Chapter 5 Results - Roches Point Model

This chapter presents the findings of our study. Many charts and diagrams are used to demonstrate the relative contribution of each outfall to the contamination of the model oyster farm in the North Channel. The results for the model oyster farm in the outer harbour are presented in Appendix C.

The reader is referred to the DVD accompanying this report which contains a number of animations highlighting the release, transport and decay of *Norovirus* from the simulation runs presented in this chapter.

5.1 Outfalls in Cork Harbour

Table 5-1 lists the outfalls that discharge treated and untreated sewage to Cork Harbour. In each case the contamination of the model oyster farm has been determined using the RP model. The one exception to this is the contribution from Carrigaline/Crosshaven which has been examined with the OH model. The results of the OH model are presented in Chapter 6[68]

Some smaller outfalls have been grouped together into a single source of *Norovirus*. For instance, the Passage West, Glenbrook and Monkstown outfalls act as a single source which is labelled PGM. It is therefore not possible to distinguish between these three separate outfalls in the model results. We examine their contribution as a group. Grouping outfalls in this manner reduces the run time of the model. In addition, results are more easily interpreted at the model oyster farms, as the contribution of minor outfalls in the harbour are hard to present graphically in the presence of much larger ones[69].

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[68] The main conclusion of Chapter 6 is that for summer conditions the contribution of Carrigaline and Crosshaven is approximately a third of the contribution of Cobh and Ringaskiddy. In winter it is approximately half.

[69] This is the case for the Carrigtohill outfall. Its relative contribution is insignificant to the contamination of the oyster farm in the North Channel and it does not register on any of the pie charts in this chapter.

	Outfalls	Treatment	Population	Flow Rate (m^3/s)
1	Cork City - Untreated	None	186,000	1.000
2	Cork City - Carrigrennan	Secondary	186,000	1.000
3	Carrigaline/Crosshaven	None	12,600	0.068
4	Cobh	None	10,000	0.054
5	Midleton - Untreated	None	7,700	0.041*
6	Midleton - Treated	Secondary	7,700	0.041*
7	Passage West	None	3,300	0.018
8	Glenbrook	None	300	0.002
9	Monkstown	None	1,000	0.005
10	Carrigtohill	Secondary	1,400	0.008
11	Whitegate/Upper Aghada	None	790	0.004
12	Cloyne	Secondary	1,000	0.005
13	Ringaskiddy	None	500	0.003
14	Saleen	None	300	0.002
15	Lower Aghada	None	200	0.001
16	Rostellan/Farsid	None	200	0.001
17	SW Overflows at Bailick 1 & 2	Screening	7,700	Timeseries
18	Houses around North Channel	None	576**	Various

* = this constant flow rate has been adjusted in the model to account for the pulsed release at Rathcoursey. Thirty minutes after high tide the effluent is released by a tidal clock for 3 hours. For the rest of the tidal cycle there is no discharge from Rathcoursey

** = 144 houses identified around North Channel. Four people per house is assumed

Table 5-1 Complete list of outfalls considered in the model

The relationship between population and flow rate in this table is approximately 480 litres per second, somewhat larger than the conventional value for "dry weather flow" used in engineering practice in Ireland. The source of this variation is the population data. The population numbers were obtained from the 2002 census. The allocation of population[70] to sewer catchments was changed a number of times during the study, but never by more than 7%[71]. There is obvious uncertainty concerning the location of a person with Winter Vomiting Disease at any moment in time: at home, at work, or in hospital, or temporarily in an institution with a mass outbreak.

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[70] The concept of "population equivalent" is not relevant, since there is no industrial waste.

[71] The population of Midleton is shown as 7,700 in the table, but is presented as 7,200 in chpt. 4.

There is further uncertainty in the assumed concentration of *Norovirus*. We have assumed a common concentration of 50,000,000 viruses per cubic metre of untreated effluent. While the graphs and plots which follow may look very precise, they must not be interpreted in this way[72]. The model producing them is simply a method of thinking about the problem at issue. Consistency is therefore a goal.

Some of the smaller discharges have been grouped together for clarity. Their outfalls remain in the correct location but the model produces one contaminant field for each group as a whole. The names of these groups and their acronyms are:

- Cobh + Ringaskiddy..**(COBH_R)**
- Passage West, Glenbrook + Monkstown........................**(PGM)**
- Cloyne + Whitegate + Upper Aghada + Saleen + Lower Aghada + Rostellan + Farsid..**(ALL_CLOY / CLOYNE)**

The other outfalls in the Harbour have been given the following acronyms in the charts and diagrams to follow:

- Cork City – Screened & Comminuted.......................**CC_S&C**
- Cork City – Carrigrennan.......................................**CG**
- Carrigaline/Crosshaven...**Carrigaline_C**
- Midleton – Screened & Comminuted at Rathcoursey....**RC_S&C**
- Midleton – Treated at Rathcoursey..........................**RC_T**
- Carrigtohill..**CH**
- SW Overflows from Bailick 1/Bailick2.................**Bailick 1/ Bailick 2**
- Houses around North Channel................................**HOUSES**

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[72] Microbiologists regard a difference in the concentration of micro-organisms of a factor of ten as significant, and a difference of 7% as of "no consequence". In certain cases measurements of numbers of micro-organisms in a sample can only be made to within a factor of ten e.g. the MPN (maximum probable number) estimates of indicator bacteria.

5.1.1 Bio-accumulation of *Norovirus* in oyster flesh

Oysters bio-accumulate viruses by a factor of 10 to 1,000. The results presented in this report do not account for this complex process. The results are simply the concentrations of model *Norovirus* in the model harbour expressed as the number of *Norovirus* per cubic metre. The timeseries presented in Section 5.4 describe the variation in concentration of model *Norovirus* at the location in which the model oyster farm is located.

5.1.2 Notes on the presentation of the results

The results presented in this chapter run from the 9:00am on the 15th of February to midnight on the 22nd of March, a simulation period of 37 days. The viral pulse lasts for 20 days from 9:00am on the 15th of February to 9:00am on the 6th of March.

All the charts and pie diagrams have the same colour palette throughout. This is to aid the reader in distinguishing between the different outfalls. The exception to this is the following section where the colour palette for the maximum concentrations of the untreated waste from Cork City is different to the rest because of its size.

5.2 Plots of Maximum concentration over the entire harbour

Over the course of the thirty seven day simulation the number of viral particles per cubic metre at each grid point will, at some specific moment, reach a maximum value. These maxima, at each and every grid point, may be extracted from the result files of a model run and plotted together on a single diagram. This diagram illustrates the spatially varying maximum concentrations over the entire simulation period for Cork Harbour. The time at which the concentration reached its peak is not considered. The maps for winter conditions (T90 = 30days) are presented in the following set of figures. The colour palette, which expresses the number of viral particles per cubic metre, is identical for all the outfalls. The exception to this is the first figure presented, which is for the untreated sewage from Cork City. The scale in this case is not a uniform scale with equal intervals assigned to each colour.

