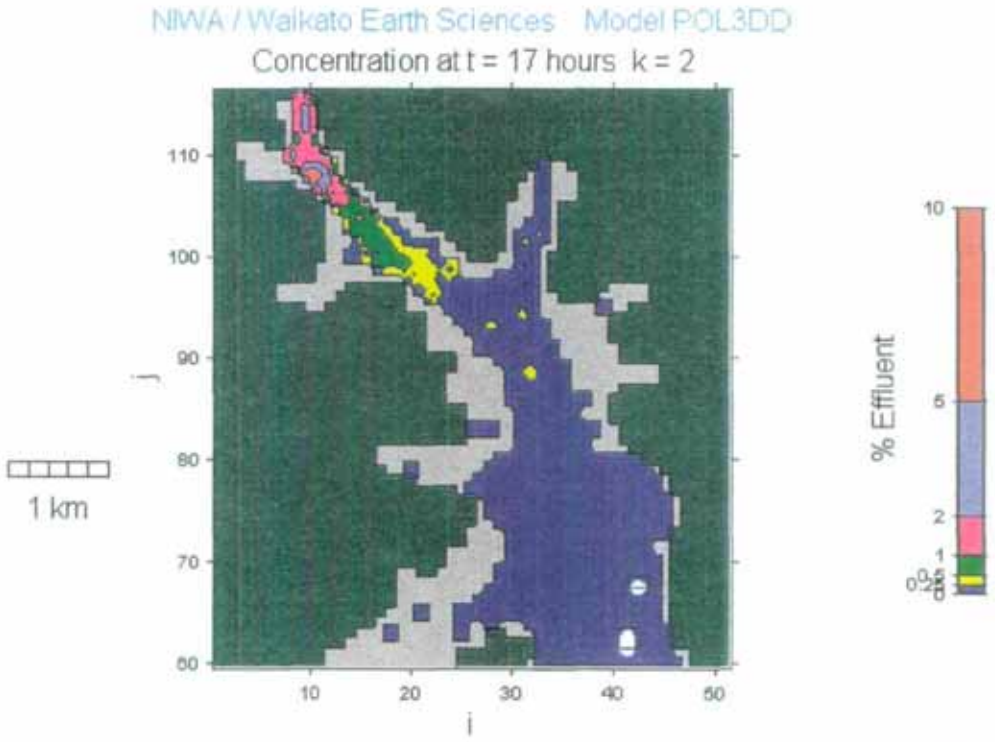


Figure 7r. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus four and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

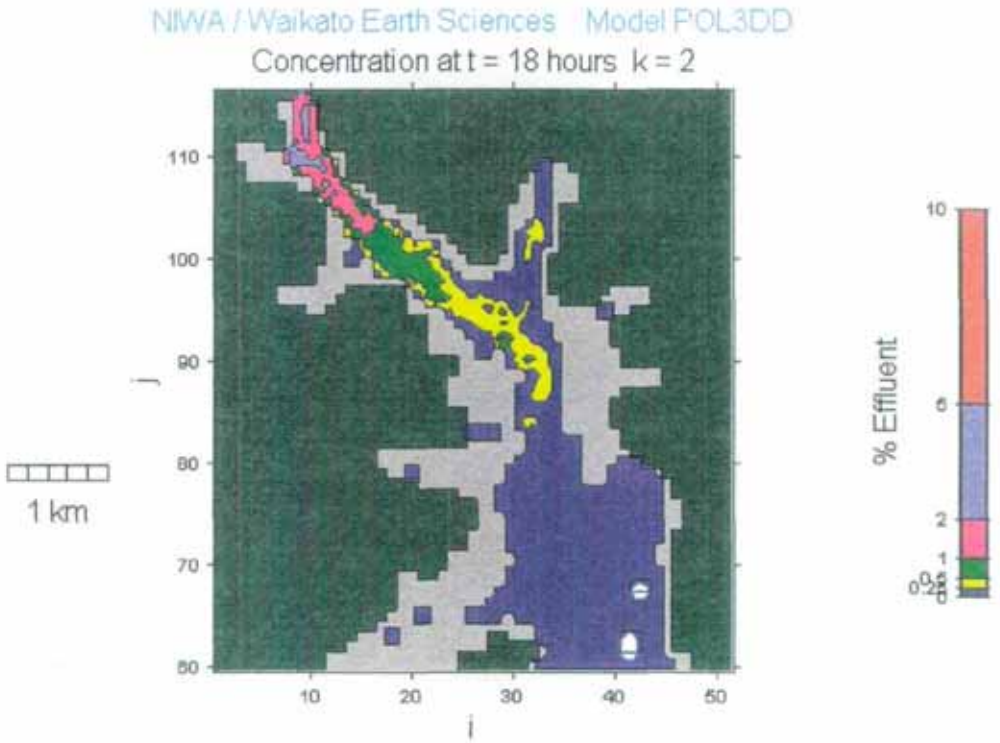


Figure 7s. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus five and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

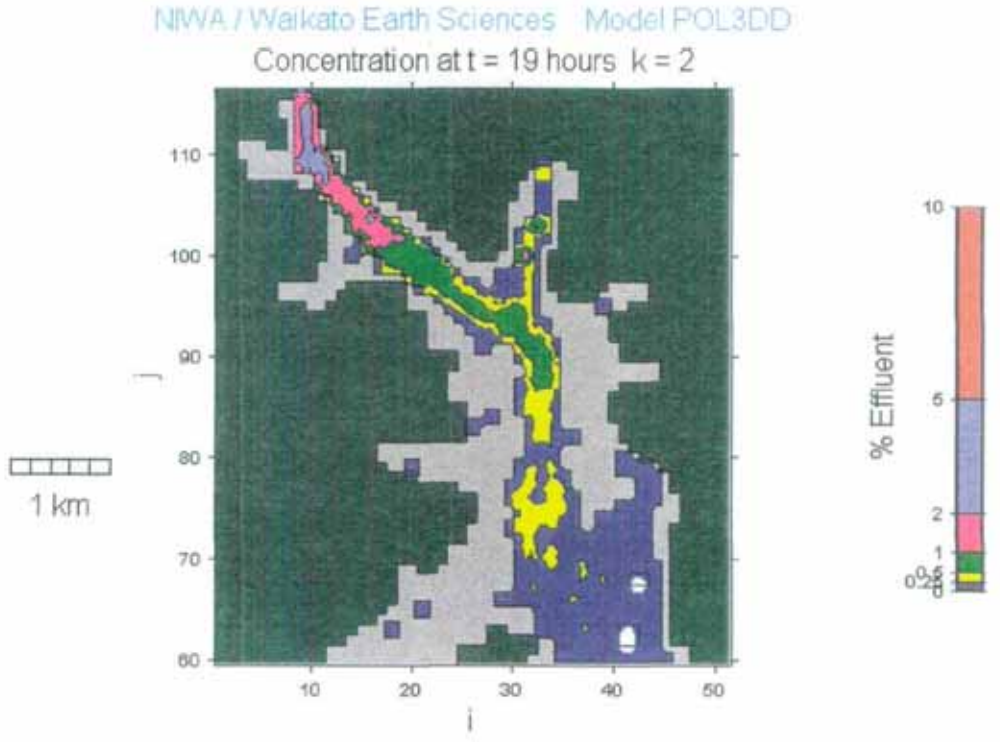


Figure 7t. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

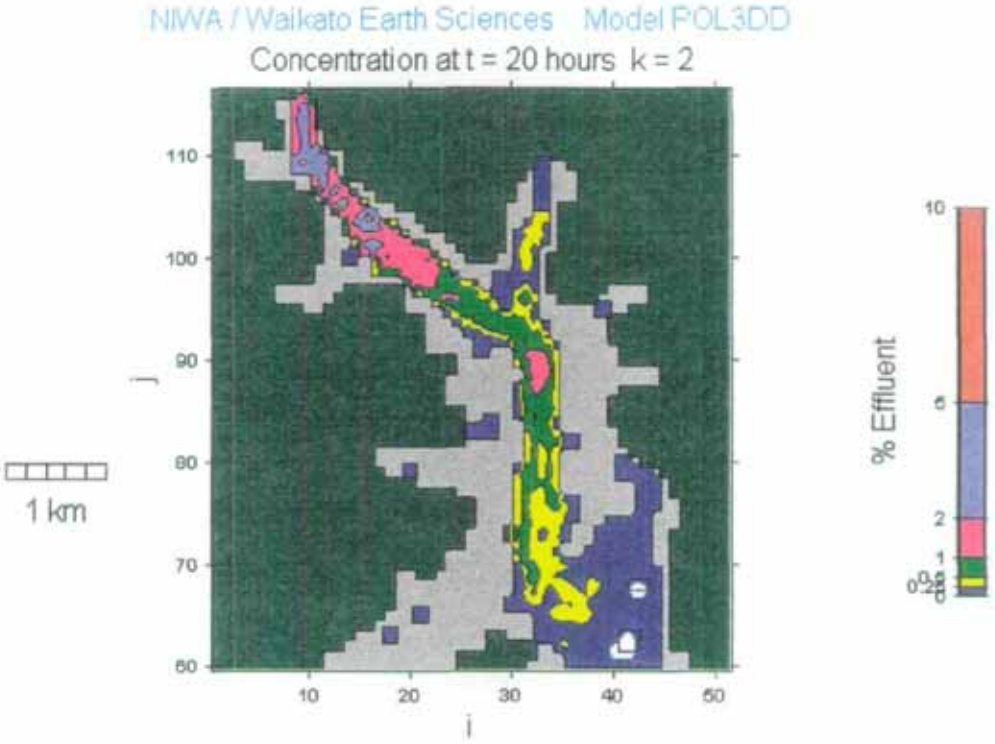


Figure 7u. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus one hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

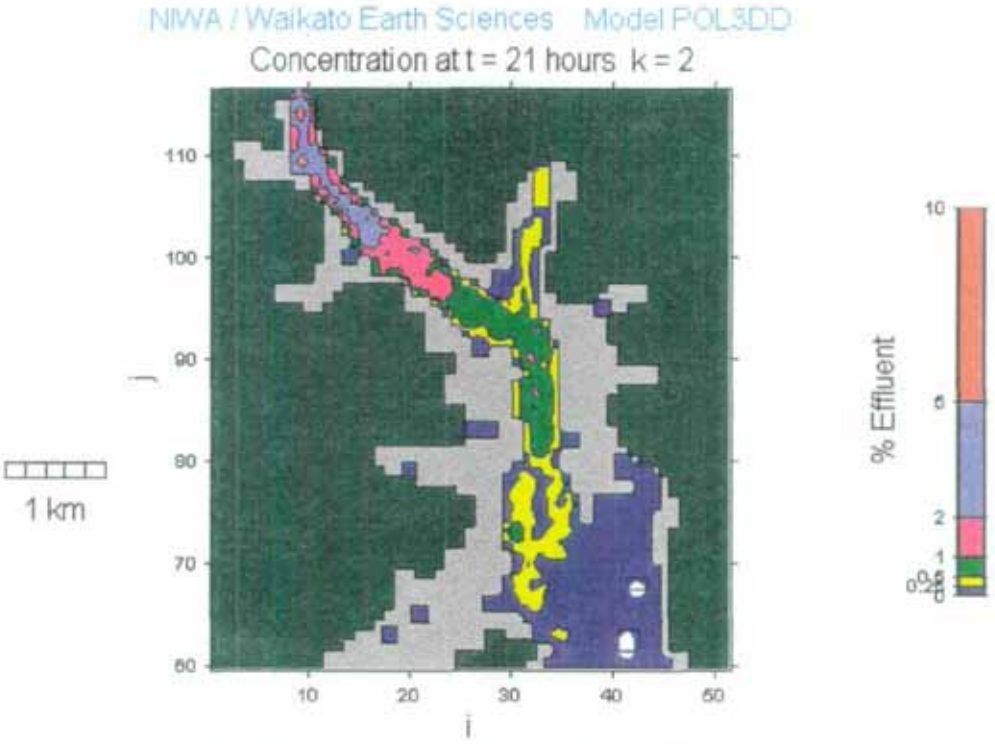


Figure 7v. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus two hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

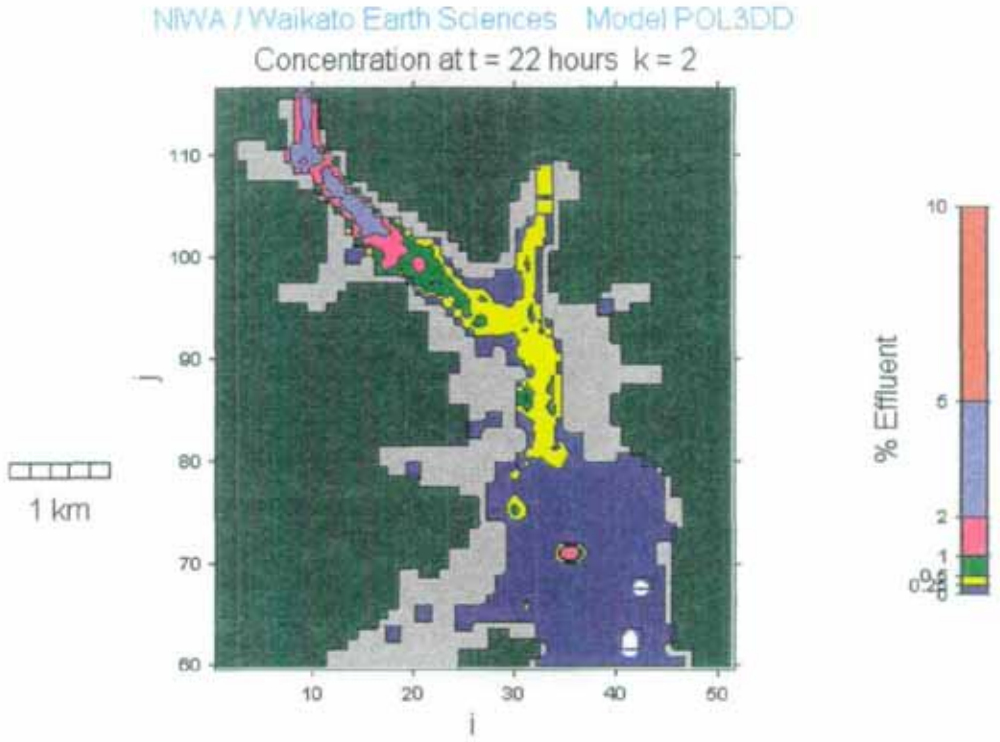


Figure 7w. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus three hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

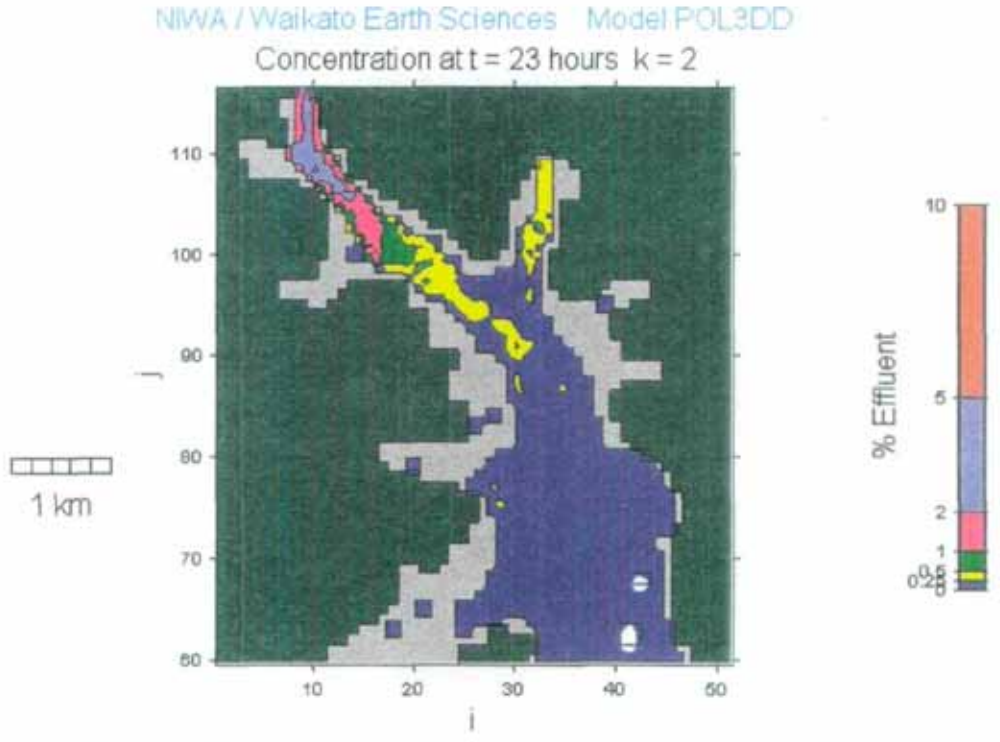


Figure 7x. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus four hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

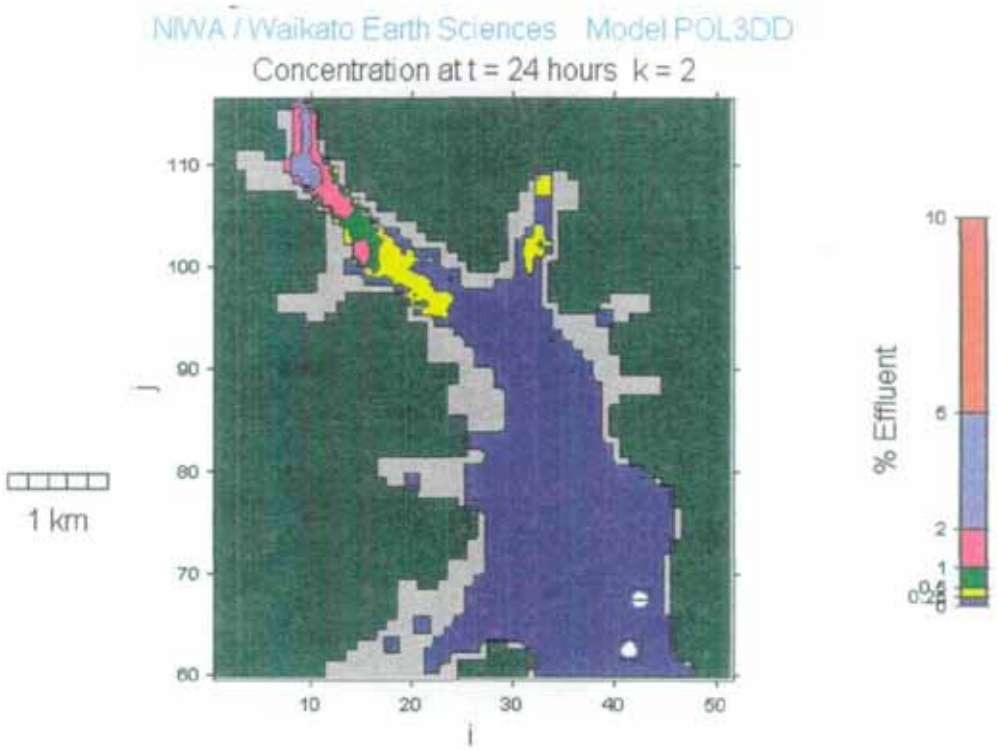


Figure 7y. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus five hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

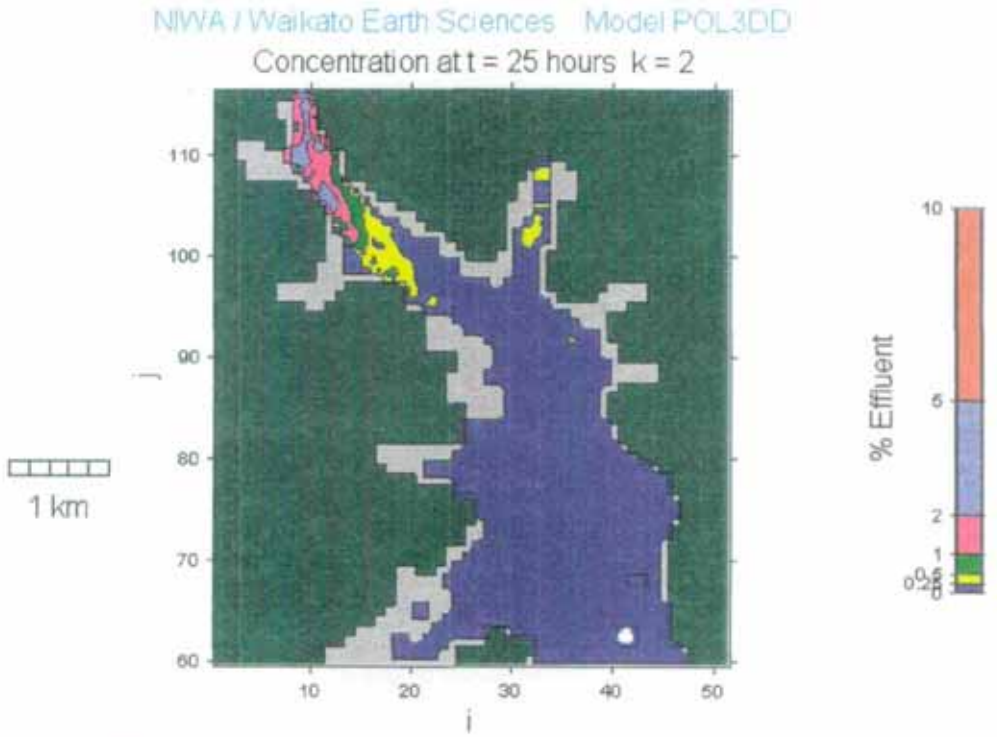


Figure 7z. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

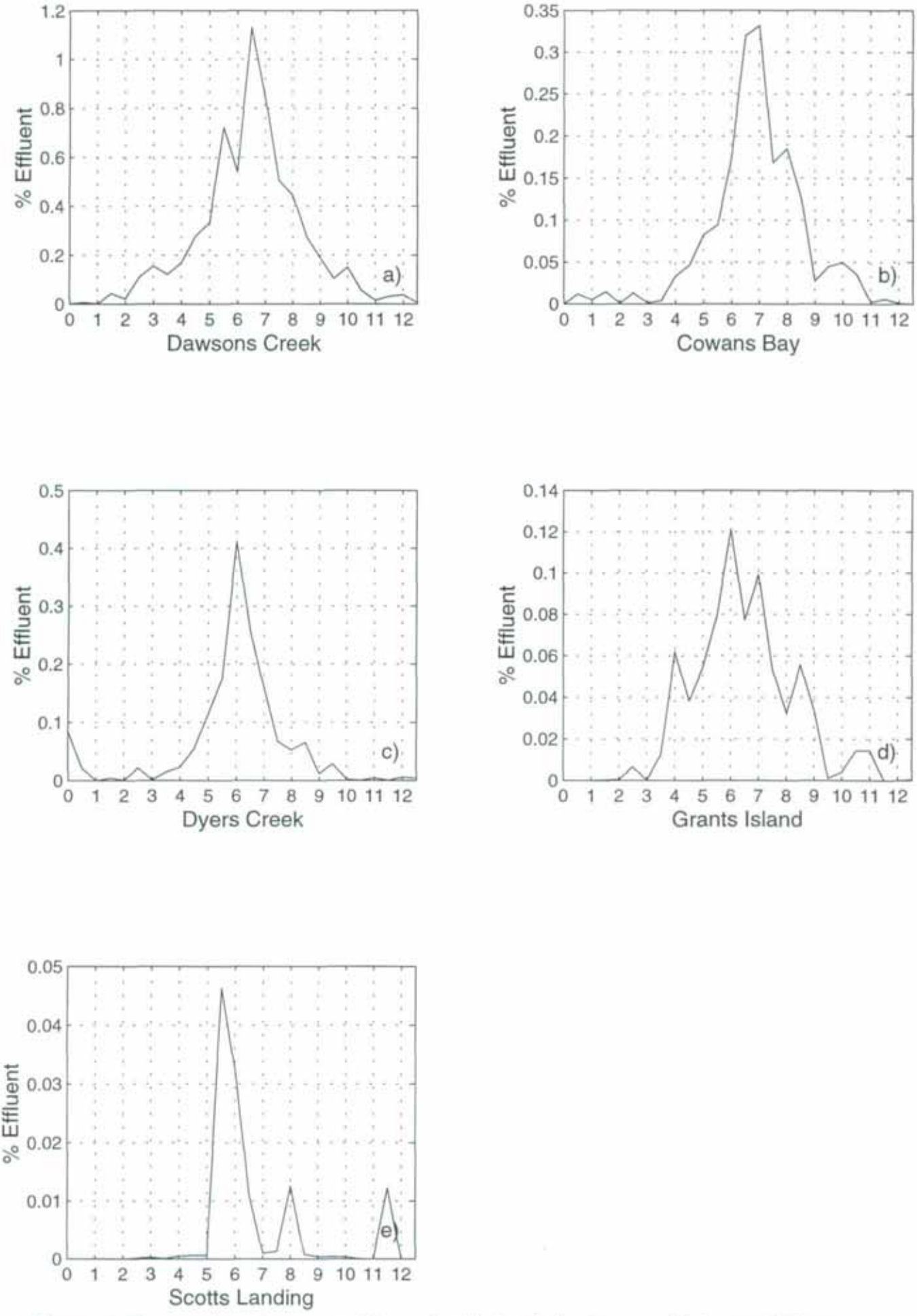


Figure 8: Time series of percent effluent for Wetland discharge to Mahurangi River for selected sites in the main channel

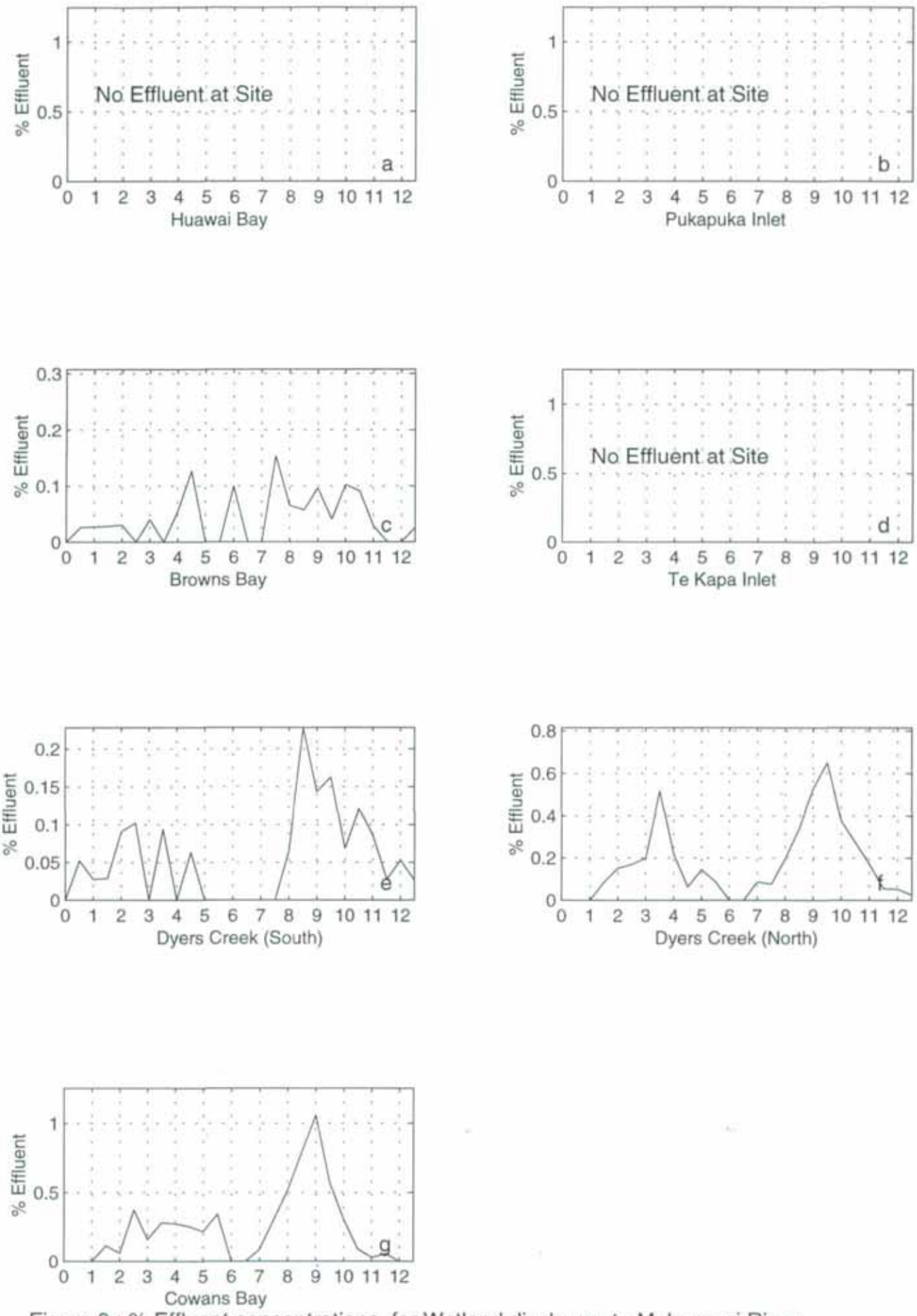


Figure 9 : % Effluent concentrations for Wetland discharge to Mahurangi River. Spatial average for oyster farms at sites as indicated

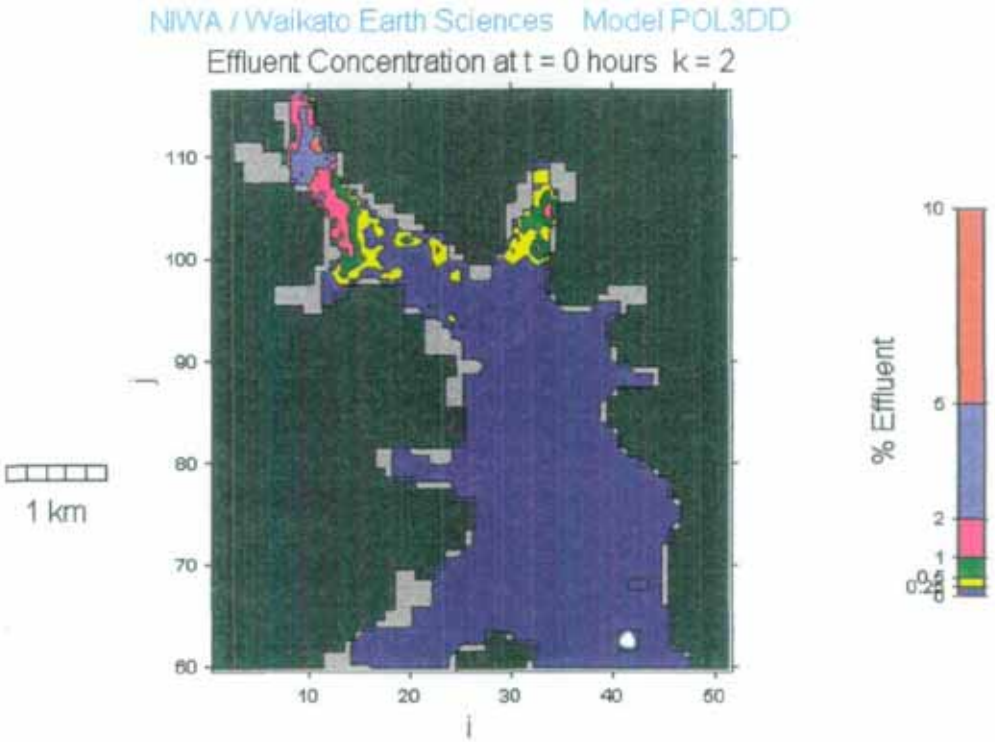


Figure 10a. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

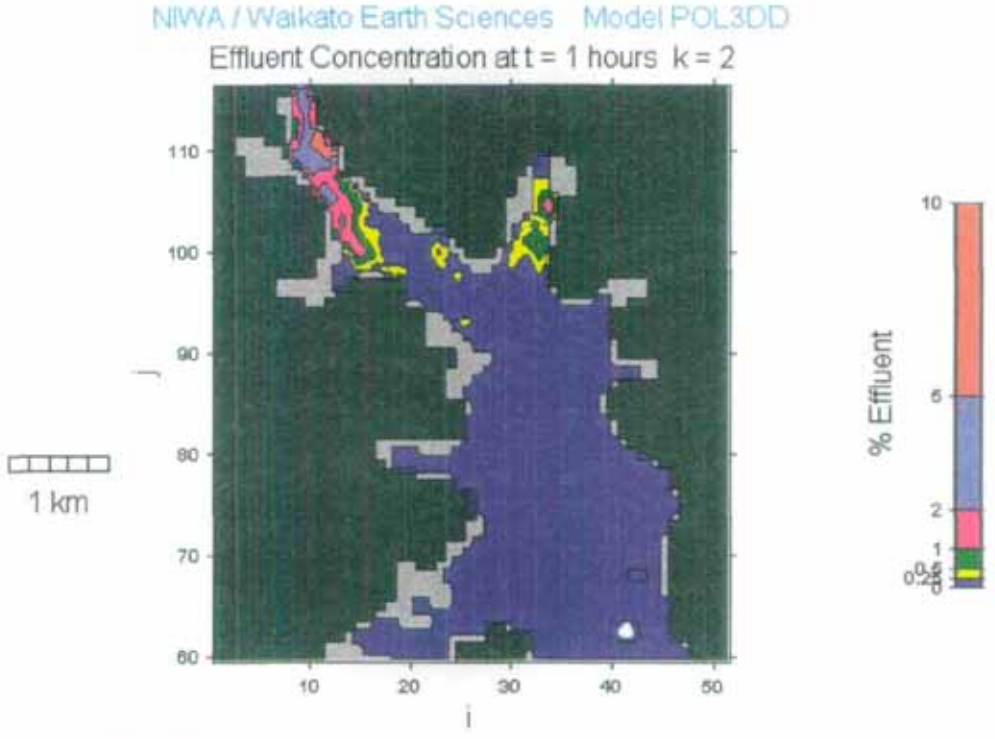


Figure 10b. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus one hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

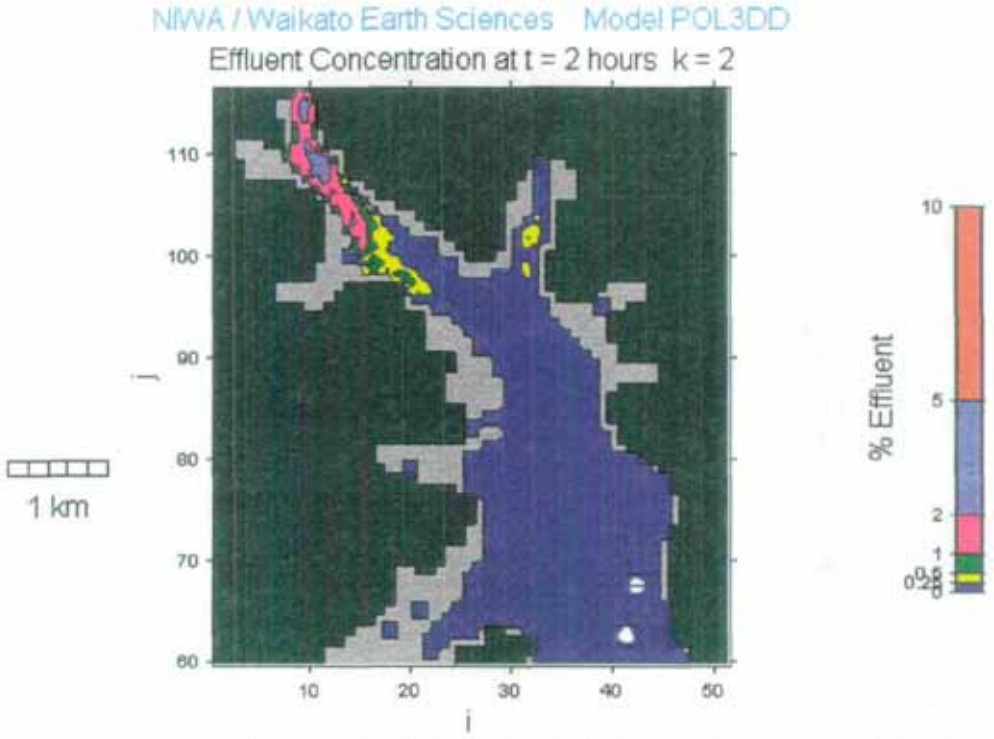


Figure 10c. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus two hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

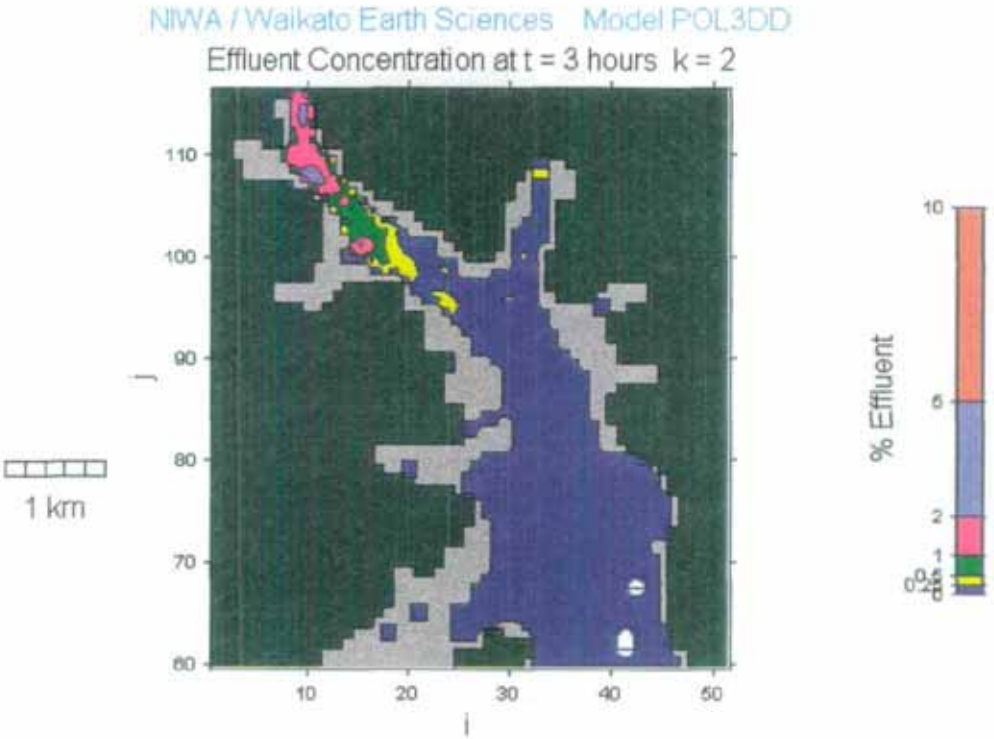


Figure 10d. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus three hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

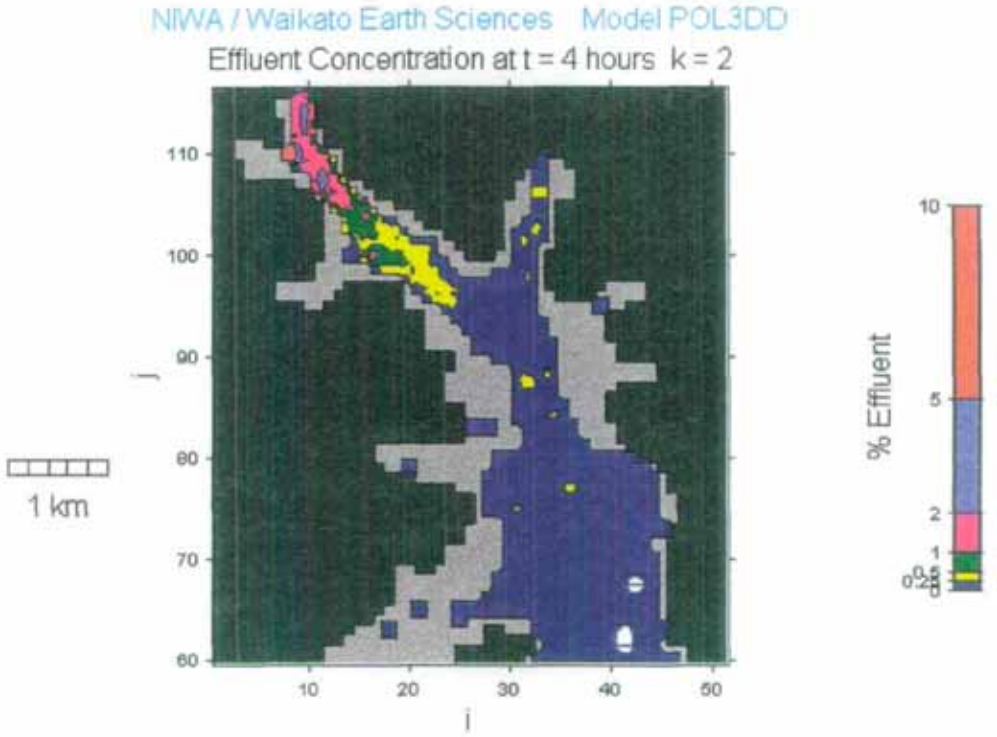


Figure 10e. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus four hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

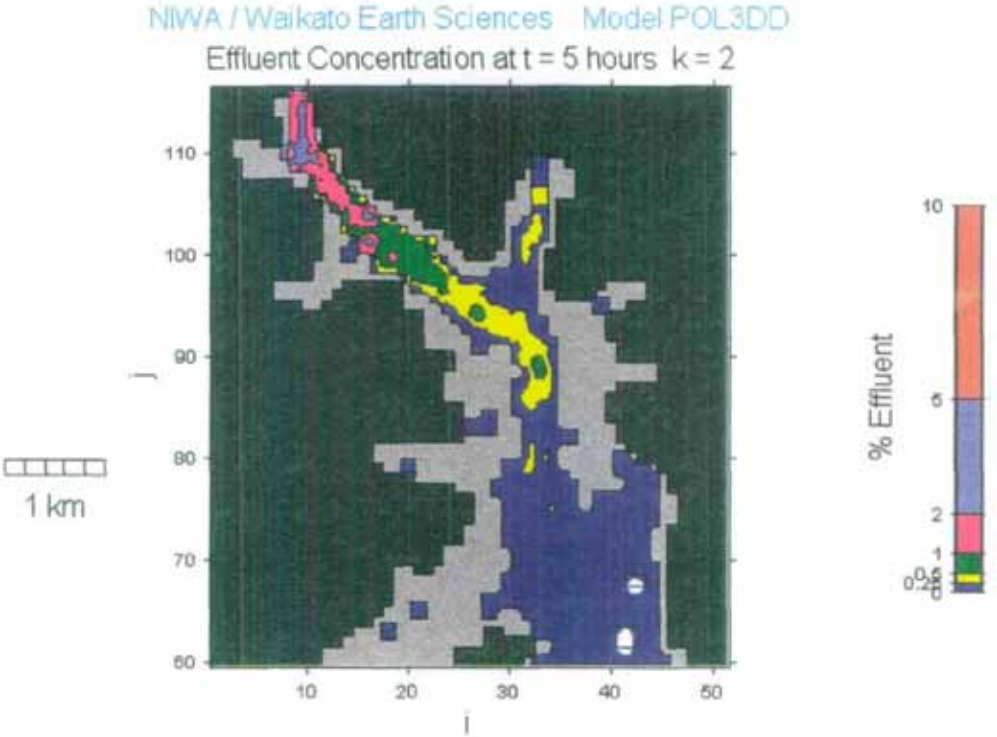


Figure 10f. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus five hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

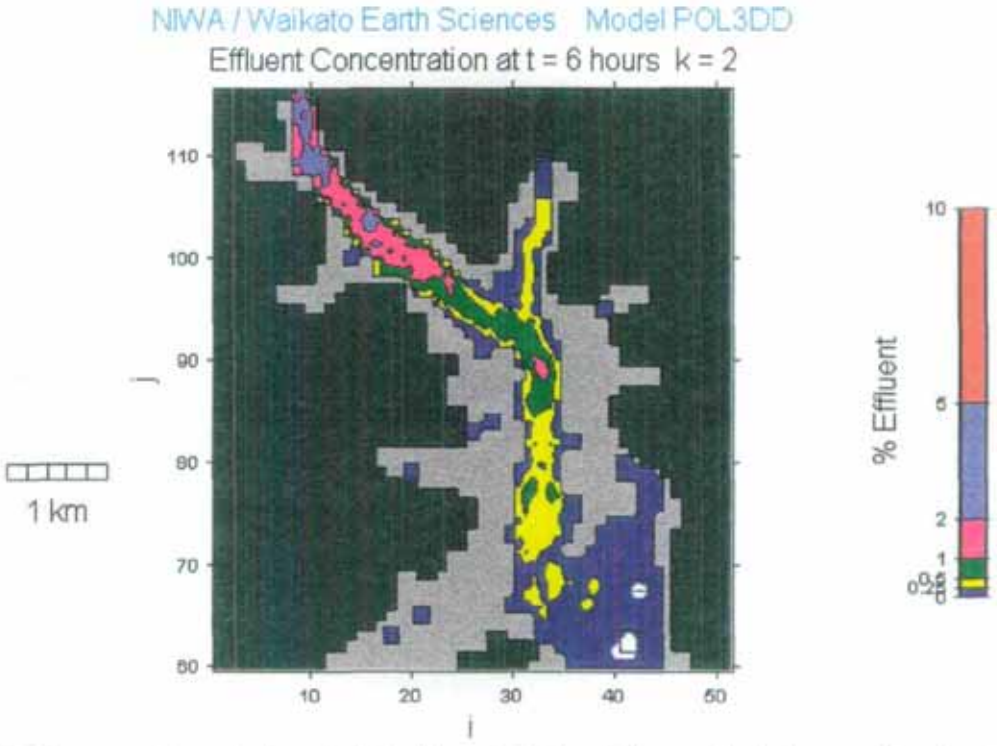


Figure 10g. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus six hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

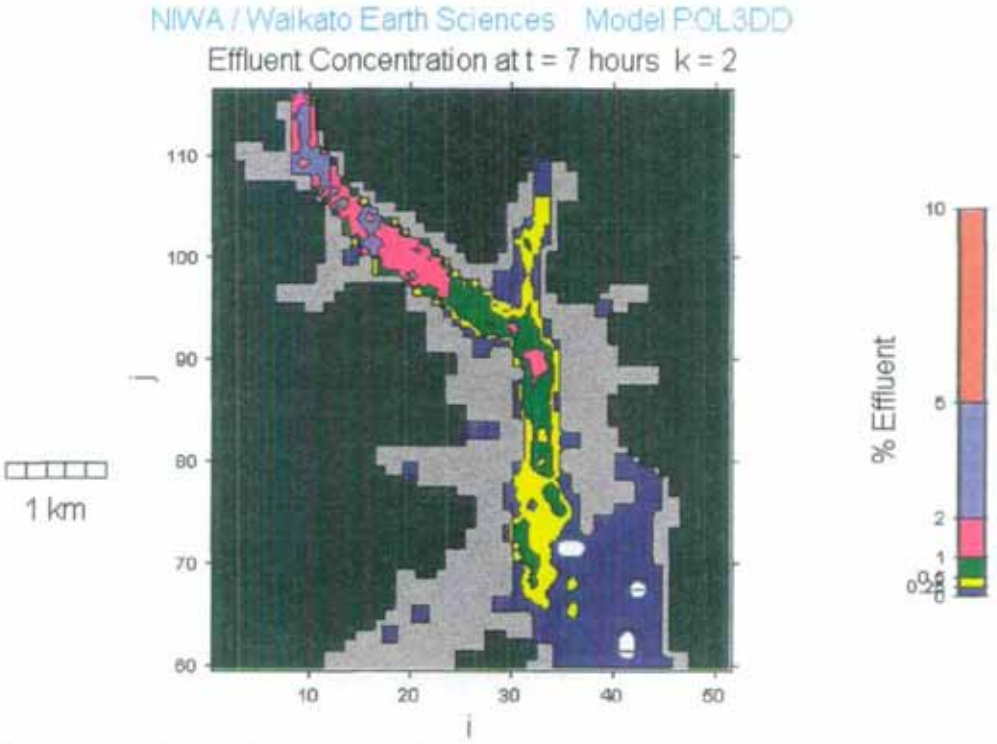


Figure 10h. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus half an hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

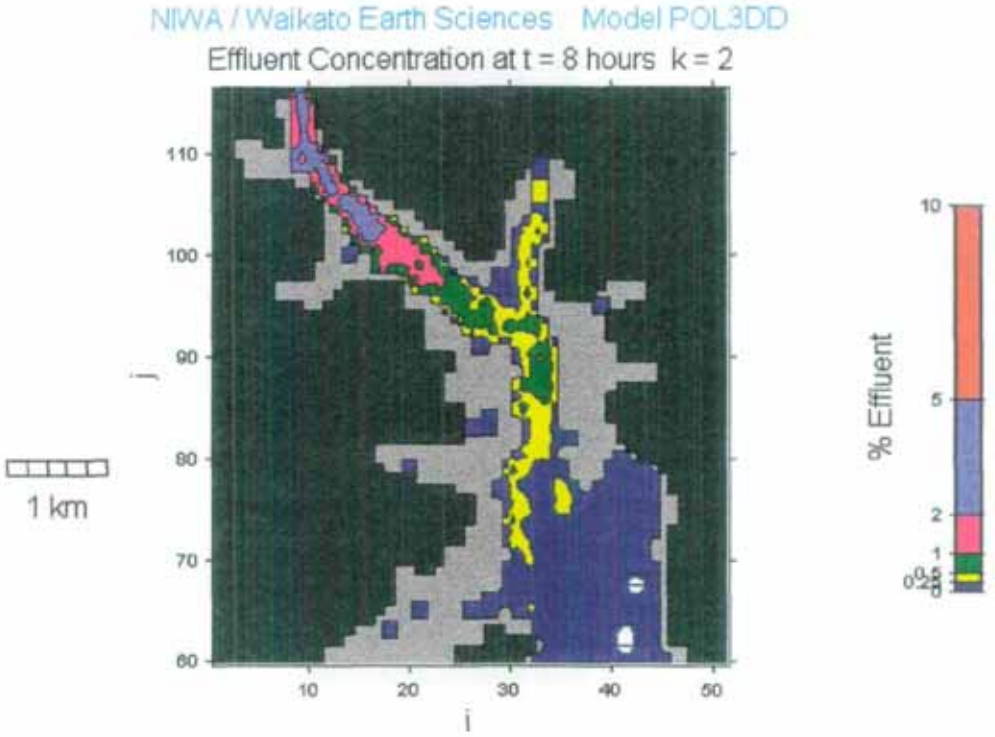


Figure 10i. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus one and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

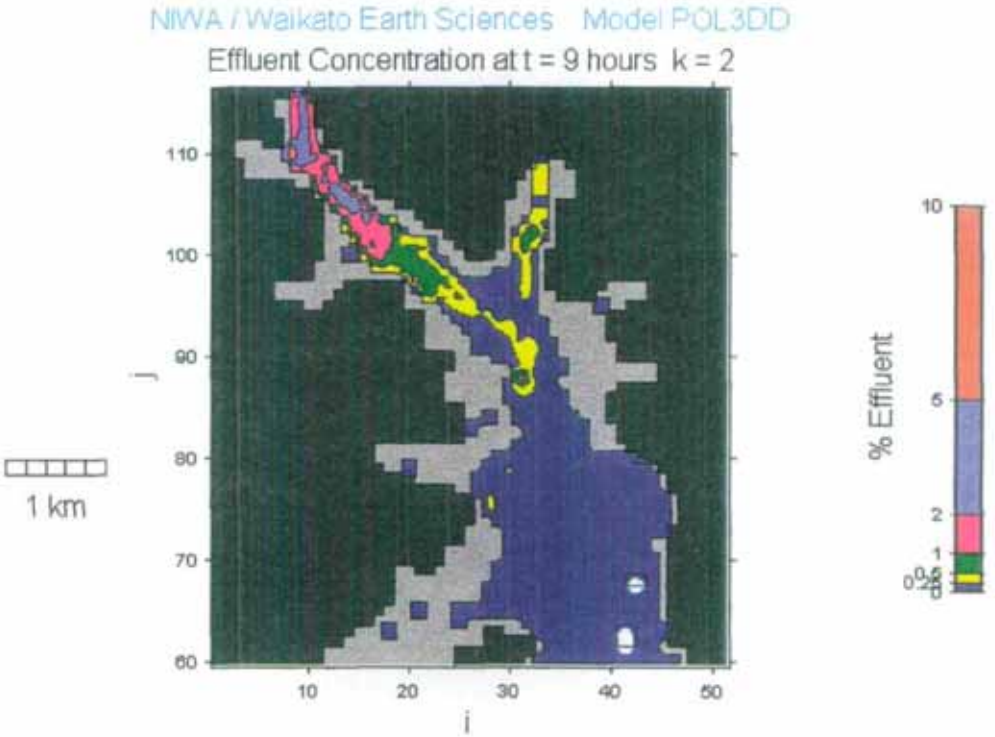


Figure 10j. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus two and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

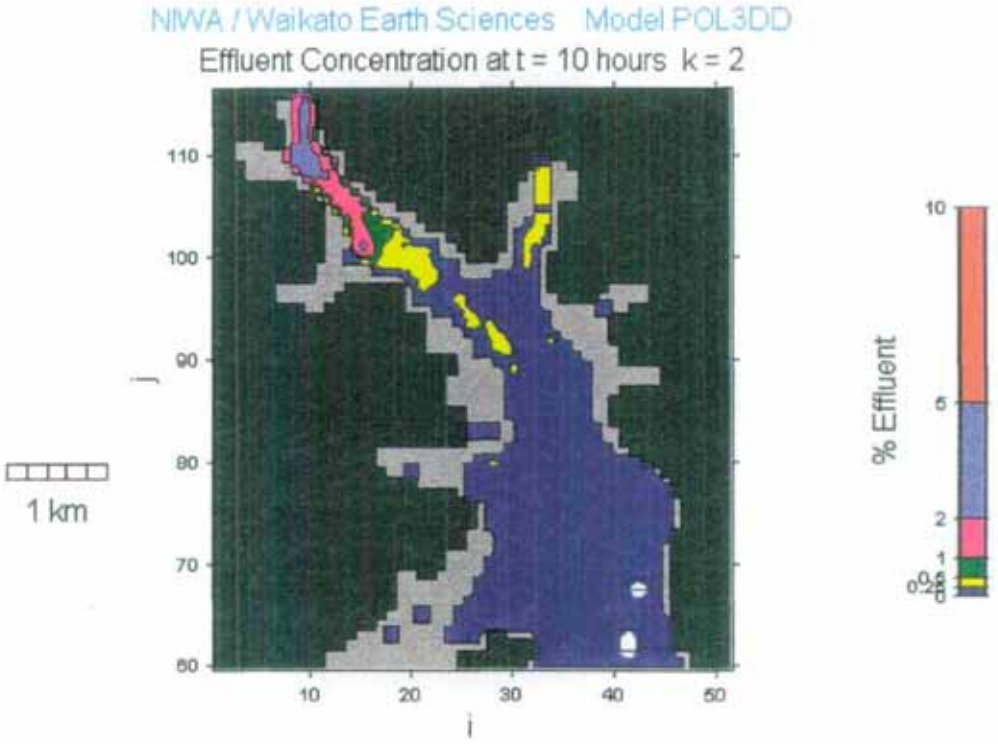


Figure 10k. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus three and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

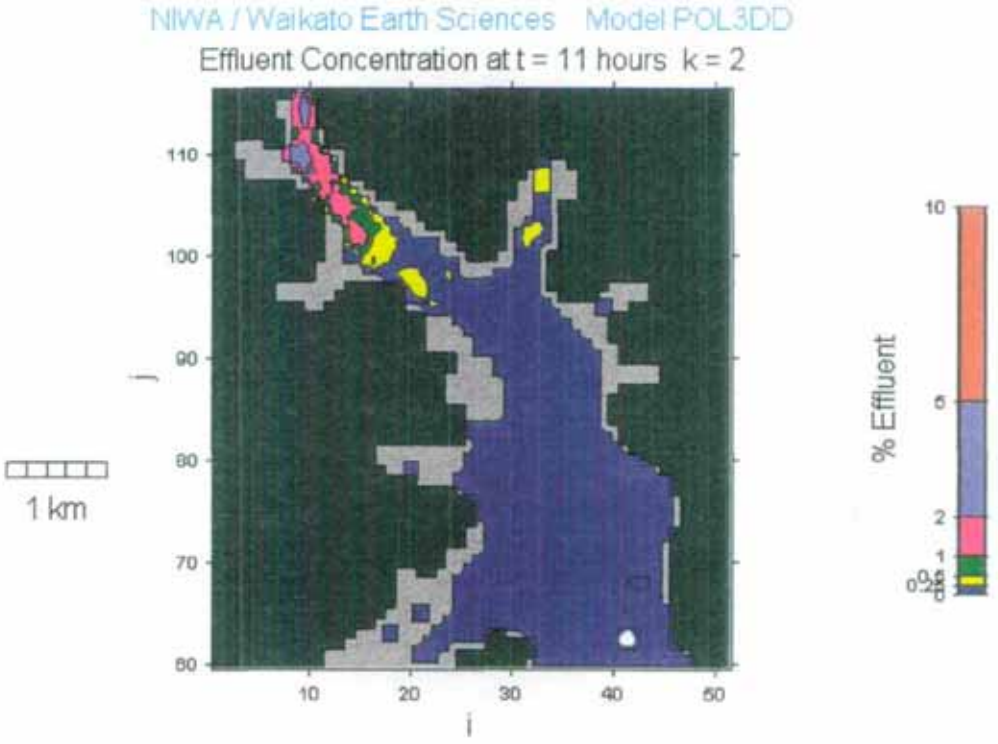


Figure 10l. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus four and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

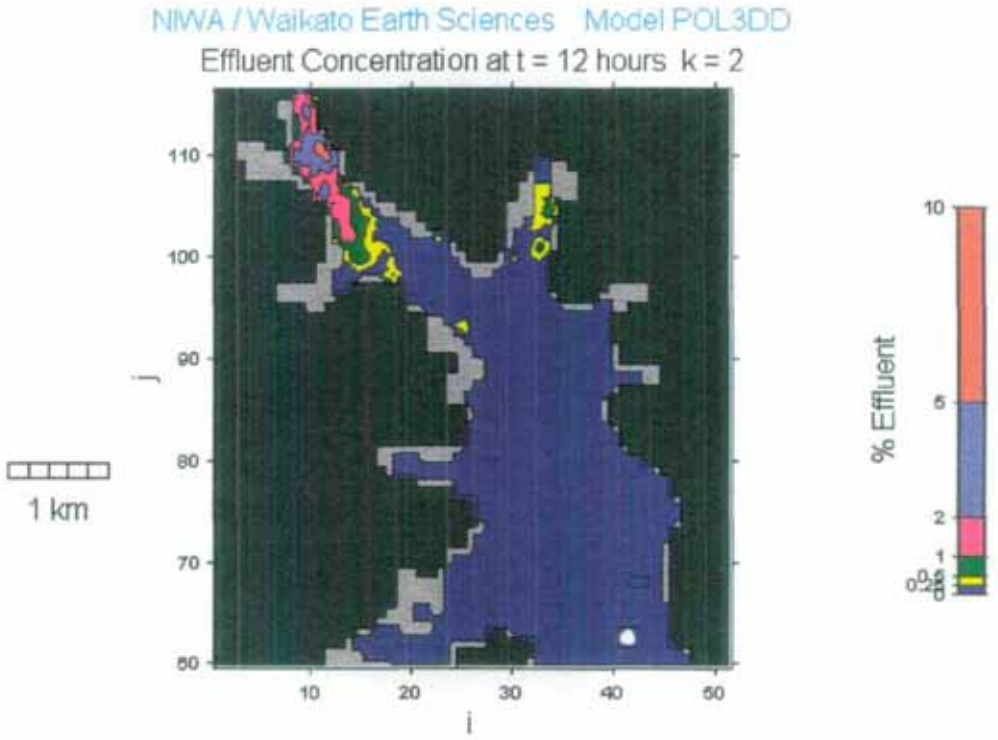


Figure 10m. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus five and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

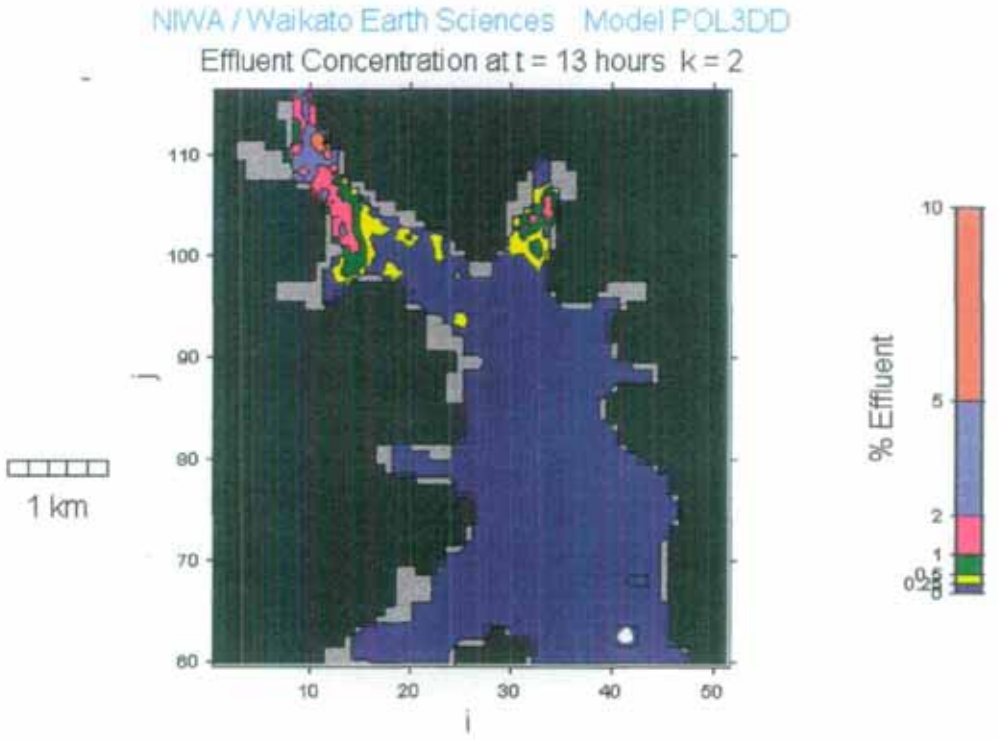


Figure 10n. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus half an hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

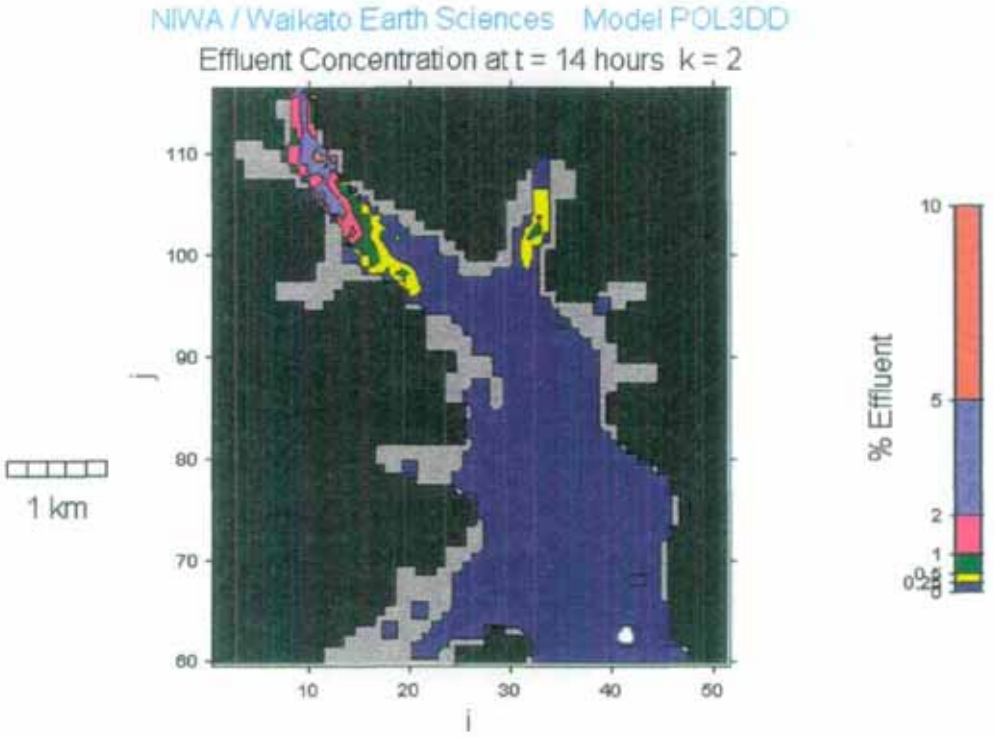


Figure 10o. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus one and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

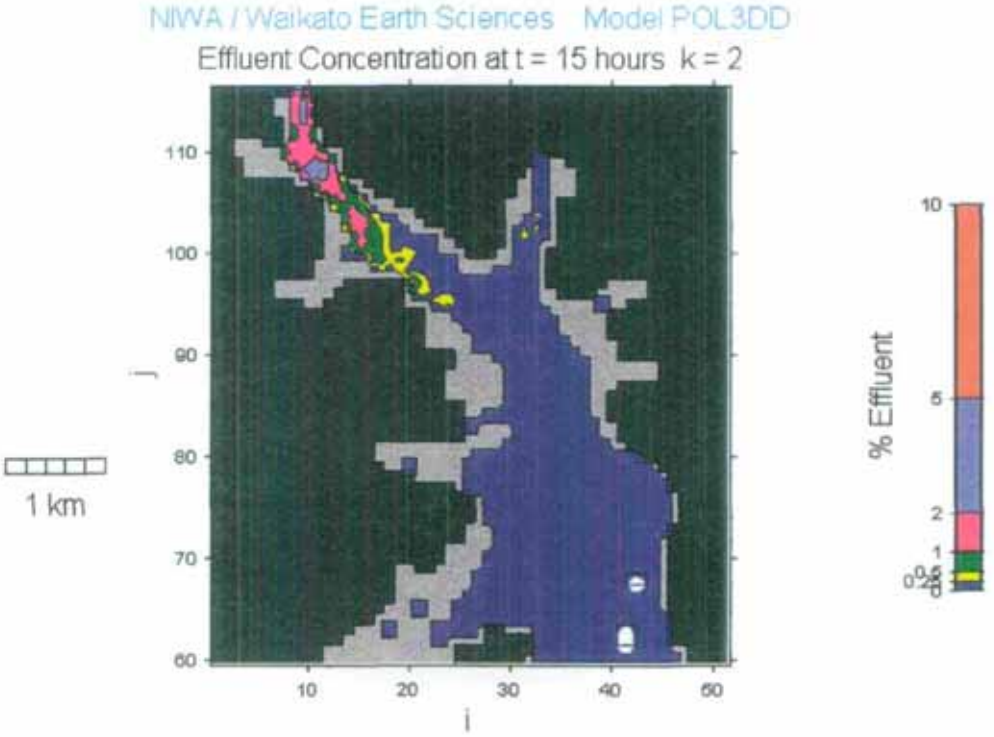


Figure 10p. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus two and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

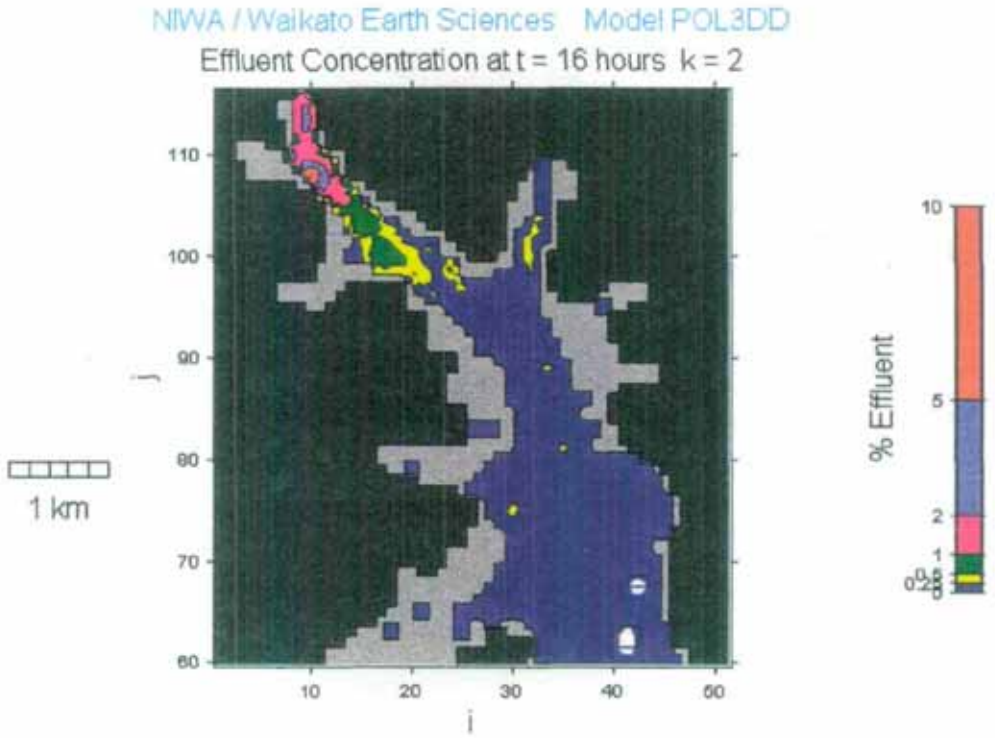


Figure 10q. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus three and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

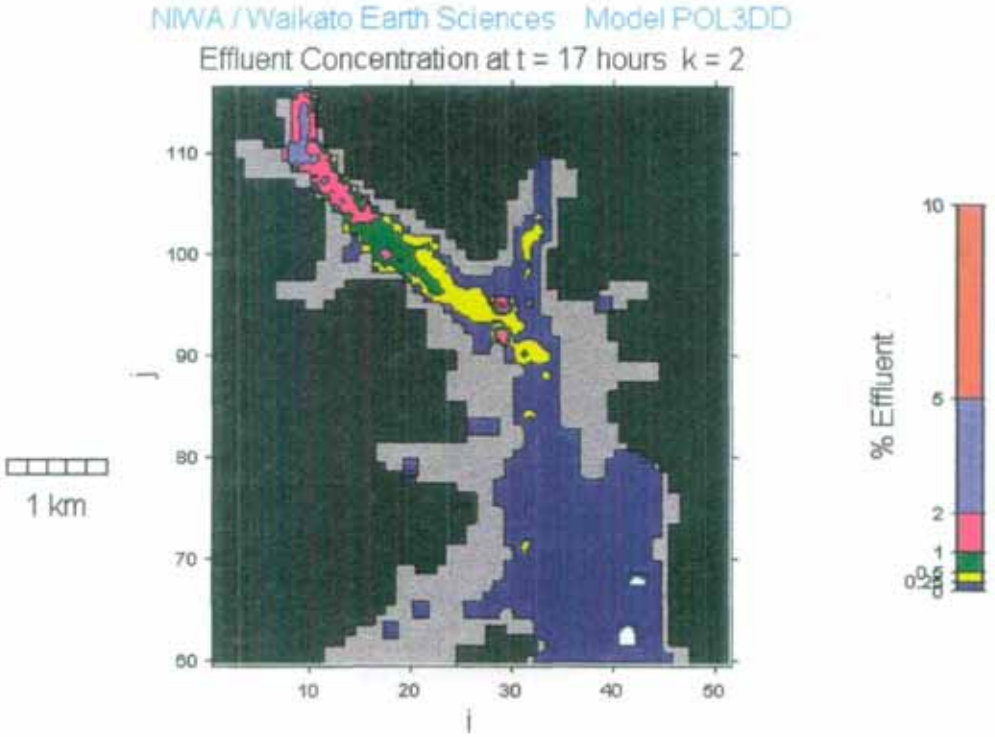


Figure 10r. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus four and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

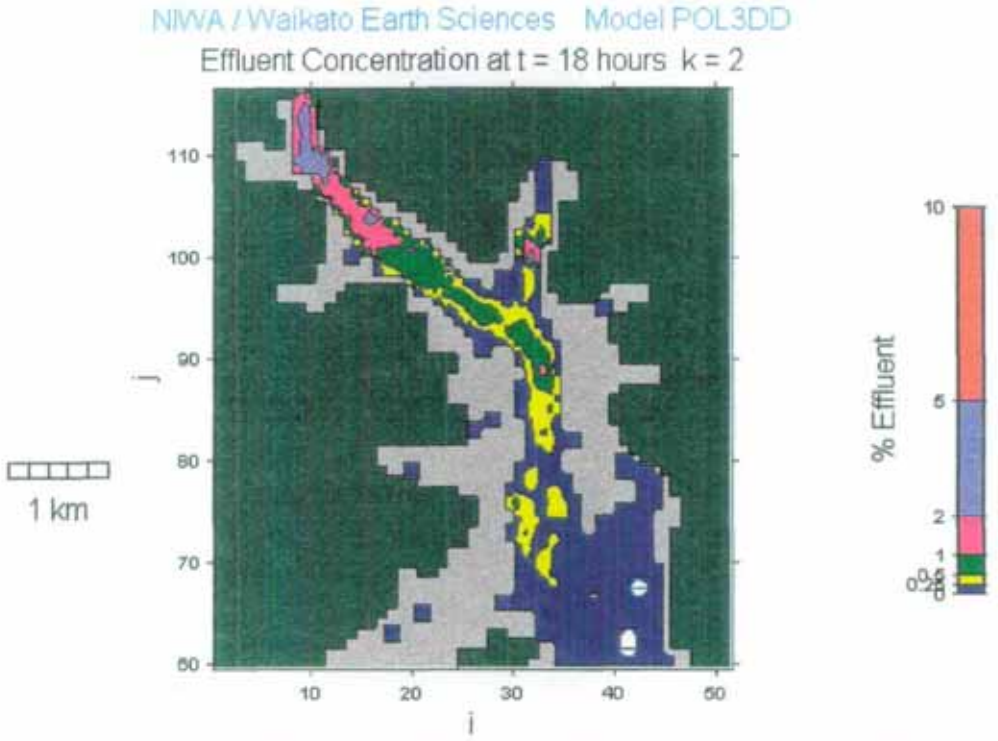


Figure 10s. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water plus five and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

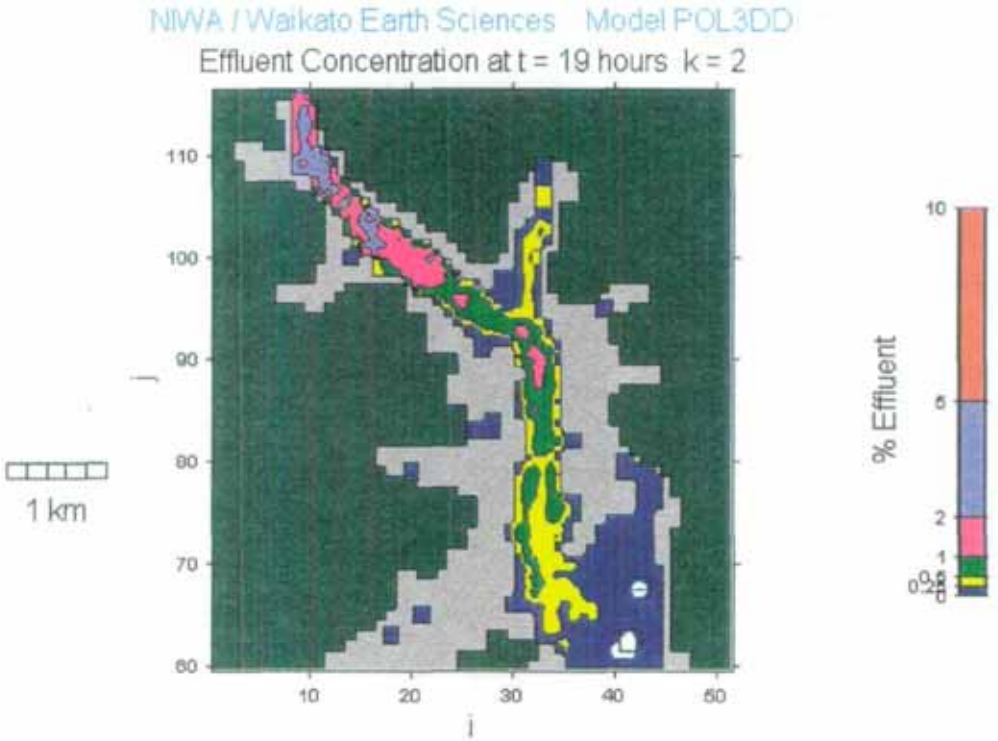


Figure 10t. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

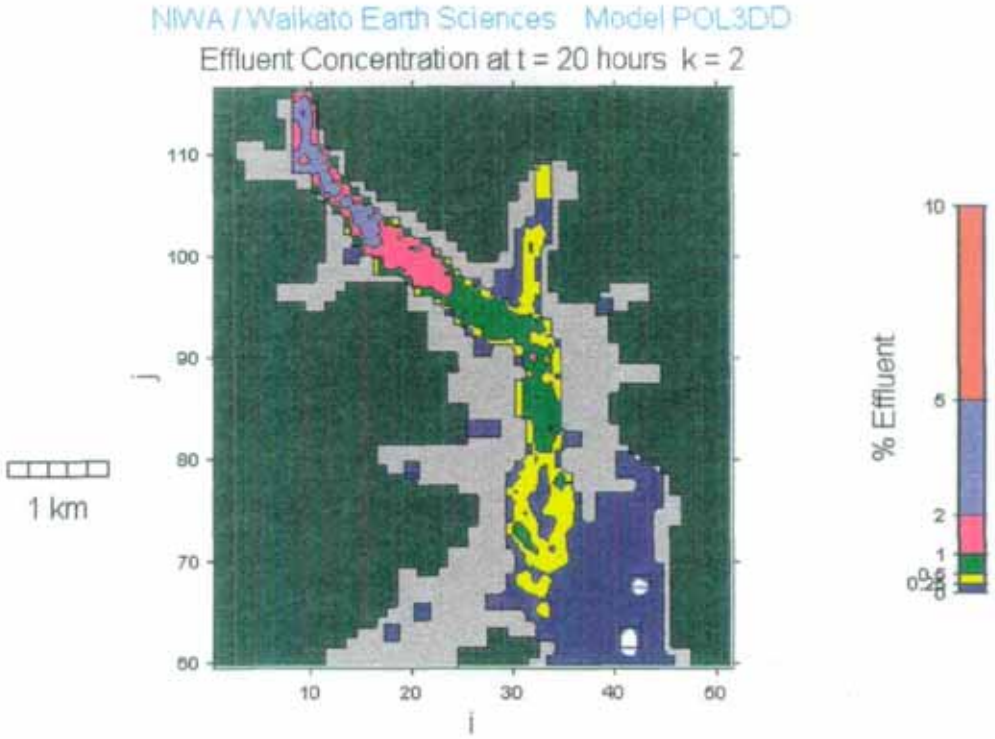


Figure 10u. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus one hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

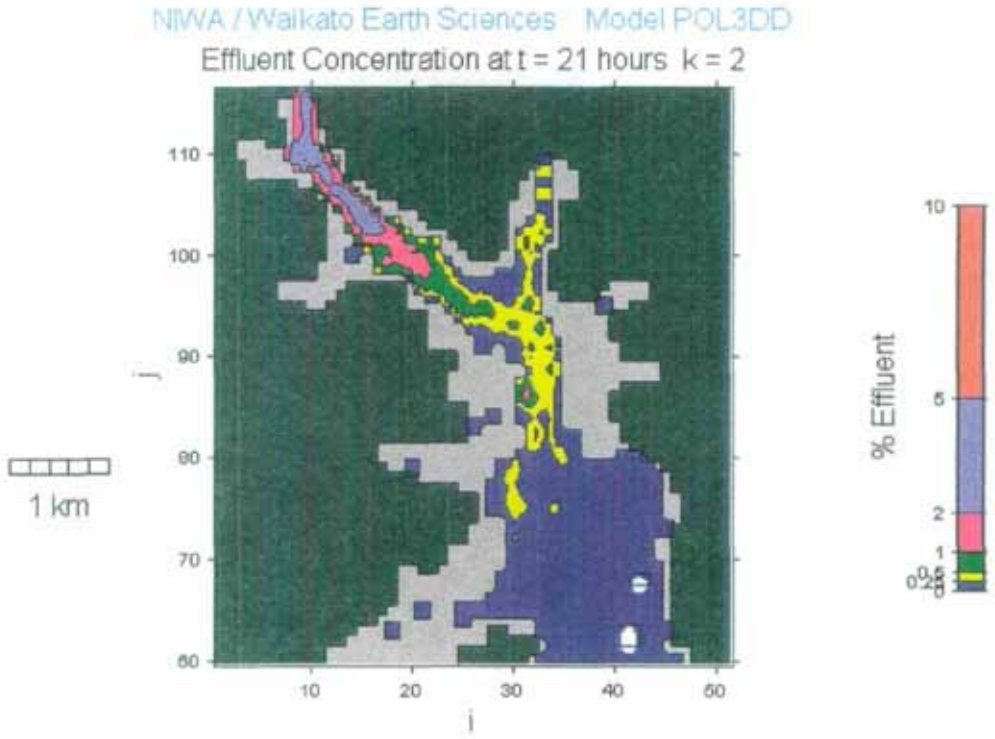


Figure 10v. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus two hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

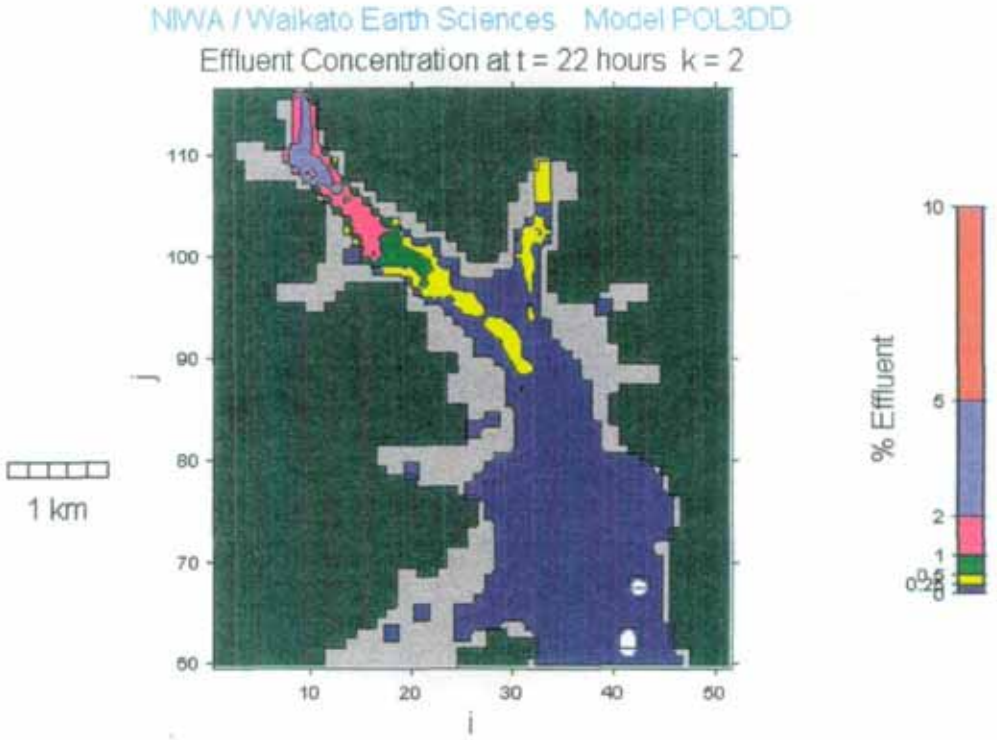


Figure 10w. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus three hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

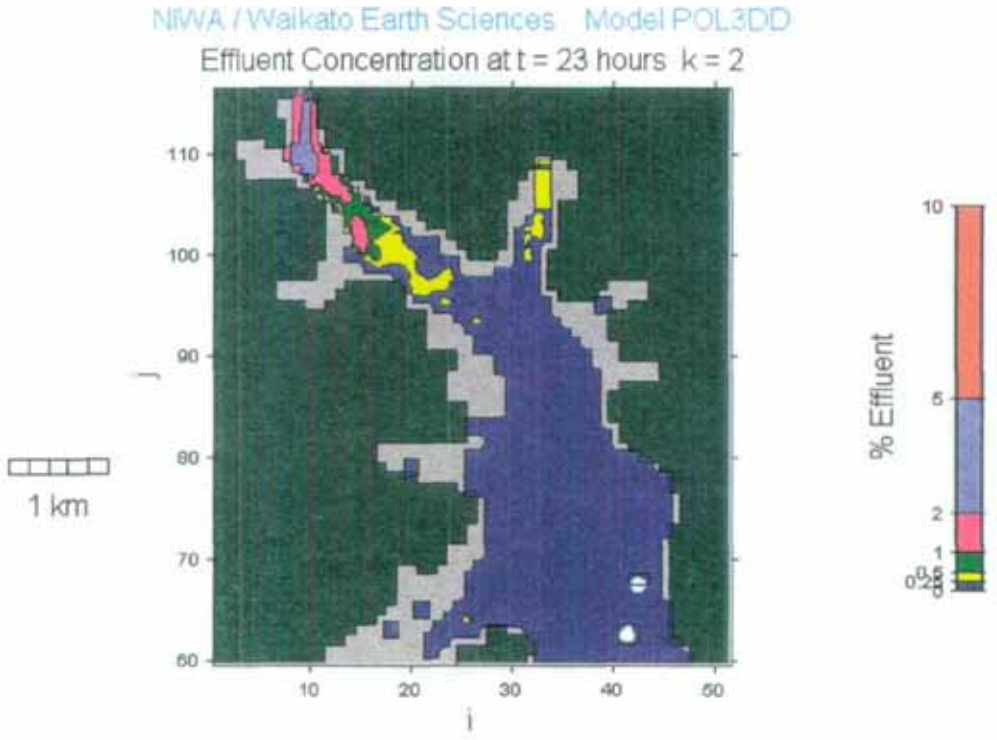


Figure 10x. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus four hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

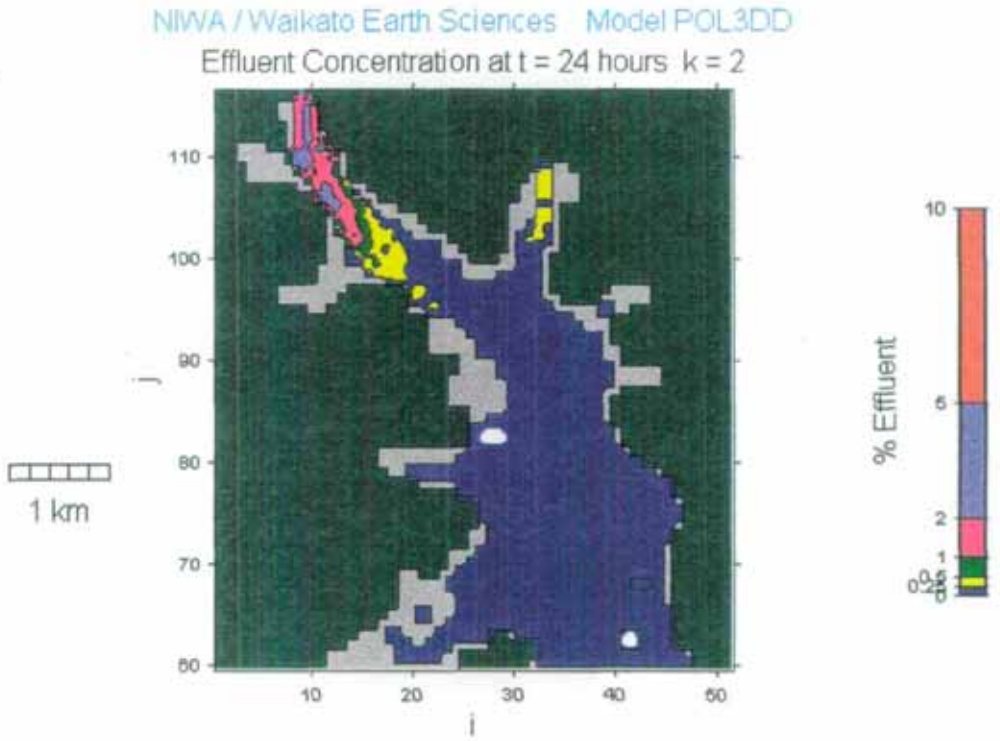


Figure 10y. Percentage effluent in the surface "fixed" layer (0-0.2m) at low water plus five hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

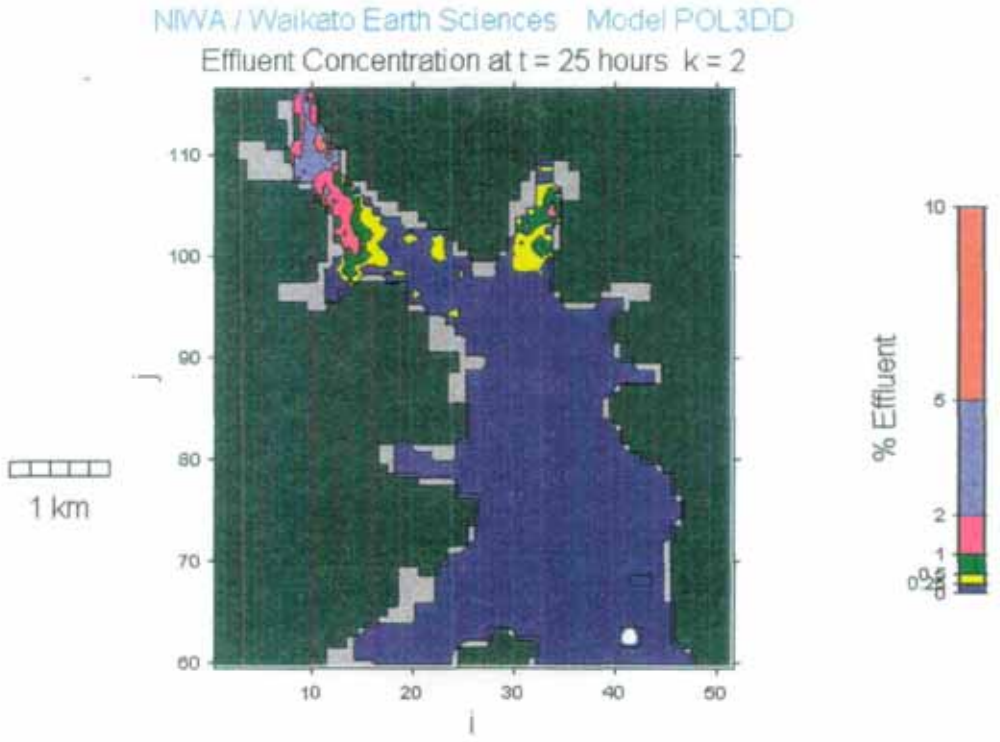


Figure 10z. Percentage effluent in the surface "fixed" layer (0-0.2m) at high water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range of 2.5 metres.