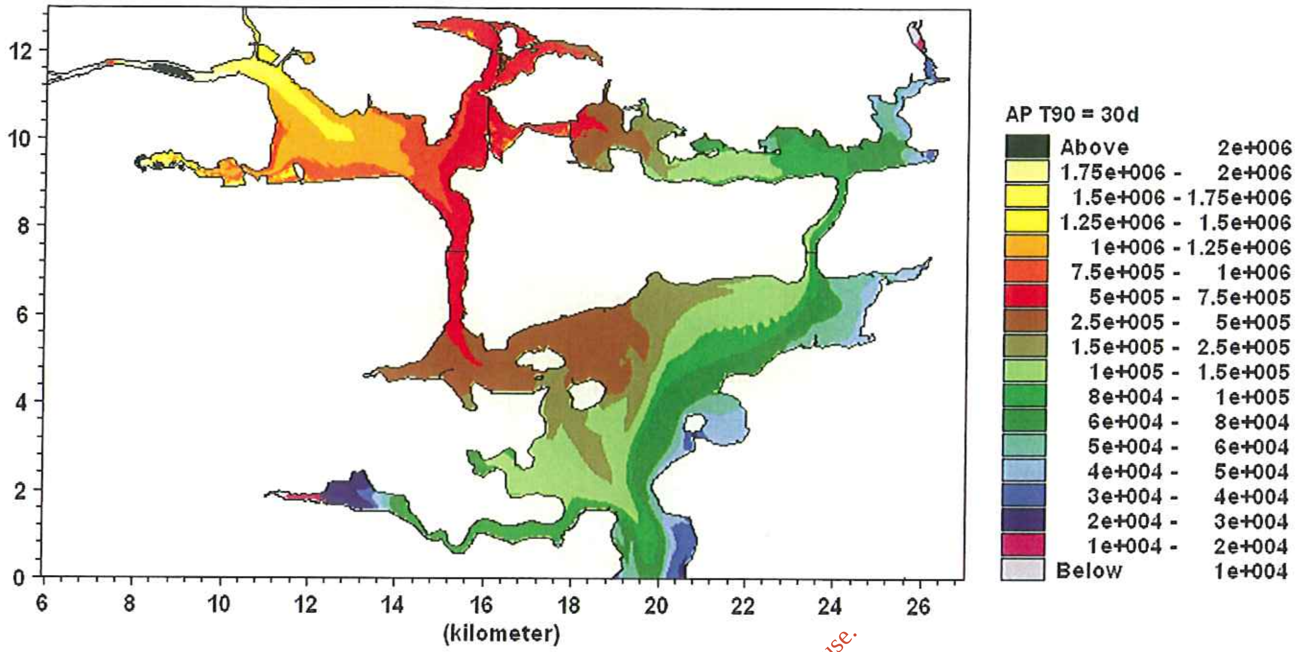

Fig. 5.1 CC_S&C maximum concentration #/m^3. Cork City sewage discharging near Kennedy Quay (Winter conditions)

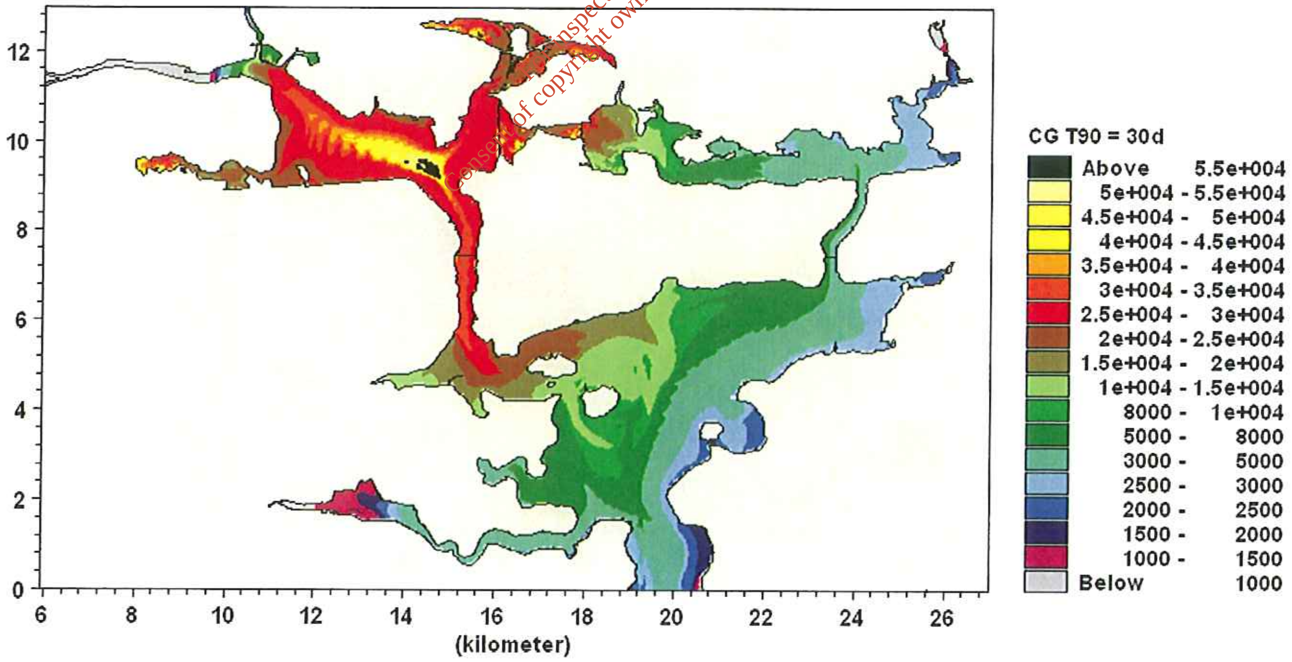

Fig. 5.2 CG maximum concentration #/m^3 (Winter conditions)

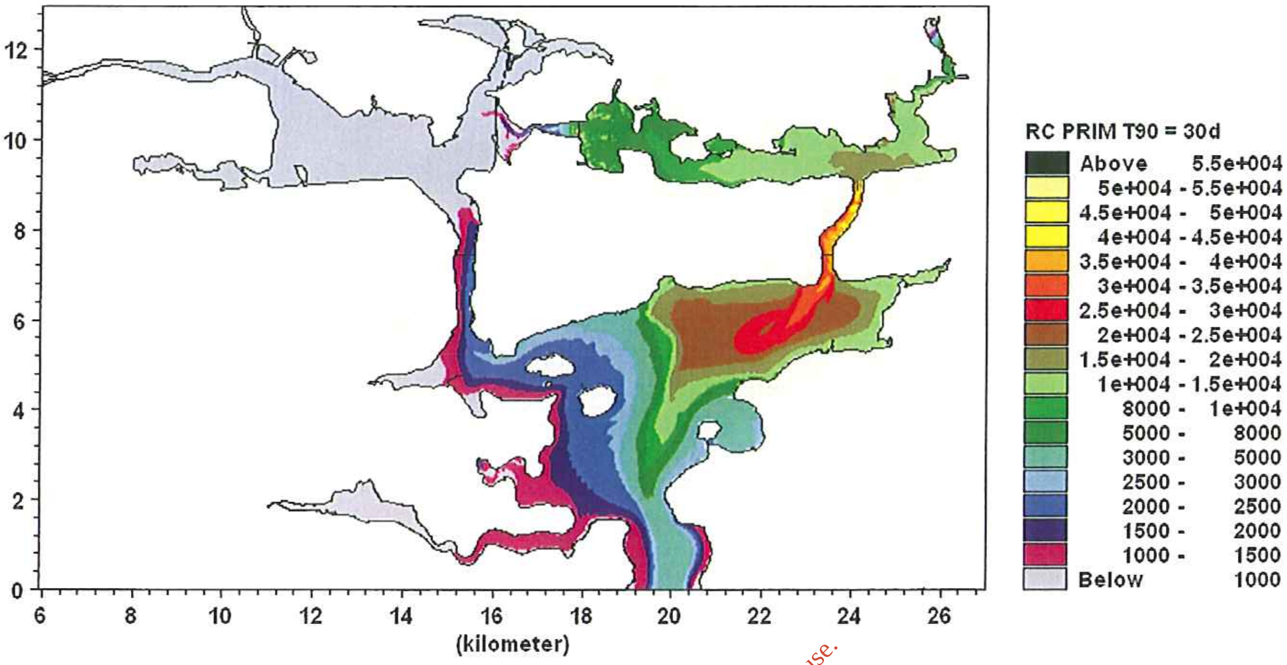

Fig. 5.3 RC_S&C maximum concentration #/m^3 (Winter conditions)

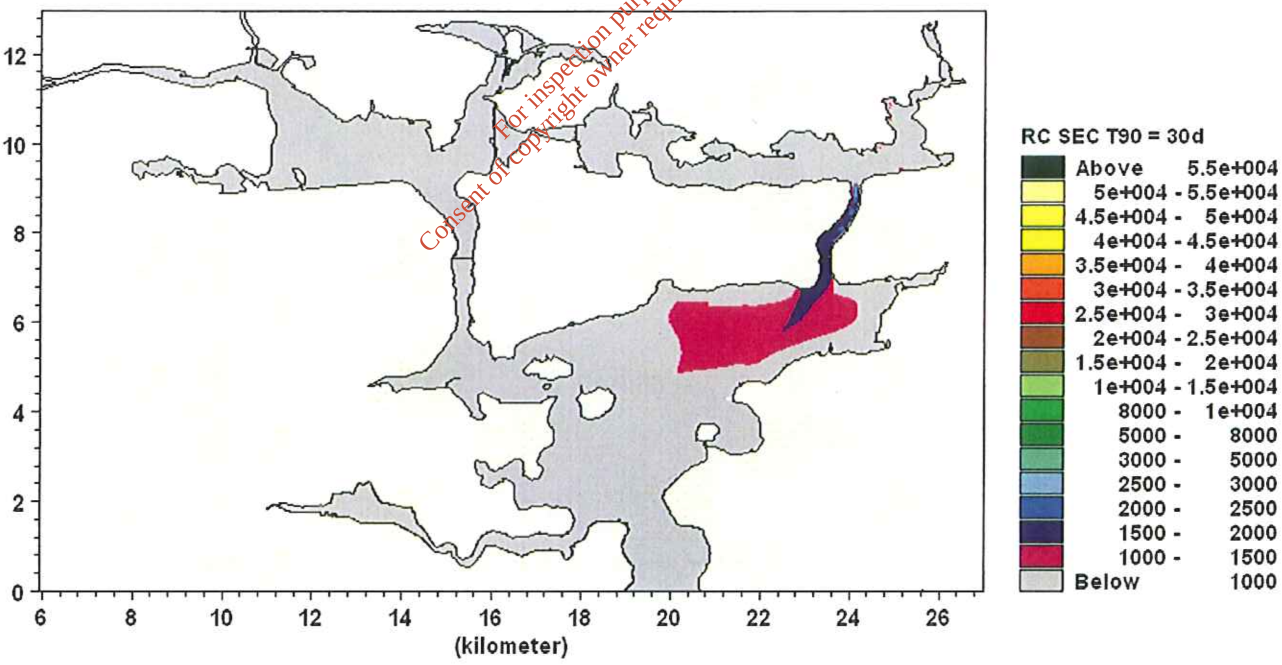

Fig. 5.4 RC_T maximum concentration #/m^3 (Winter conditions)

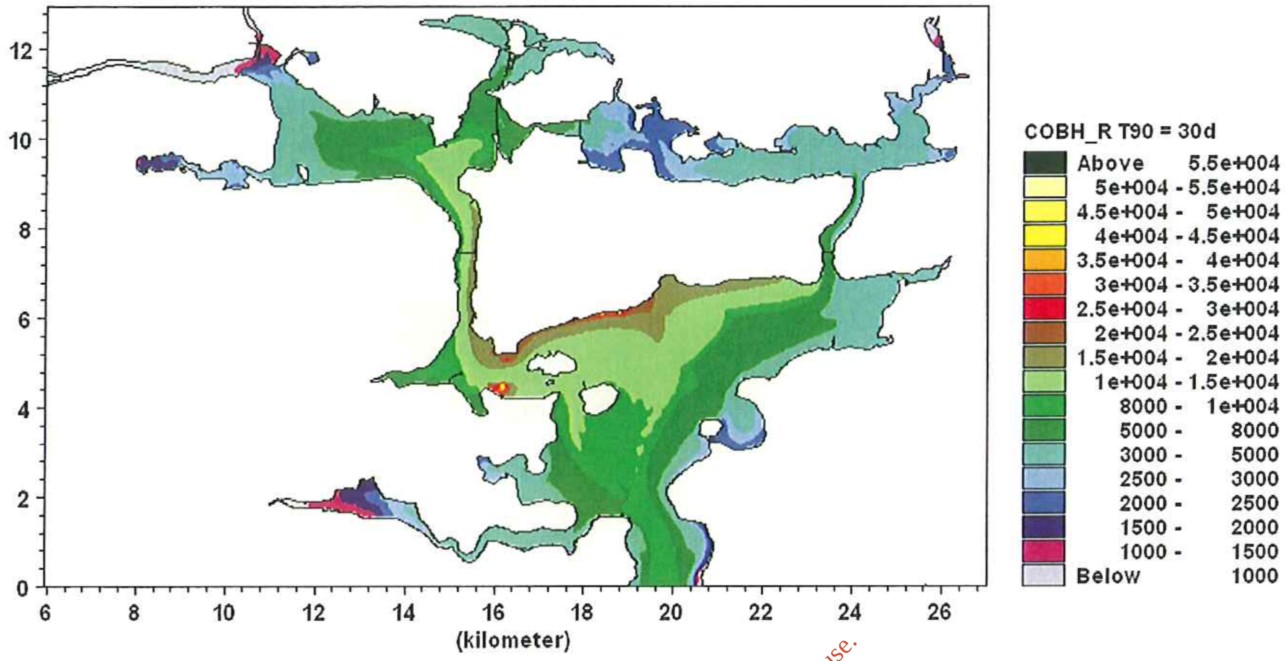

Fig. 5.5 COBH_R maximum concentration #/m^3 (Winter conditions)

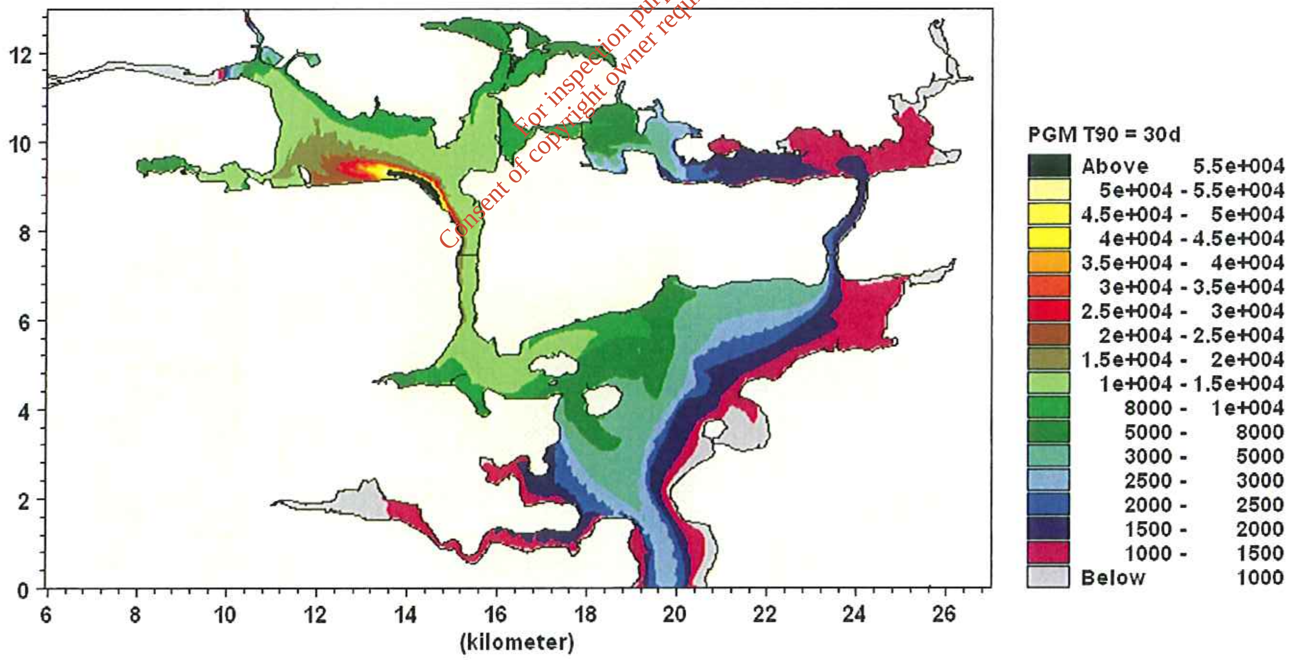

Fig. 5.6 PGM maximum concentration #/m^3 (Winter conditions)