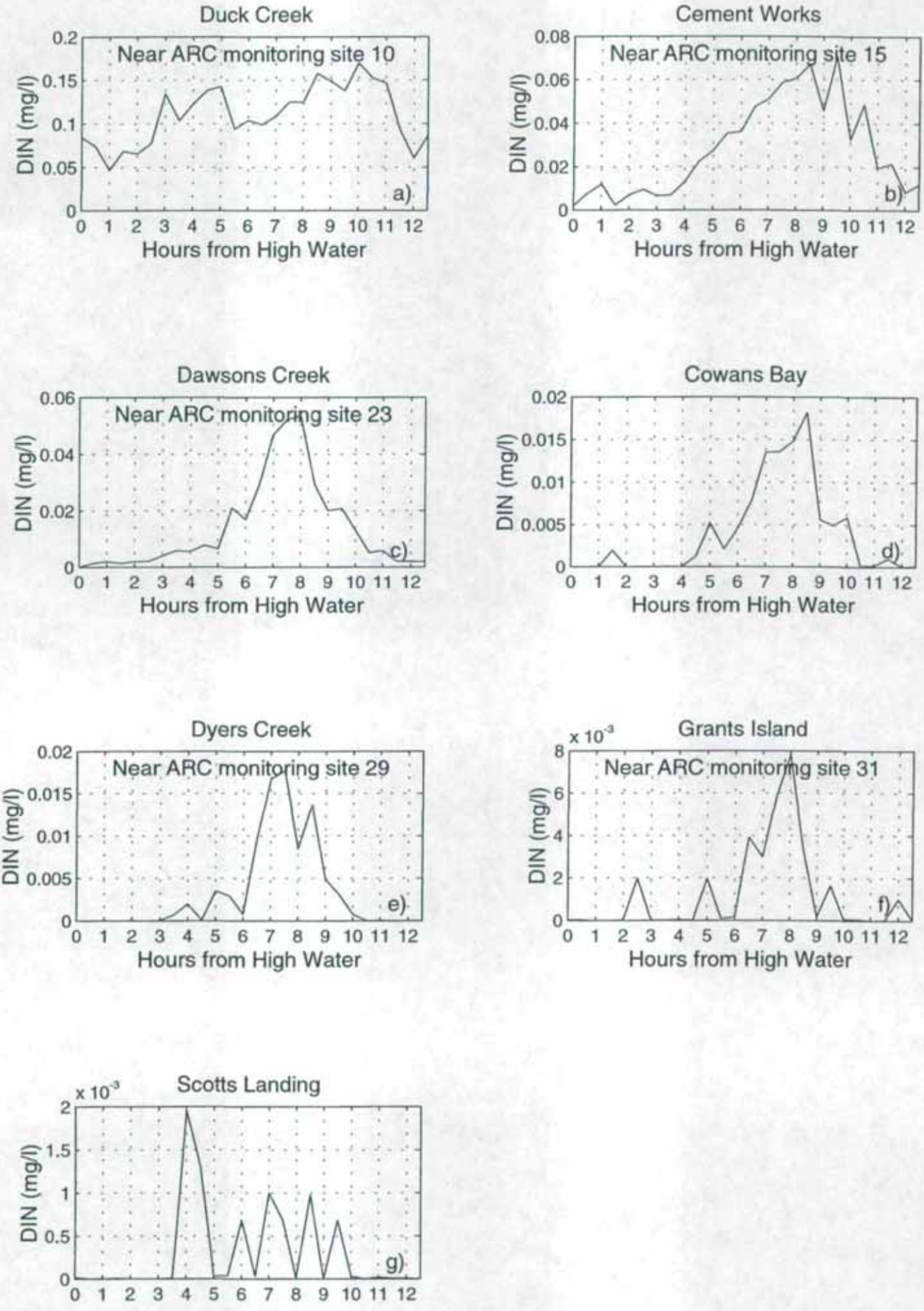


Figure 11 : Time series of Nitrogen concentration for Staged discharge to Mahurangi River for selected sites in the main channel

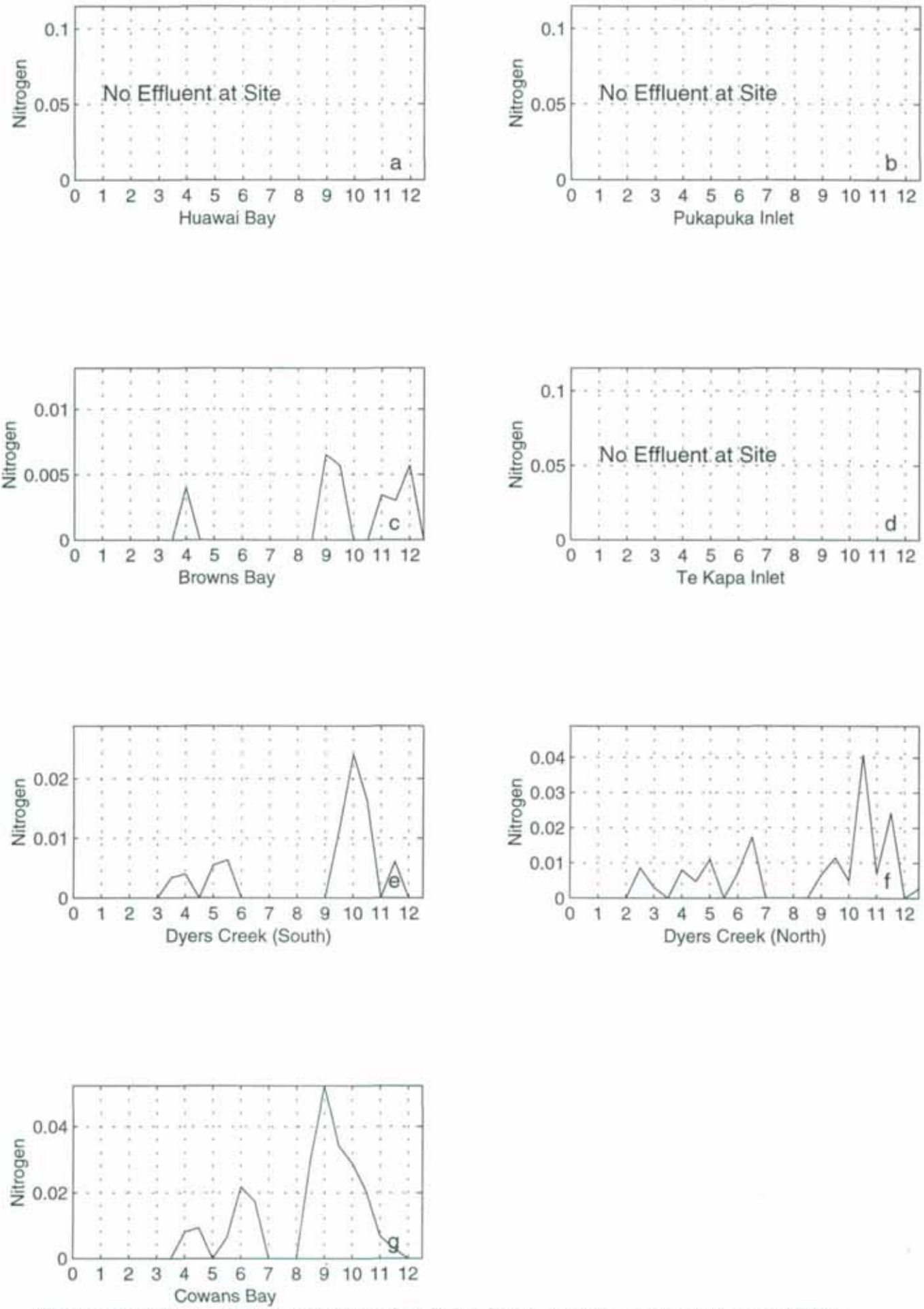


Figure 12 : Nitrogen concentrations (mg/l) for Staged discharge to Mahurangi River. Spatial average for oyster farms at sites as indicated

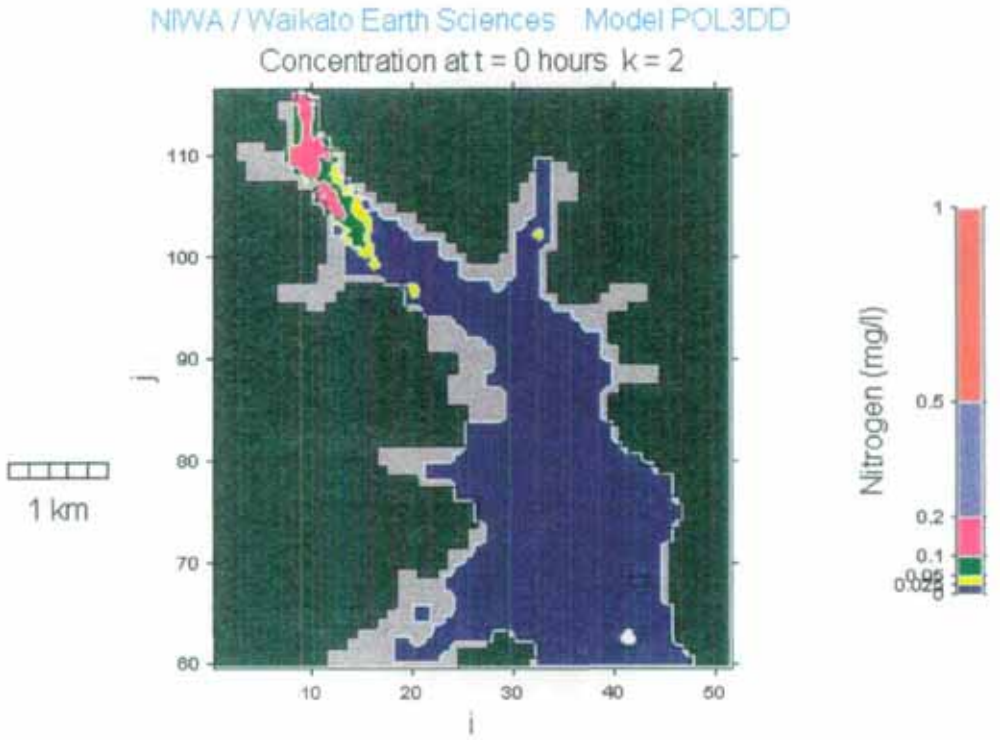


Figure 13a. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

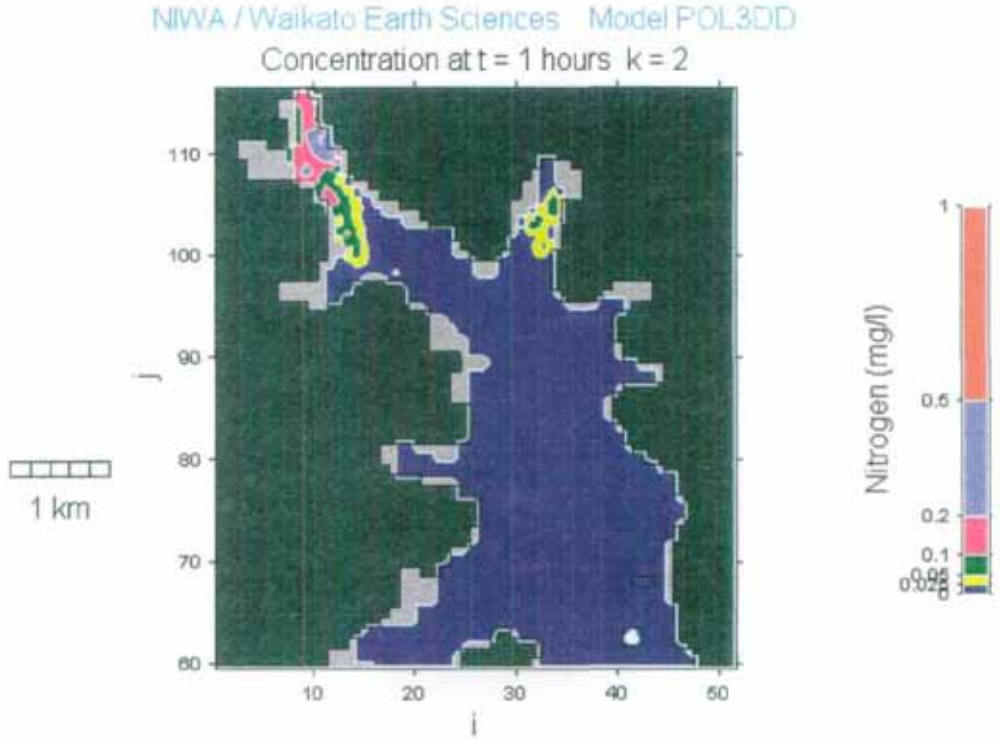


Figure 13b. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

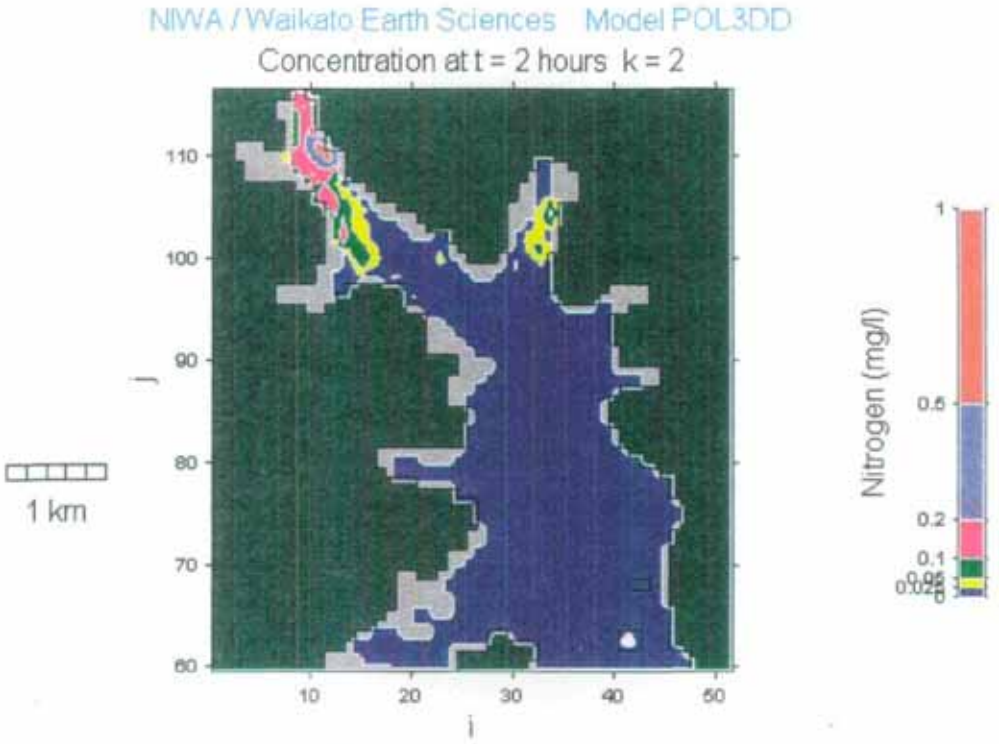


Figure 13c. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

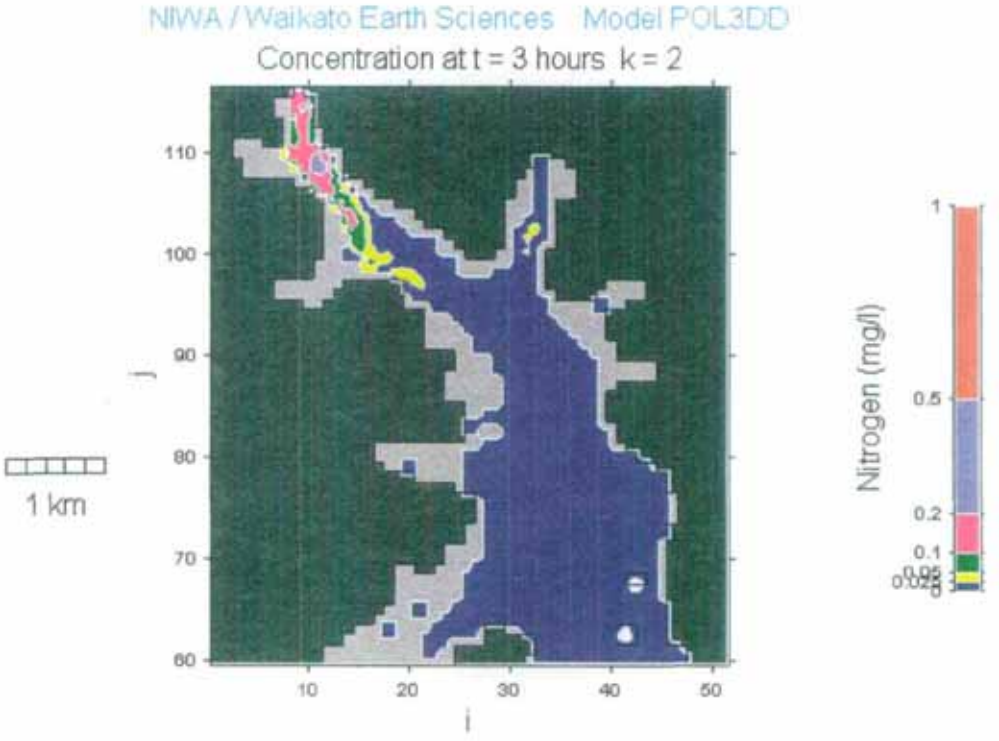


Figure 13d. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

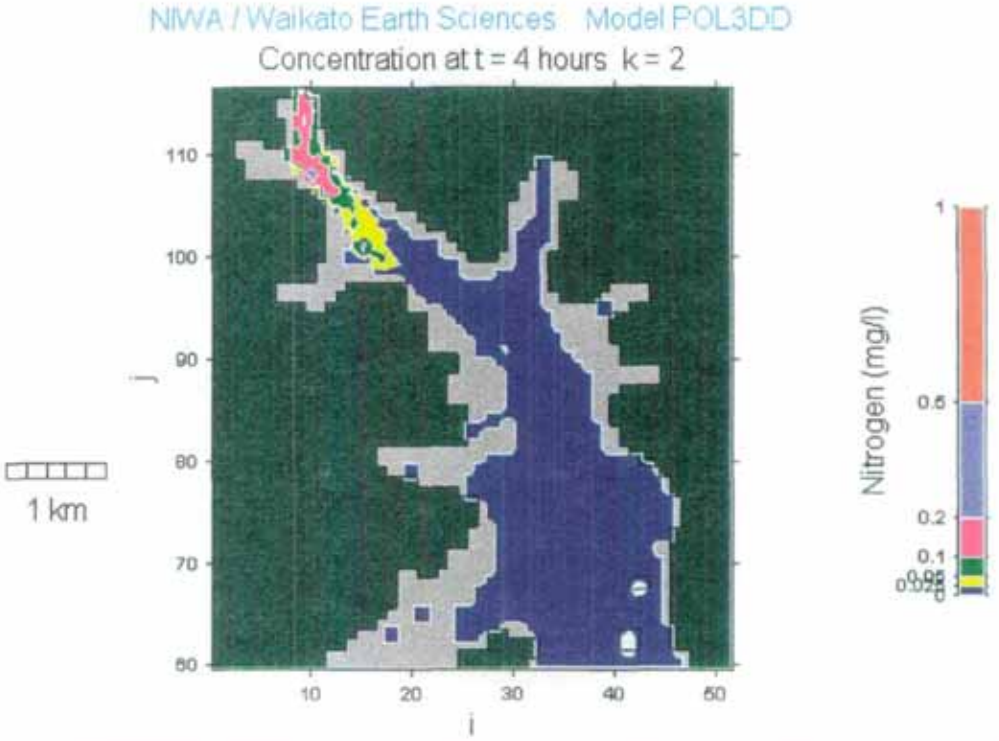


Figure 13e. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

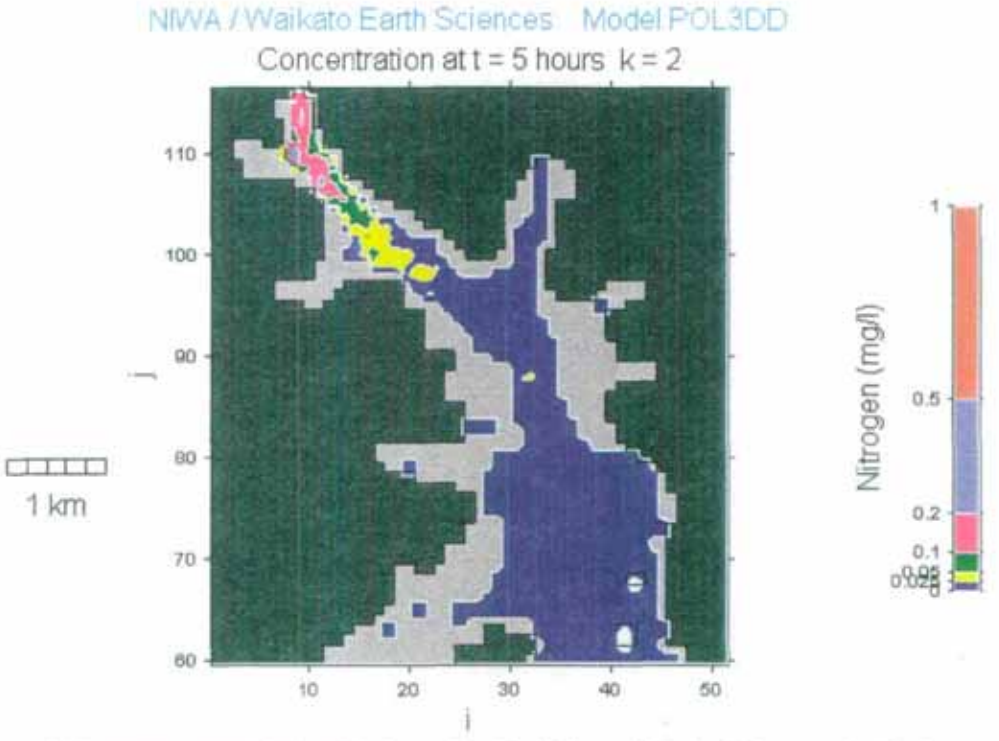


Figure 13f. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

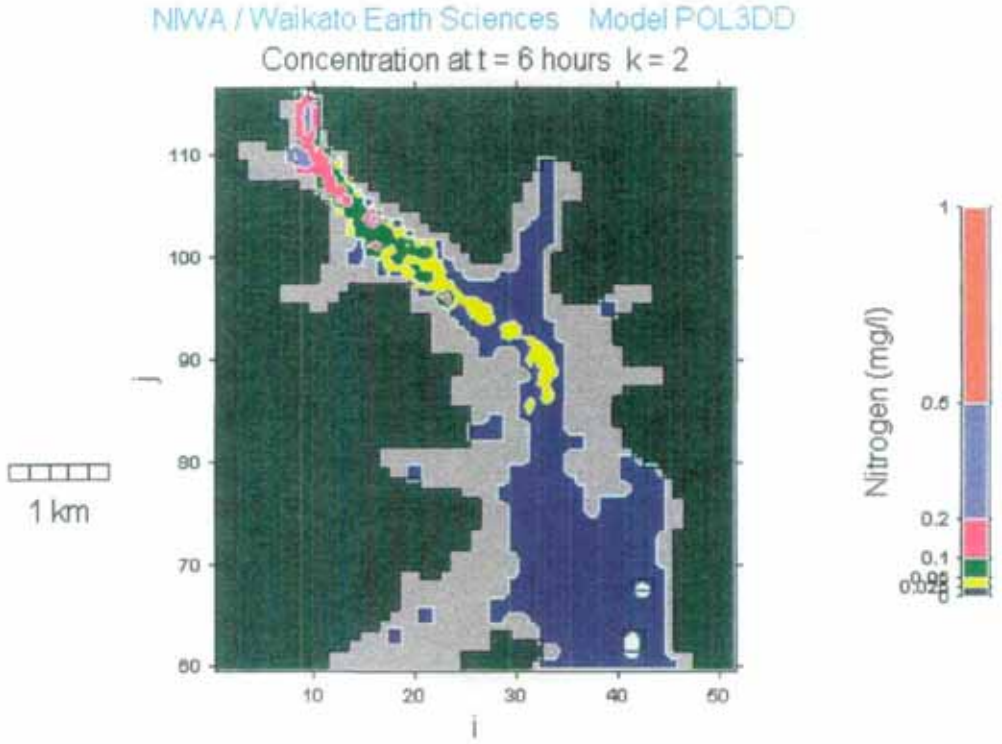


Figure 13g. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus six hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

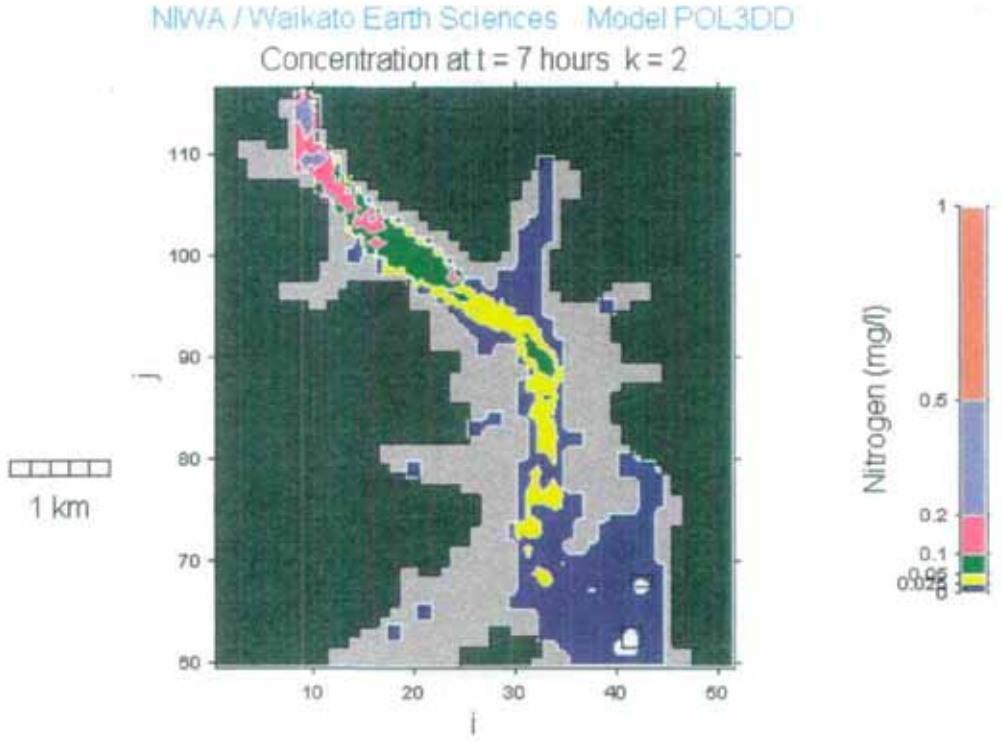


Figure 13h. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus half an hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

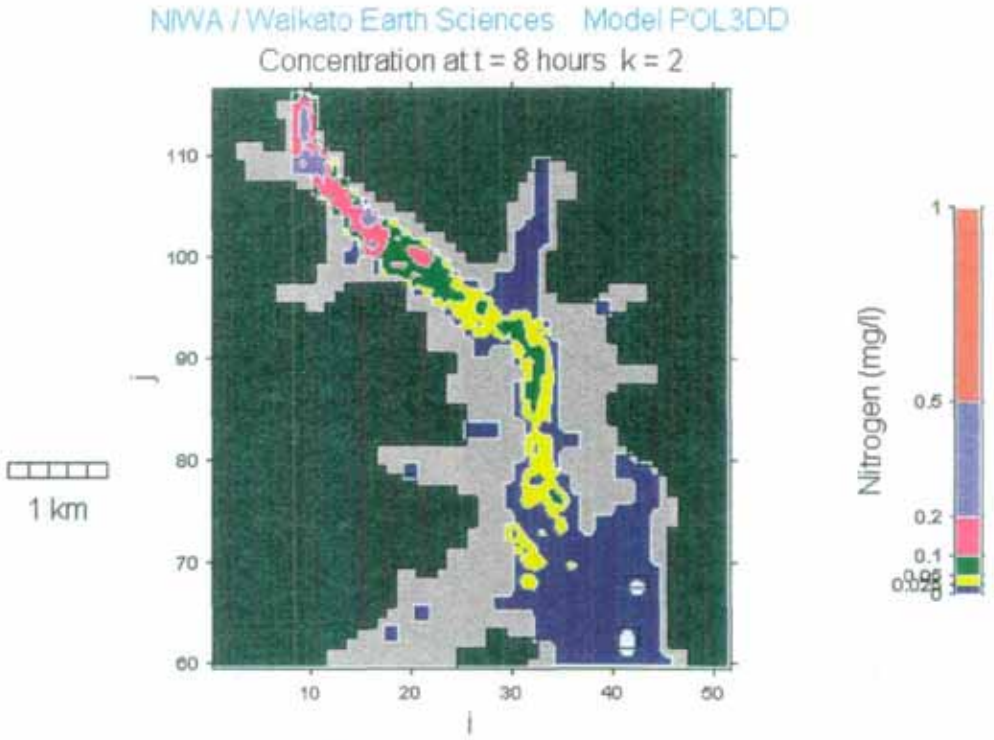


Figure 13i. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

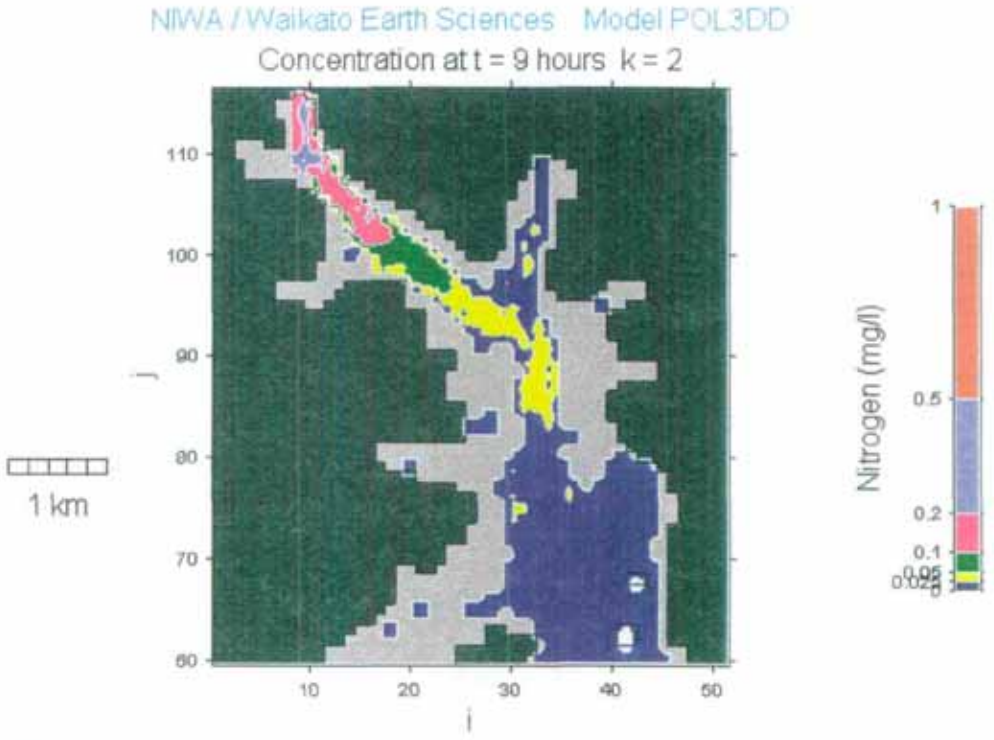


Figure 13j. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

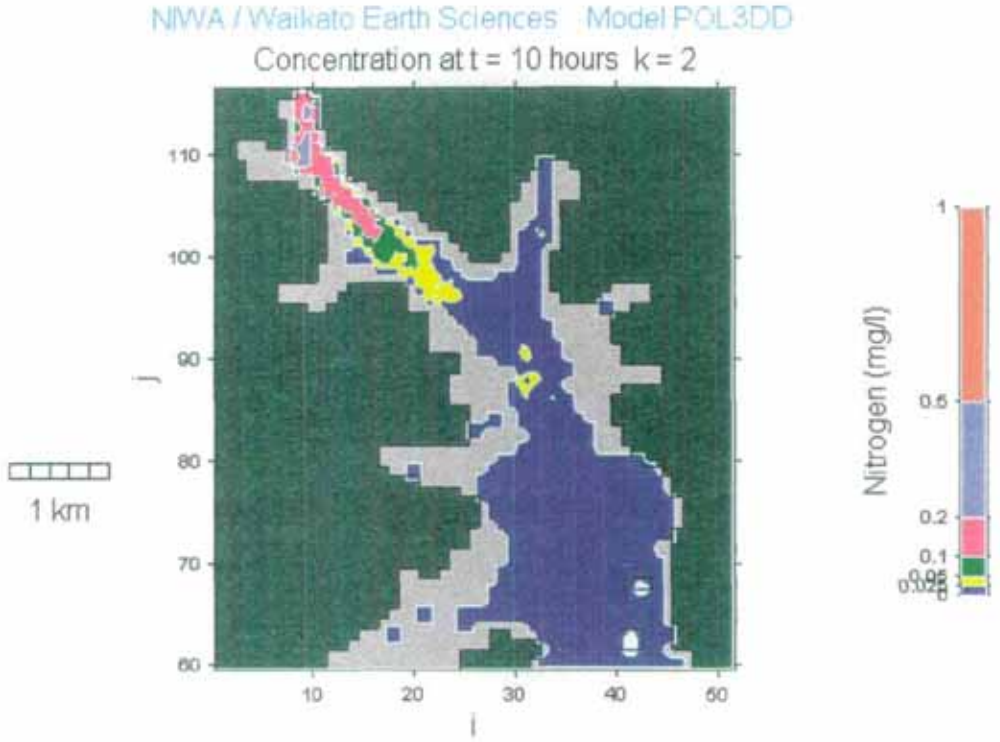


Figure 13k. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

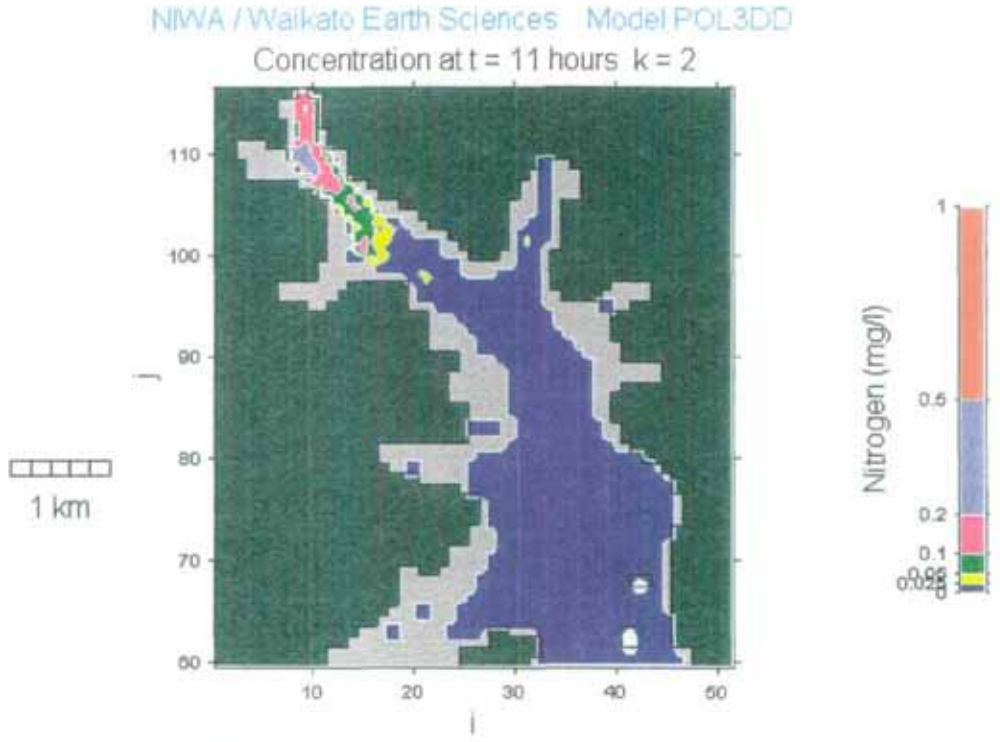


Figure 13l. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

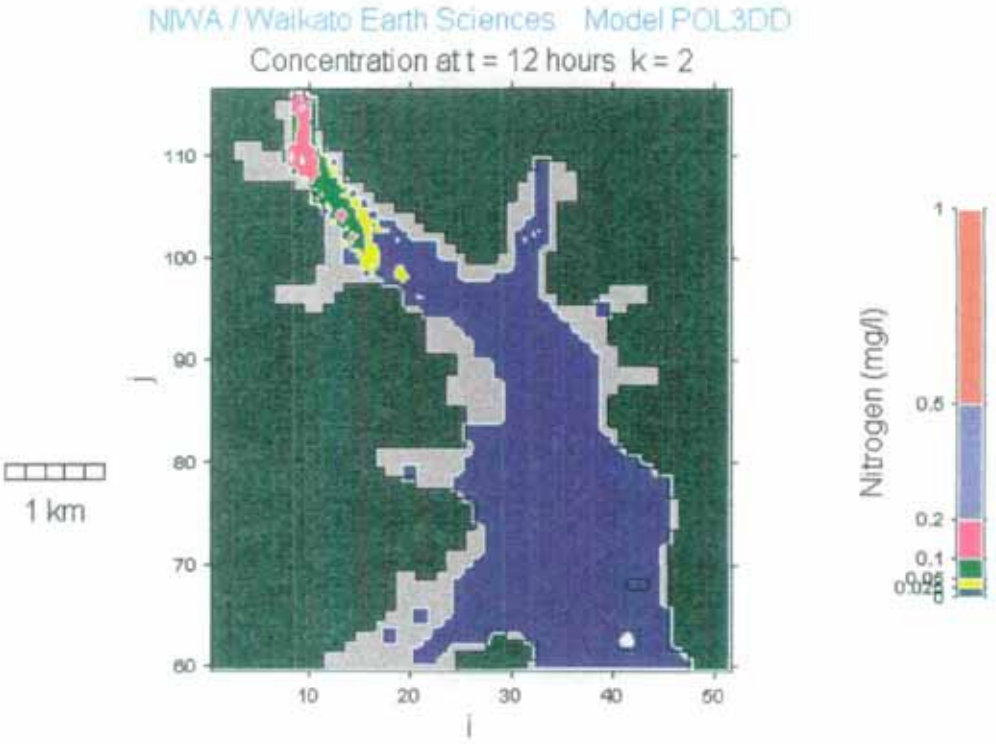


Figure 13m. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

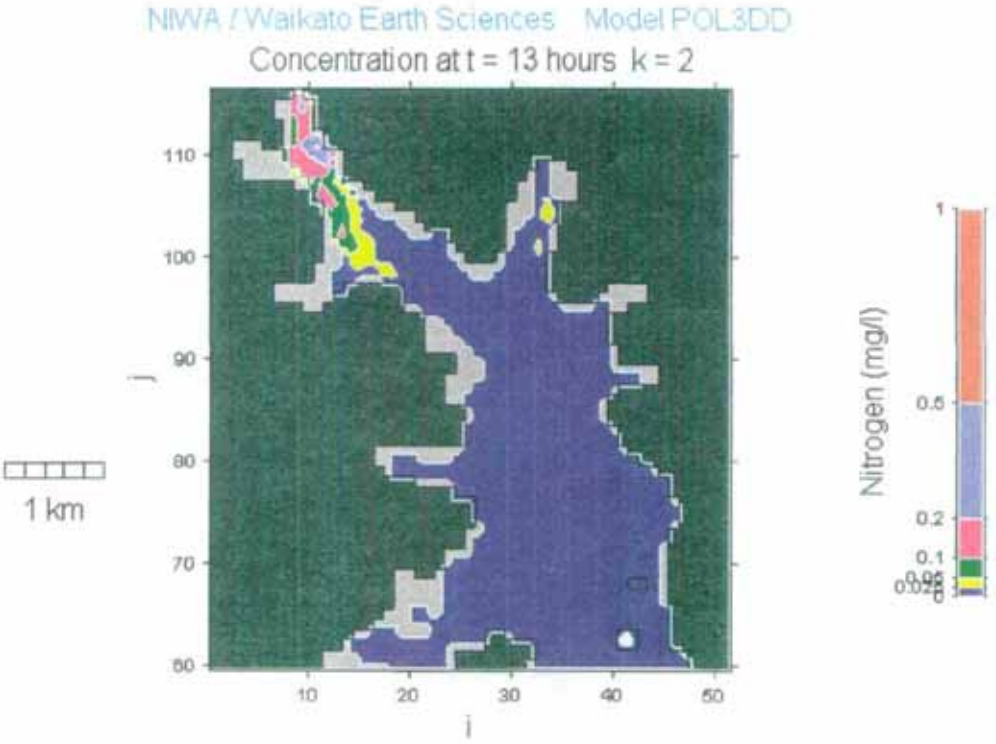


Figure 13n. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus half an hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

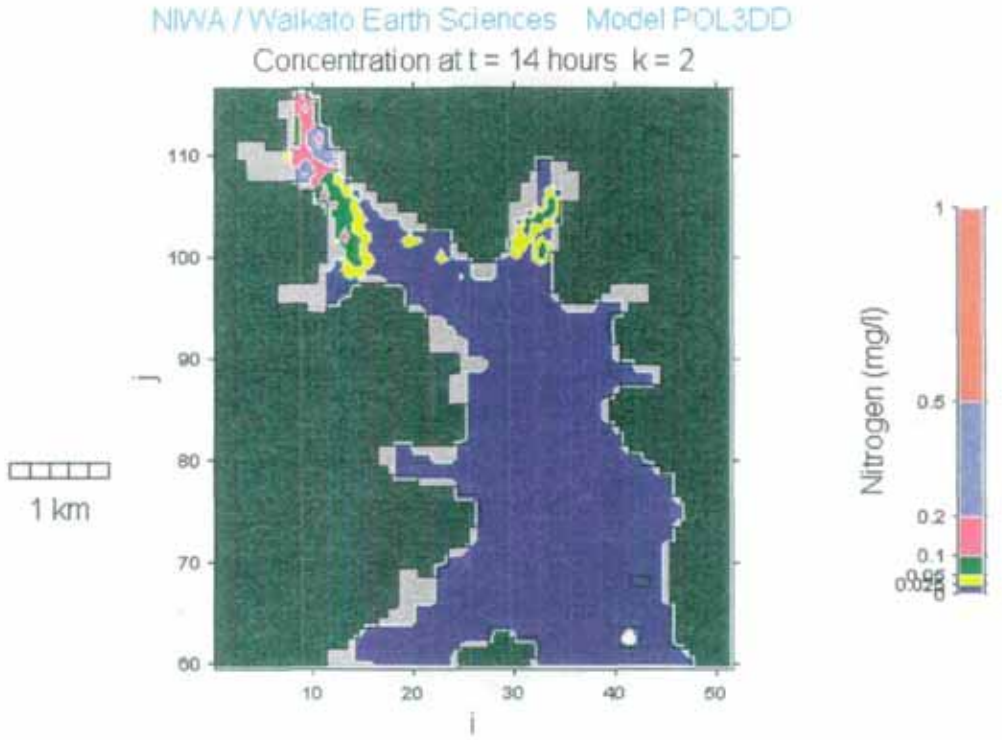


Figure 13o. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

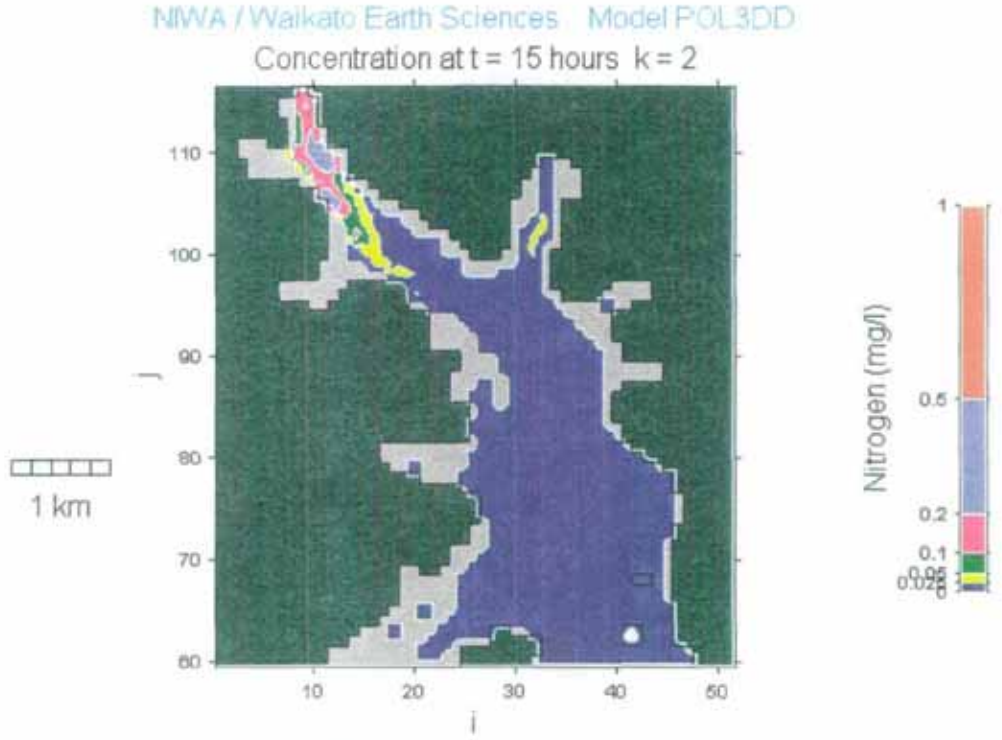


Figure 13p. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

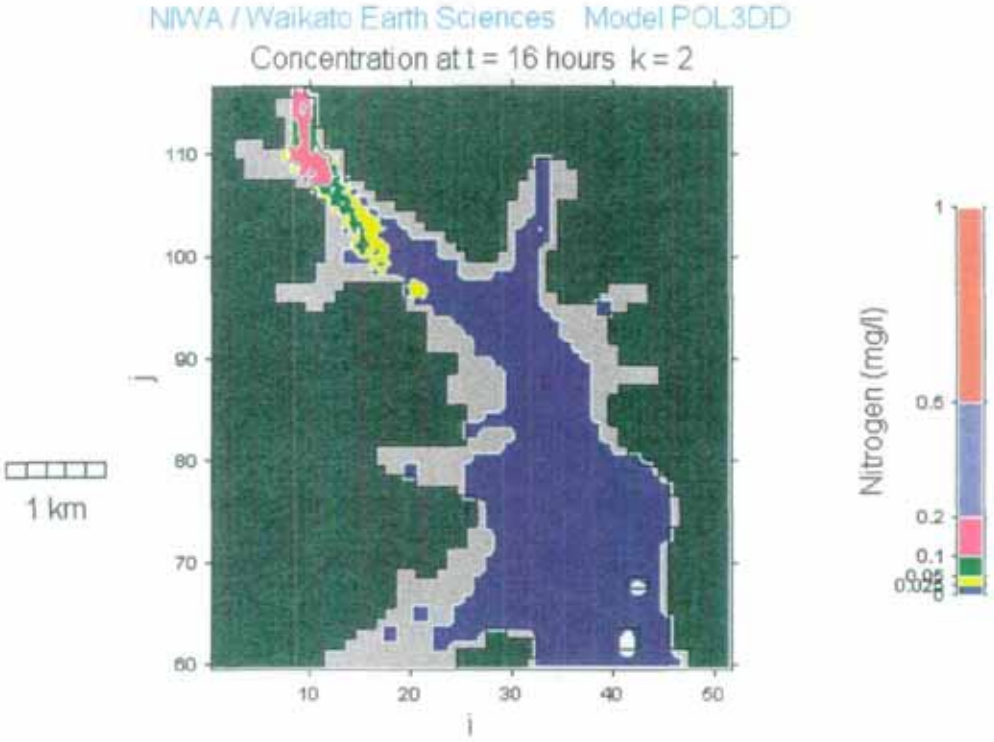


Figure 13q. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

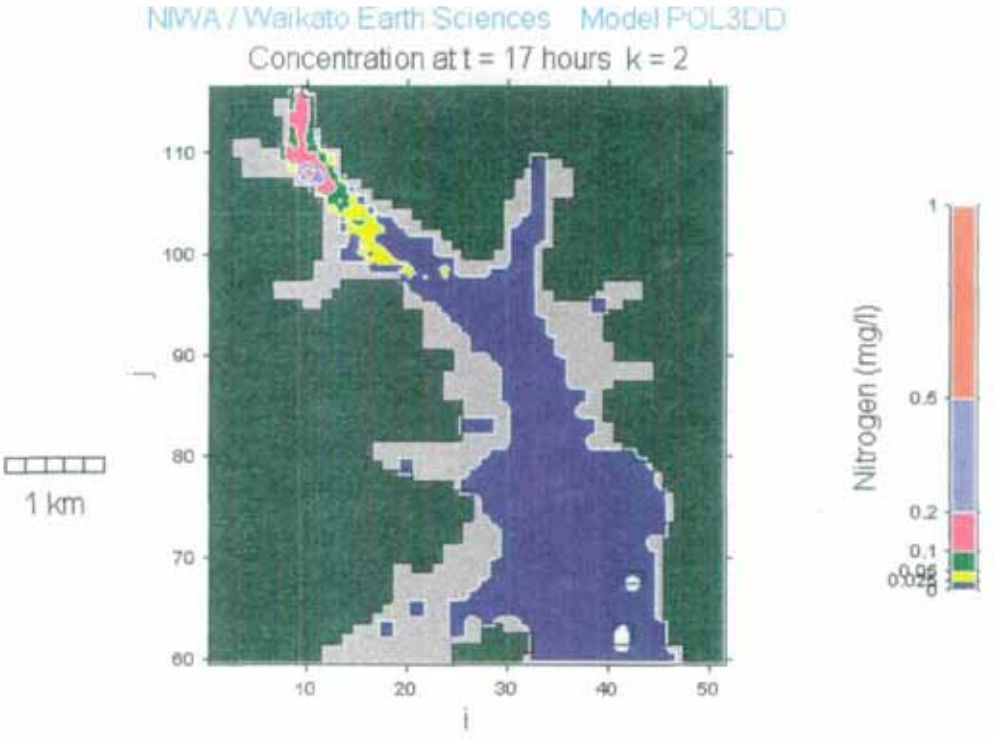


Figure 13r. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

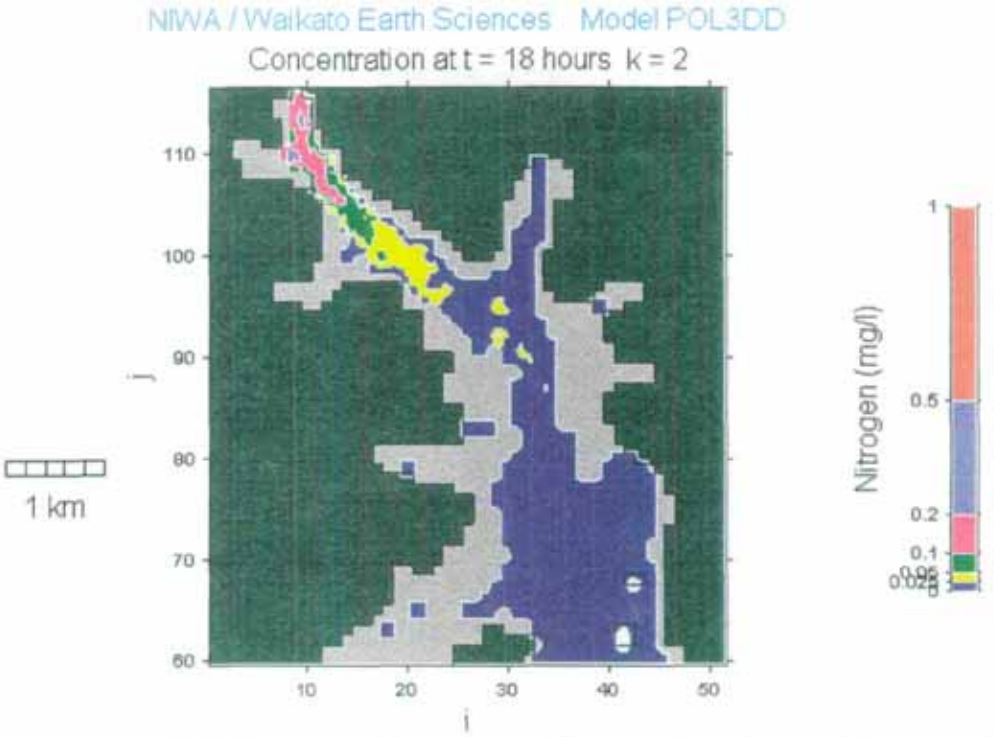


Figure 13s. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

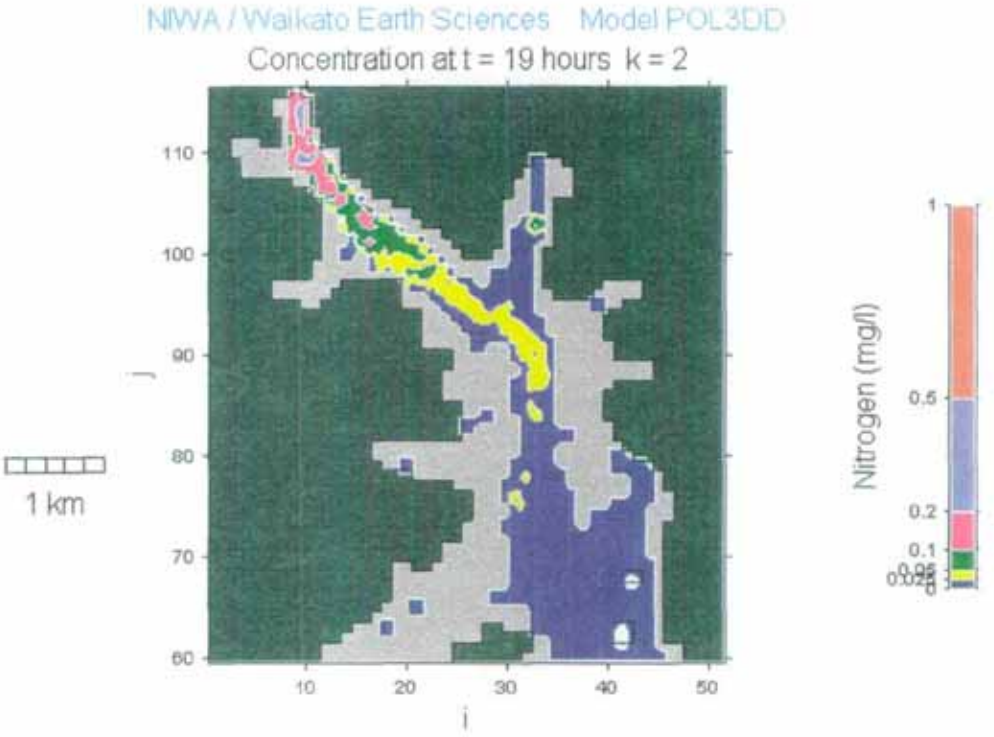


Figure 13t. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

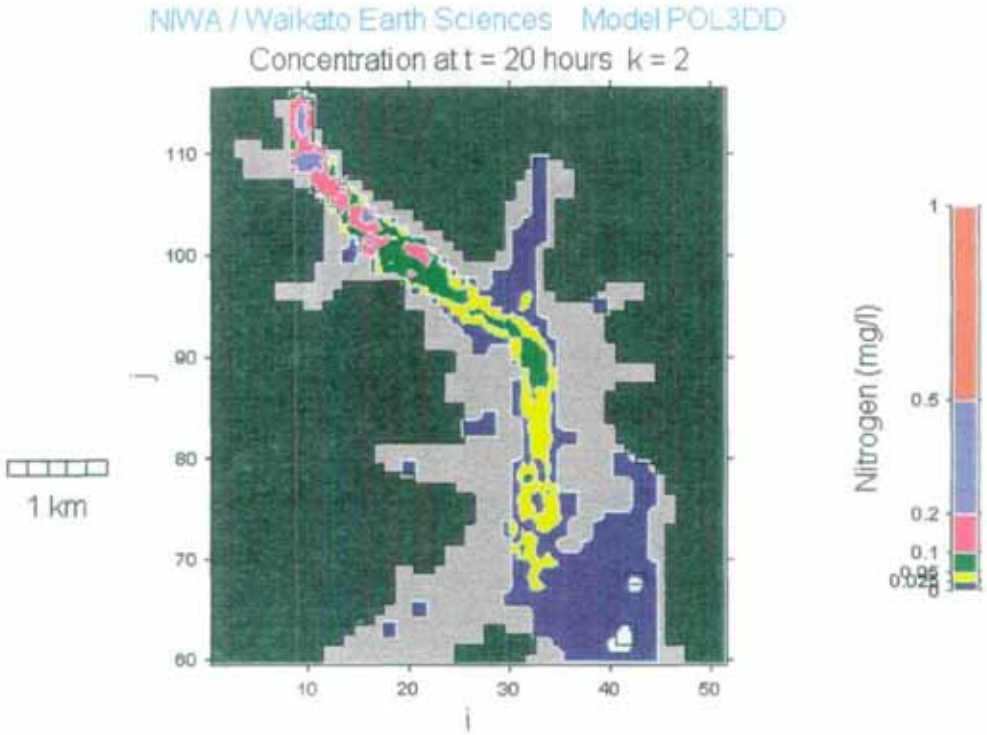


Figure 13u. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

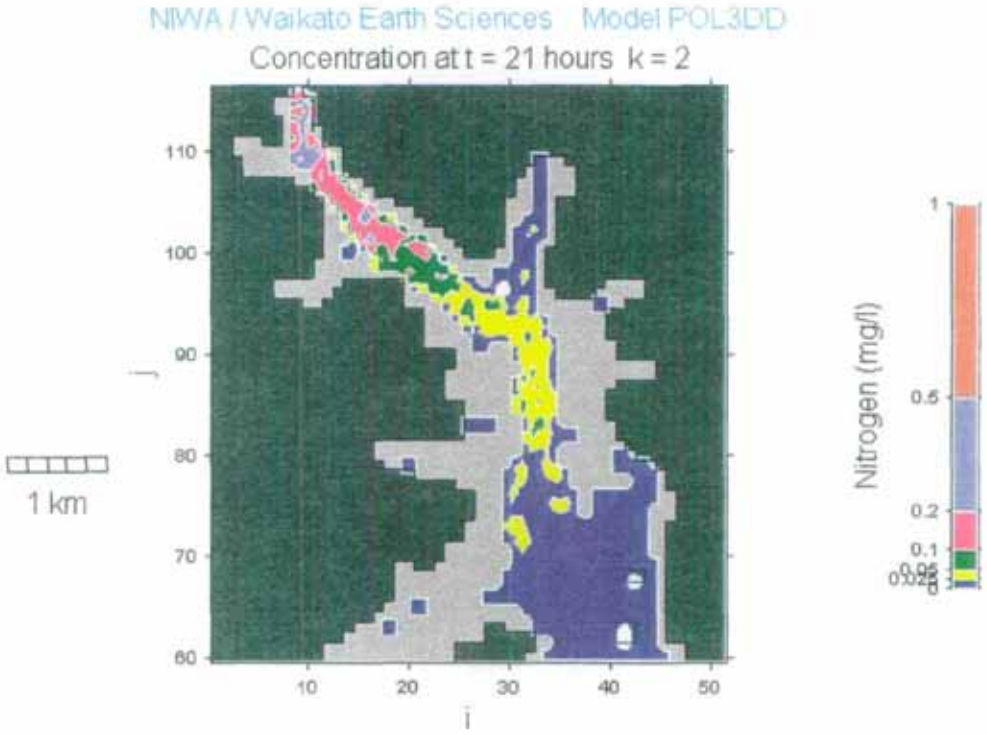


Figure 13v. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

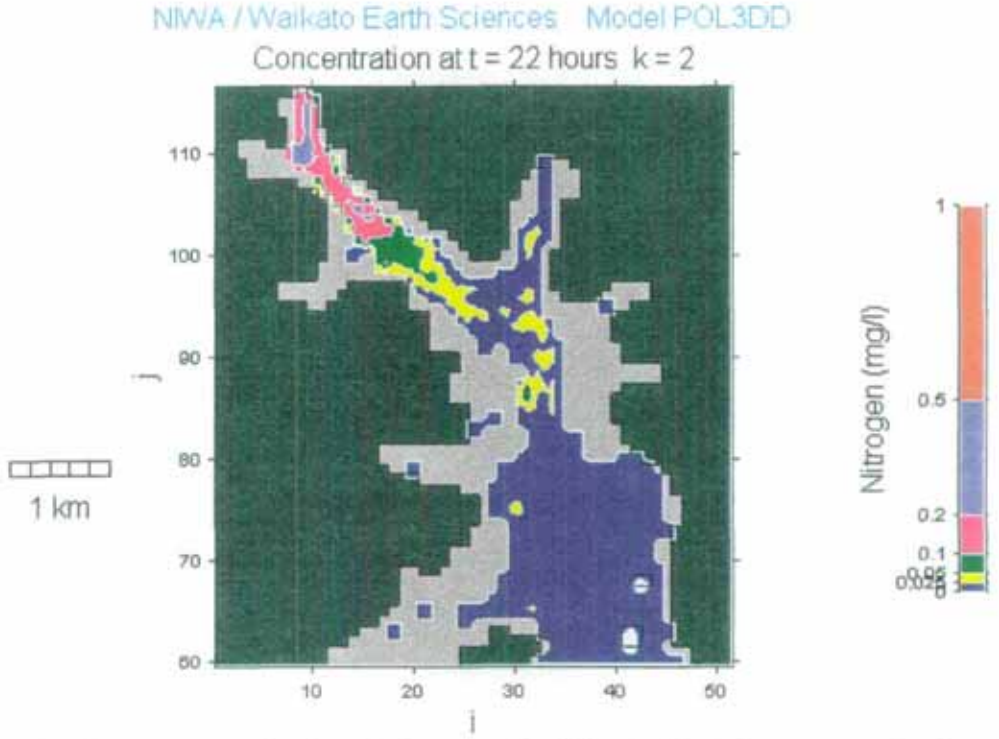


Figure 13w. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

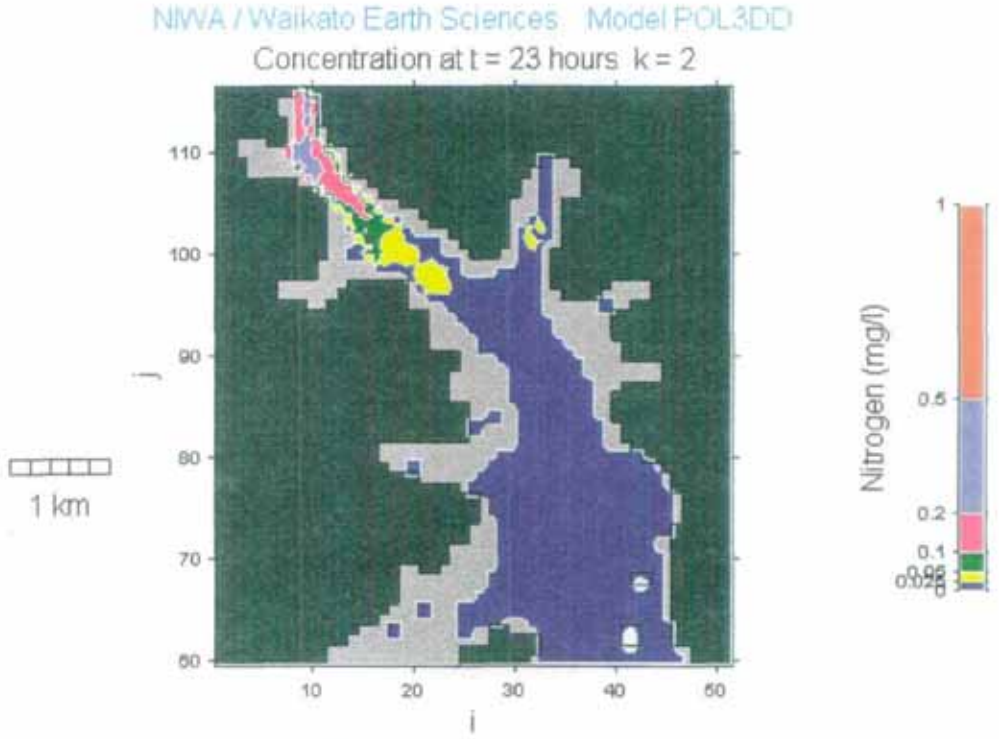


Figure 13x. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

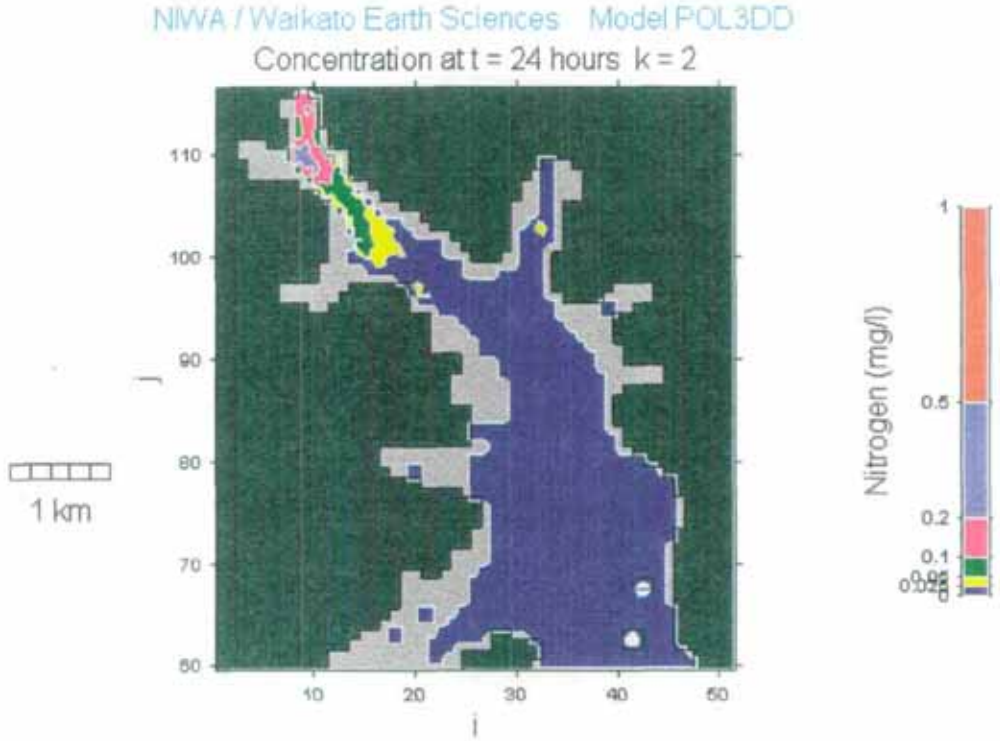


Figure 13y. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

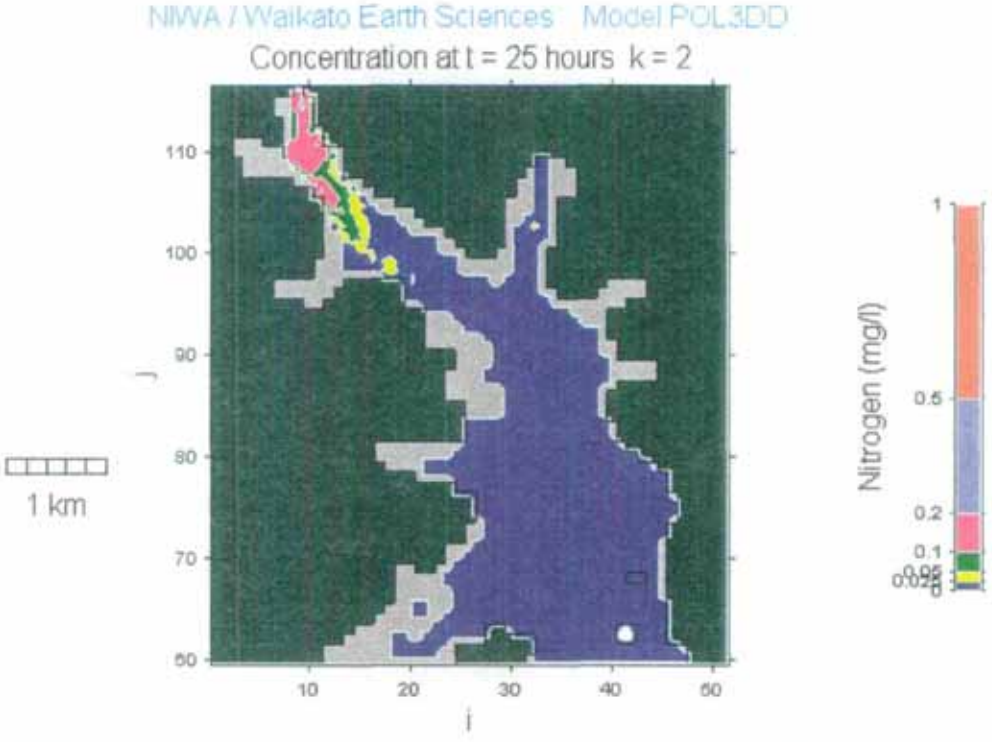


Figure 13z. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

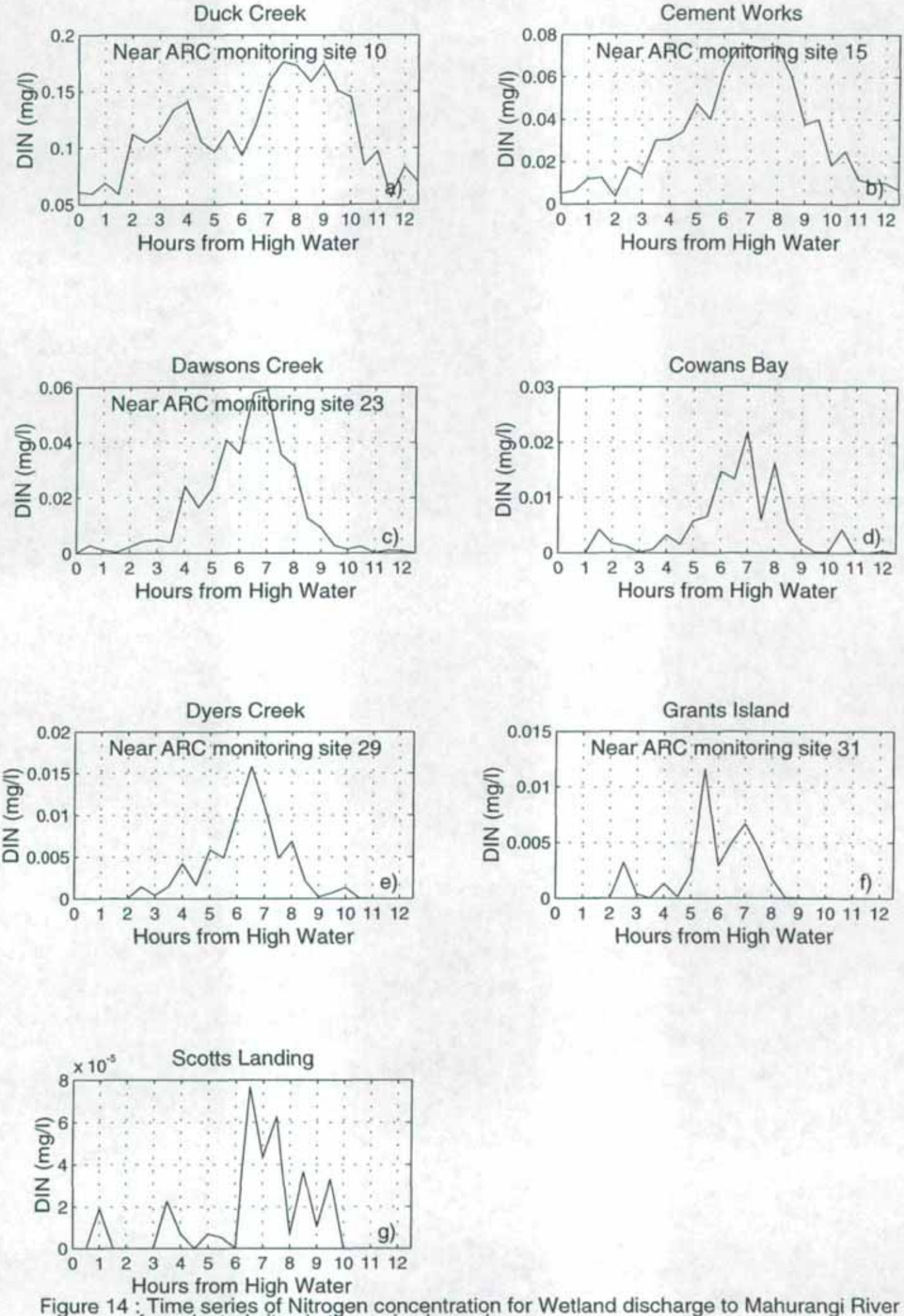


Figure 14 : Time series of Nitrogen concentration for Wetland discharge to Mahurangi River for selected sites in the main channel

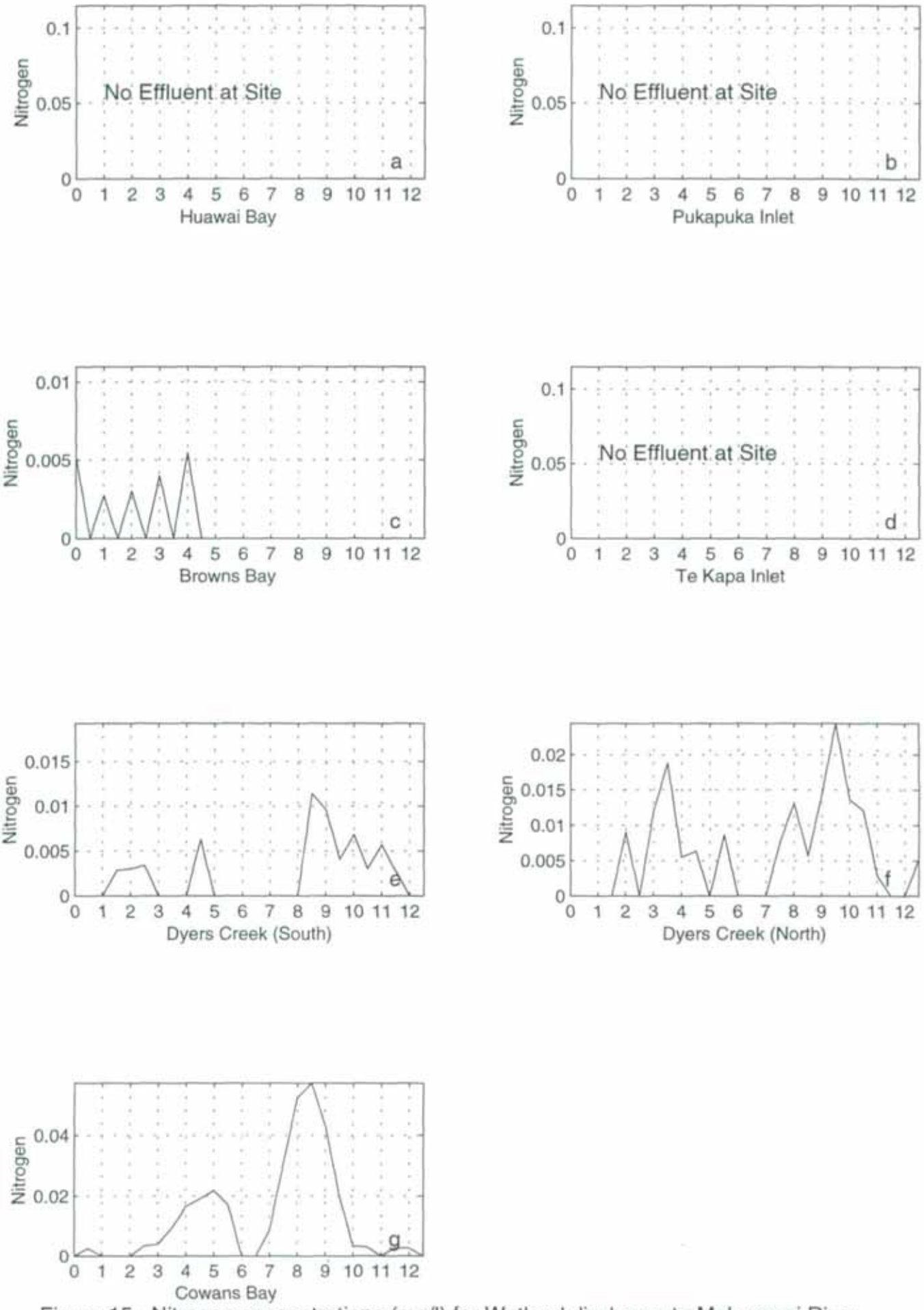


Figure 15 : Nitrogen concentrations (mg/l) for Wetland discharge to Mahurangi River. Spatial average for oyster farms at sites as indicated

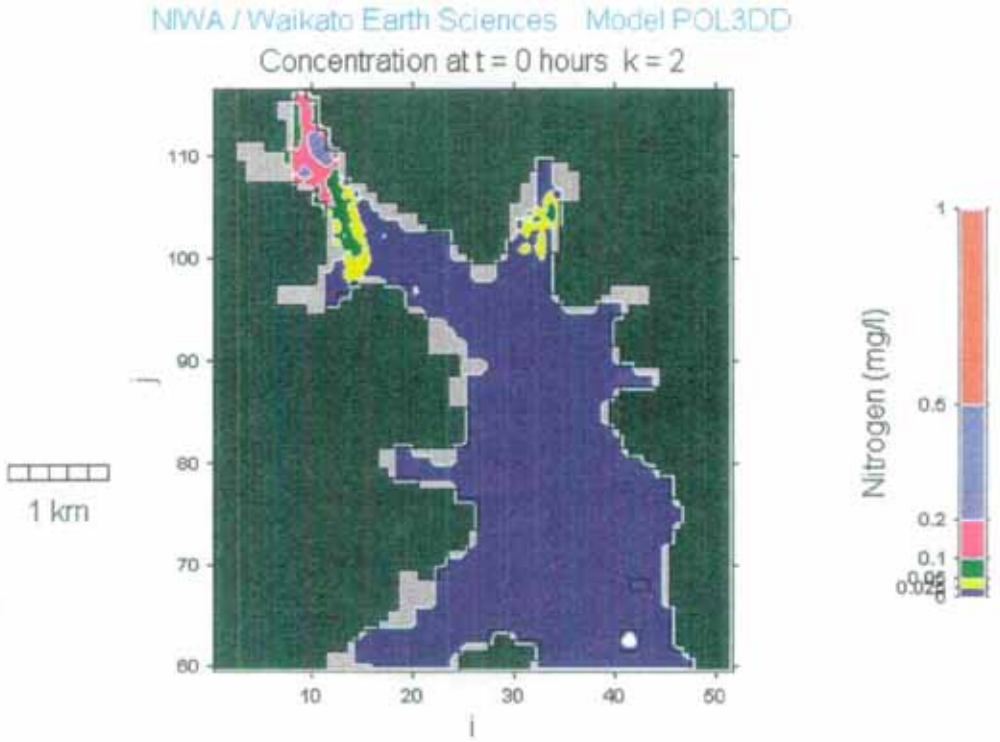


Figure 16a. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

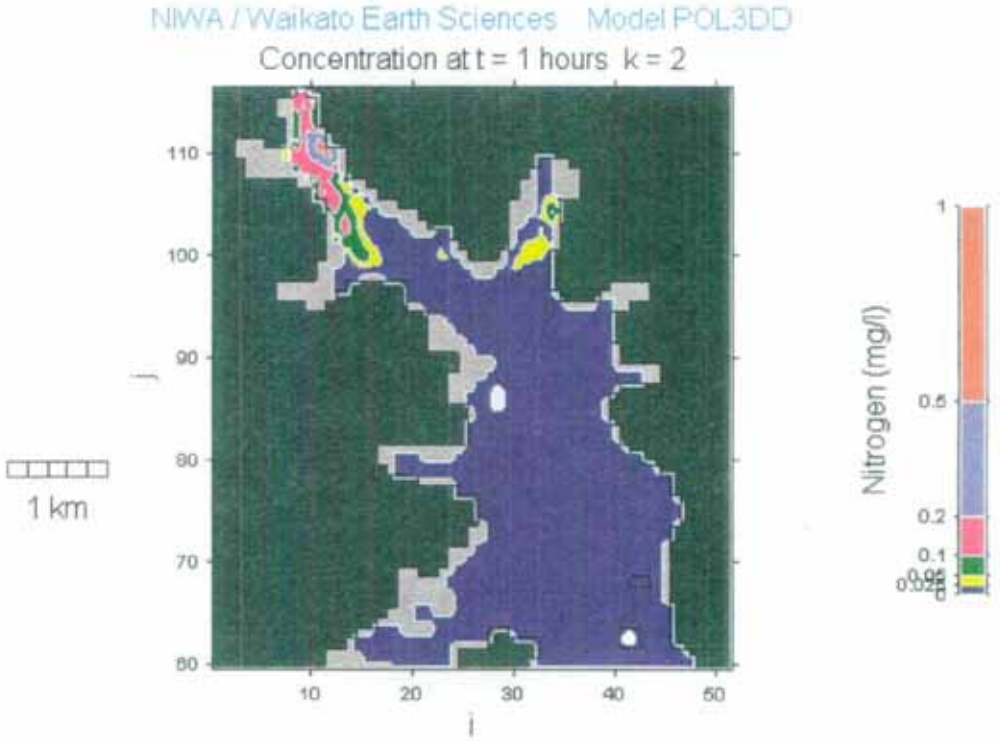


Figure 16b. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

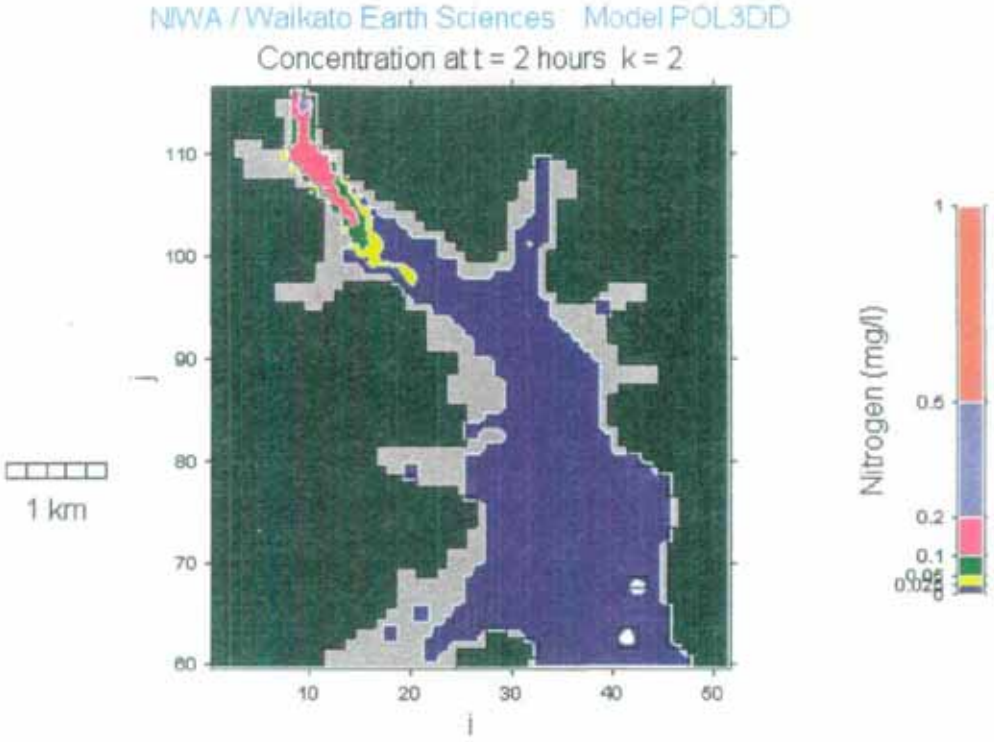


Figure 16c. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

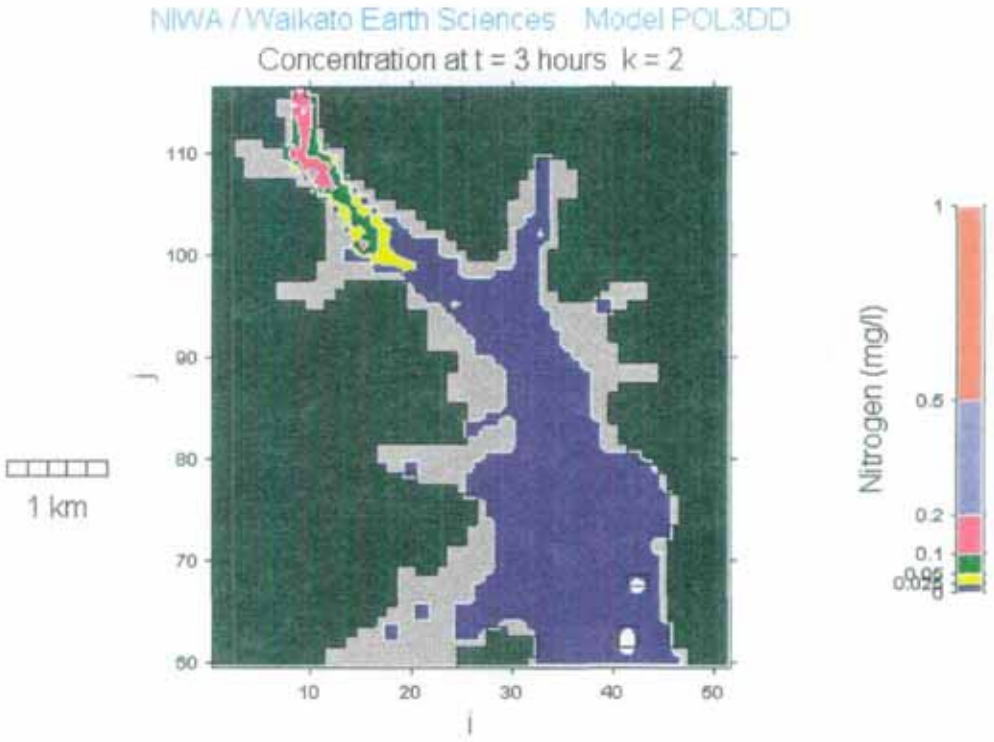


Figure 16d. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

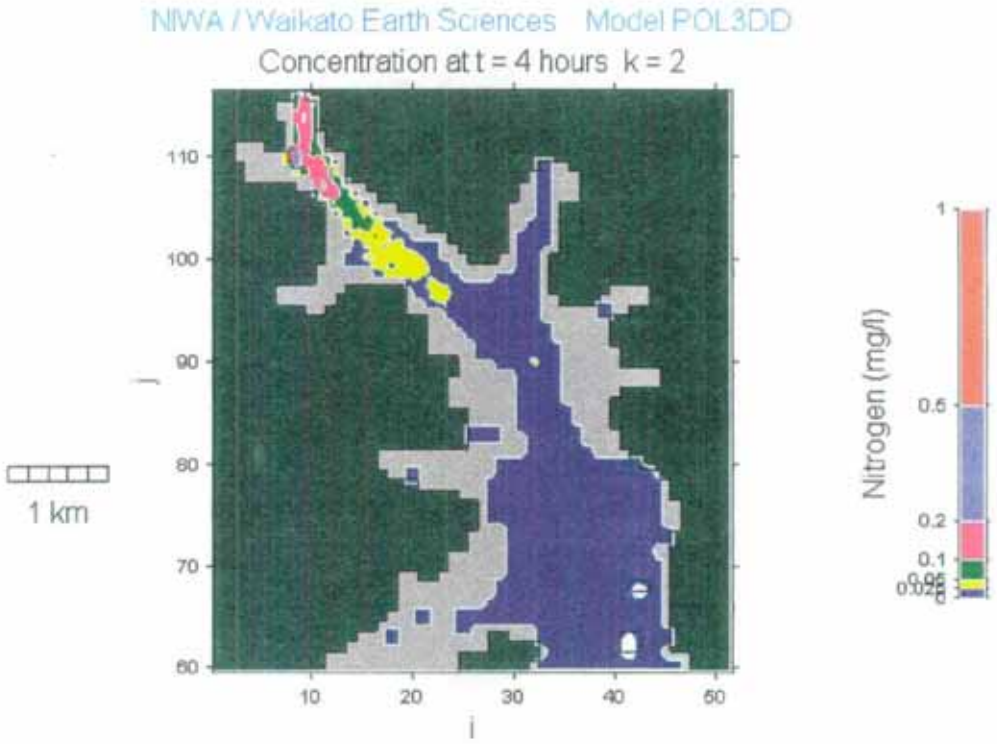


Figure 16e. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

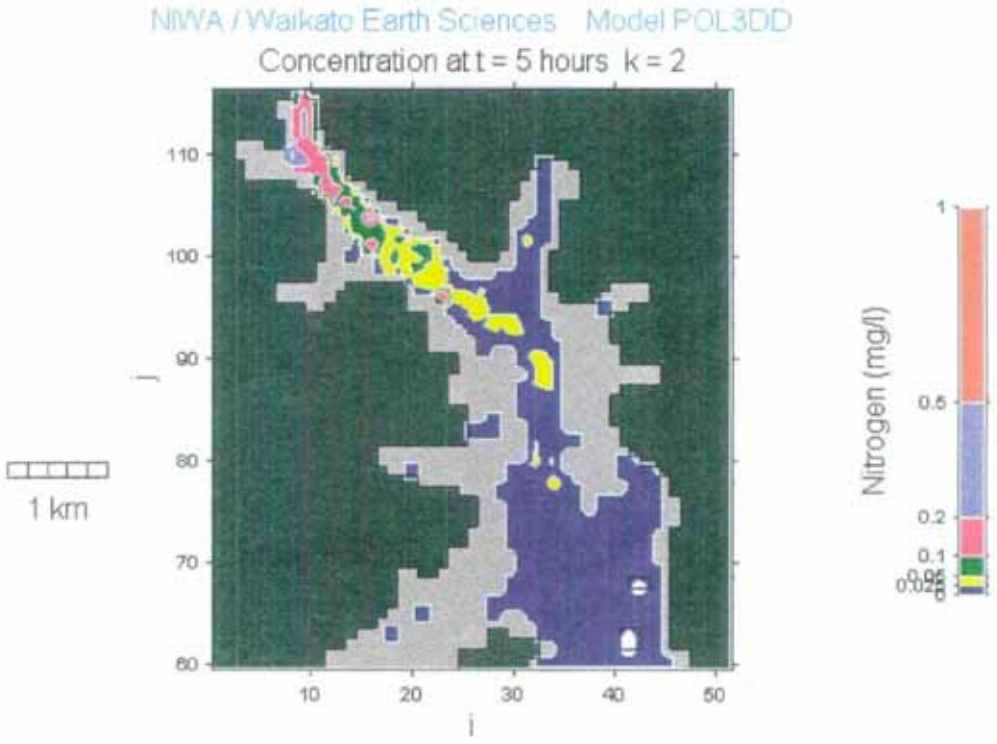


Figure 16f. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

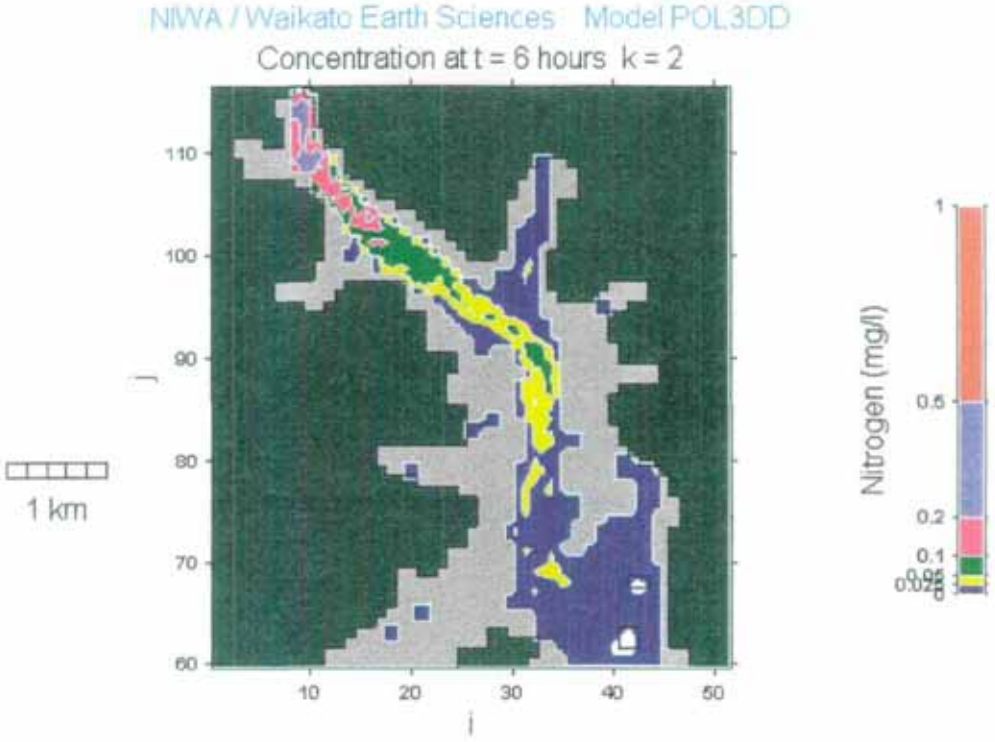


Figure 16g. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus six hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