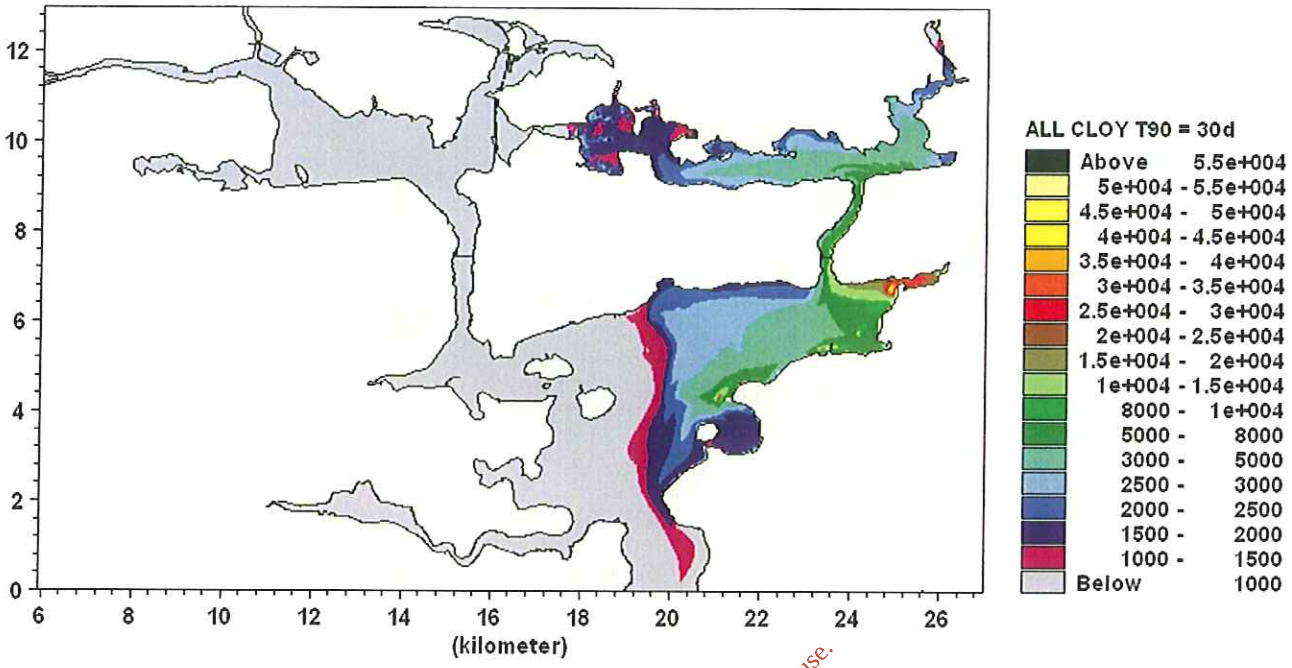

Fig. 5.7 ALL_CLOY maximum concentration #/m^3 (Winter conditions)

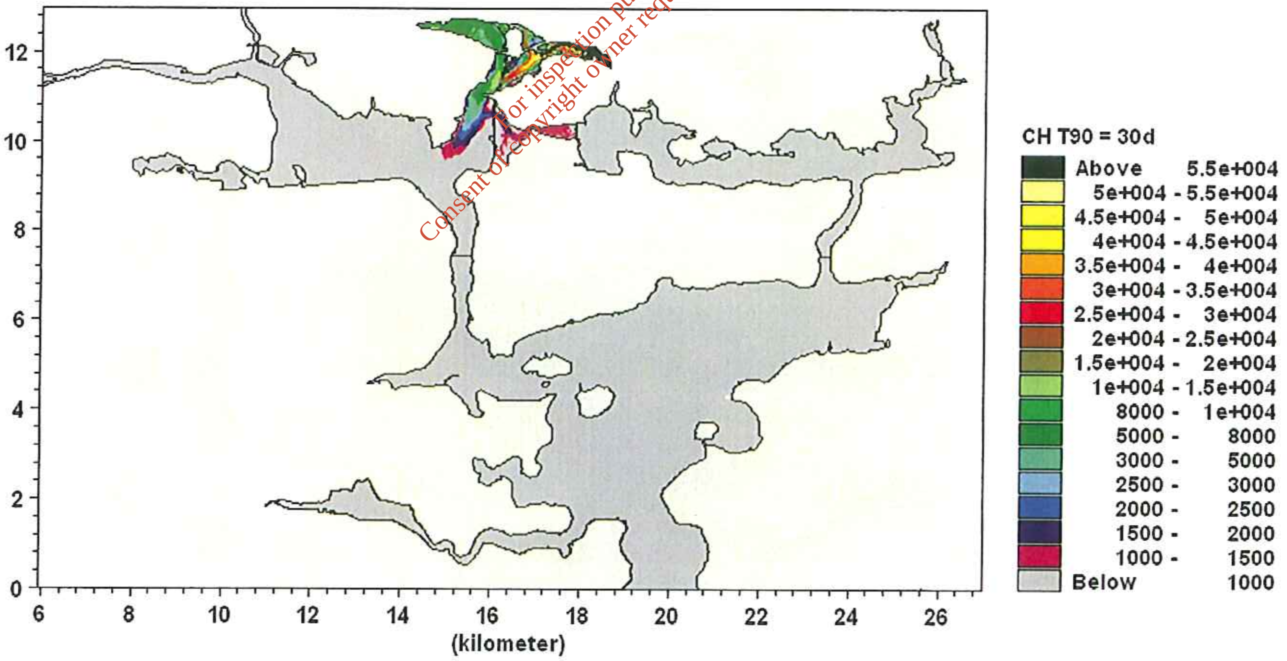

Fig. 5.8 CTH maximum concentration #/m^3 (Winter conditions)

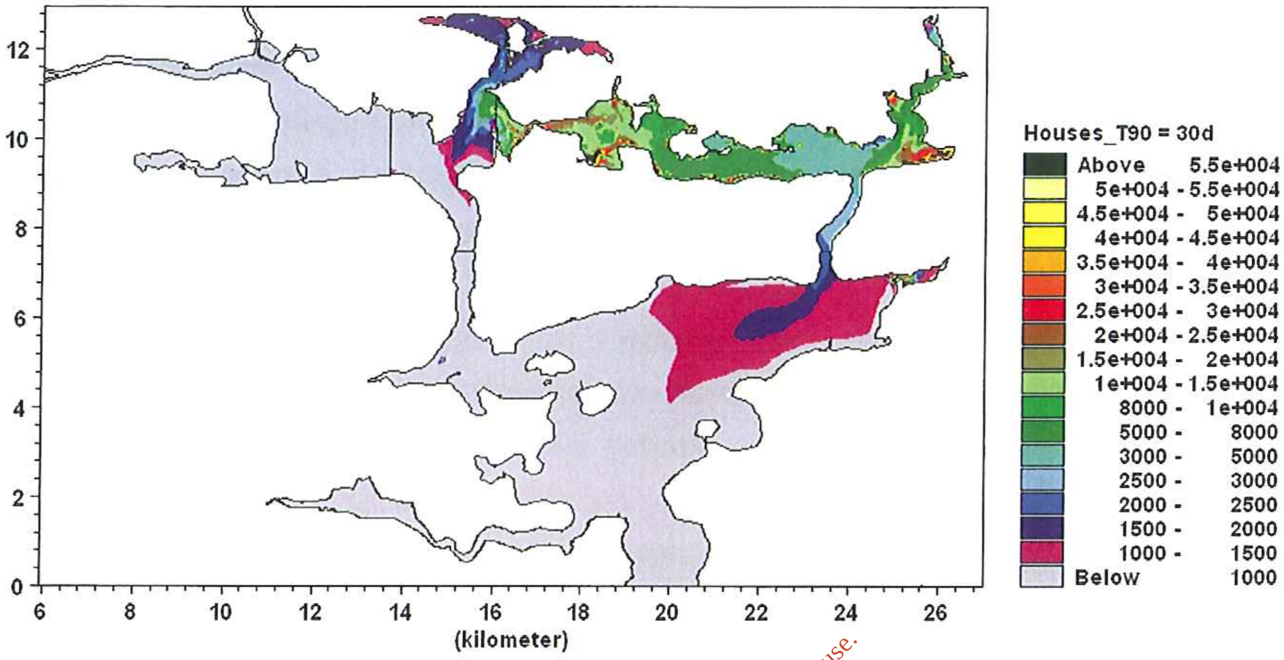

Fig. 5.9 HOUSES maximum concentration #/m^3 (Winter conditions)