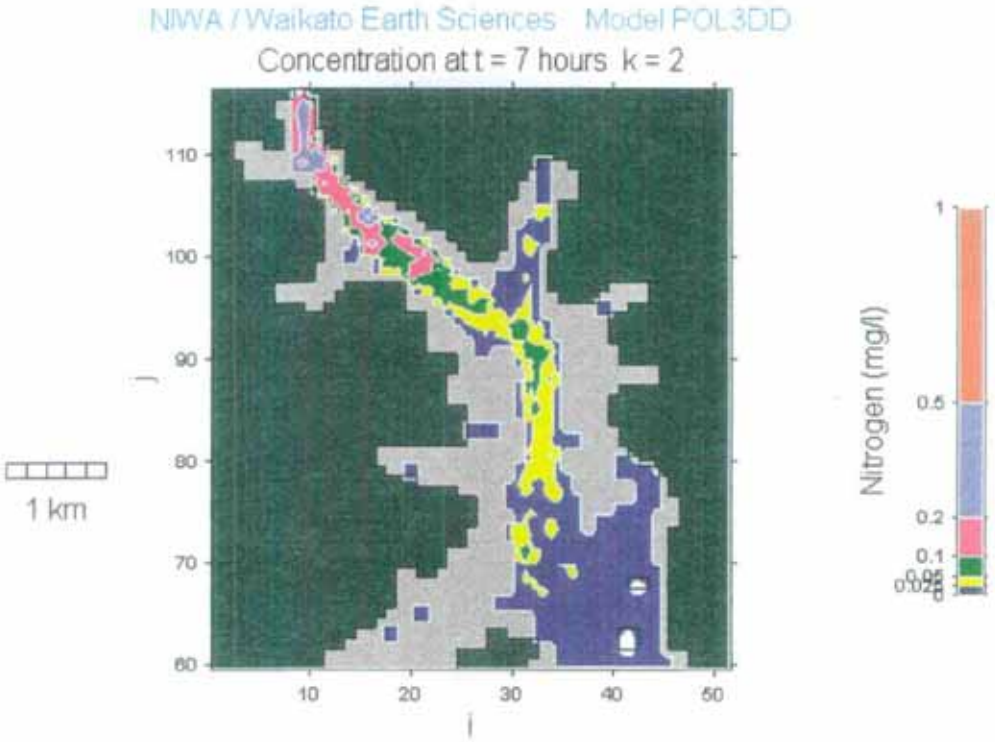


Figure 16h. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus half an hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

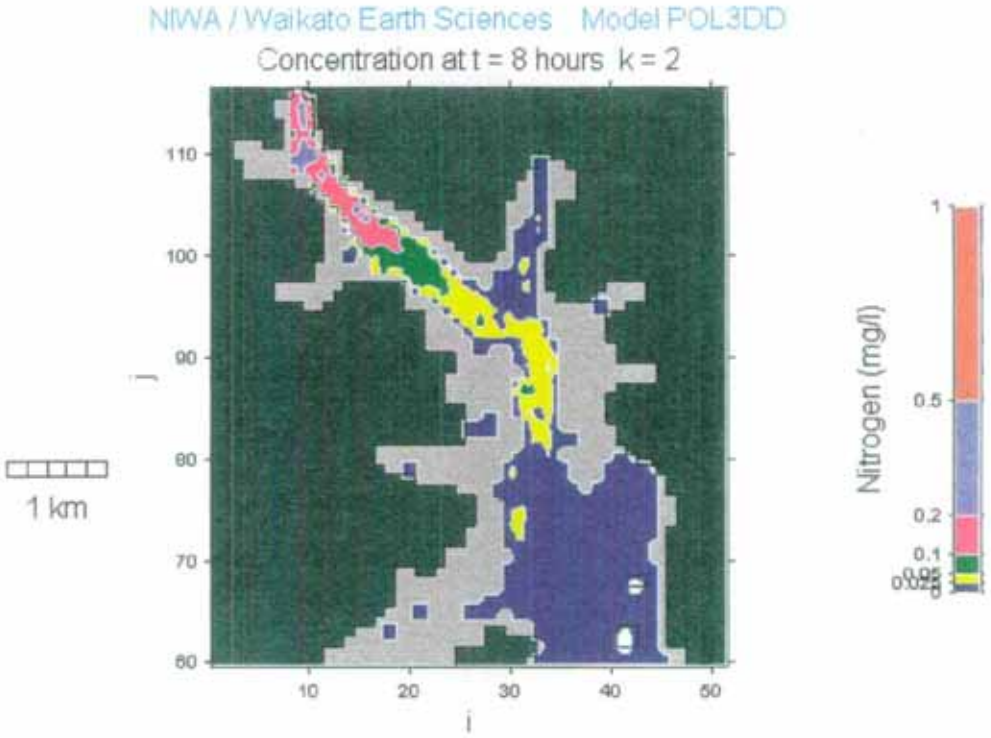


Figure 16i. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

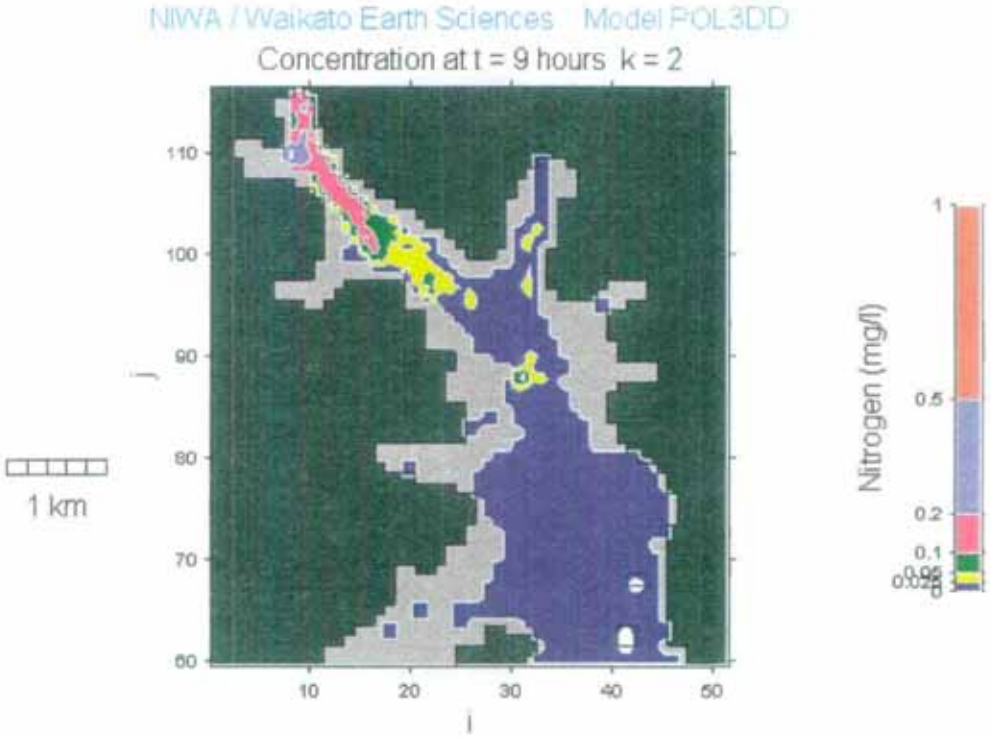


Figure 16j. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

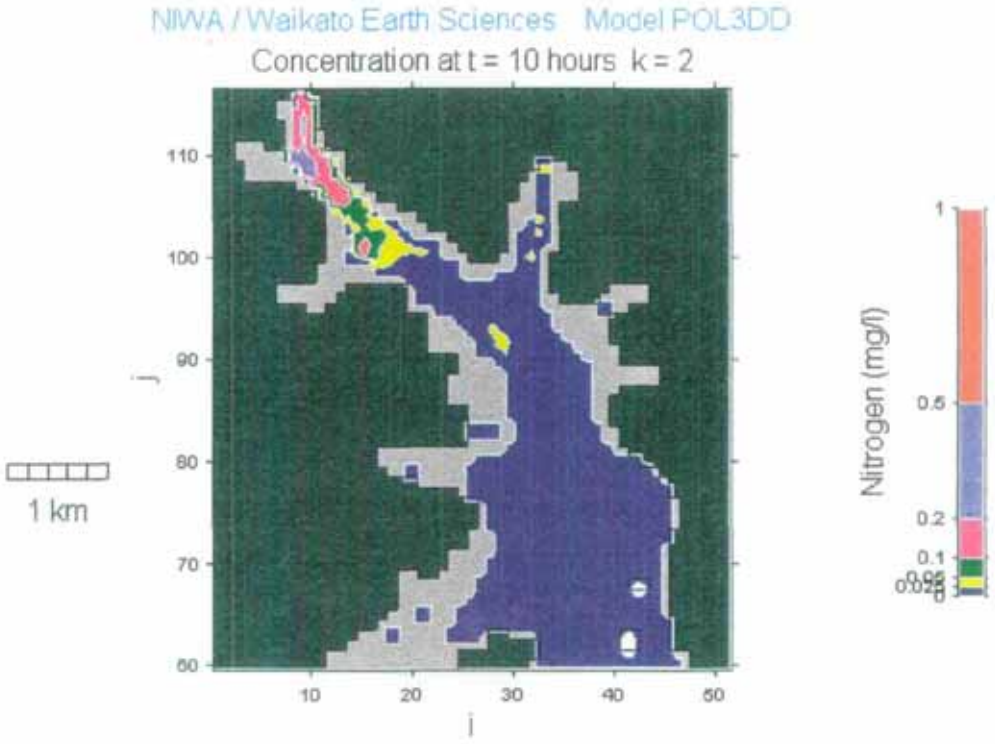


Figure 16k. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

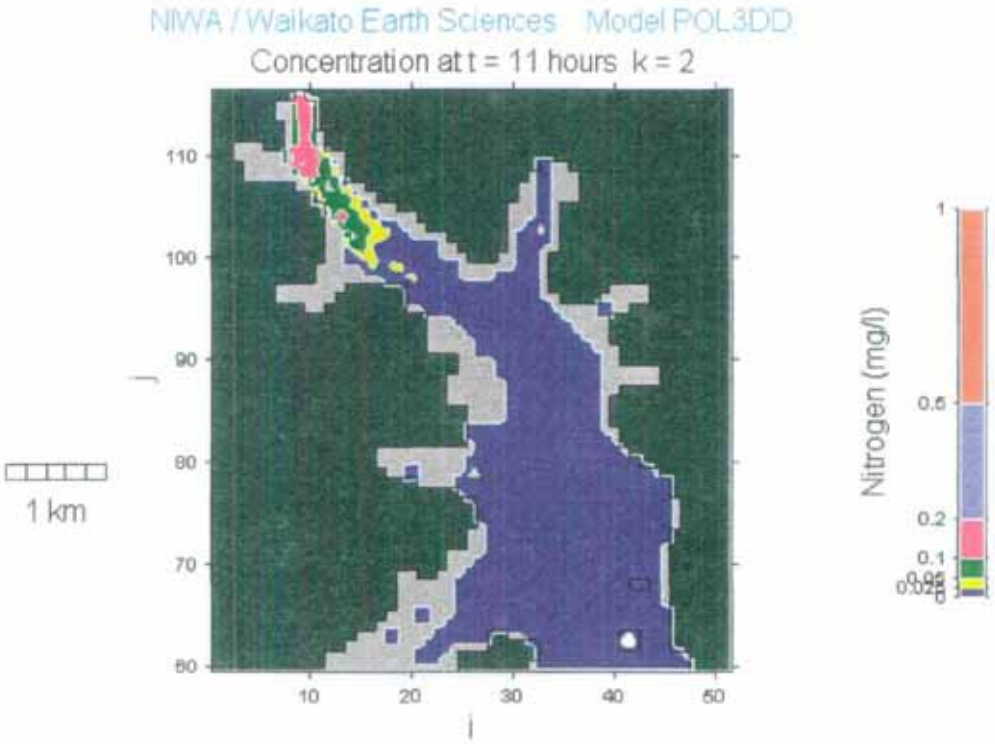


Figure 16l. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

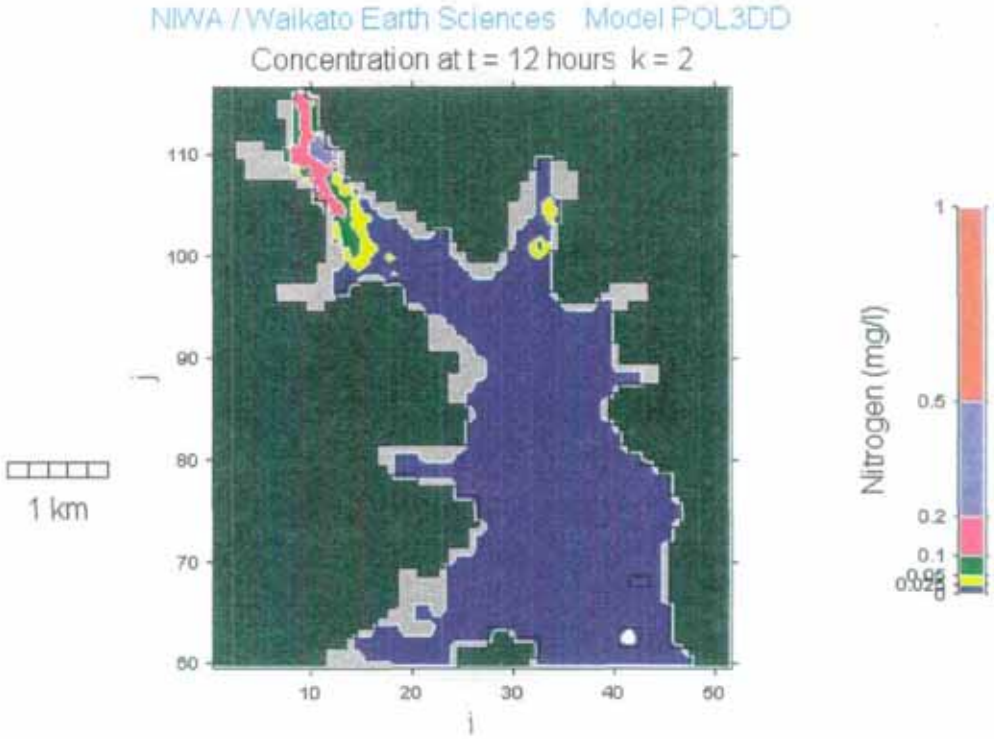


Figure 16m. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

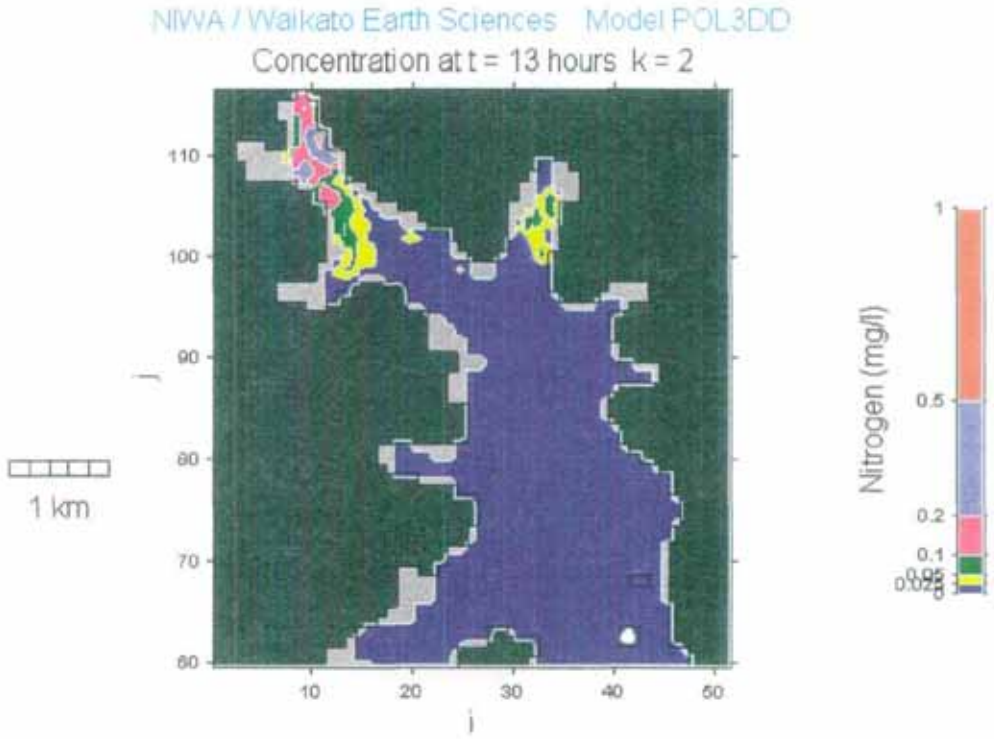


Figure 16n. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus half an hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

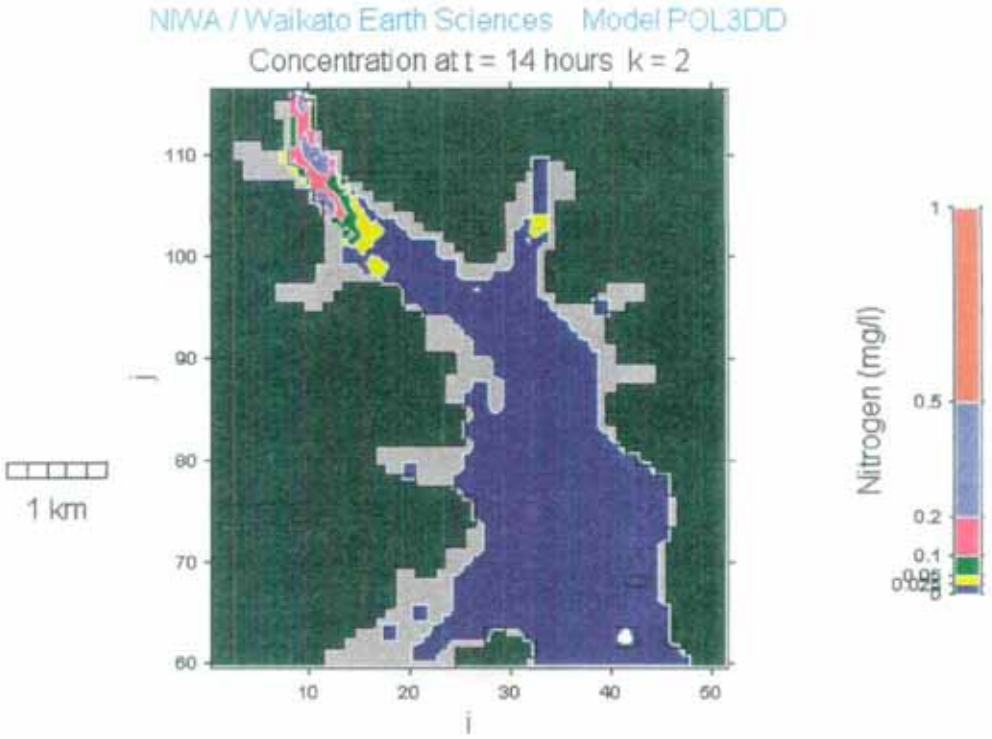


Figure 16o. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

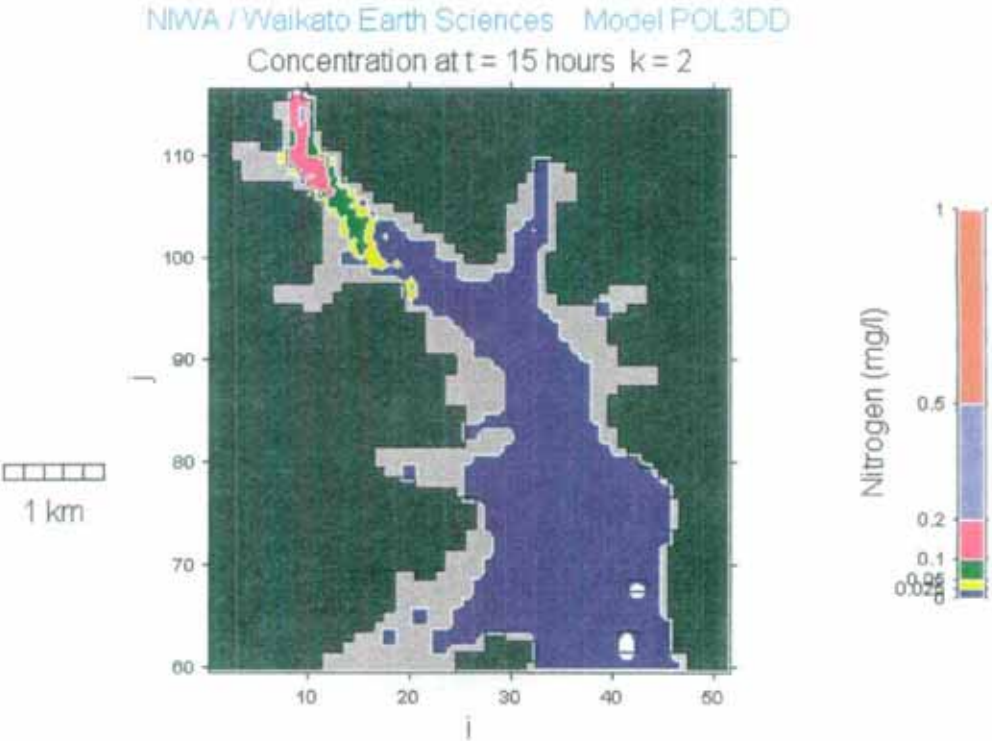


Figure 16p. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

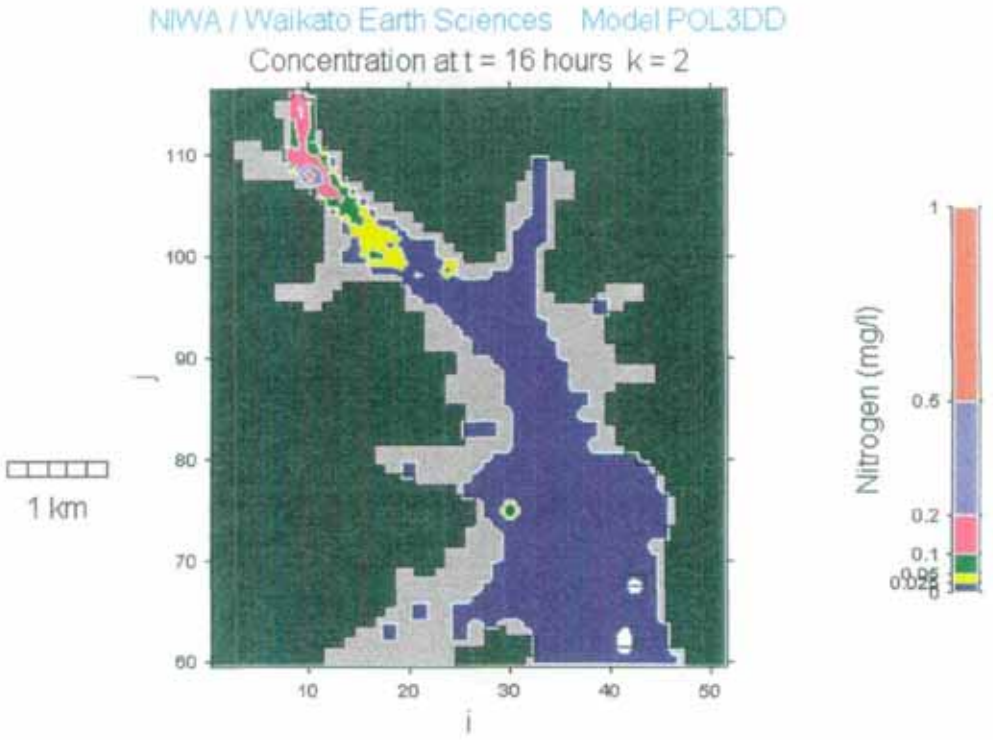


Figure 16q. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

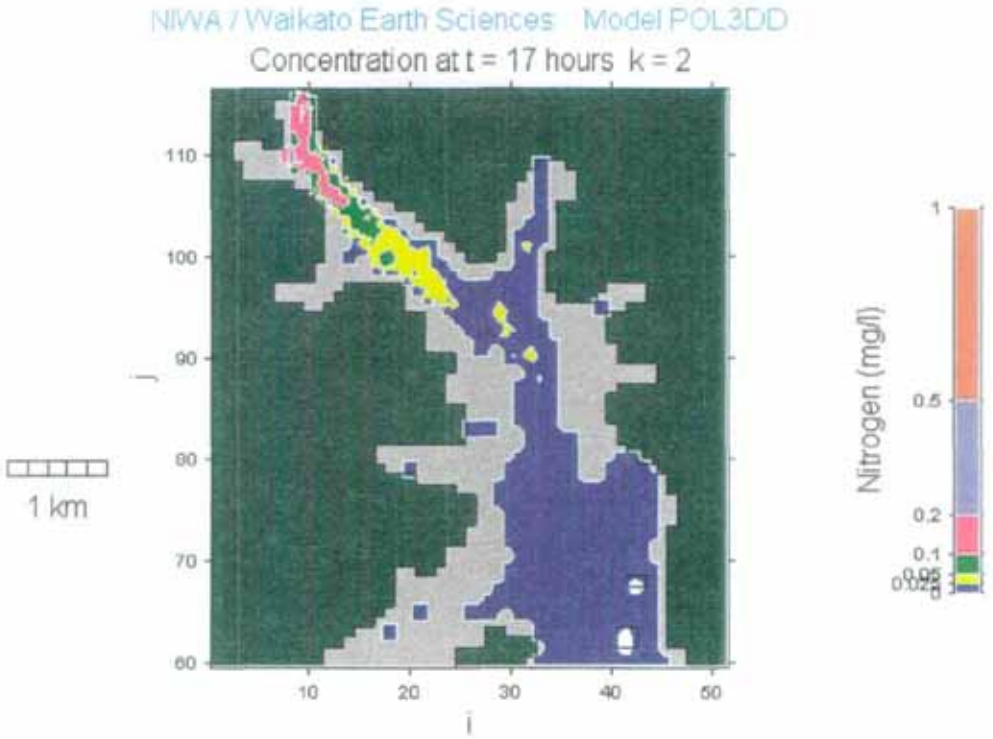


Figure 16r. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

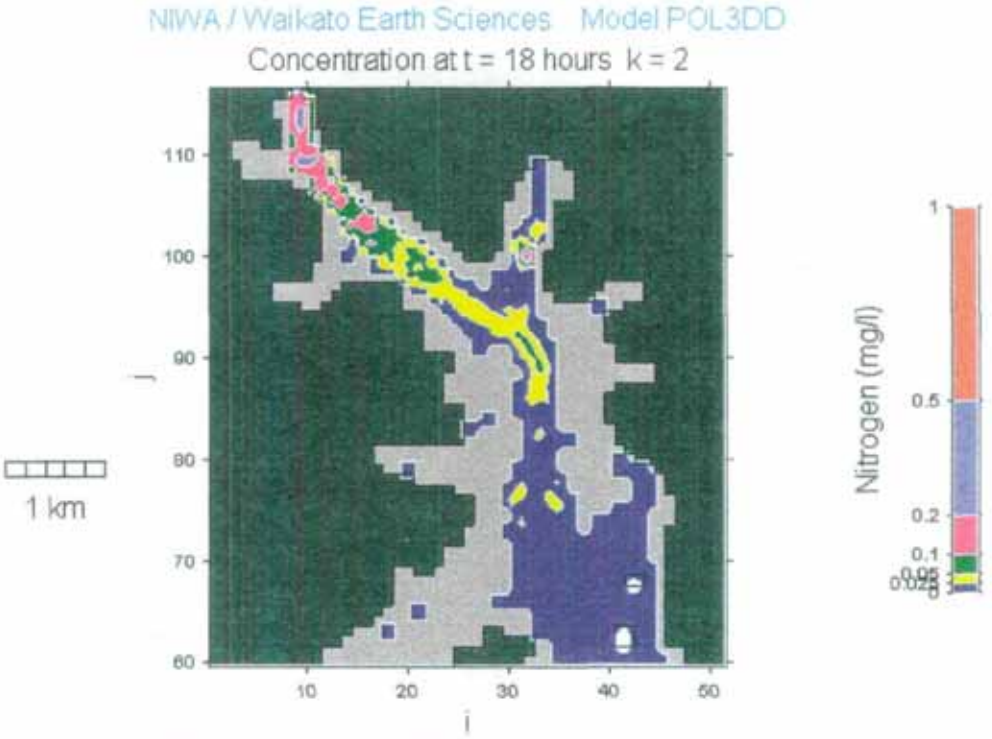


Figure 16s. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

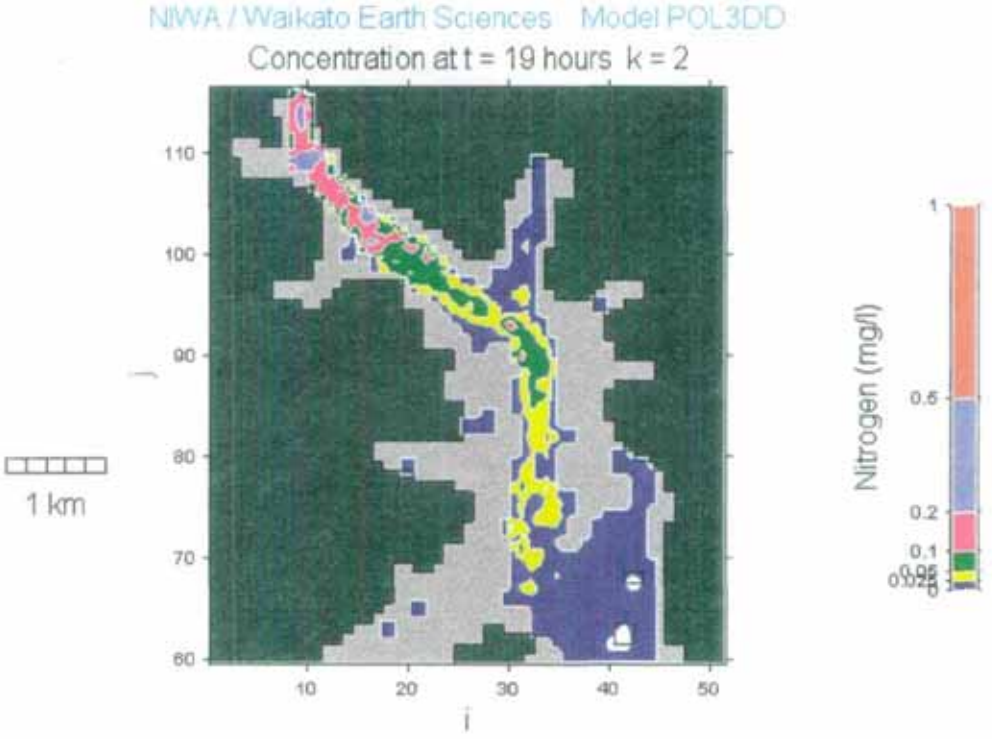


Figure 16t. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

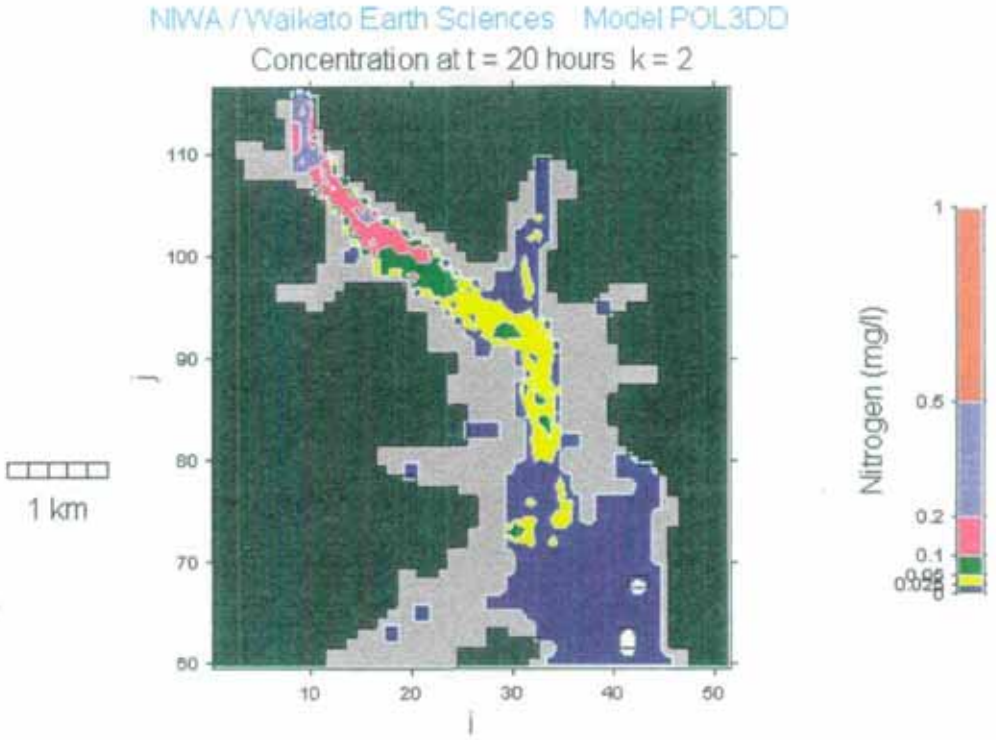


Figure 16u. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

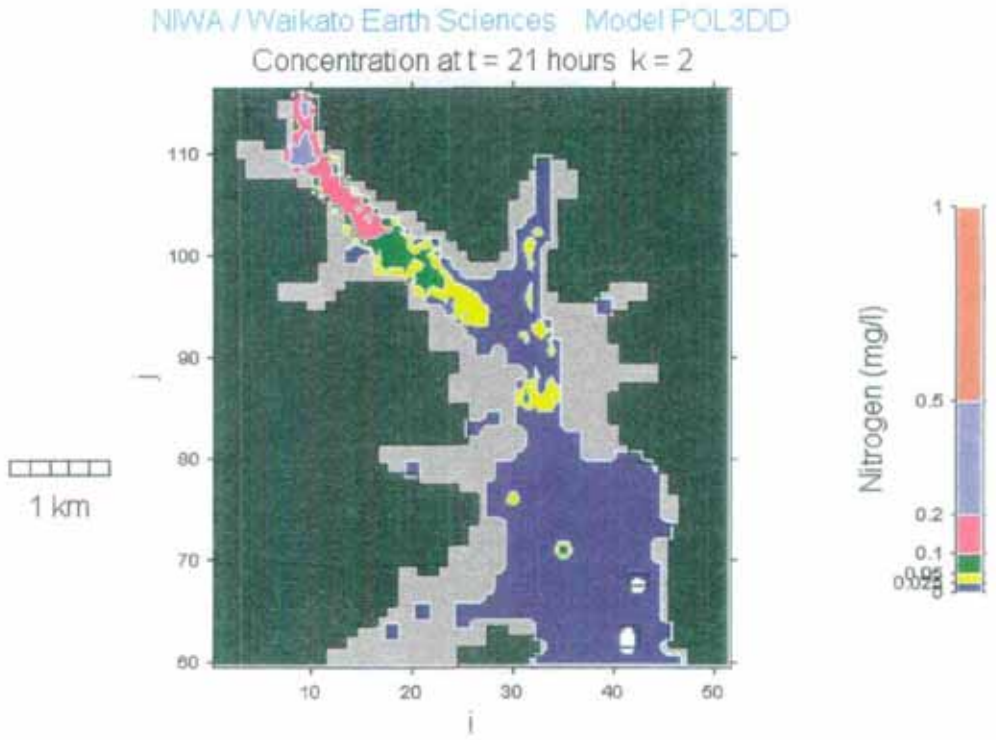


Figure 16v. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

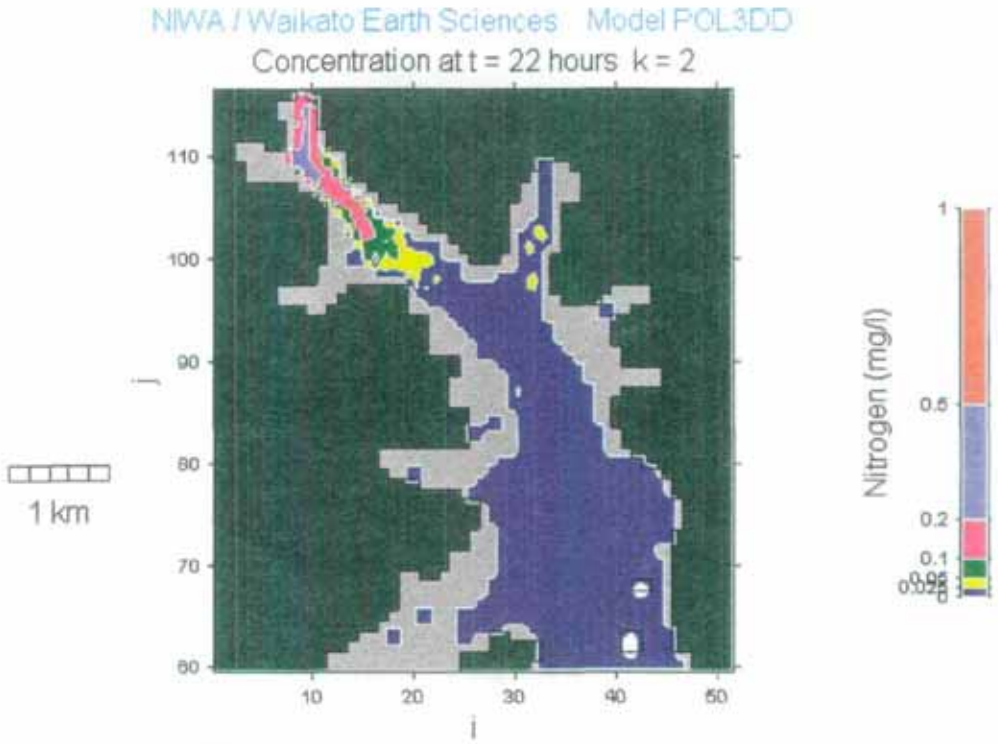


Figure 16w. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

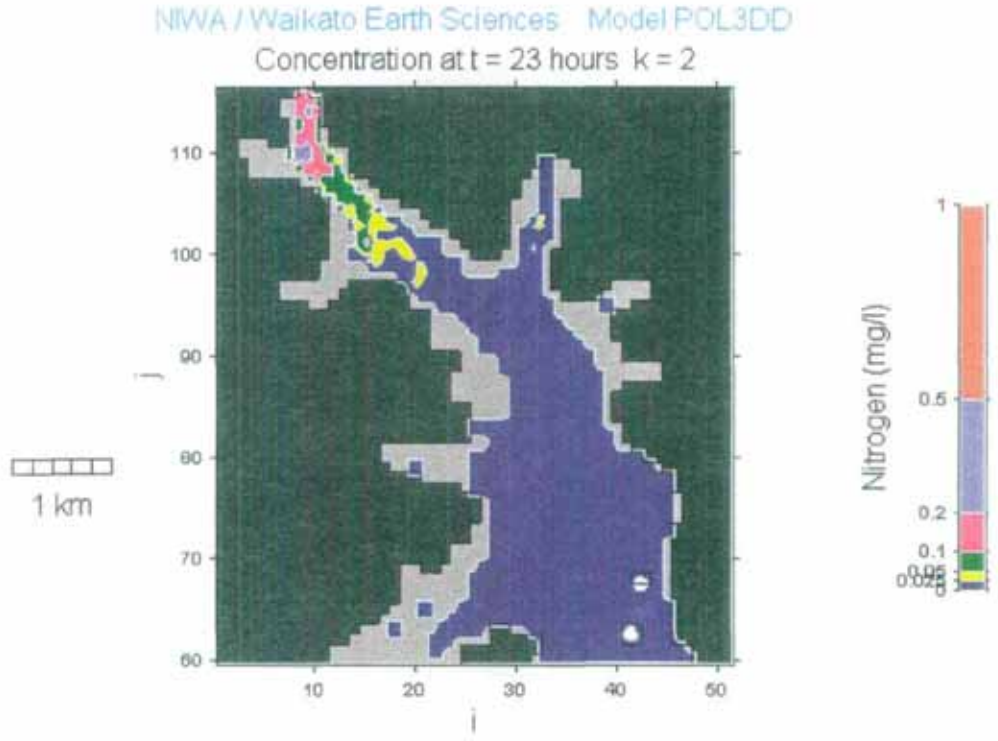


Figure 16x. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

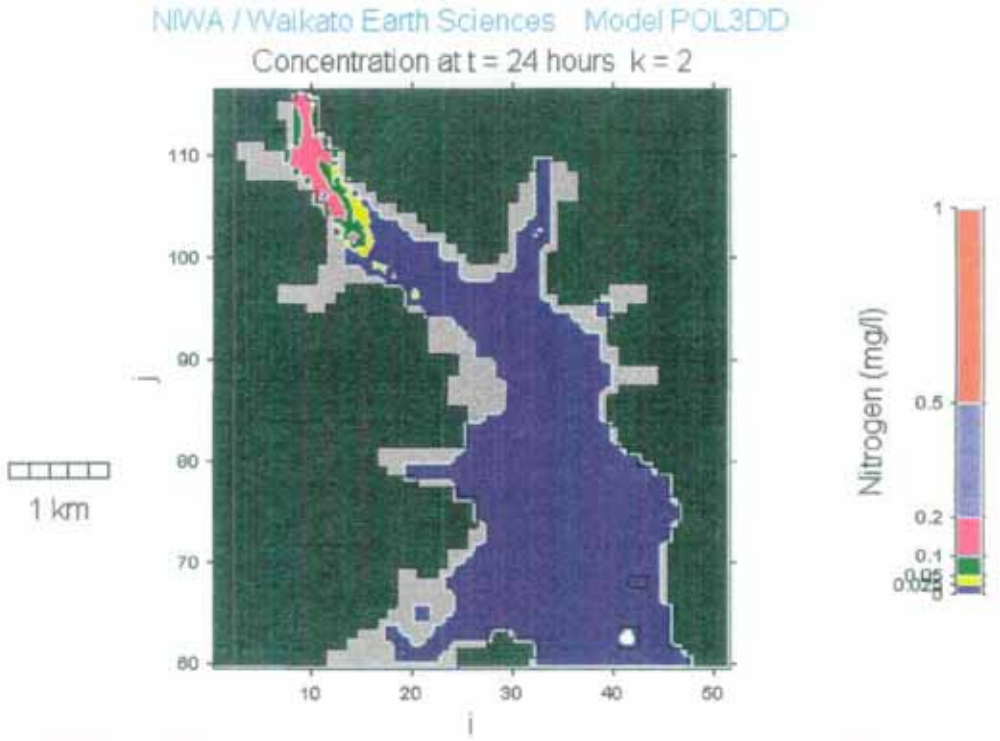


Figure 16y. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

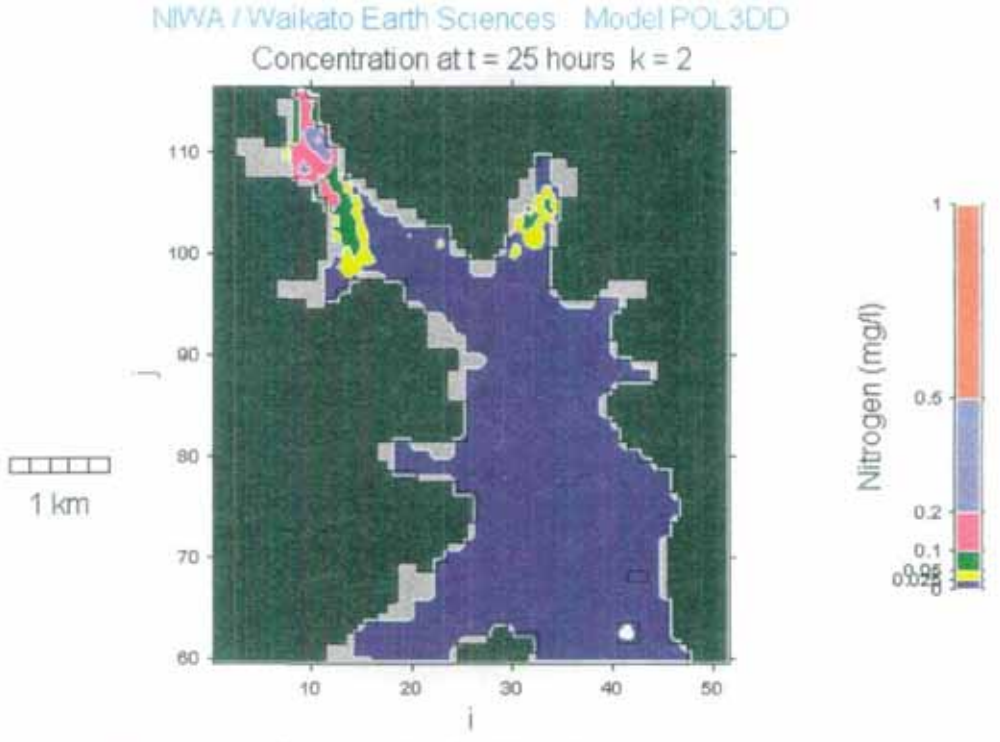


Figure 16z. Nitrogen concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

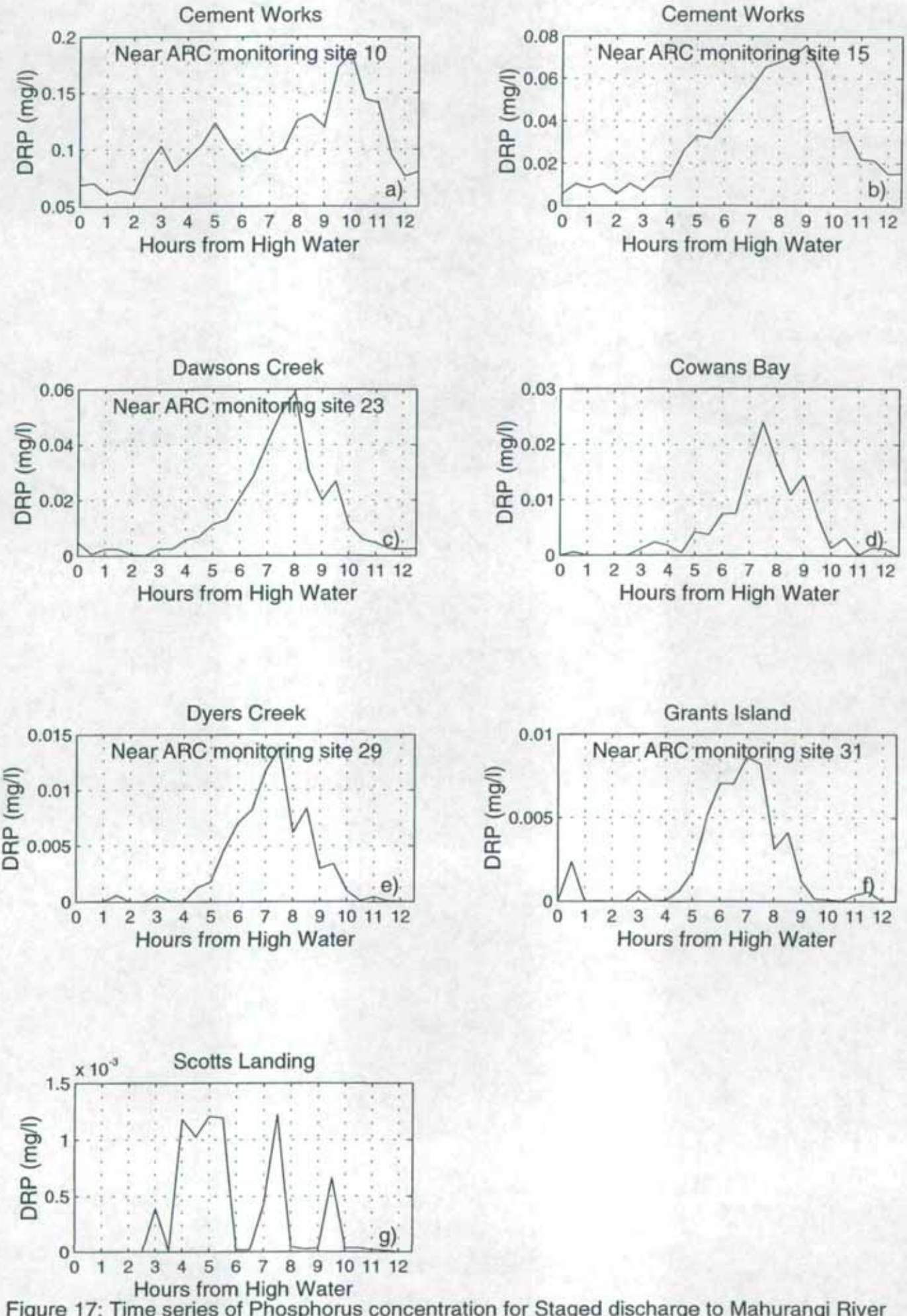


Figure 17: Time series of Phosphorus concentration for Staged discharge to Mahurangi River for selected sites in the main channel

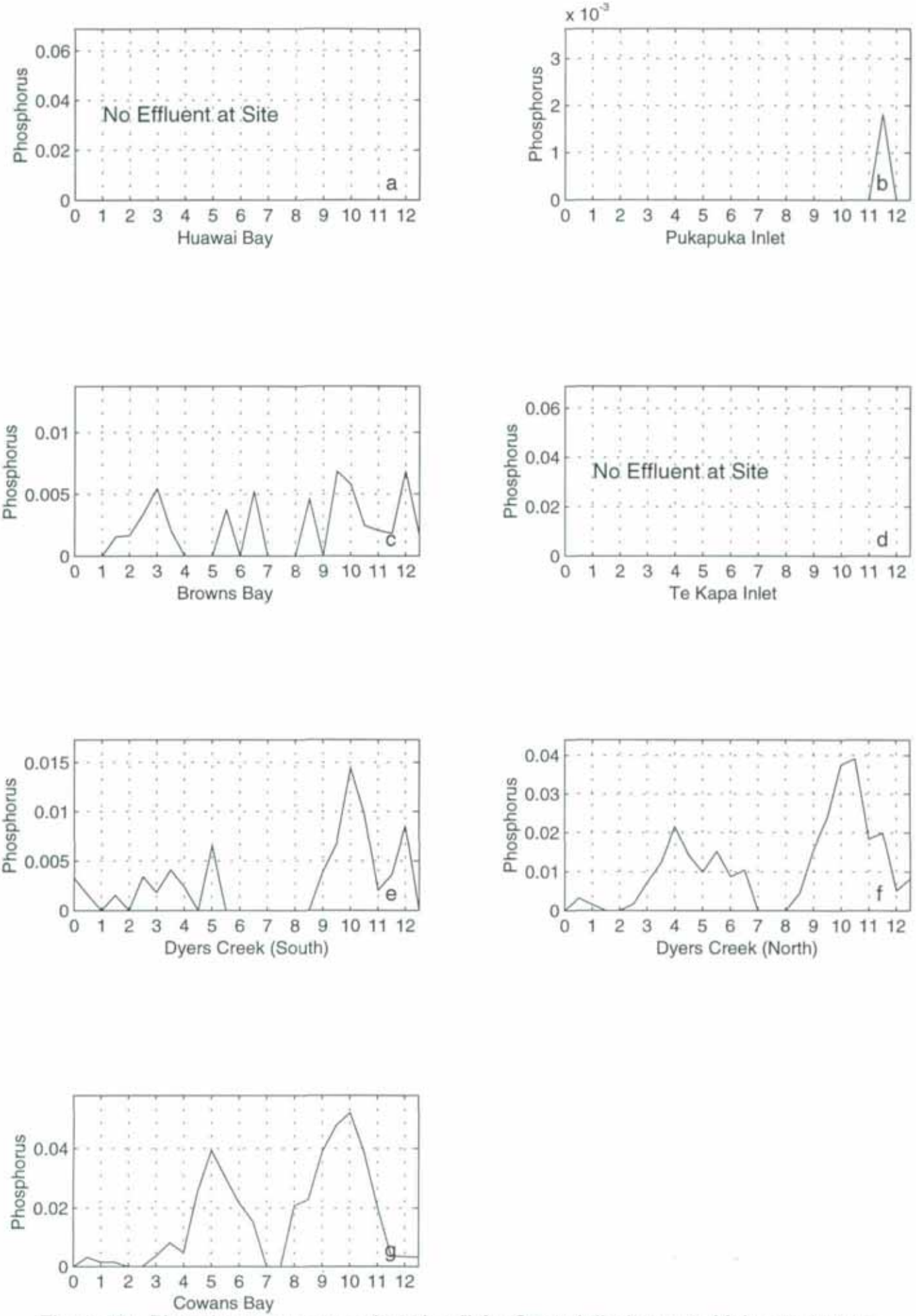


Figure 18 : Phosphorus concentrations (mg/l) for Staged discharge to Mahurangi River. Spatial average for oyster farms at sites as indicated

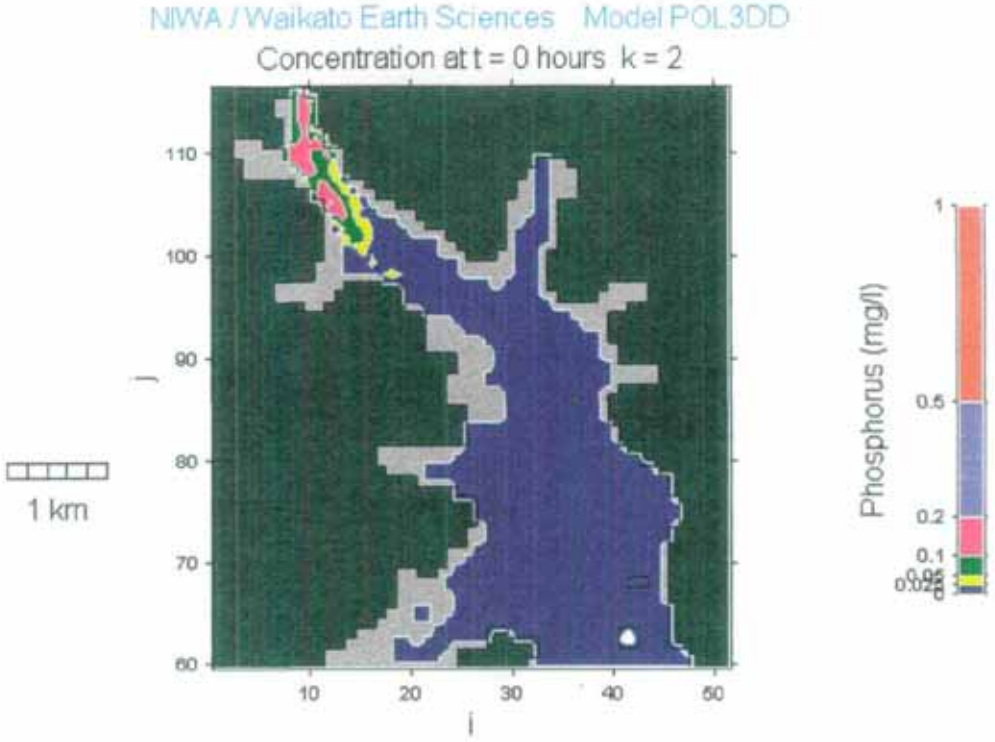


Figure 19a. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

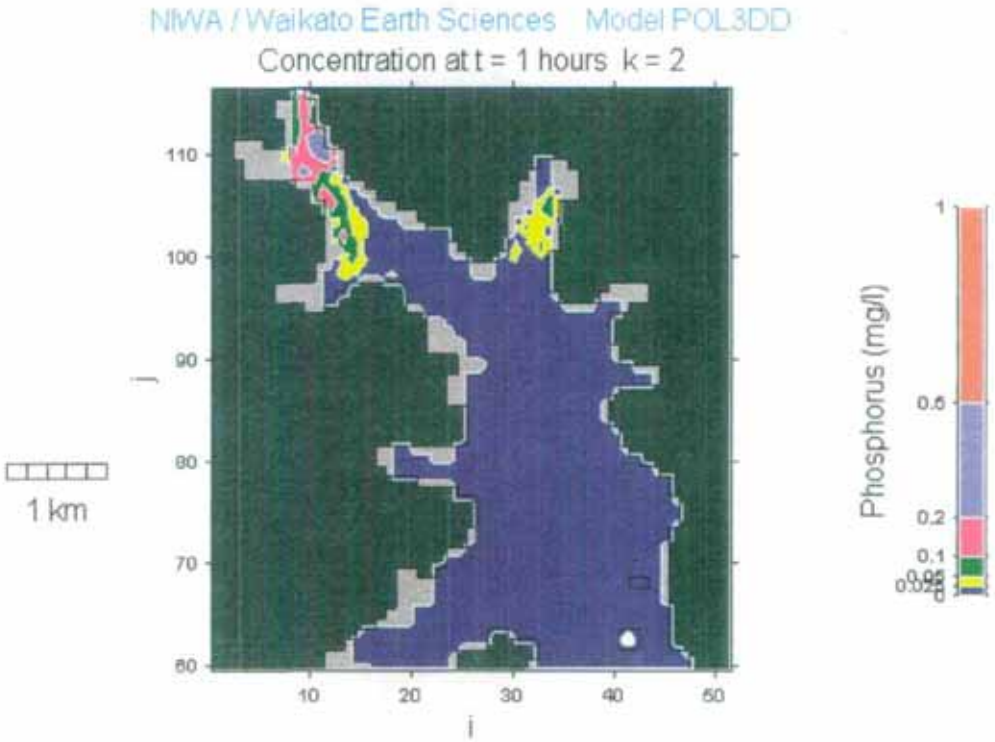


Figure 19b. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

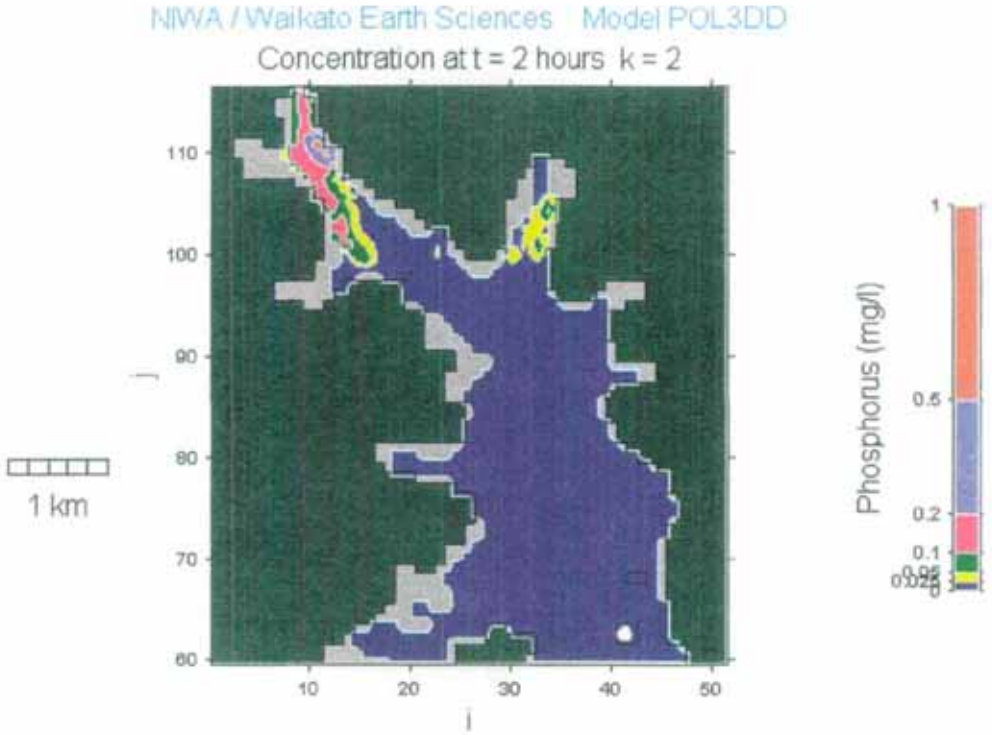


Figure 19c. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

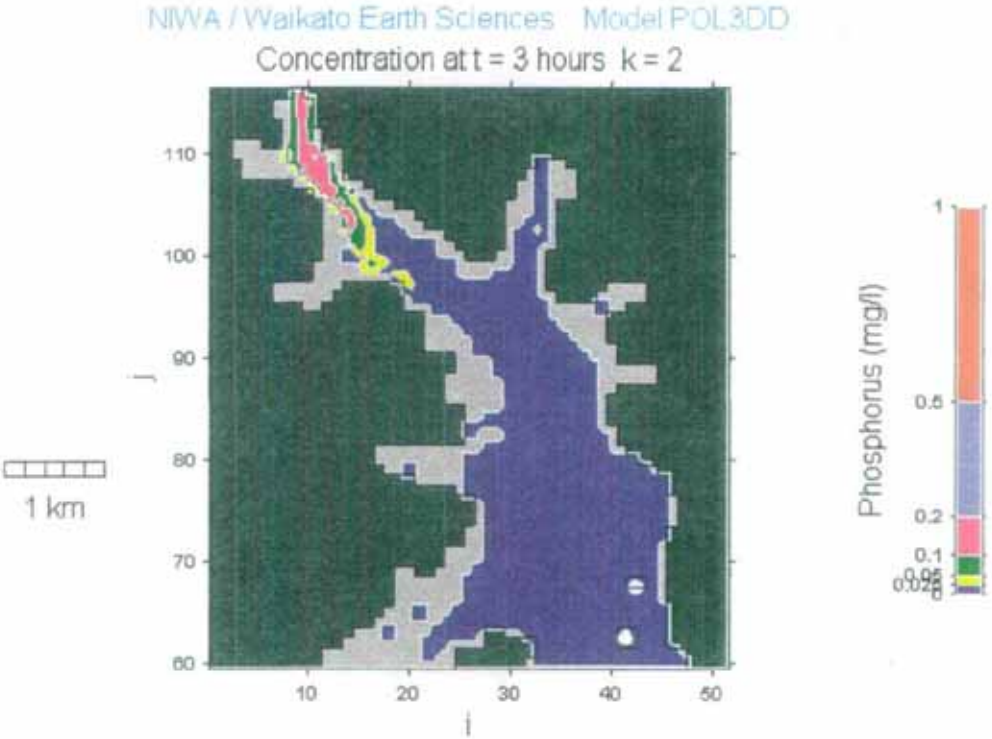


Figure 19d. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

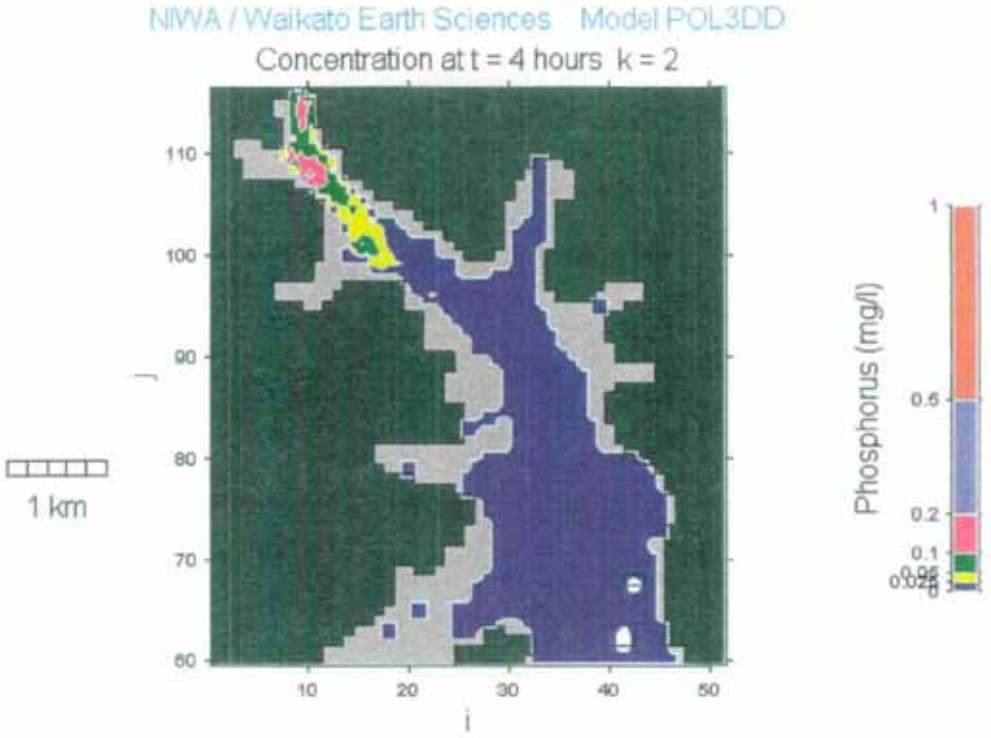


Figure 19e. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

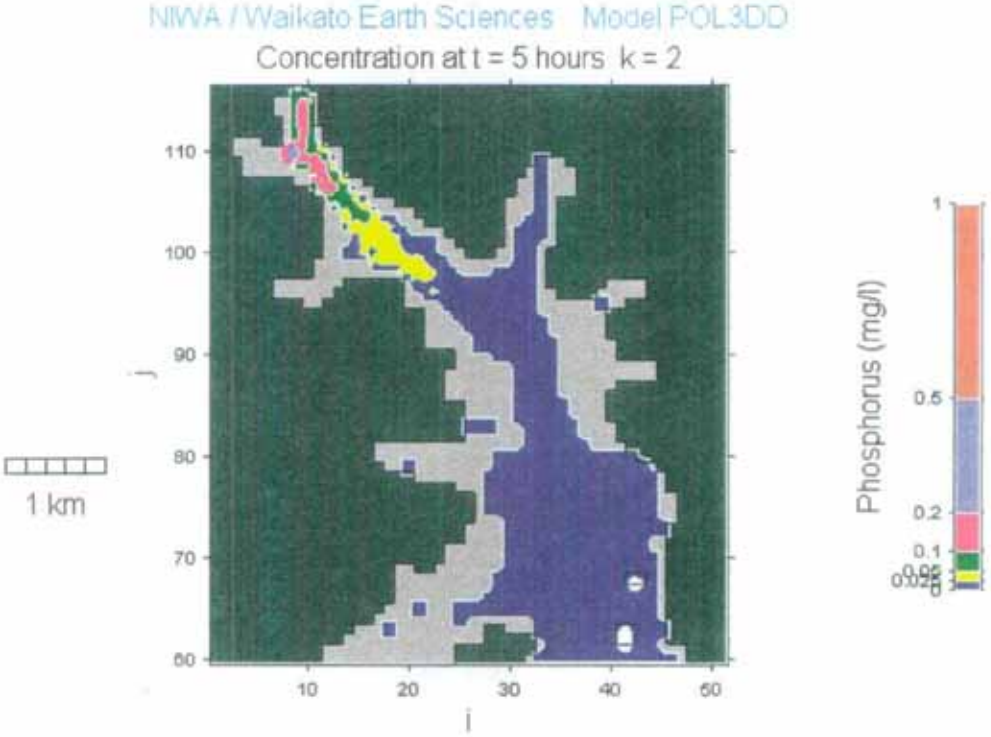


Figure 19f. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

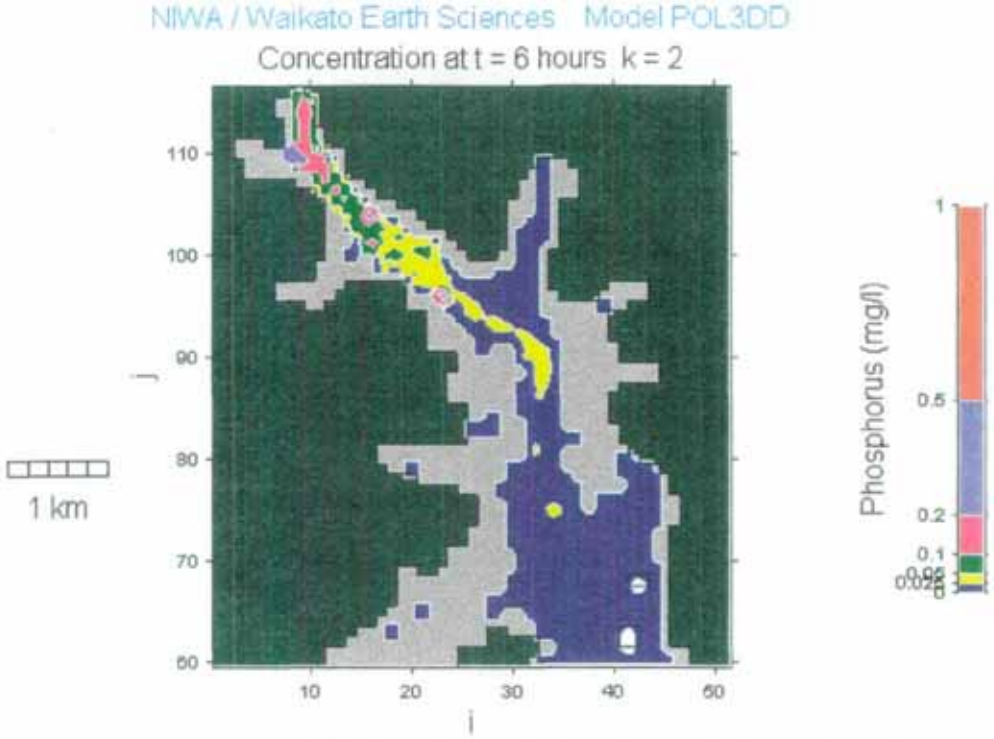


Figure 19g. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus six hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

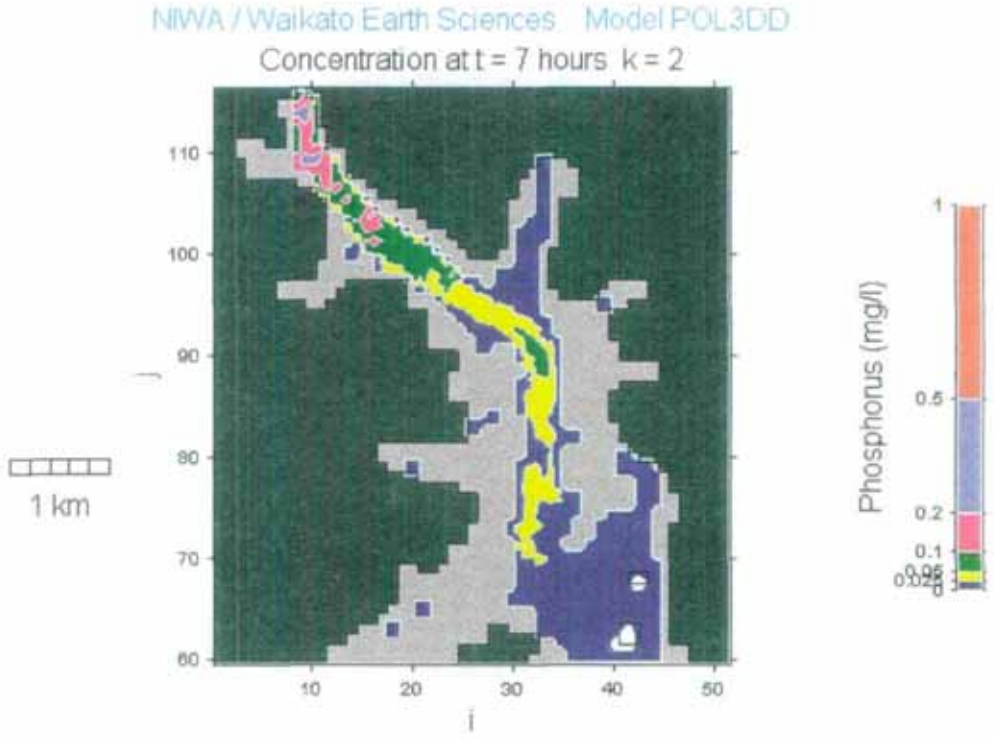


Figure 19h. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus half an hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

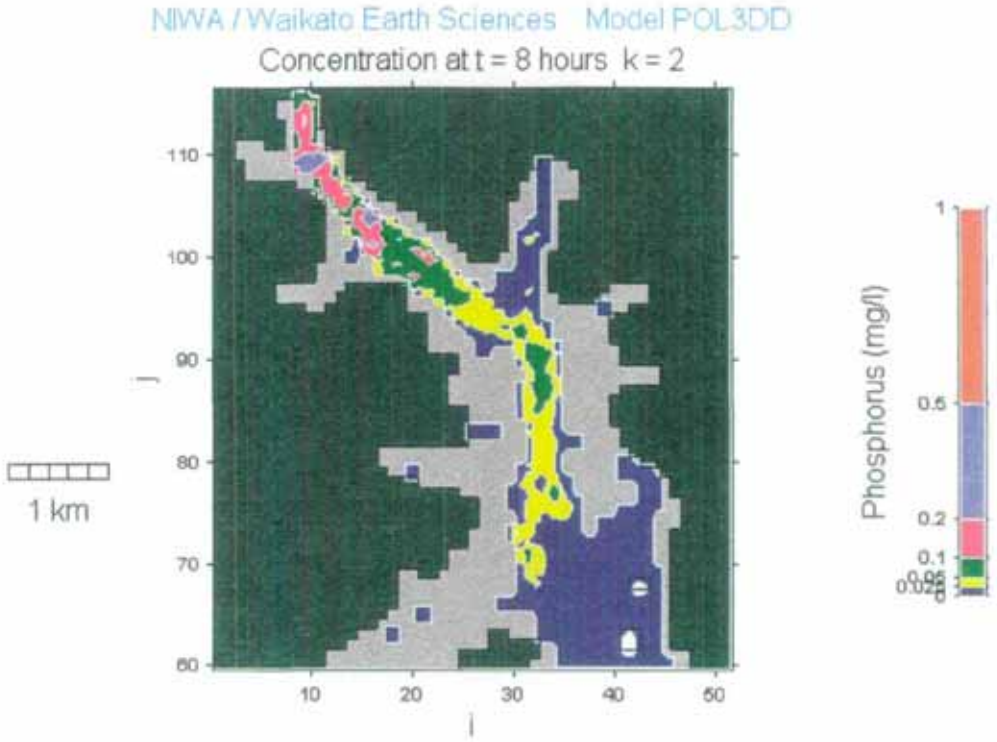


Figure 19i. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

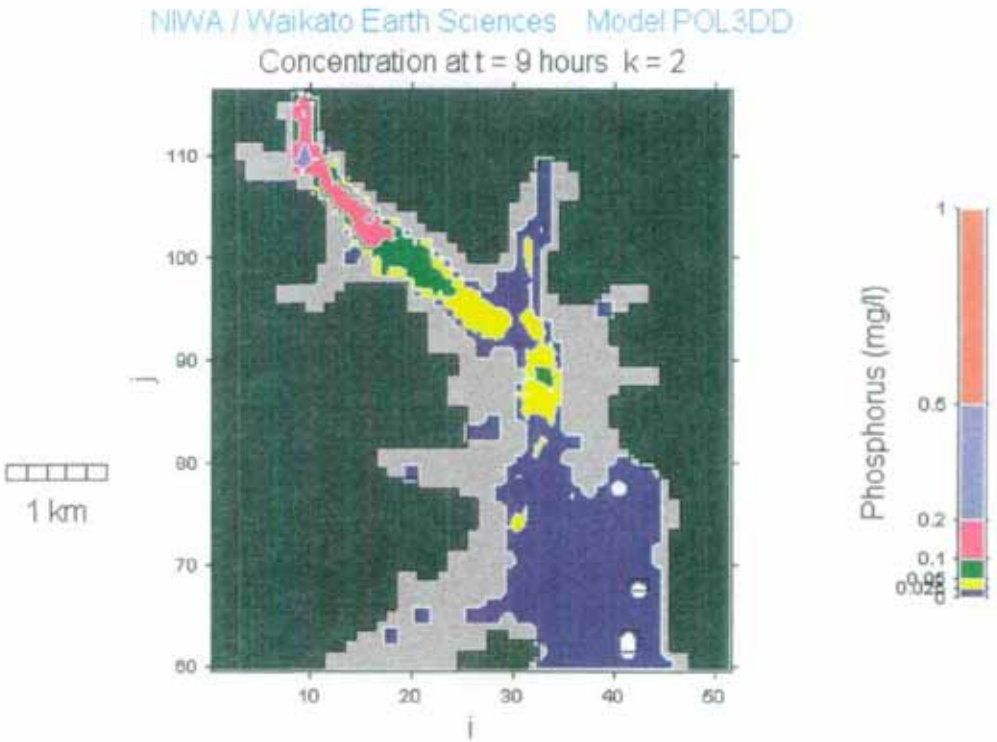


Figure 19j. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

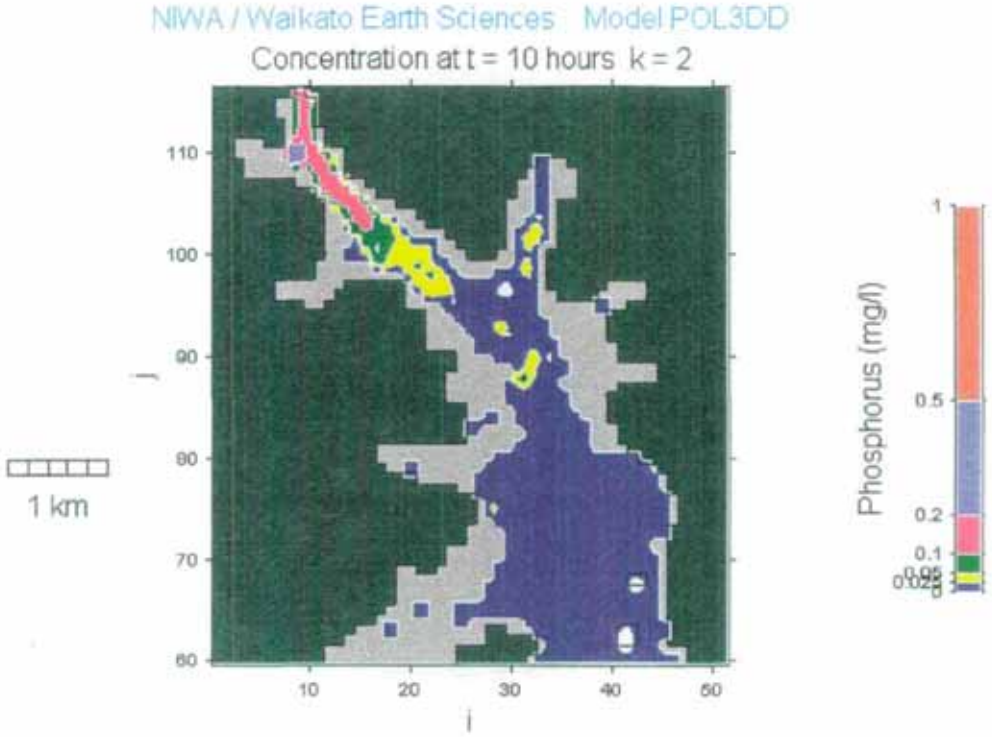


Figure 19k. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

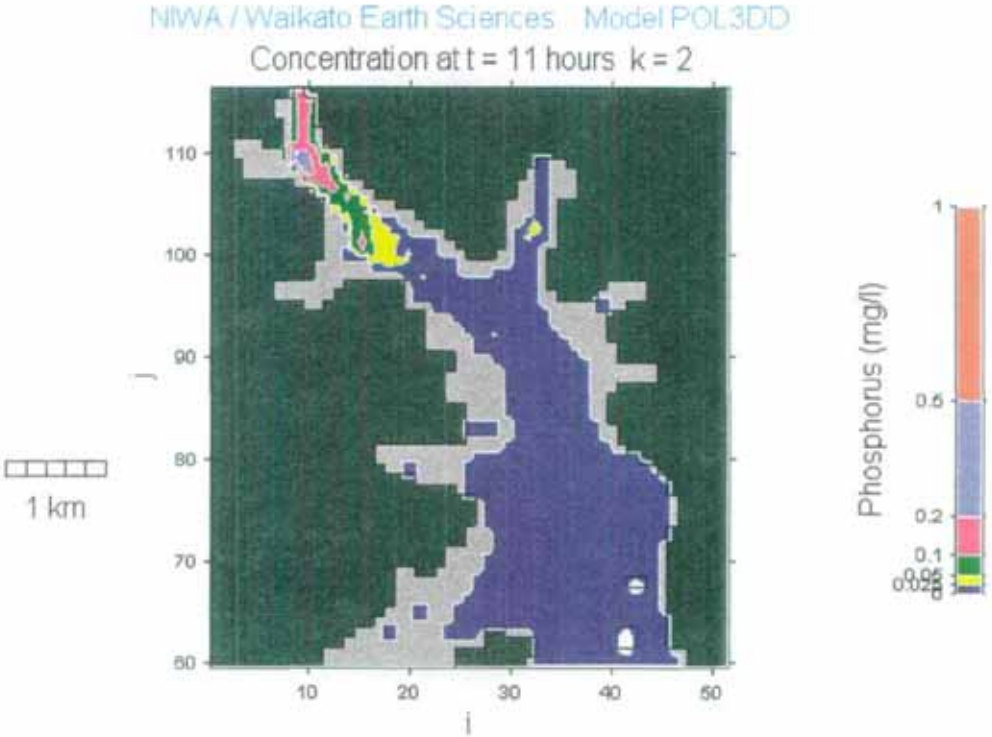


Figure 19l. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

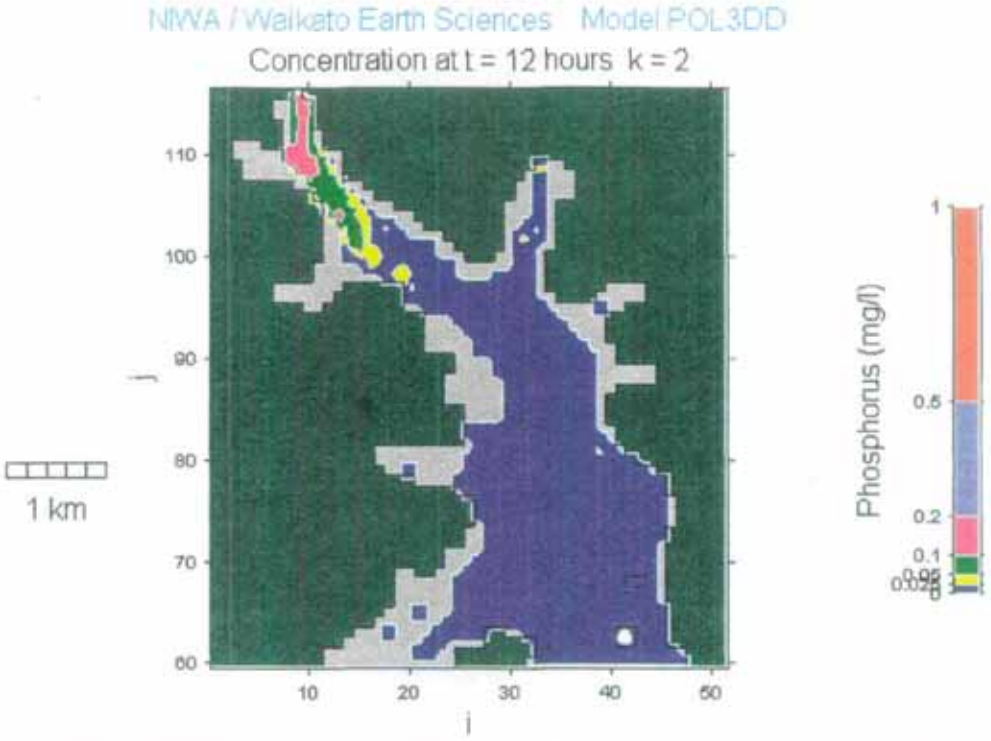


Figure 19m. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

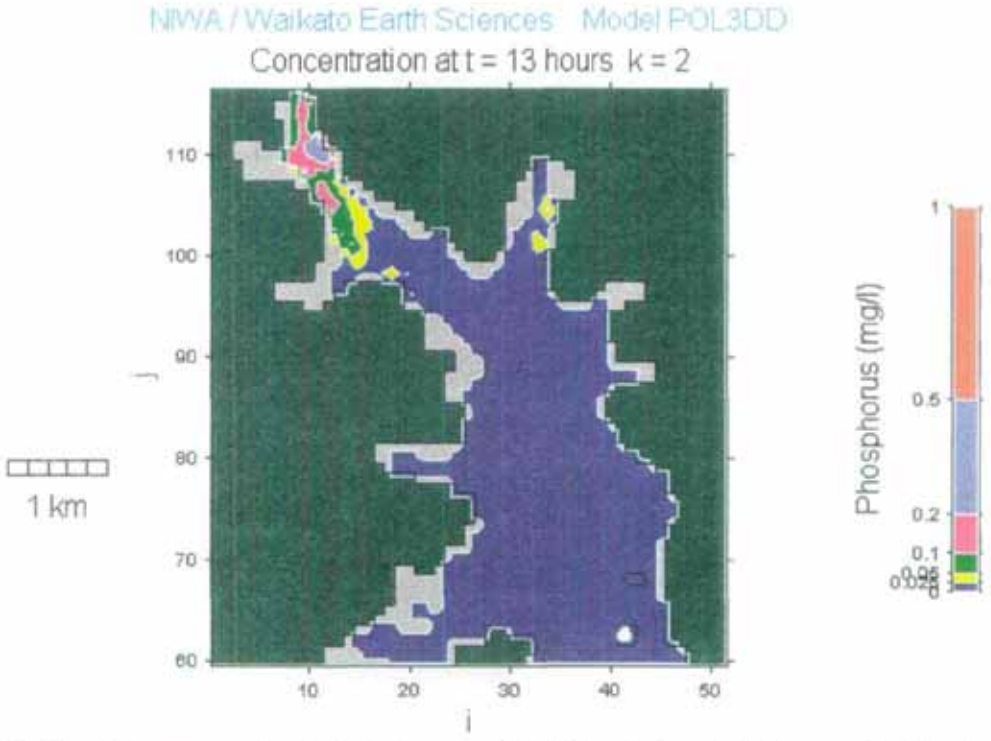


Figure 19n. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus half an hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

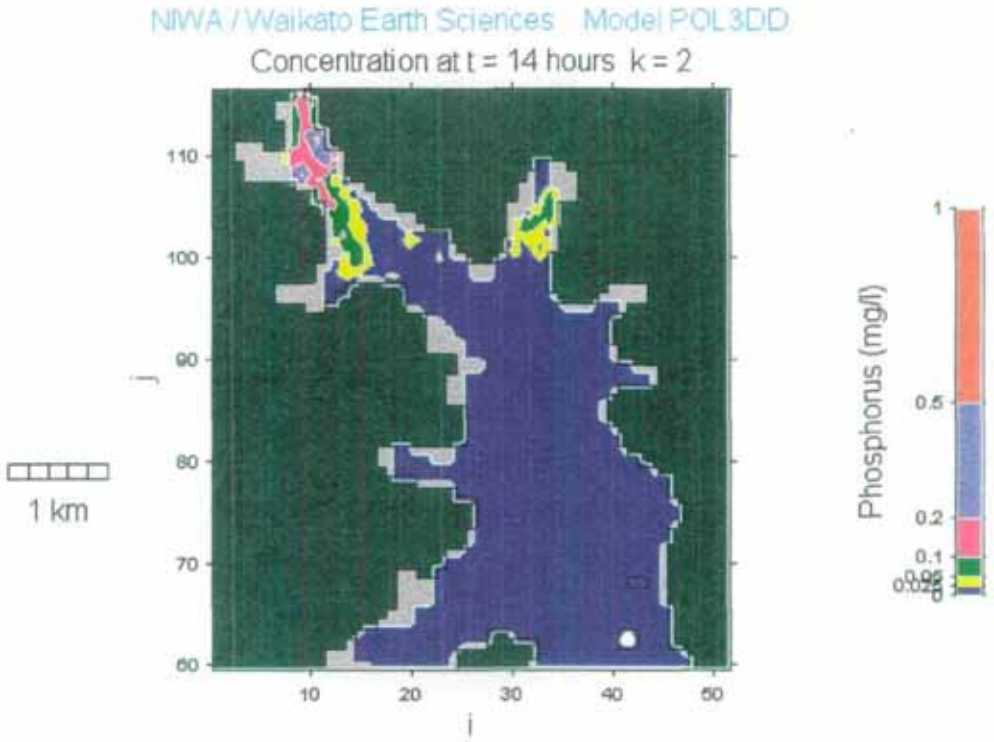


Figure 19o. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

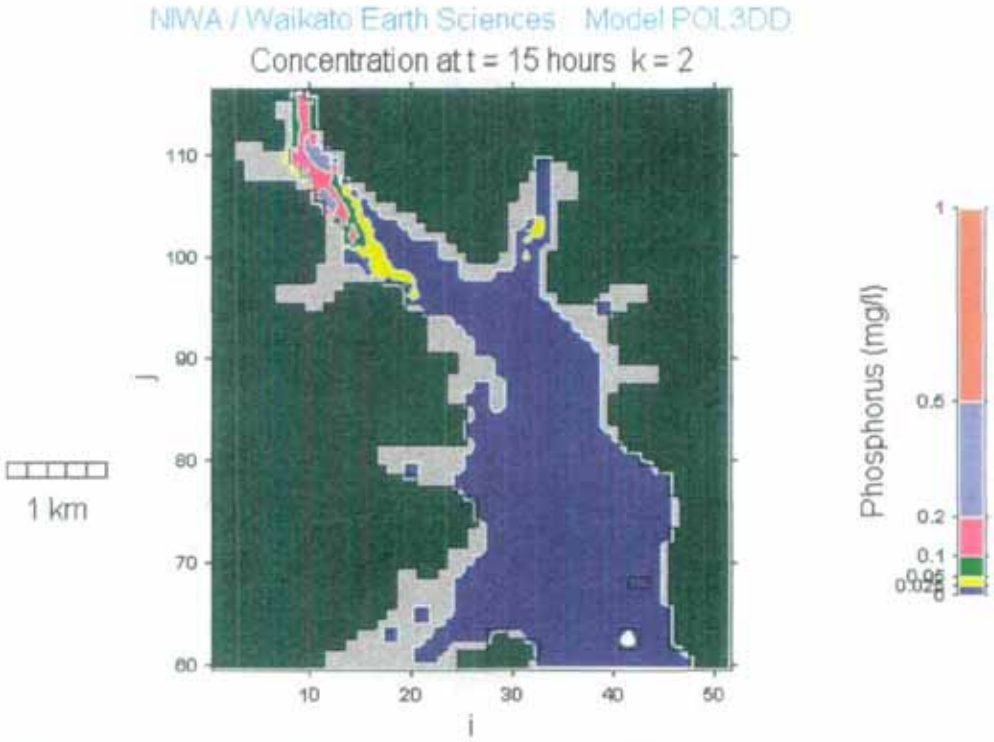


Figure 19p. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

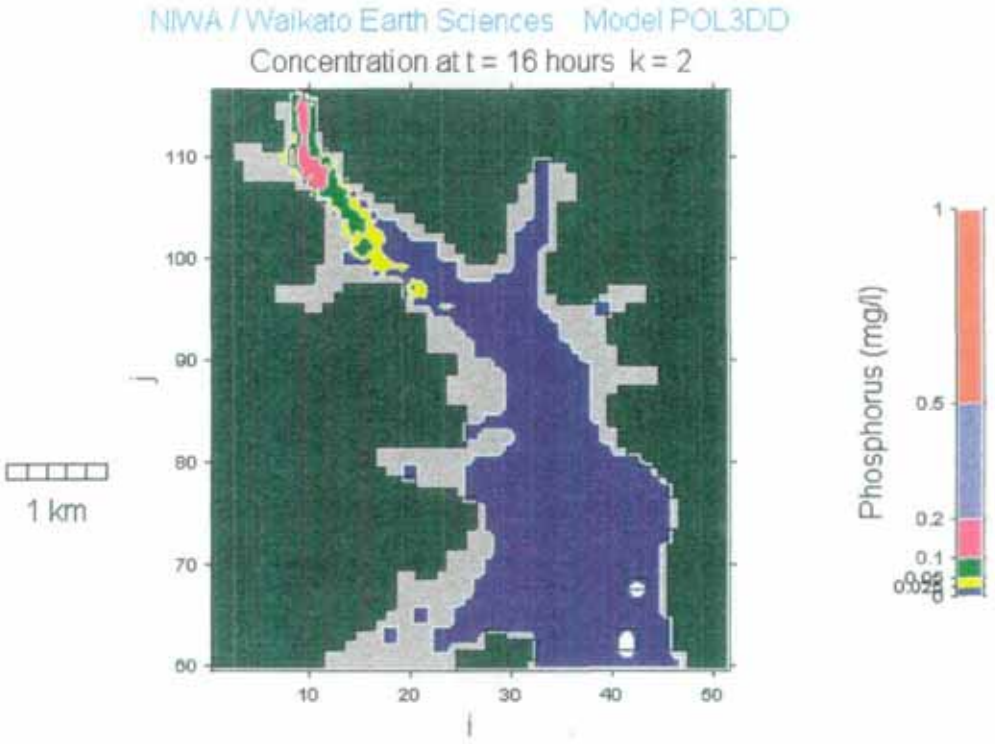


Figure 19q. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

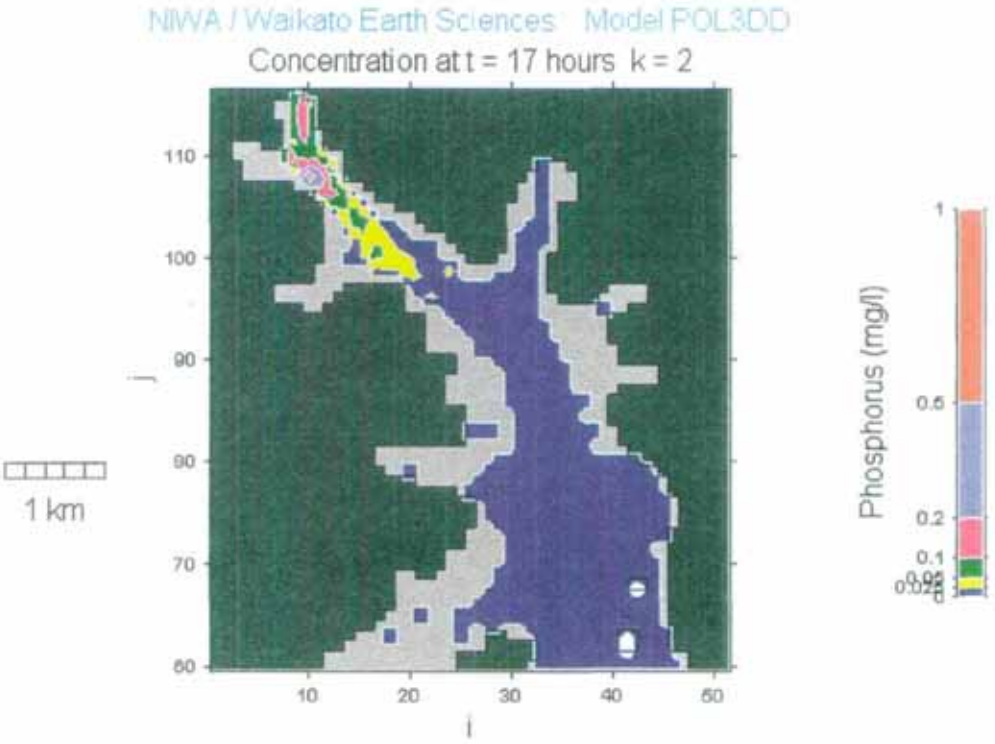


Figure 19r. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

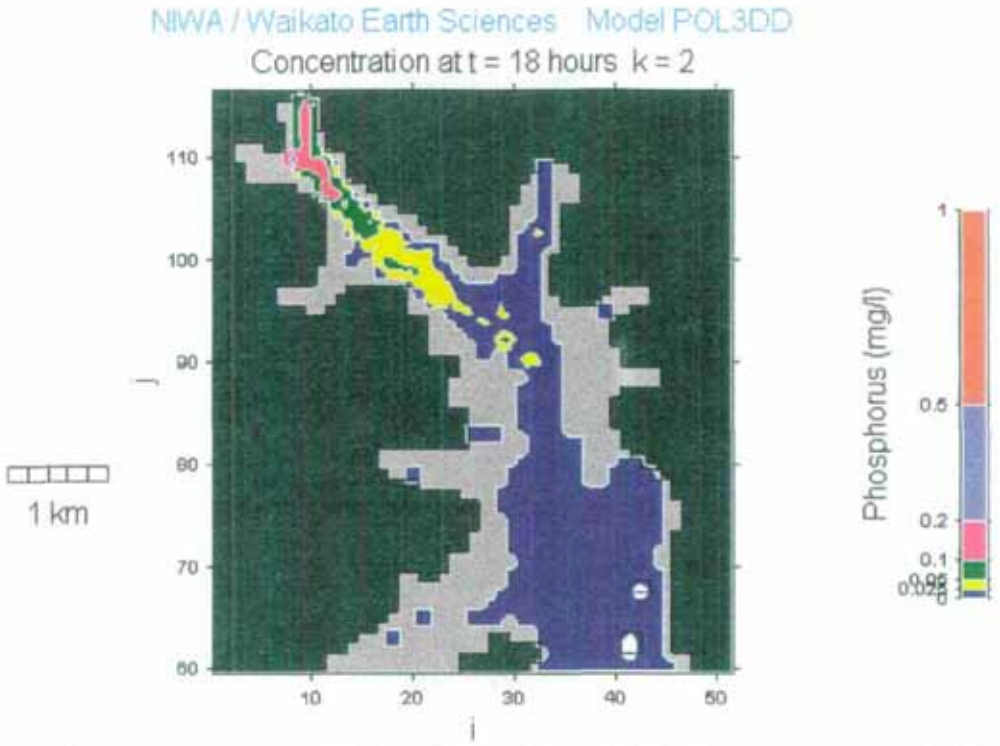


Figure 19s. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five and a half hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