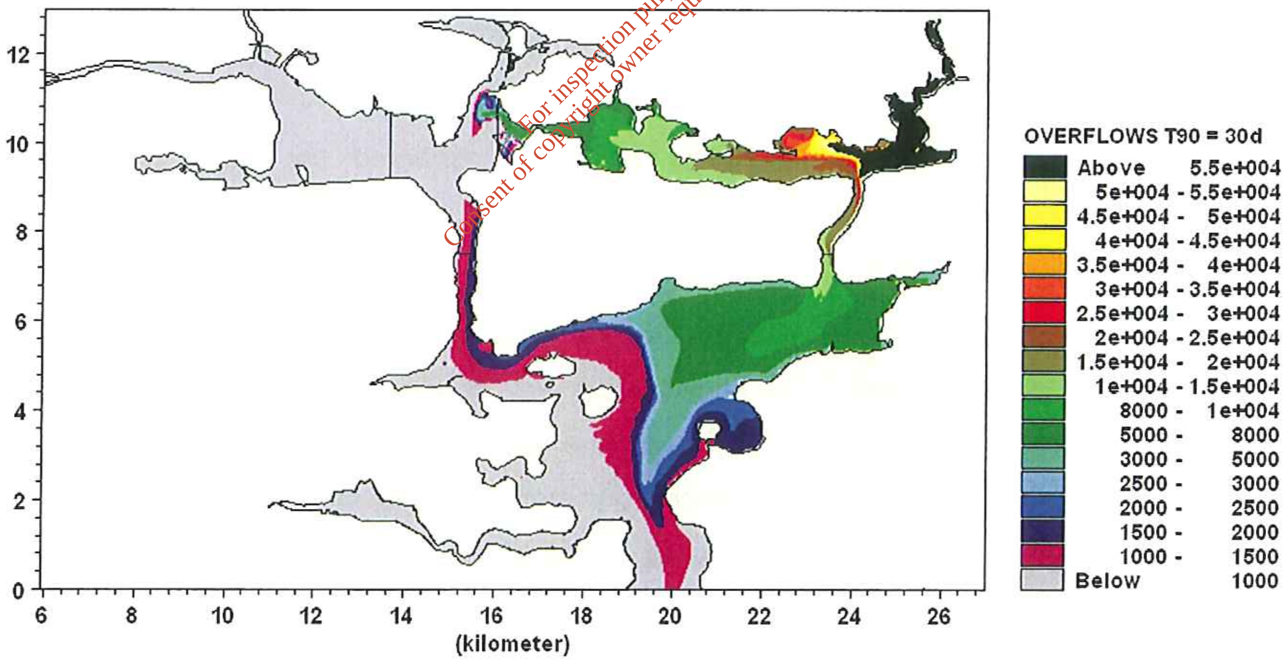

Fig. 5.10 SW OVERFLOWS – Bailick 1 maximum concentration #/m^3 (Winter conditions)

5.2.1 Plots of maximum concentrations: conclusions

Cork Harbour is a shallow lens of water, tens of kilometres wide, and tens of metres deep. It is a macro-tidal estuary with a daily variation in water level of the order of 4m during spring tides and 2m during neap tides. Conservation of water mass implies that this vertical motion is accompanied by a large horizontal oscillatory motion of the order of 5 to 10km. This very important characteristic of Cork Harbour is the most important factor in the model in promoting the widespread dispersal of discharges of *Norovirus*. In 6 hours contaminants can be spread over 10km by water flowing past the point of discharge. Peaks in concentration are created at slack water when the tide turns. For short periods of time, every six hours and twelve minutes, there is very little flow past an outfall to dilute the carrier flow with its load of viruses. The ensuing peaks[73] in concentration are advected back and forth with the tide.

Every time a parcel of water passes an outfall the burden of viruses is increased. The concentrations continue to grow until the twenty-day pulse has come to an end. The plots record the concentration maxima reached at all points in the model harbour.

Broadly speaking, the bigger the viral load discharged, the bigger and more widespread the contaminant field. The closer the outfall is, the bigger its immediate impact.

The process of decay, and the decline from maximal values, only becomes visible after the pulse has ended. Changes in tide, wind, river flow, salinity, discharge and decay rates of viruses, are secondary factors that modify, but do not replace, the large scale oscillatory motion of the model estuary, and the consequent dilution and spreading of the contaminating virus. To see these processes at work we must study time series of viral concentration at fixed locations, especially the time-series at the centres of the oyster farms.

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[73] The tidal clock and holding tank at Rathcoursey is intended to avoid these peaks by discharging on the ebb-tide into strong currents through a multi-port diffuser.

5.3 Point of extraction of the timeseries

The following sections in this chapter present time series of the number of viral particles per cubic metre at the centre of the model oyster farm in the North Channel. The extent of the oyster farm has, for this study, been assumed to be equivalent to the concession granted by the Department of the Marine[74]. The concession runs from the "most southerly point of HW mark of Brick Island extending due south, to the most southerly point of Brown Island extending due south[75]." (Fig. 5.11)

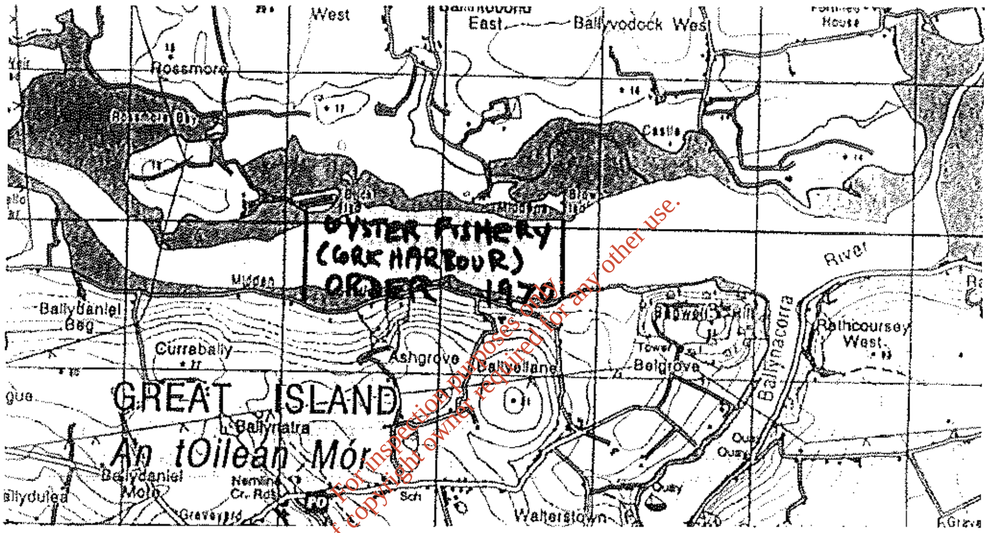

Fig. 5.11 Oyster concession in the North Channel[76]

The coordinates of the central point of the oyster concession in the 18m grid of the RP model are (1100, 111) (Fig. 5.12). The variation in concentration across the oyster farm is considered in a later section.

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[74] The farm operations may extend some distance to the east beyond the concession.

[75] Personal communication with the owner of the concession

[76] This map has been provided by the owner of the concession

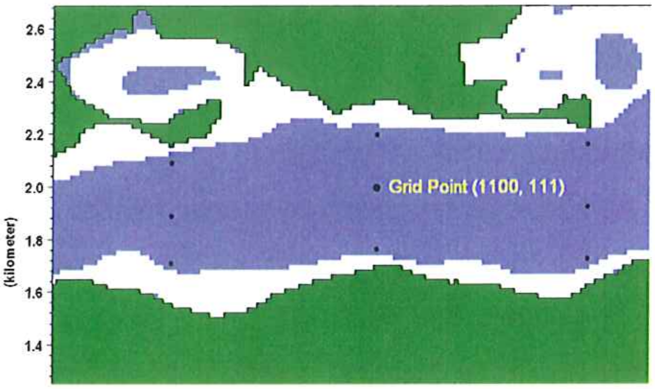

Fig. 5.12 Location of grid point (1100, 111) in the 18m grid. The extent of the oyster concession is indicated by the black dots in the diagram.

5.3.1 Cases considered

Three separate periods, each with winter and summer conditions, were considered as part of the study. These six cases are:

Case No.	Timeline	Conditions
1	Period One *(up to 1st July 2000 – before Midleton WWTP was built)*	Summer
2	"	Winter
3	Period Two *(1st July 2000 – 24th July 2003, after Midleton WWTP, before CG WWTP)*	Summer
4	"	Winter
5	Period Three *(24th July 2003 onwards – after CG WWTP was constructed)*	Summer
6	"	Winter

Table 5-2 List of cases considered for study

The five main graphs that are presented for each of the six cases are:

1. Time-series of variations in concentration for all the outfalls over the simulation period. This provides a general overview of the relative contributions to the contamination.

2. Moving averages[77] of the time-series presented in the first graph.
3. The moving averages expressed as percentages. The principle of superposition allows the concentrations of all the individual outfalls to be added together to determine the total concentration. This allows the relative contribution of each outfall to be determined as a percentage by dividing the total concentration by the individual concentration and multiplying by 100. These plots present the relative contributions of the outfalls over the entire simulation period.
4. The maximum contributions plotted as a pie chart. Each outfall has a maximum value over the simulation period. The diagram presents the maximum values for each of the outfalls as a percentage of the total[78]. The different times at which the maximum values occur are not considered.
5. The average concentrations plotted a pie chart. The average value of the concentration over the entire simulation period for each outfall is plotted on a pie diagram. This graph presents the relative contributions for each of the six periods in terms of the average contamination.

The first case considered (Period 1, Summer conditions) contains a large number of plots. These have been included to highlight a number of important features which are common to all six cases.

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[77] Every point in this time-series is the average concentration over a 12.25 hour period, a full tidal cycle. The averaging filters out the high frequency components due to the oscillatory motion of the water over the 37 day period. The twice daily maxima associated with slack water are eliminated and the effect of secondary factors such as the spring/neap cycle, wind speed and direction can be examined.

[78] Superposition does not apply to maxima, since maxima occur at different times for each individual discharge. Consequently, dividing by the sum of the maxima simply normalises, or measures, each individual maximum on a common scale, the scale of the sum of maxima.

5.4 Period One

5.4.1 CASE 1 - Summer conditions

The variation in the number of viral particles per cubic metre at the centre of the oyster farm for the untreated discharges from Cork City (CC_S&C) is presented in Fig. 5.13. This viral contamination of the model oyster farm is the result of *Norovirus* being advected from the CC_S&C outfall into the North Channel through the Belvelly Channel and around Cobh Island. Initially the transport through Belvelly is the main route of contamination but after approximately two weeks the viruses will make their way around Cobh Island in significant numbers and greatly add to the contamination coming through Belvelly.

The main forcing functions of the model are presented in Fig. 5.14. The influence of the tidal signal (red line in Fig. 5.14) on the contamination of the oyster farm is clearly evident in Fig. 5.13.

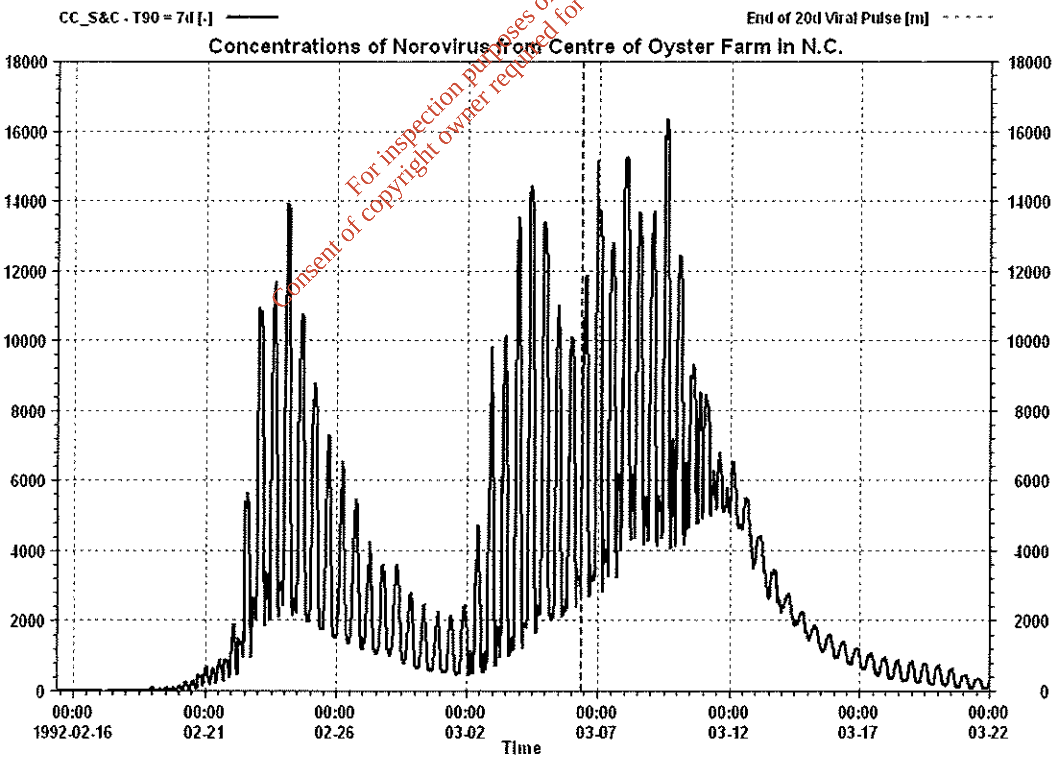

Fig. 5.13 CC_S&C time-series from the centre of oyster farm-Summer conditions. The vertical green line marks the end of the 20 day viral pulse

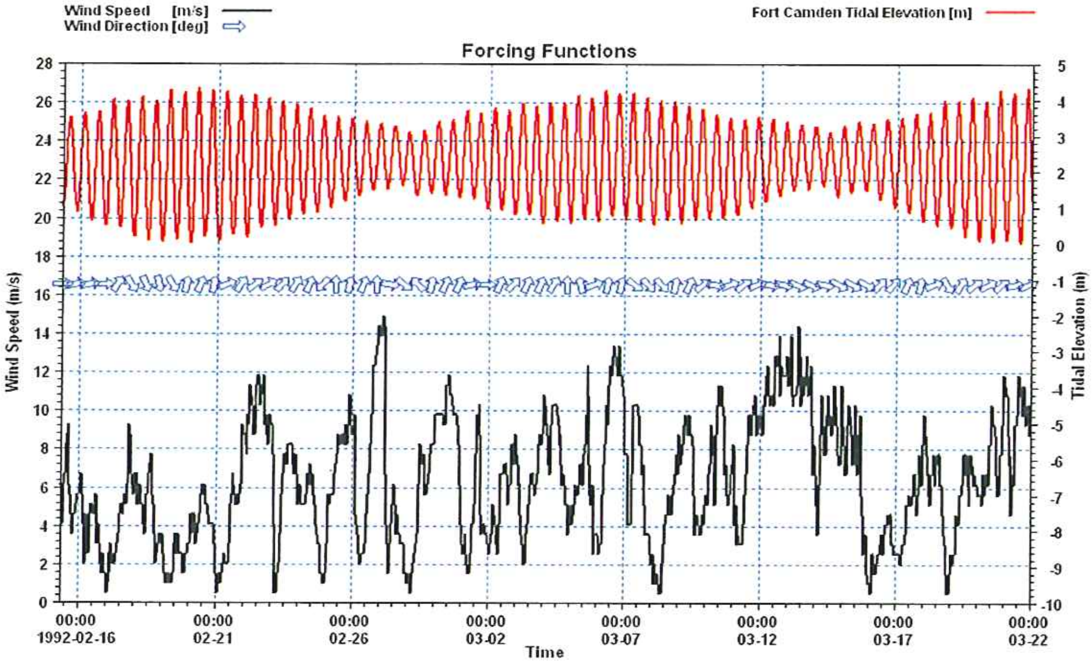

Fig. 5.14 Main forcing functions – tide, wind speed and direction

We can see from the figure that the concentrations oscillate between two maximum and two minimum values each day caused by the continual flooding and ebbing of the tide. On the flood tide viral particles from CC_S&C are advected into the Belvelly Channel area of Cork Harbour and pass through the Belvelly Bridge. As the flow to the east of Belvelly divides with the turning of the tide, some of the viral particles travel west, back through the Belvelly Channel, while some travel east into the North Channel. The number of viral particles that travel east is influenced by the spring to neap tidal variation and the magnitude and direction of the wind. A greater number of viral particles will travel east under spring tides as the higher velocities and water levels ensure a greater number are advected through the Belvelly Channel.

The influence which the wind exerts on the number of viruses entering the North Channel through the Belvelly Channel is illustrated in the following set of figures. Fig. 5.15 plots the concentration of CC_S&C with the concentration from the comminuted sewage from Rathcoursey (RC_S&C).