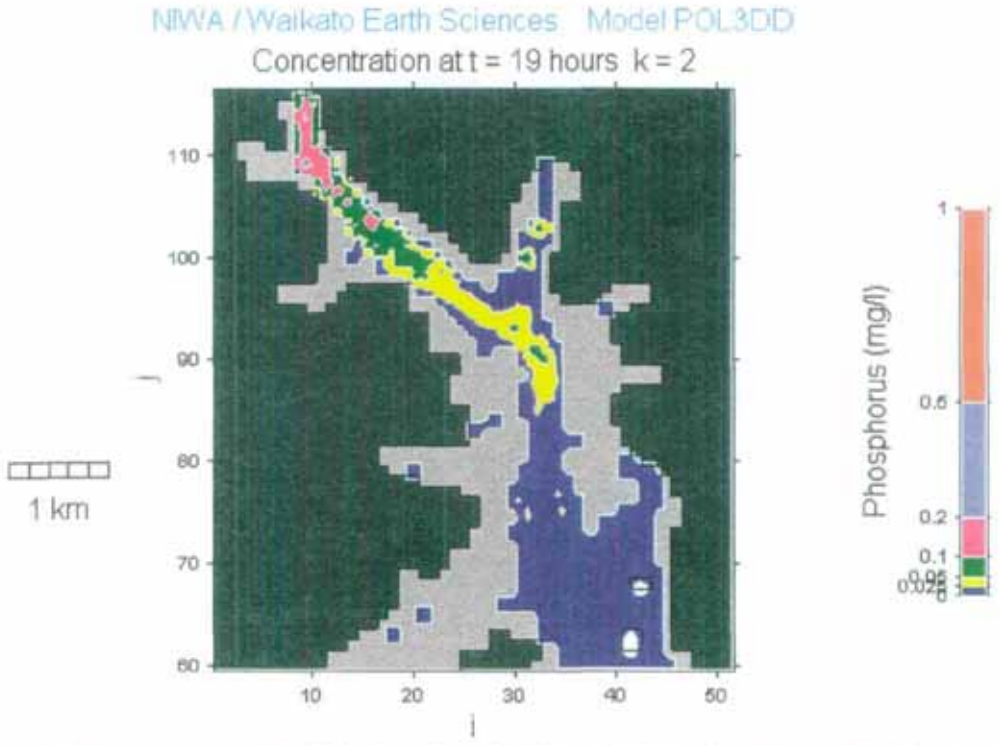


Figure 19t. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

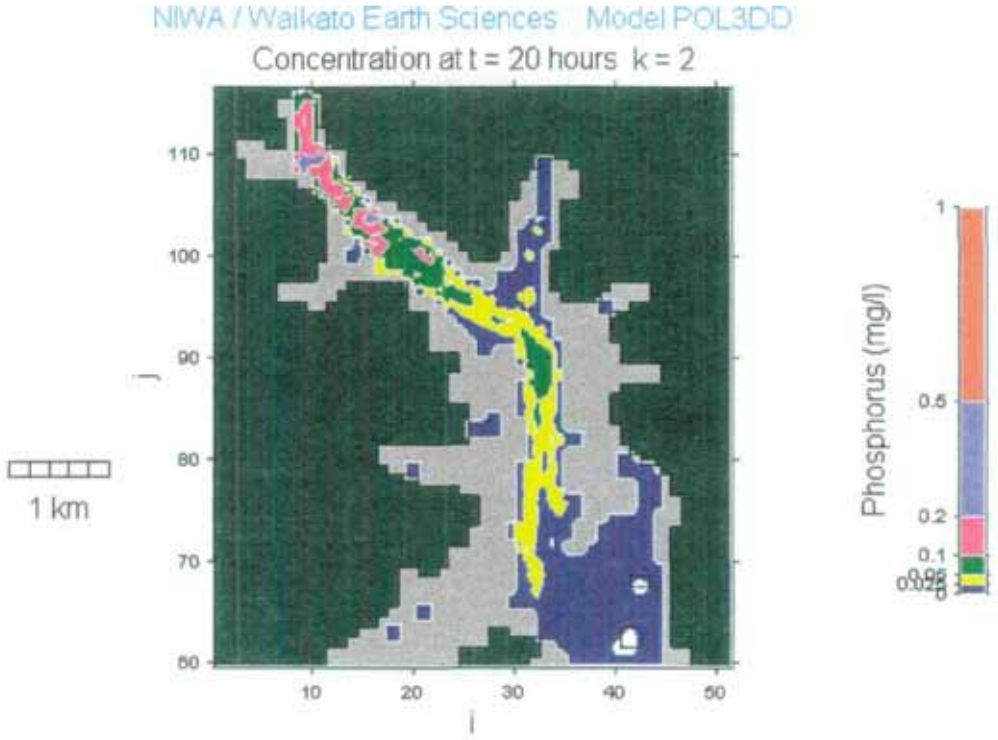


Figure 19u. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one hour resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

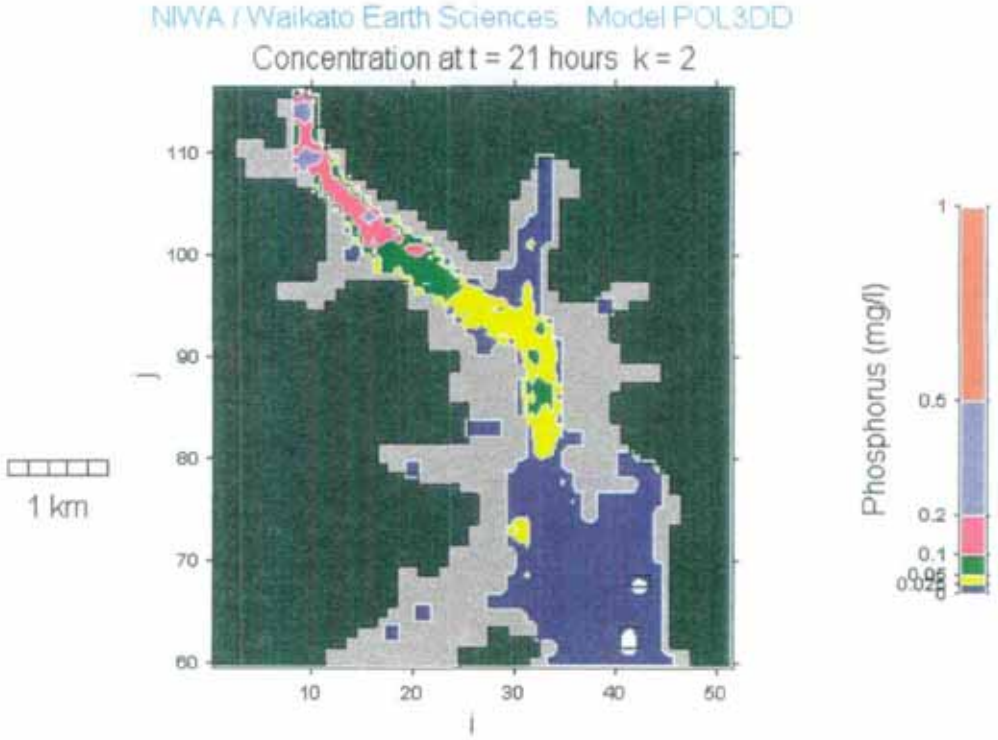


Figure 19v. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

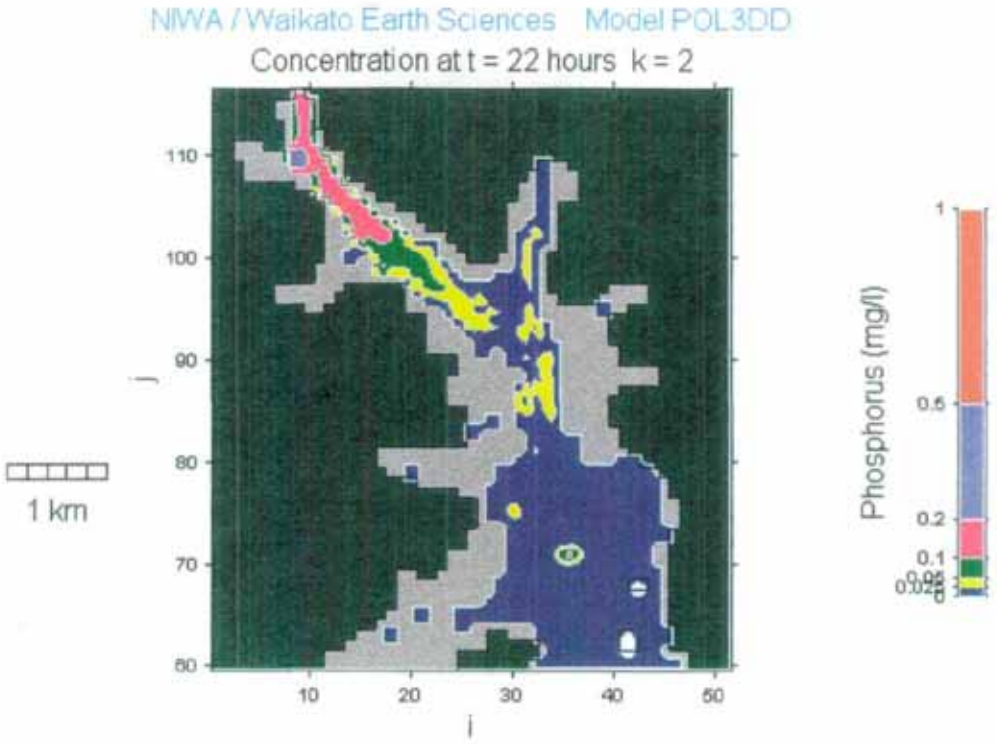


Figure 19w. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

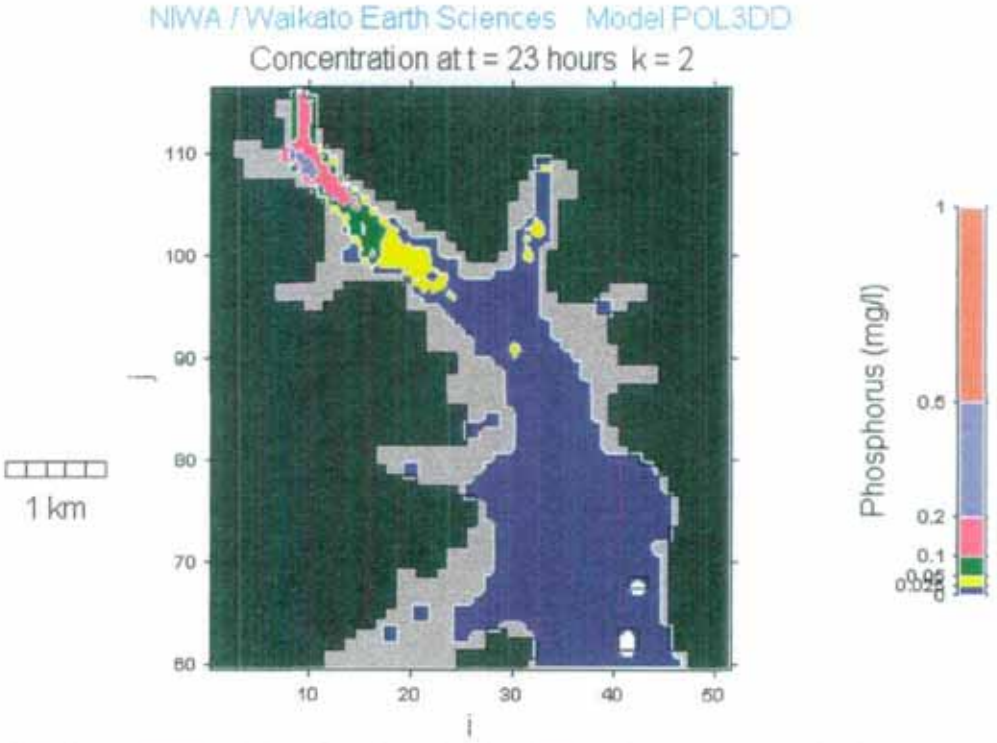


Figure 19x. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

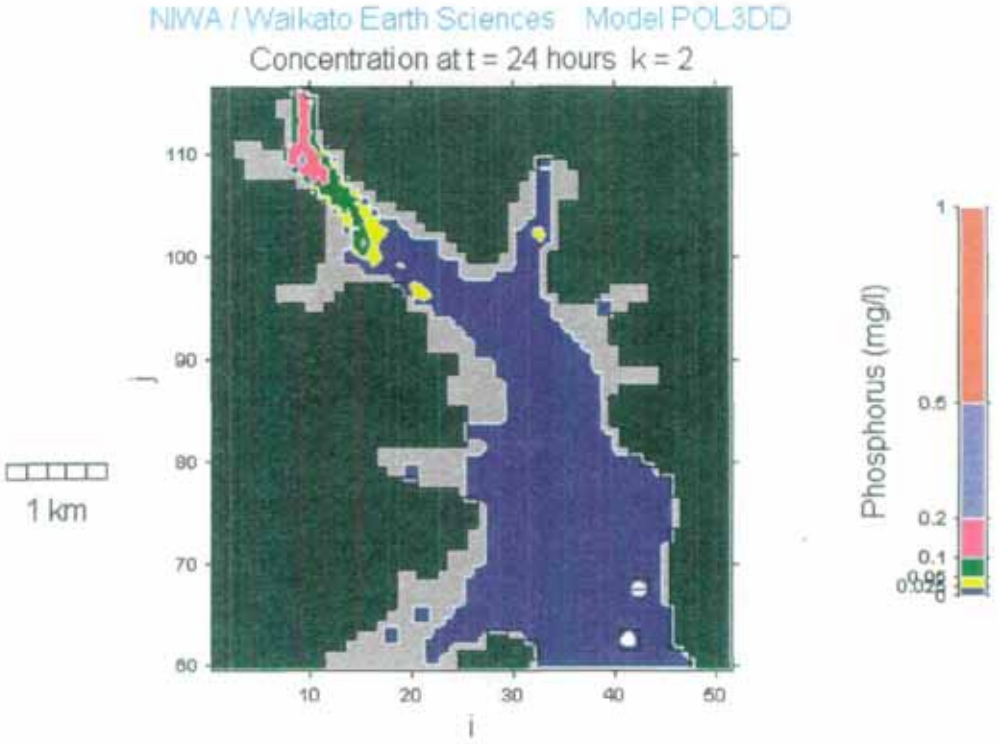


Figure 19y. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five hours resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

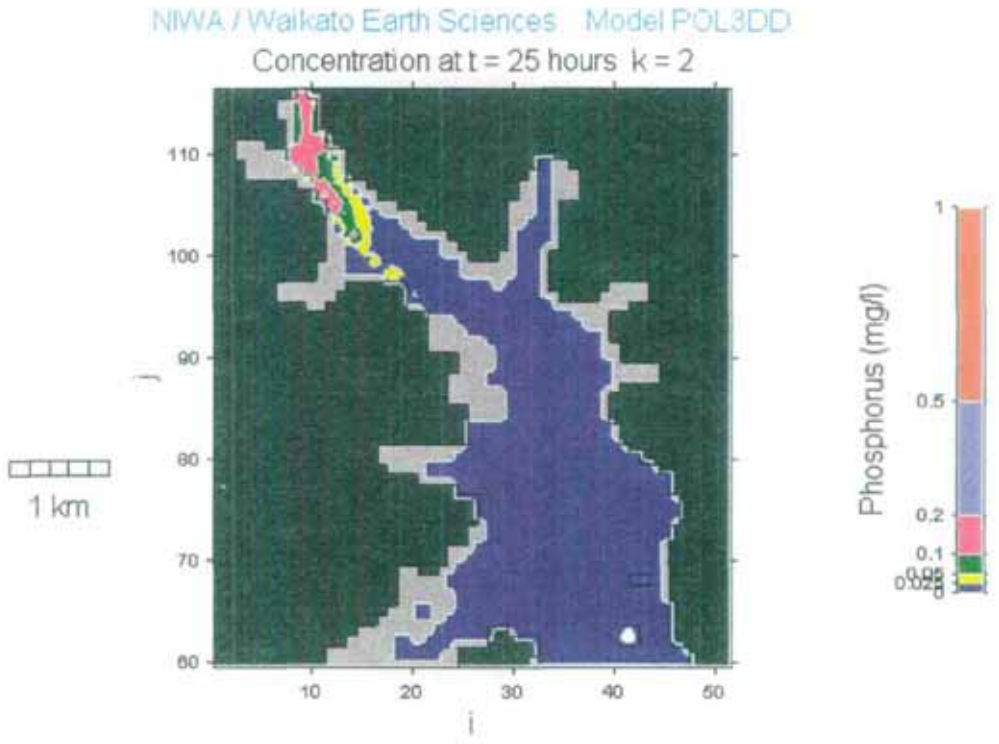


Figure 19z. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the tidally staged discharge from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

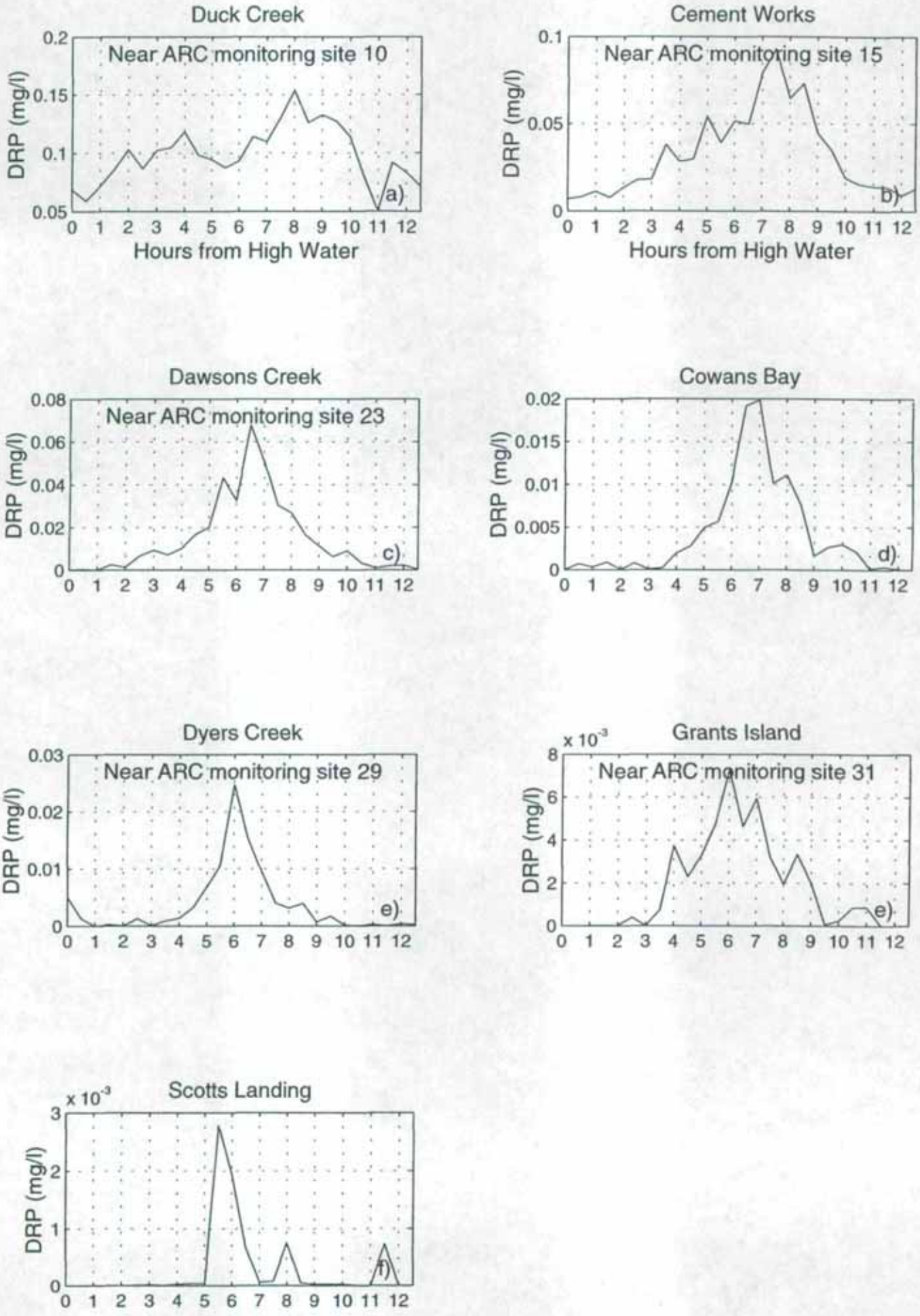


Figure 20 : Time series of Phosphorus concentration for Wetland discharge to Mahurangi River for selected sites in the main channel

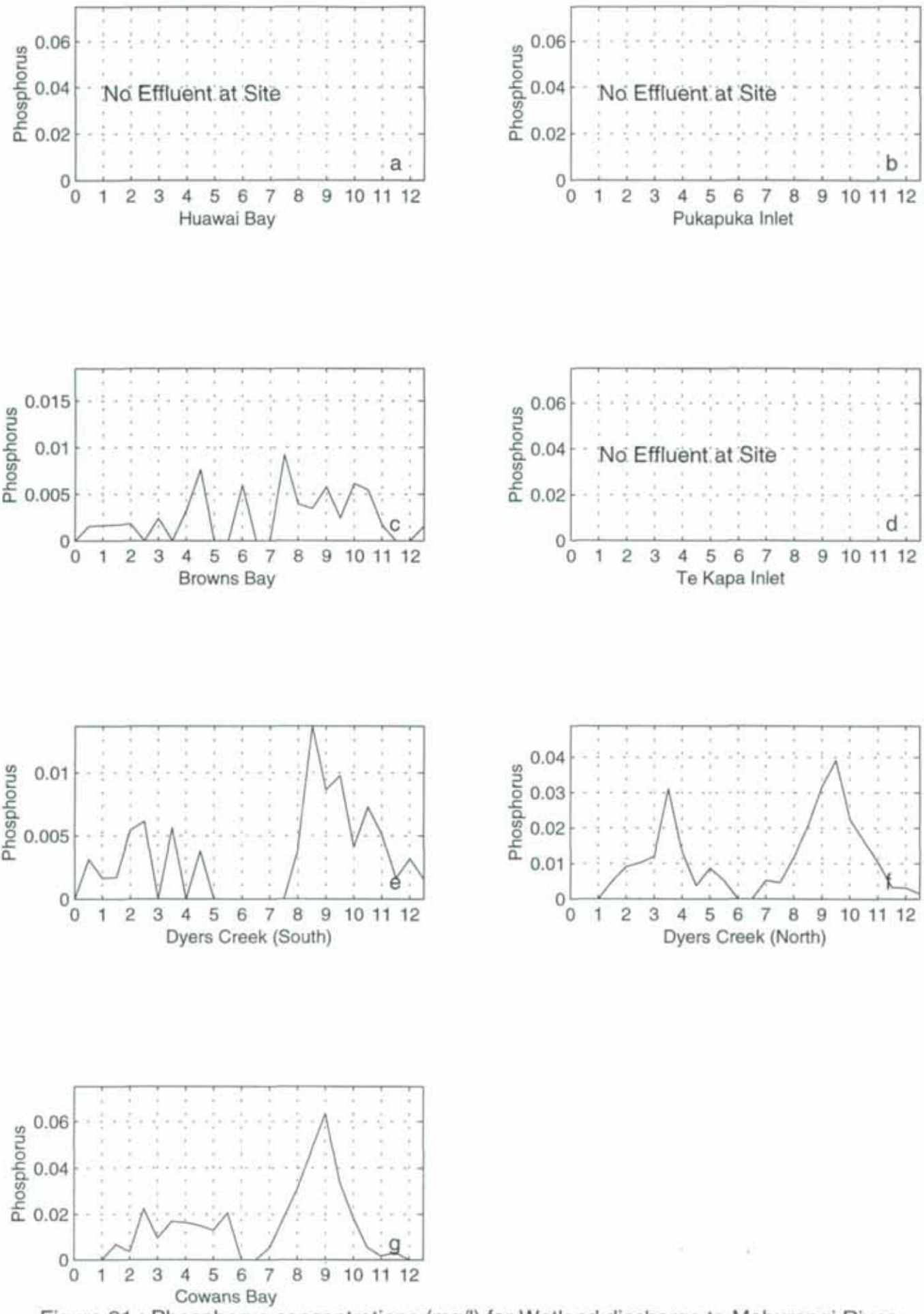


Figure 21 : Phosphorus concentrations (mg/l) for Wetland discharge to Mahurangi River. Spatial average for oyster farms at sites as indicated

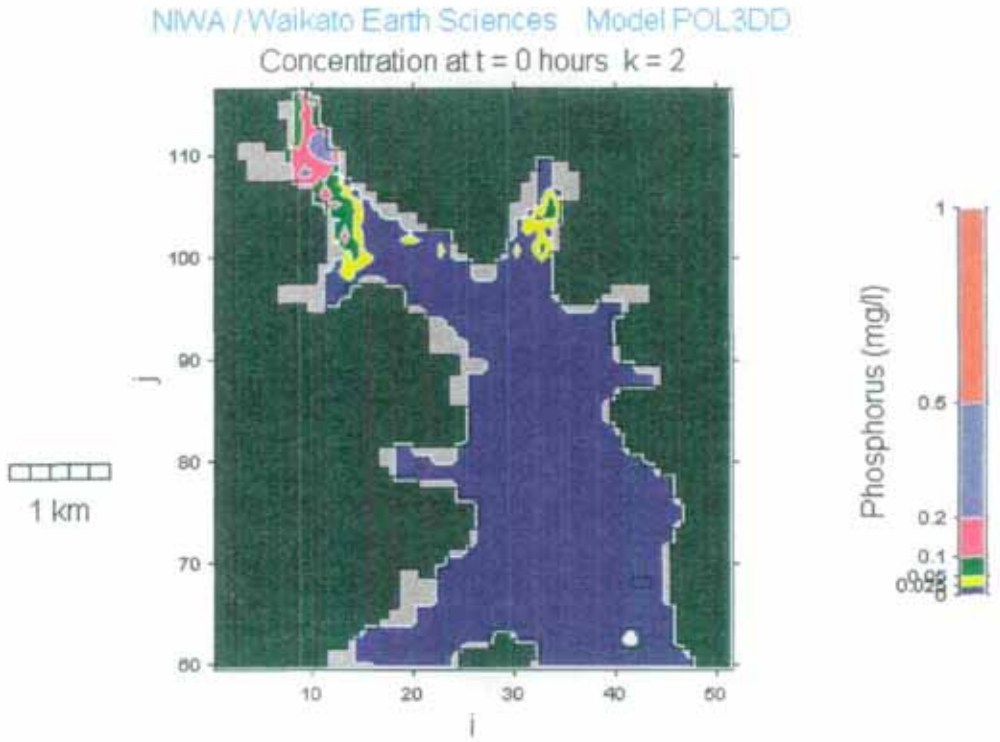


Figure 22a. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

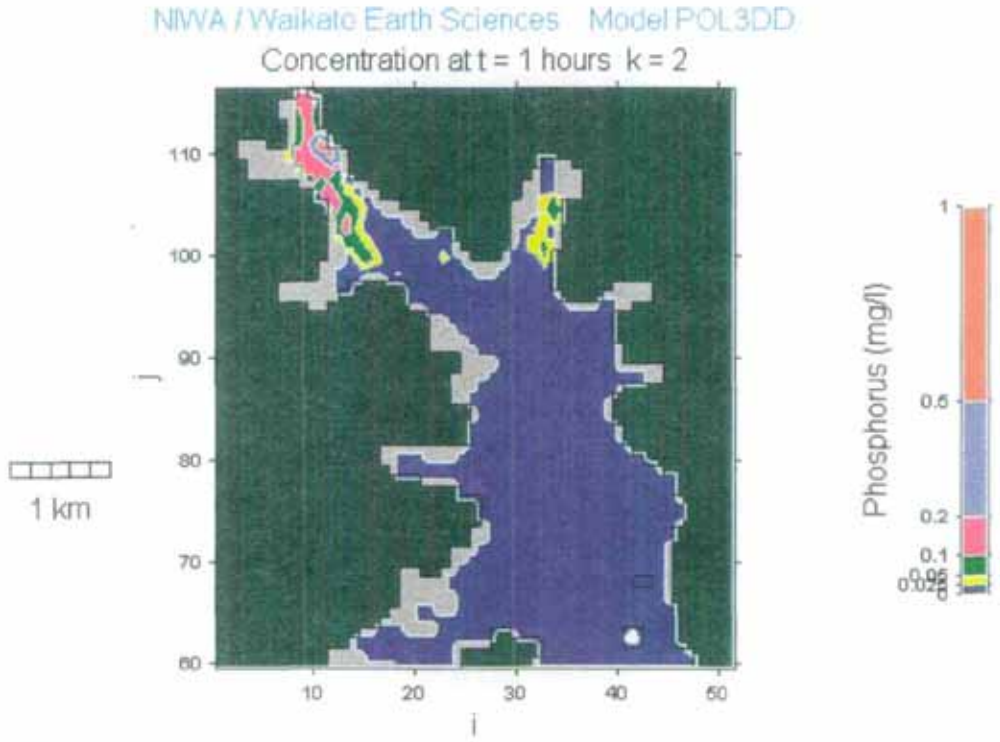


Figure 22b. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

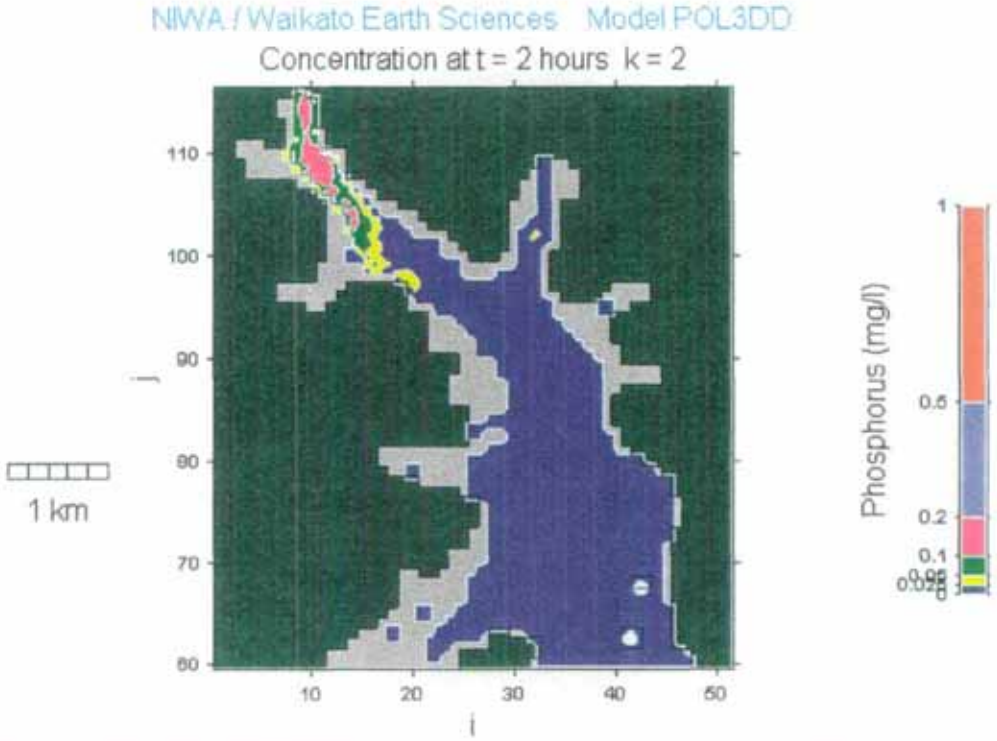


Figure 22c. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

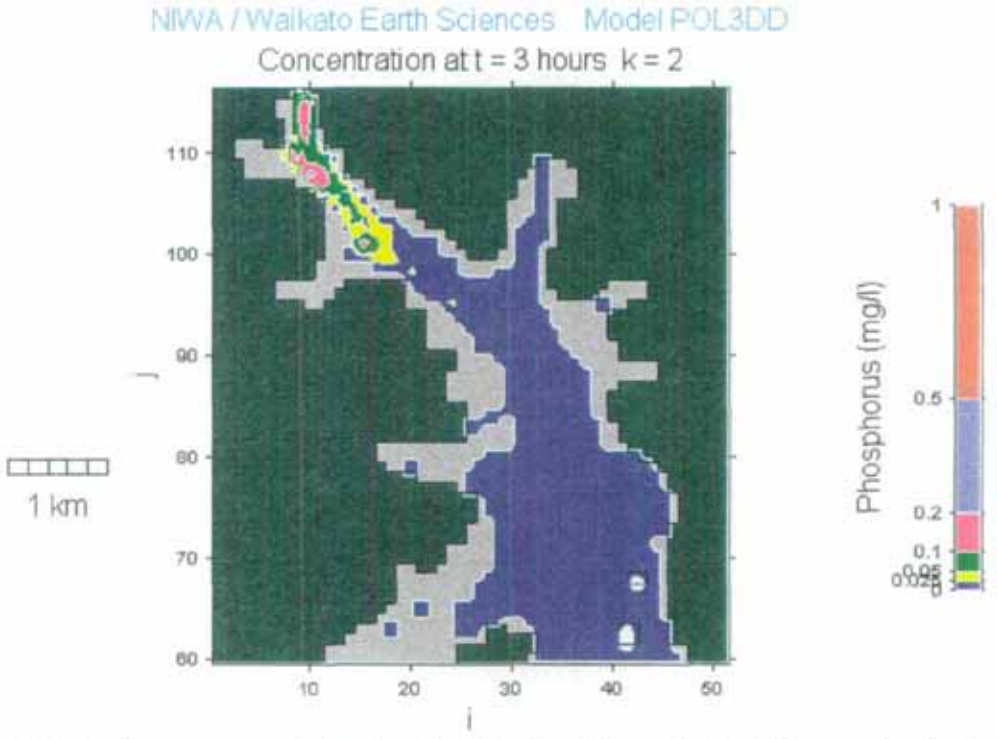


Figure 22d. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

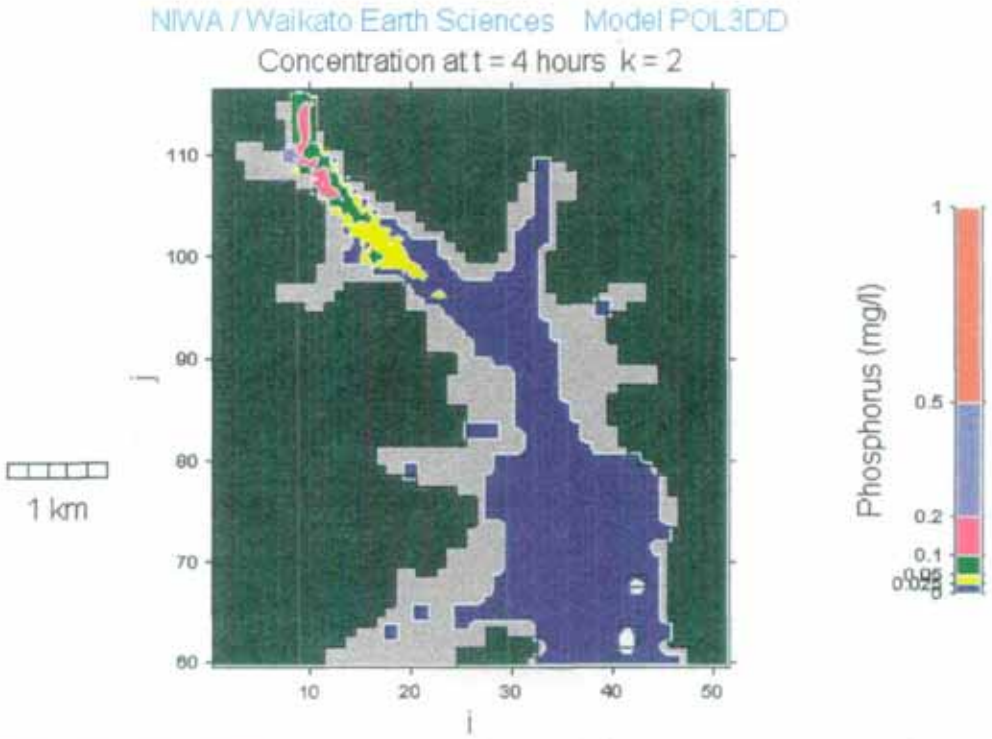


Figure 22e. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

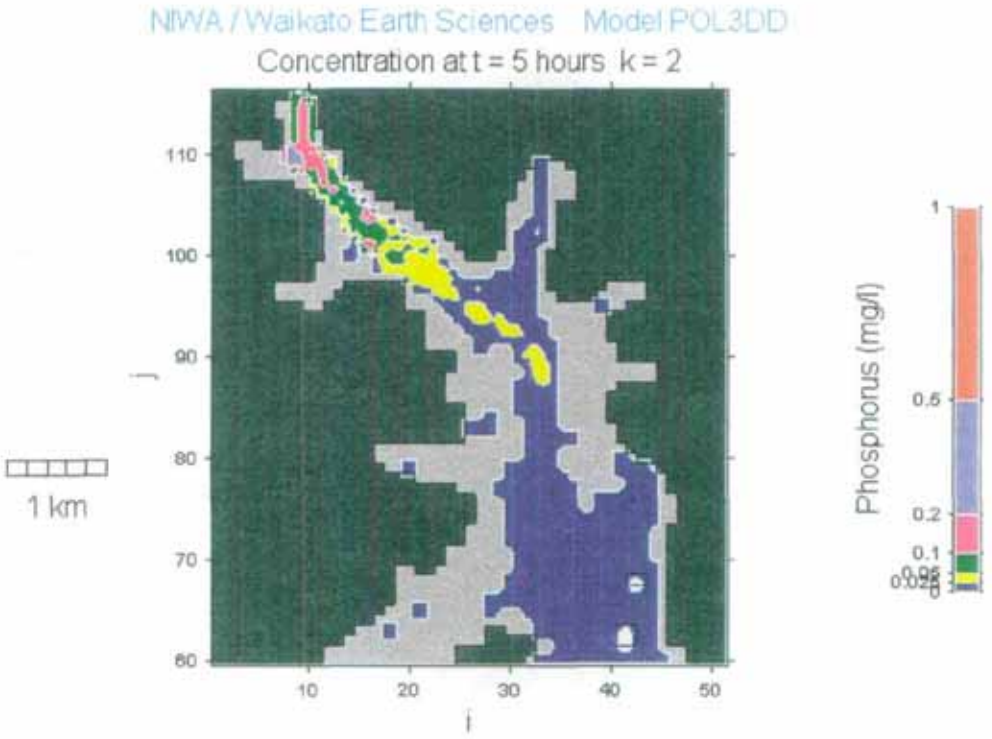


Figure 22f. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

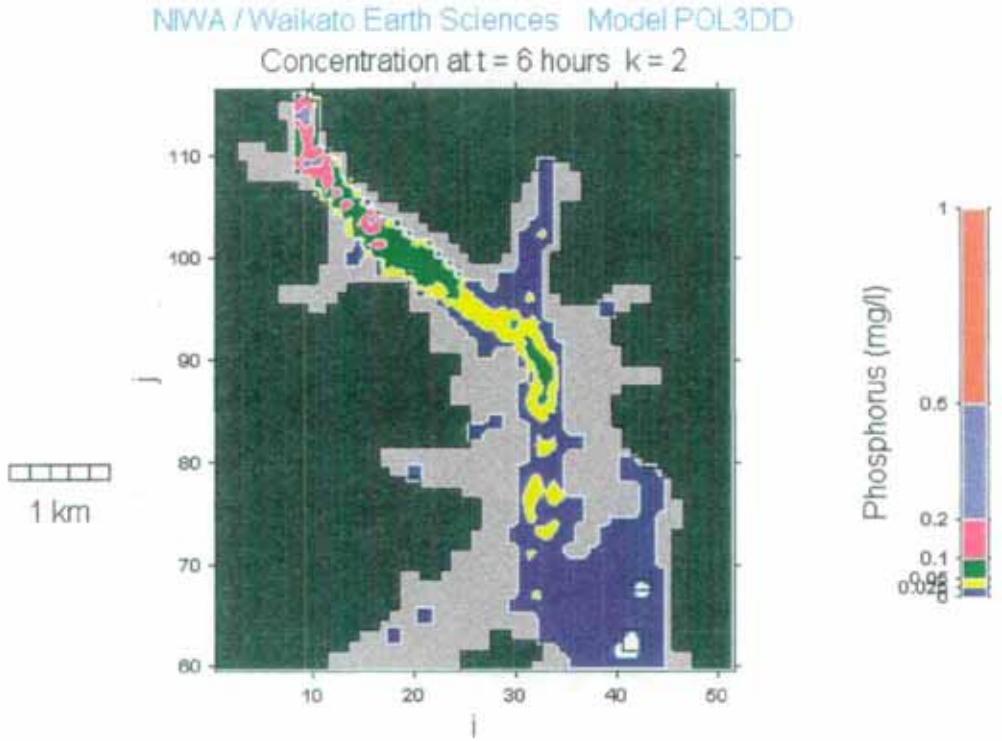


Figure 22g. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus six hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