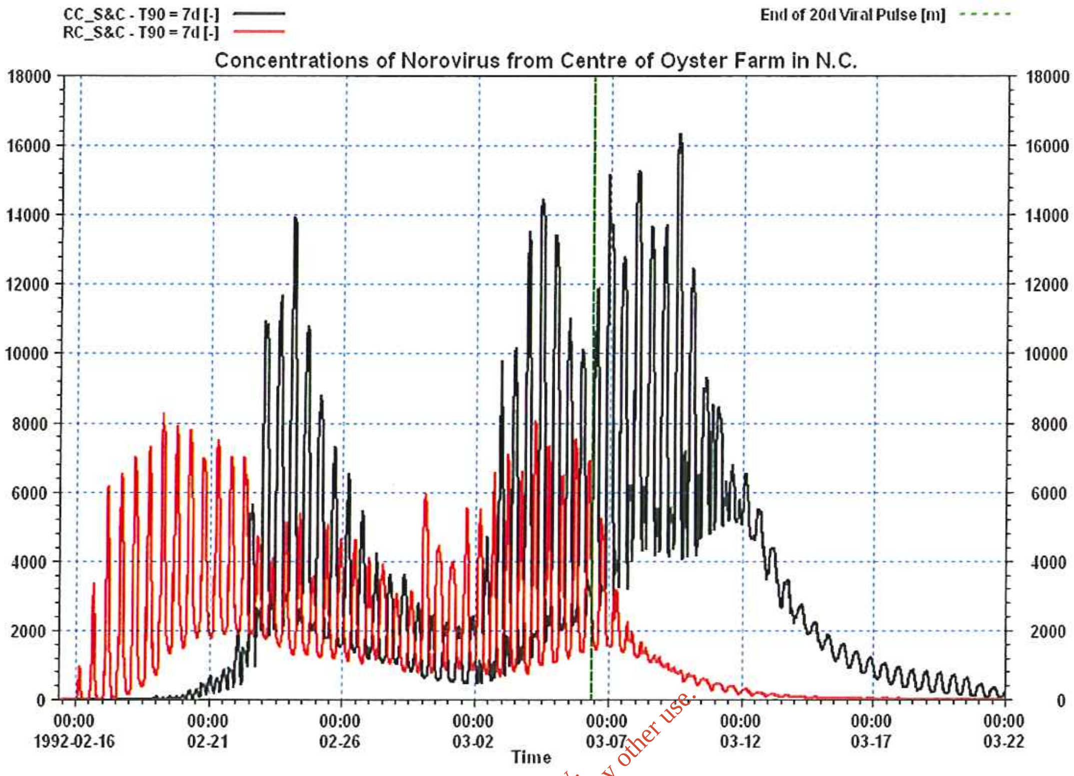

Fig. 5.15 CC_S&C and RC_S&C from centre of oyster farm. Summer conditions.

The period from the 21st to the 23rd of February is presented in Fig. 5.16 (the concentrations) and in Fig. 5.17 (the forcing functions). We can see from Fig. 5.16 that the number of viral particles from CC_S&C increases significantly over a very short period. We can also see a noticeable decrease in the number of viral particles from RC_S&C. These significant jumps in concentration can be attributed to the influence of the wind on the movement of viruses in the Harbour.

If we examine Fig. 5.17 closely[79] we can see that a wind with a speed in excess of 8m/s is blowing from the south-west in the period leading up to the shift in concentrations. This shear stress on the water surface drives a greater volume of water in a north-easterly direction. This in turn will lead to an increase in the number of viral particles being carried in the same direction.

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[79] The wind speed is plotted on the left hand axis with the black line. The direction in which the wind is blowing is given by the blue arrows.

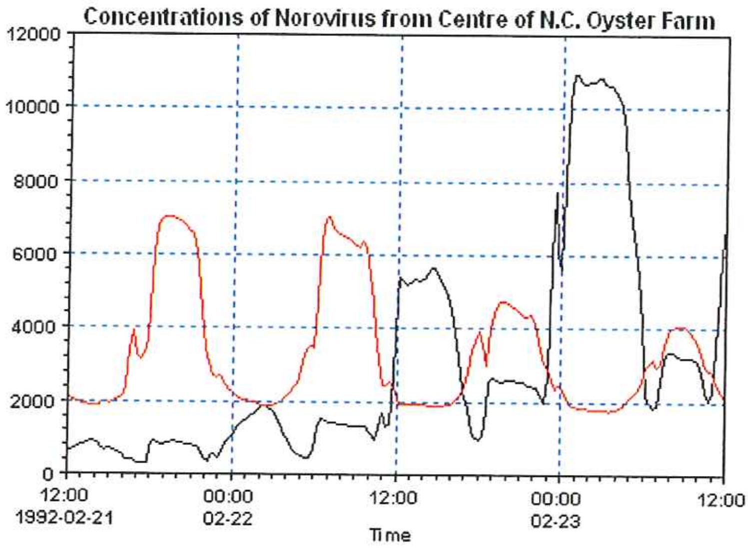

Fig. 5.16 Variation in CC_S&C (black) and RC_S&C (red). Summer conditions.

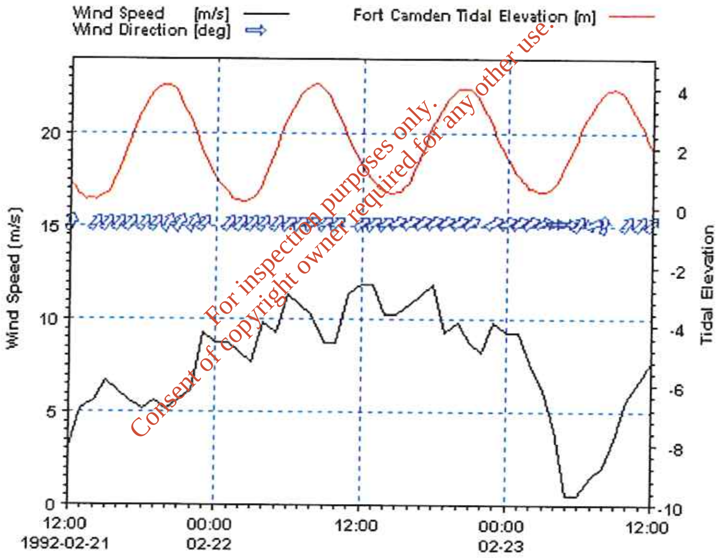

Fig. 5.17 Forcing Functions for period in the figure above

As CC_S&C is on the Western side of Belvelly a greater number of viruses will travel through the channel when wind with this speed and direction is blowing. As RC_S&C is on the Eastern side a reduction in the number of viruses contaminating the model oyster farm will occur as the wind from this direction forces more viruses up the Owenacurra estuary. A wind from the opposite direction would have the reverse effect.

There is a noticeable decline in the contribution of CC_S&C after this period as the viruses which have made their way into the North Channel are decaying relatively quickly in the summer conditions. Strong winds have ceased to blow from a westerly direction and so there is no significant pulse of viruses through Belvelly. However *Norovirus* continue to be advected through the Belvelly channel in this period but to a lesser extent. This is discussed in greater detail in section 5.4.3.

For the winter conditions described in the next section[80] the viruses decay much more slowly (T90 = 30d) such that the influence of the wind is felt for a longer period afterwards. The 1992 wind rose for Cork Airport is presented in Fig. 5.18.

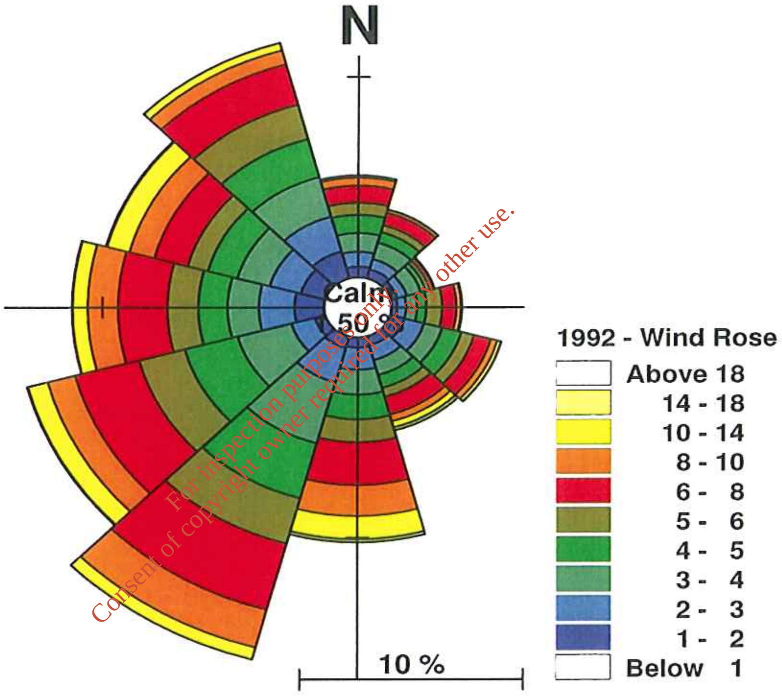

Fig. 5.18 Wind Rose for all of 1992 – Cork Airport; units are m/s

We can see from the figure that winds from the West and South Westerly direction are the most prevalent. The wind speeds, from this direction, frequently exceed 6m/s.