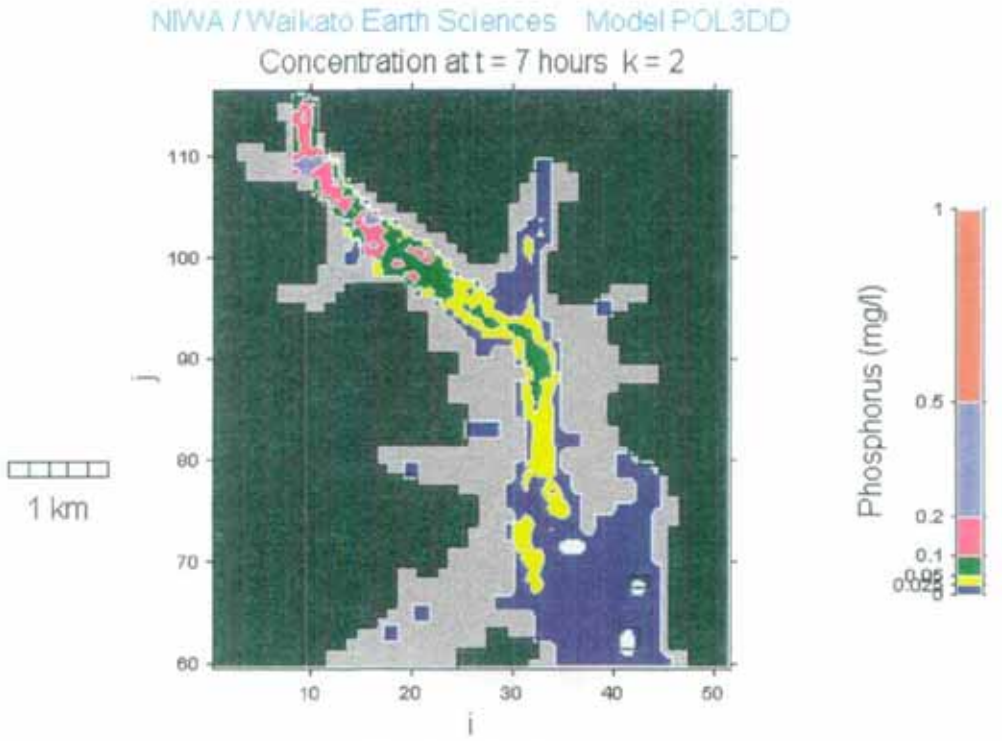


Figure 22h. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus half an hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

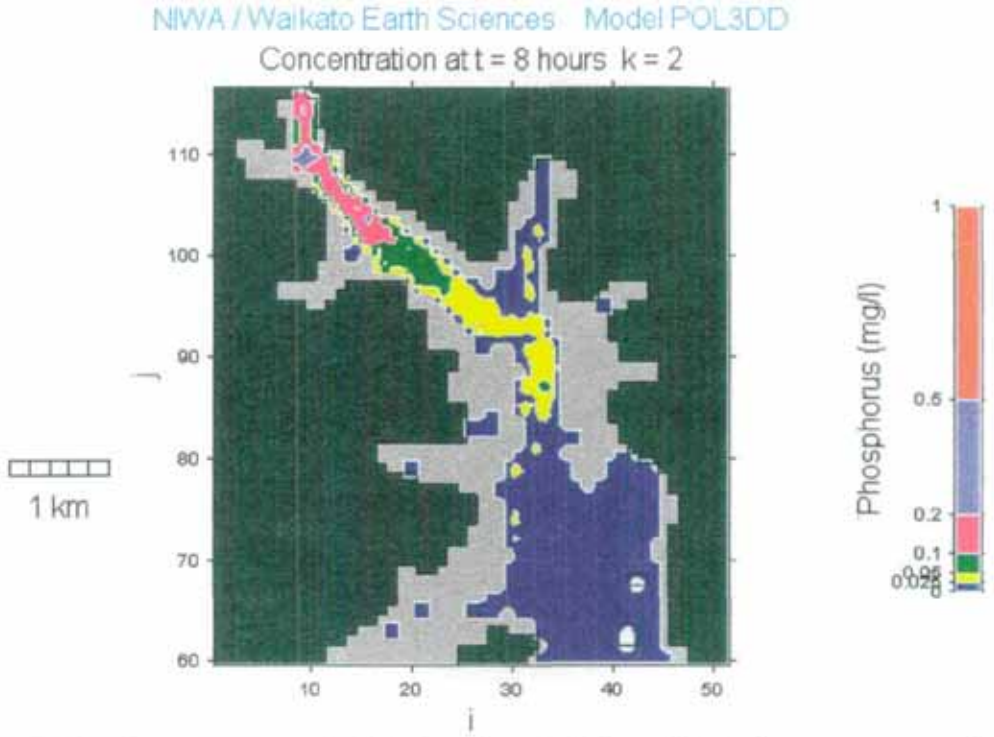


Figure 22i. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

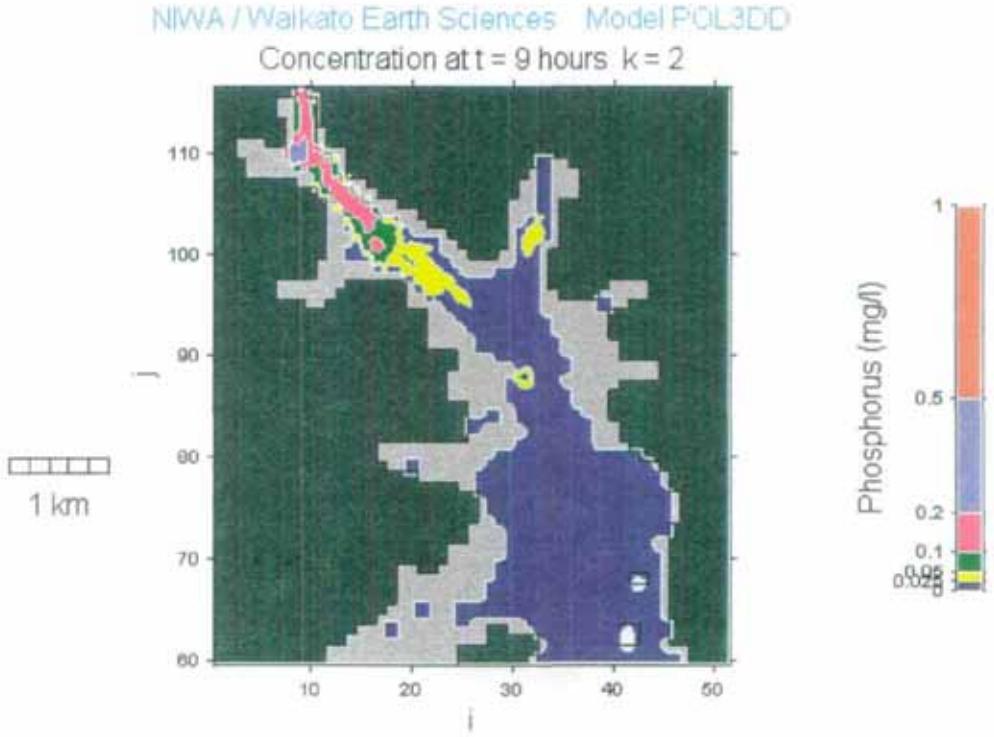


Figure 22j. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

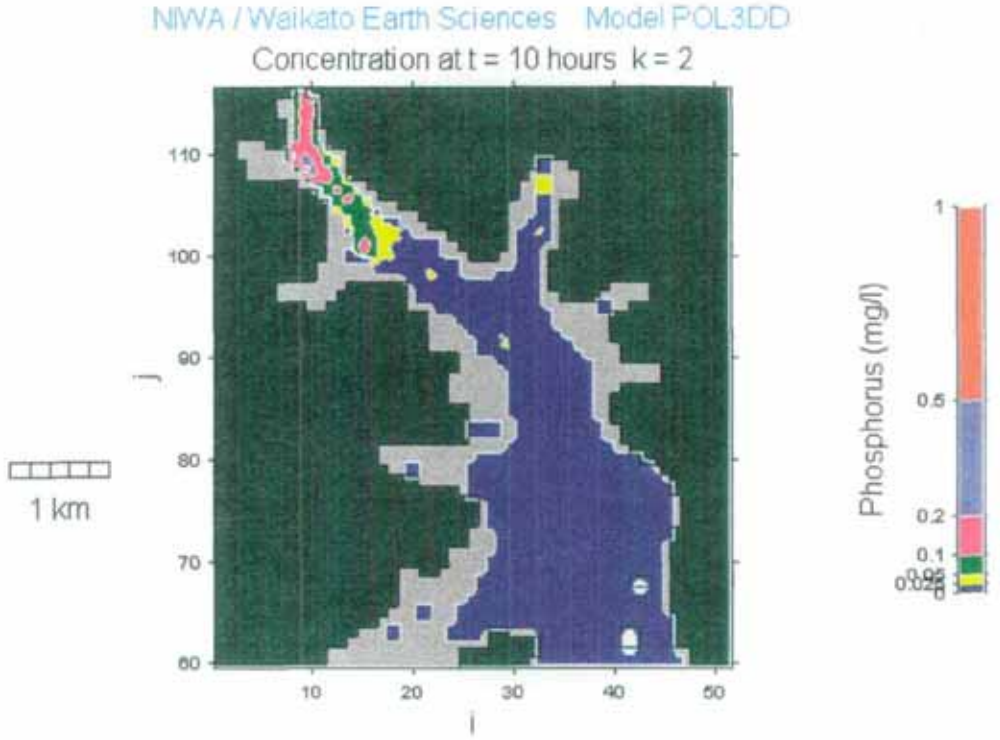


Figure 22k. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

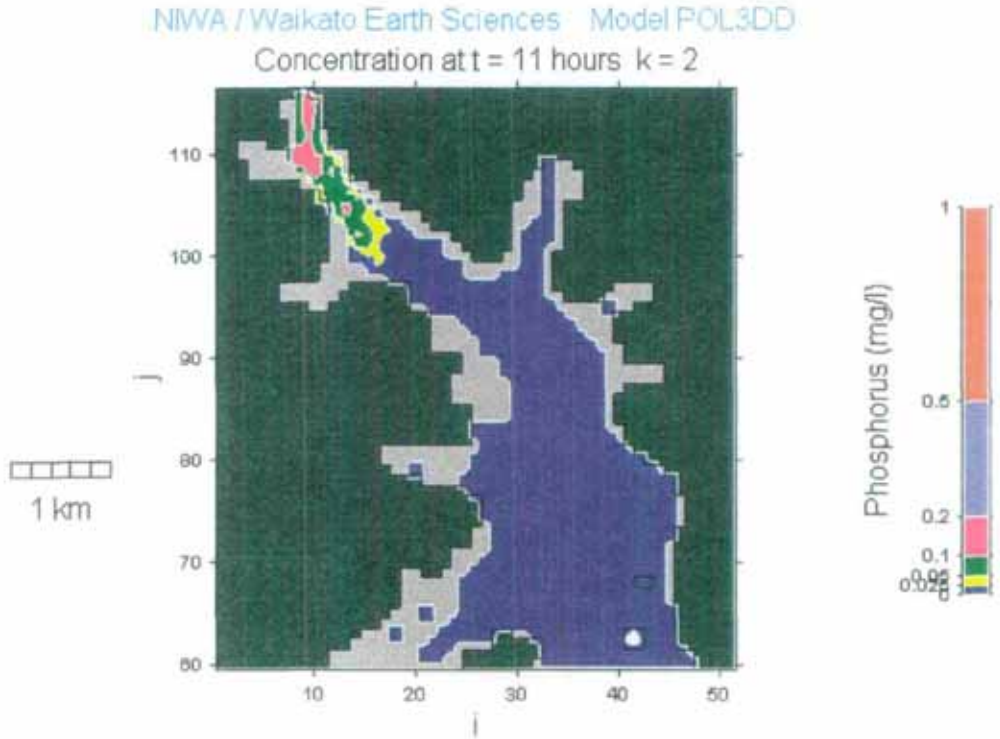


Figure 22l. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

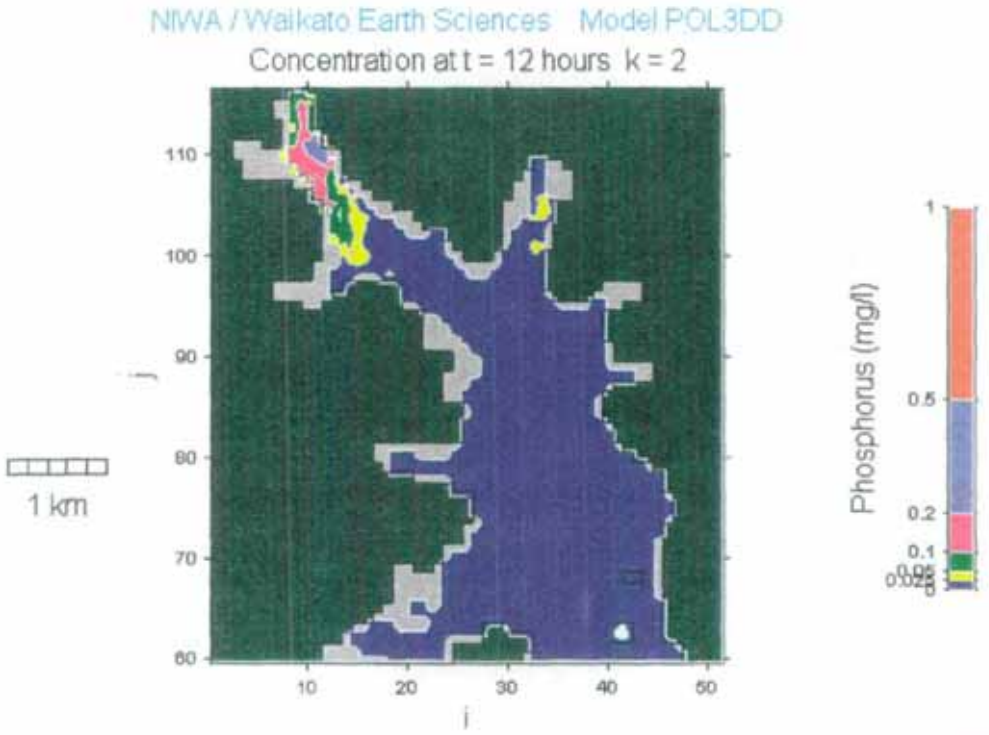


Figure 22m. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

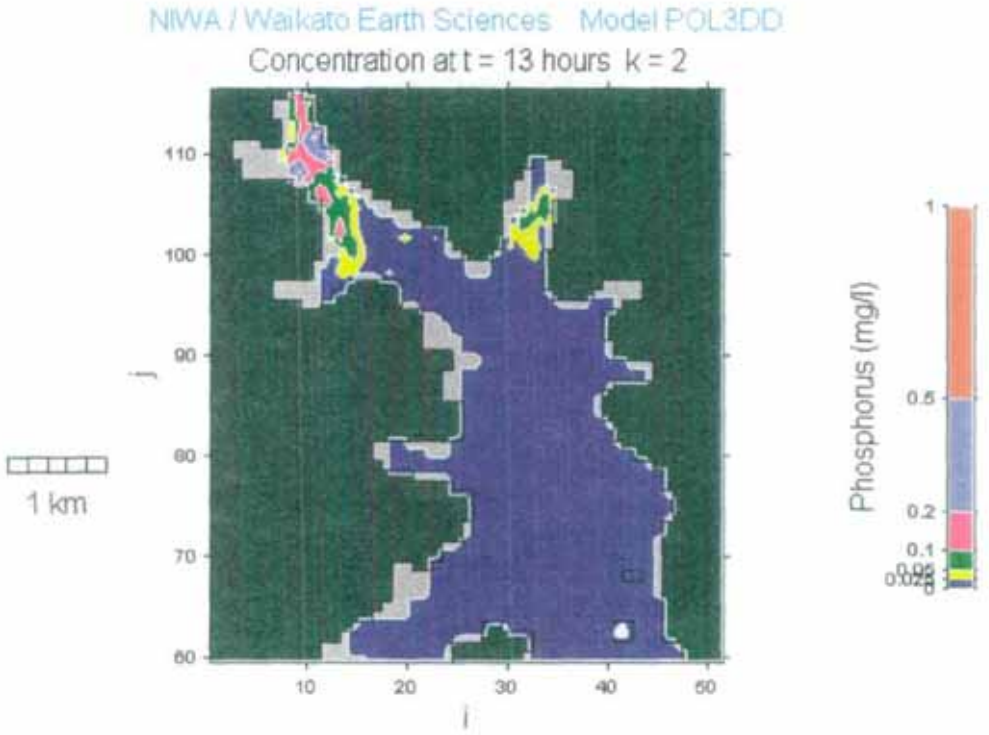


Figure 22n. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus half an hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

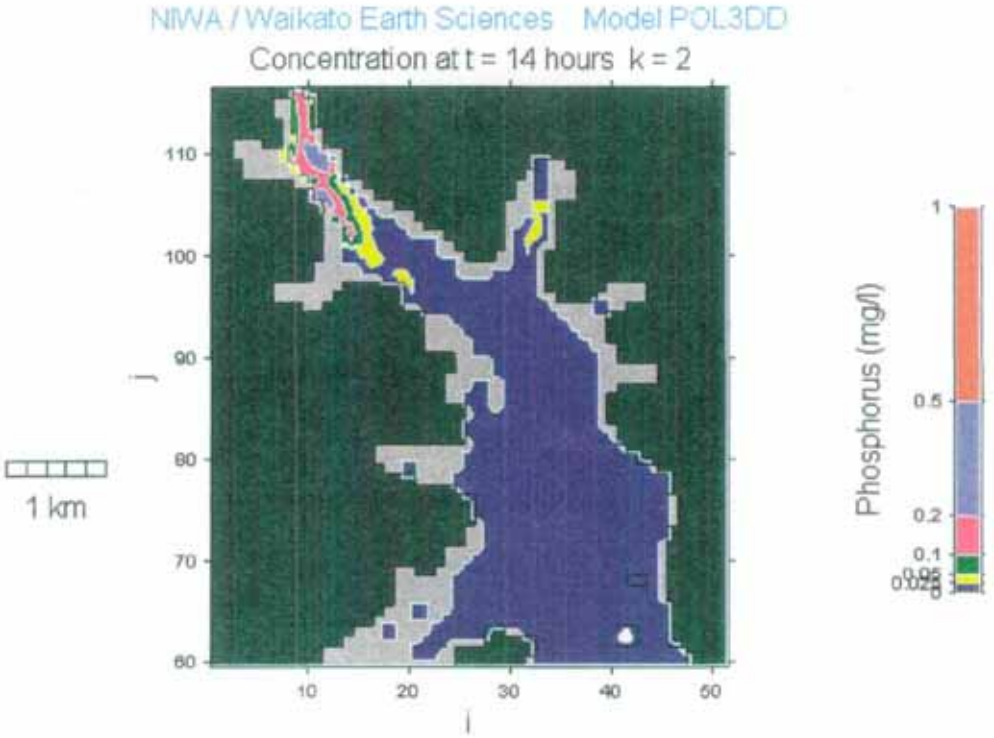


Figure 22o. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus one and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

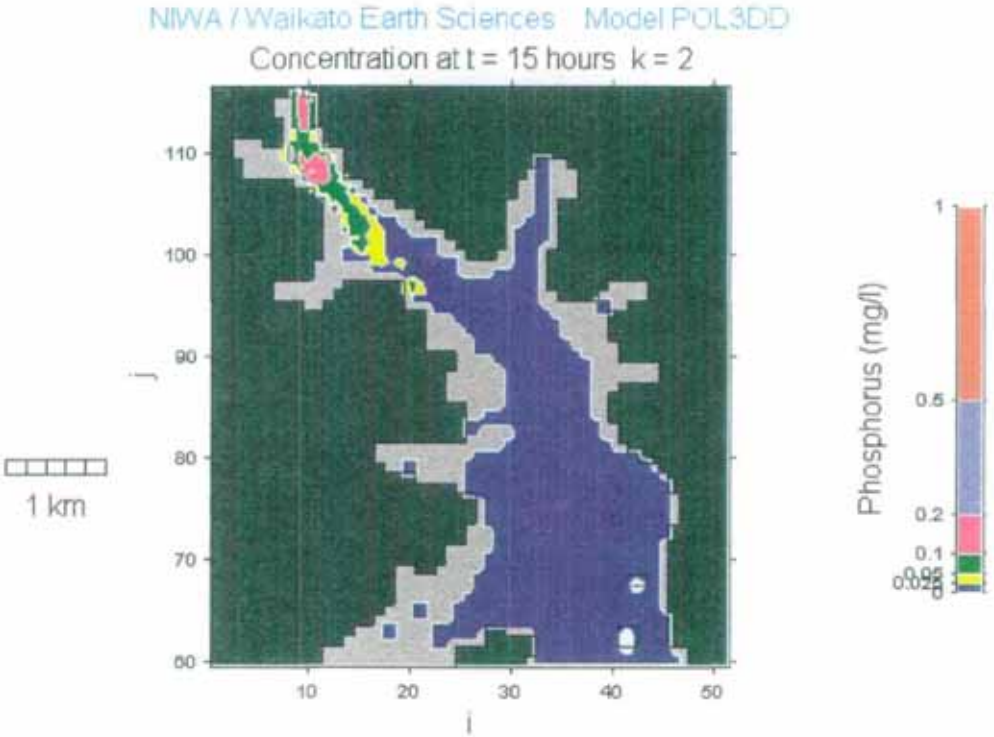


Figure 22p. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus two and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

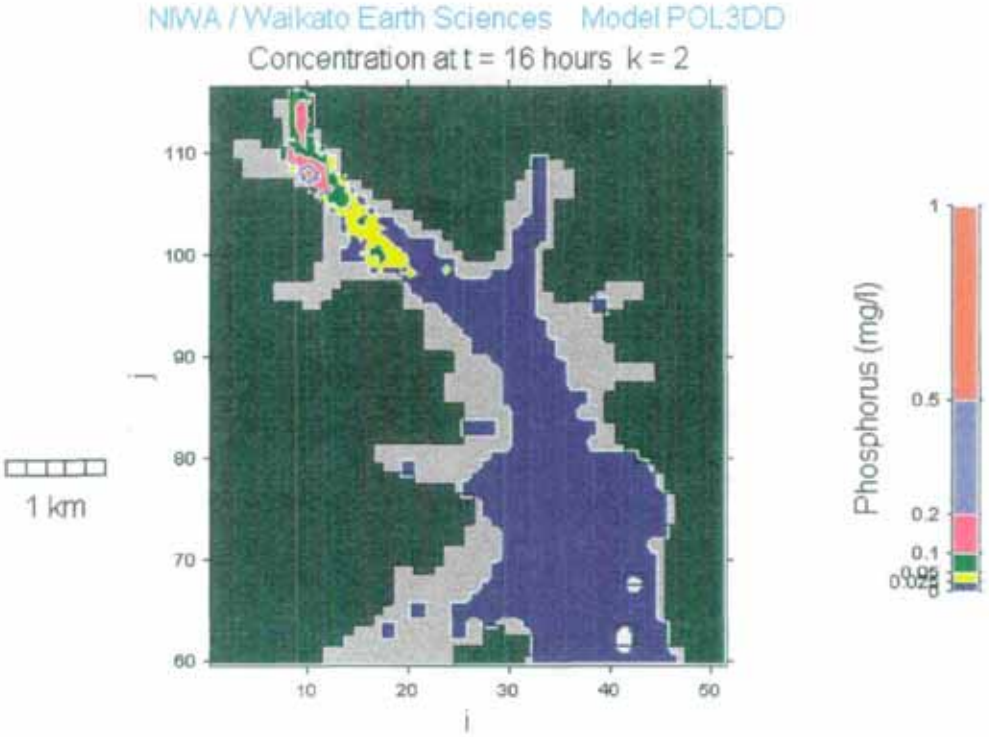


Figure 22q. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus three and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

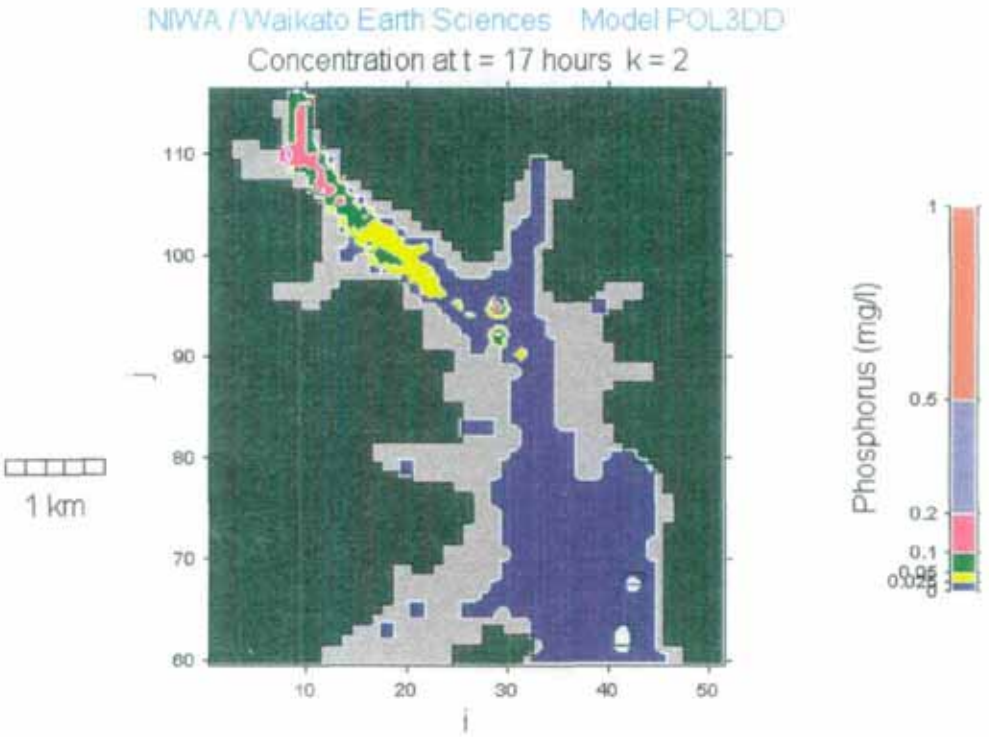


Figure 22r. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus four and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

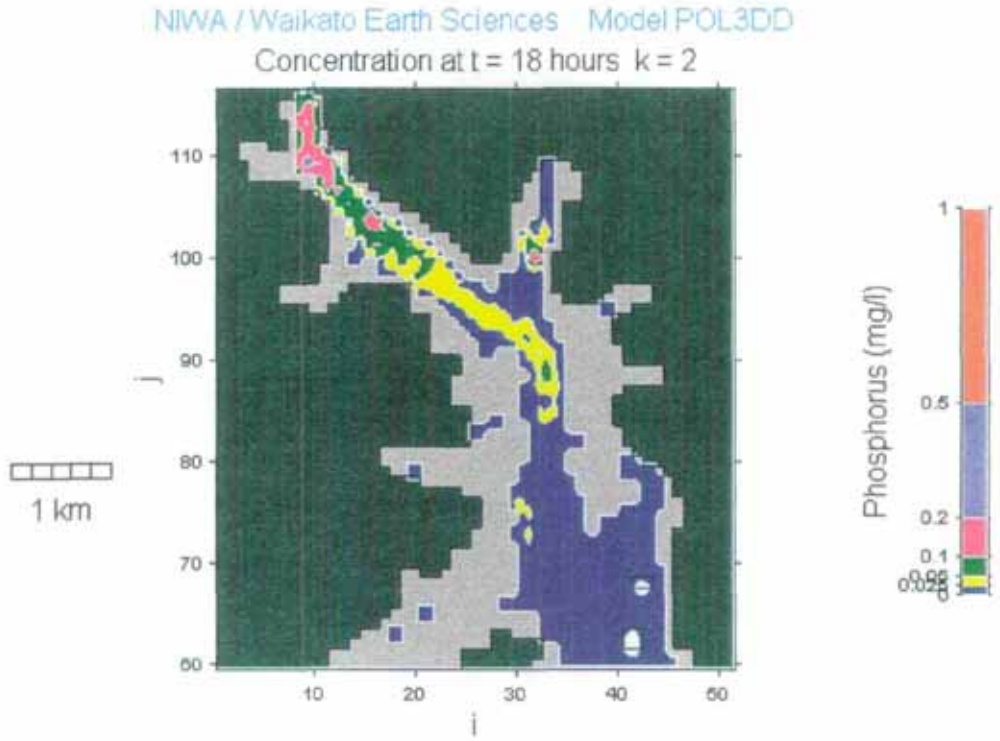


Figure 22s. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water plus five and a half hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

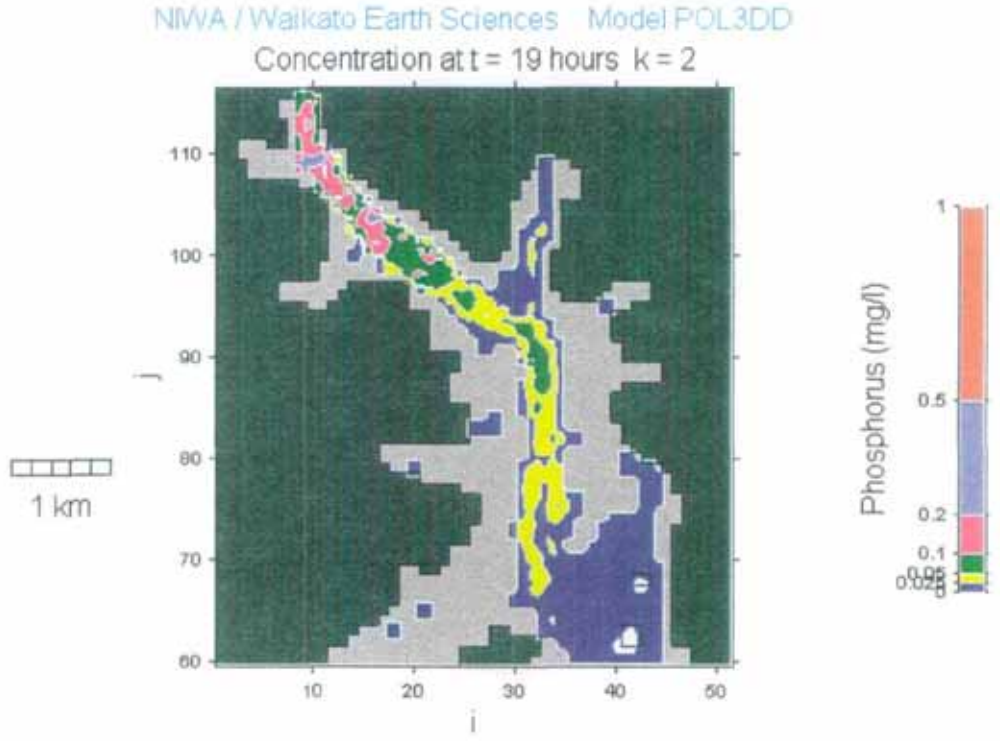


Figure 22t. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

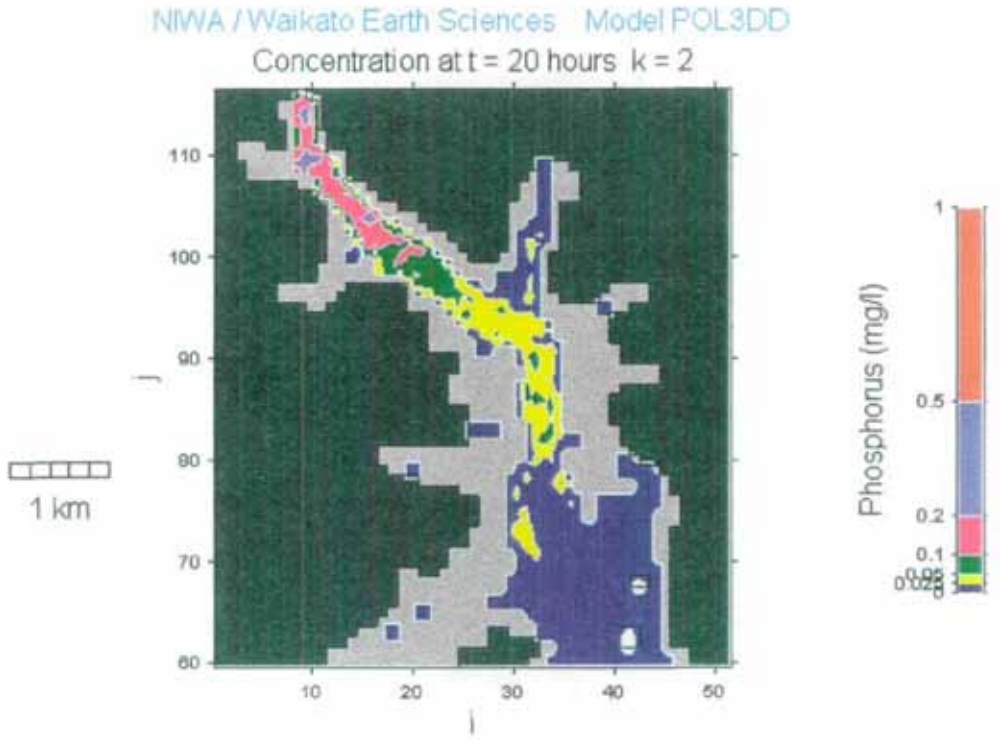


Figure 22u. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus one hour resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

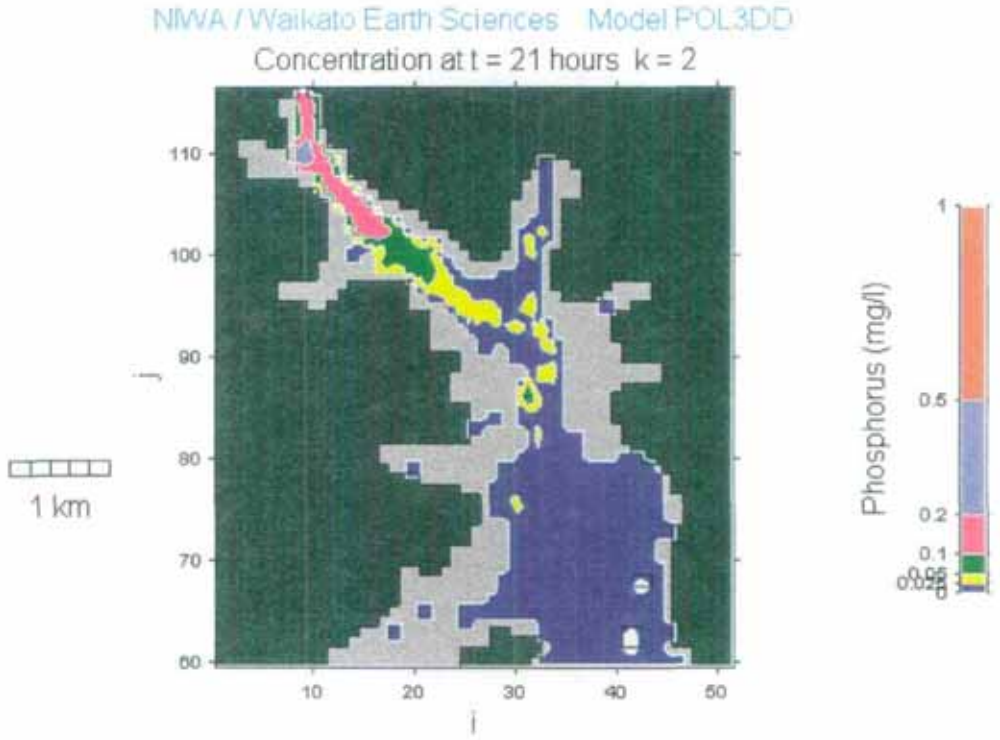


Figure 22v. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus two hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

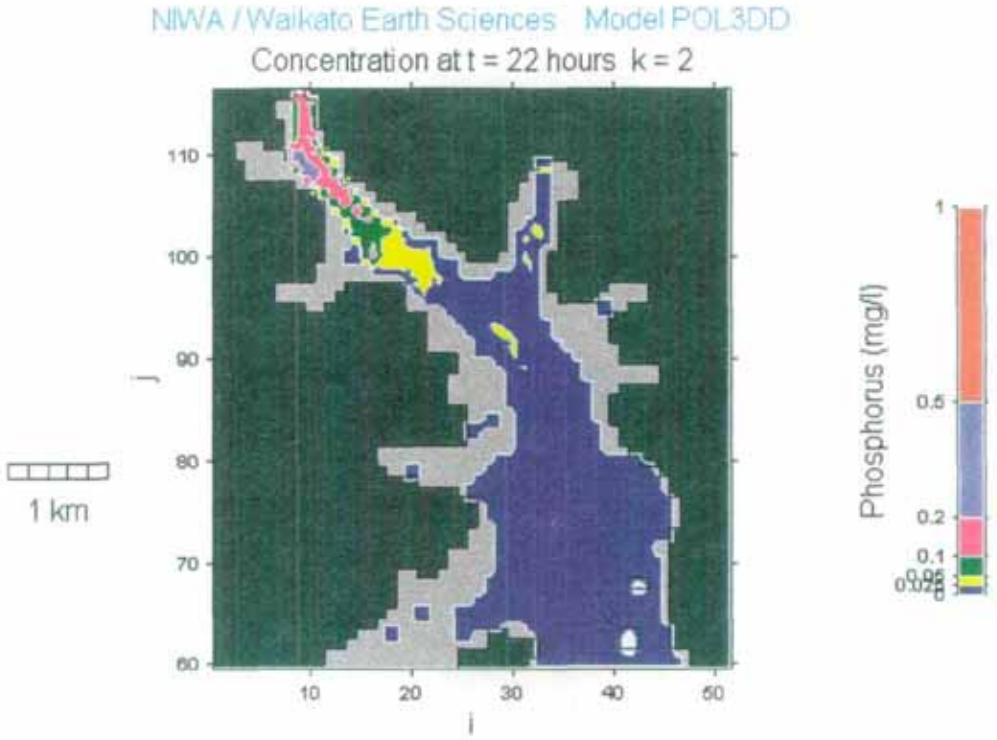


Figure 22w. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus three hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

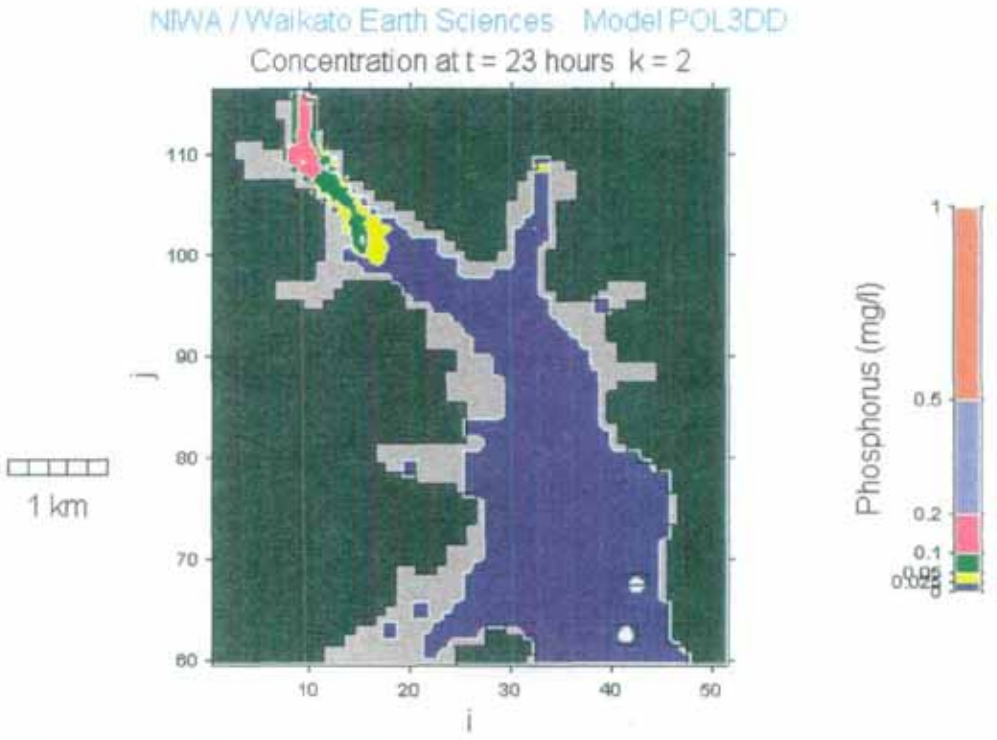


Figure 22x. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus four hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

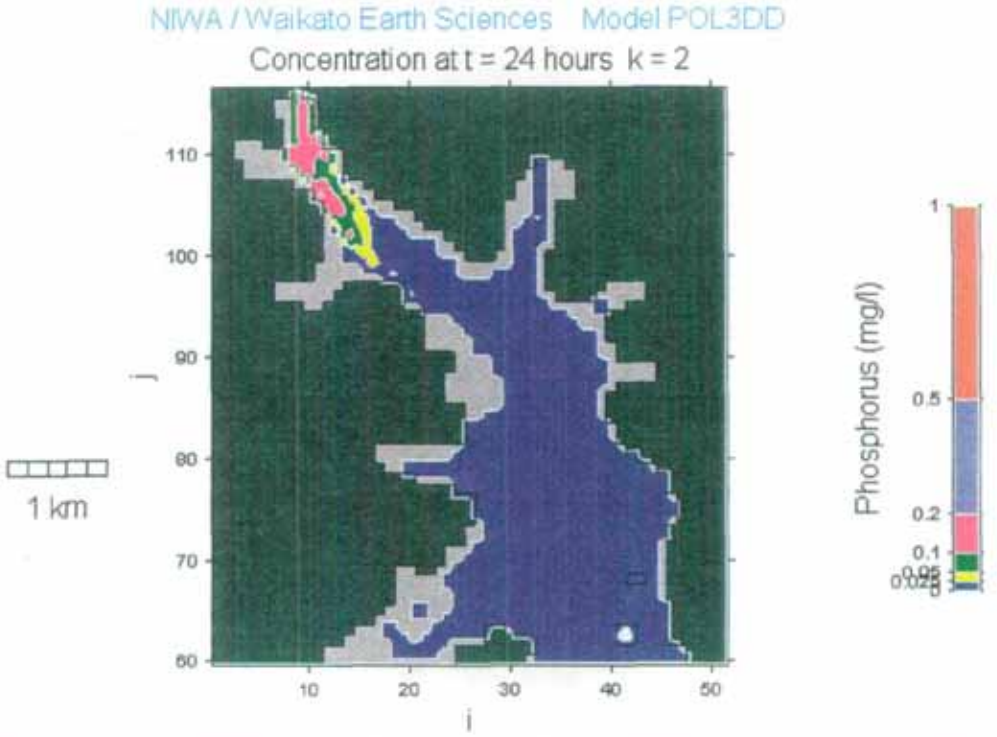


Figure 22y. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at low water plus five hours resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).

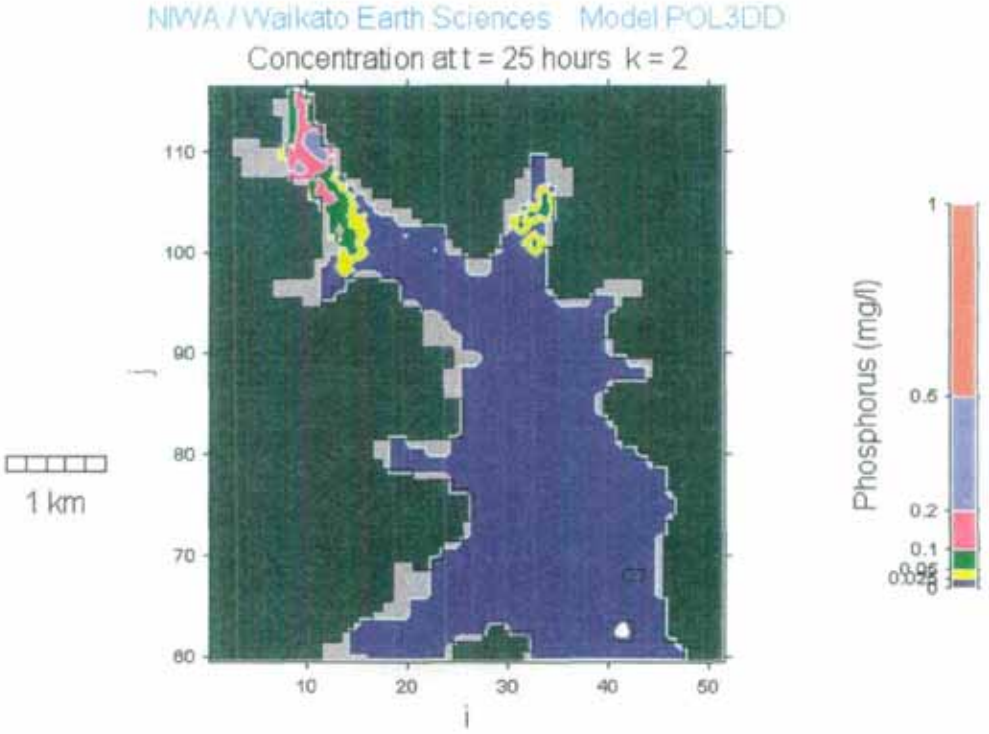


Figure 22z. Phosphorus concentration (mg/l) in the surface "fixed" layer (0-0.2m) at high water resulting from the discharge via wetland from the Warkworth sewage treatment works. River flow at 1 cumec and a mean tidal range (2.5 metre range).