There is a noticeable increase in the concentrations from RC_S&C at the start of the 29th of February. If we examine the forcing functions for this period we can see another example of the significant influence which the wind exerts on the

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[80] The same wind forcing was used for both the summer and winter conditions

movement of viruses in the model harbour. A 10m/s wind is blowing from the south which carries a greater volume of water up the East and West Passages. This increases the contribution of RC_S&C but has a negligible effect on CC_S&C. Later in the simulation (2nd of March) however we can see that when a wind with a similar magnitude blows from the same direction there is a noticeable increase in the concentrations from CC_S&C. By this stage viruses from CC_S&C are present in the outer harbour in significant numbers just as they are for RC_S&C. A large number of them are advected up the East passage and contribute to the contamination of the model oyster farm just as for RC_S&C. By this stage the model oyster farm is being contaminated from both directions. The transport of viruses around Cobh Island is discussed in greater detail in section 5.4.3.

The following series of figures compare the contribution of CC_S&C with the contribution of each of the other outfalls. We can see from the figures that CC_S&C is contributing far more viral particles than any of these outfalls.

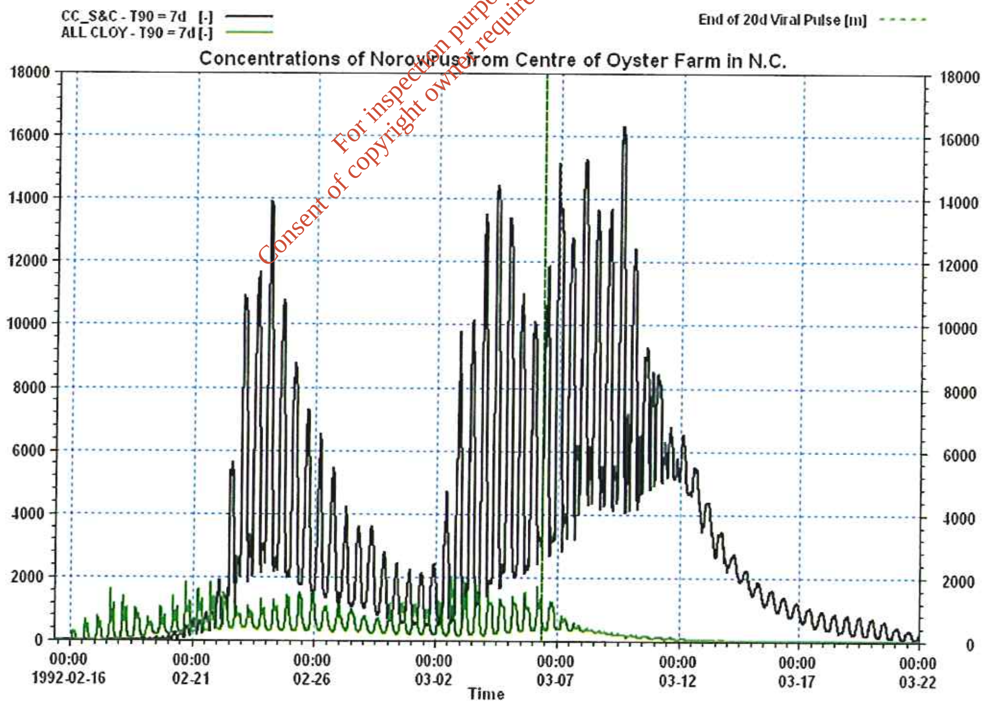

Fig. 5.19 CC_S&C and ALL_CLOY. Summer conditions.

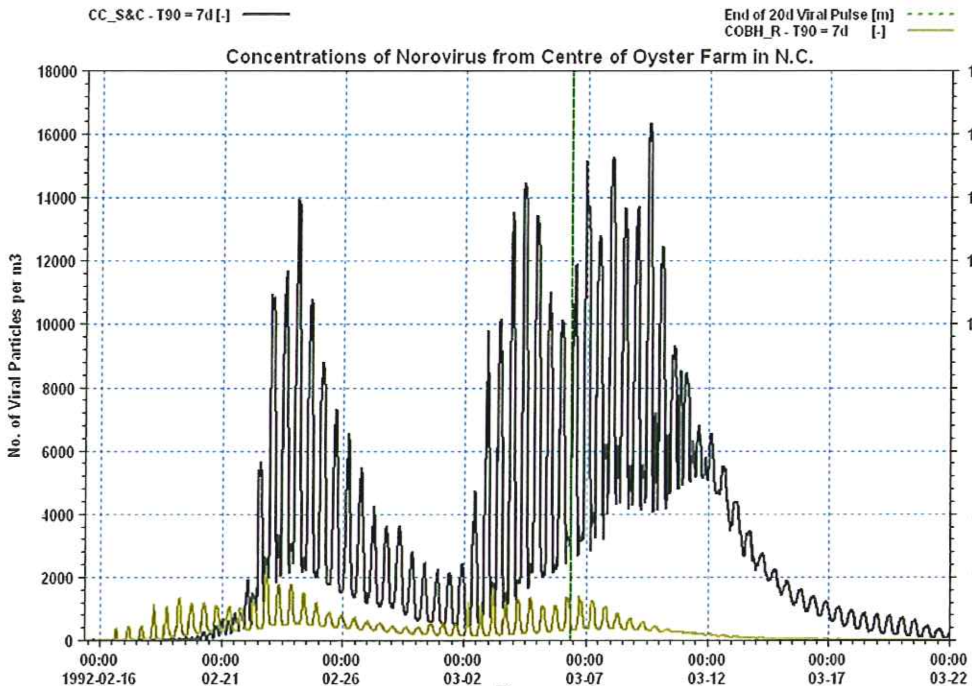

Fig. 5.20 CC_S&C and COBH_R. Summer conditions. NC-north channel.

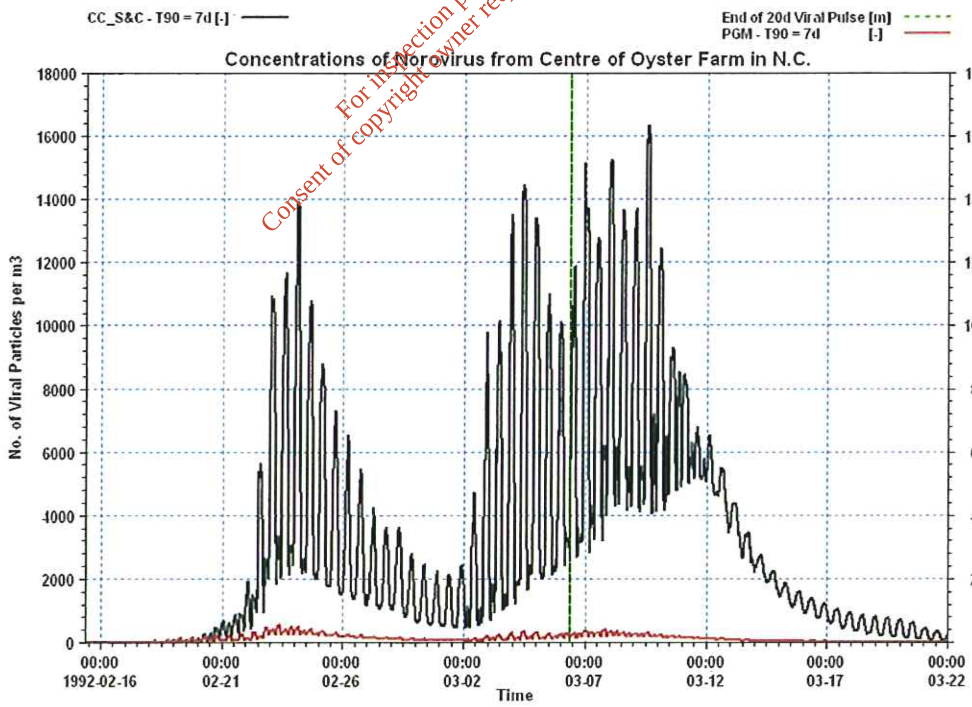

Fig. 5.21 CC_S&C and PGM. Summer conditions.

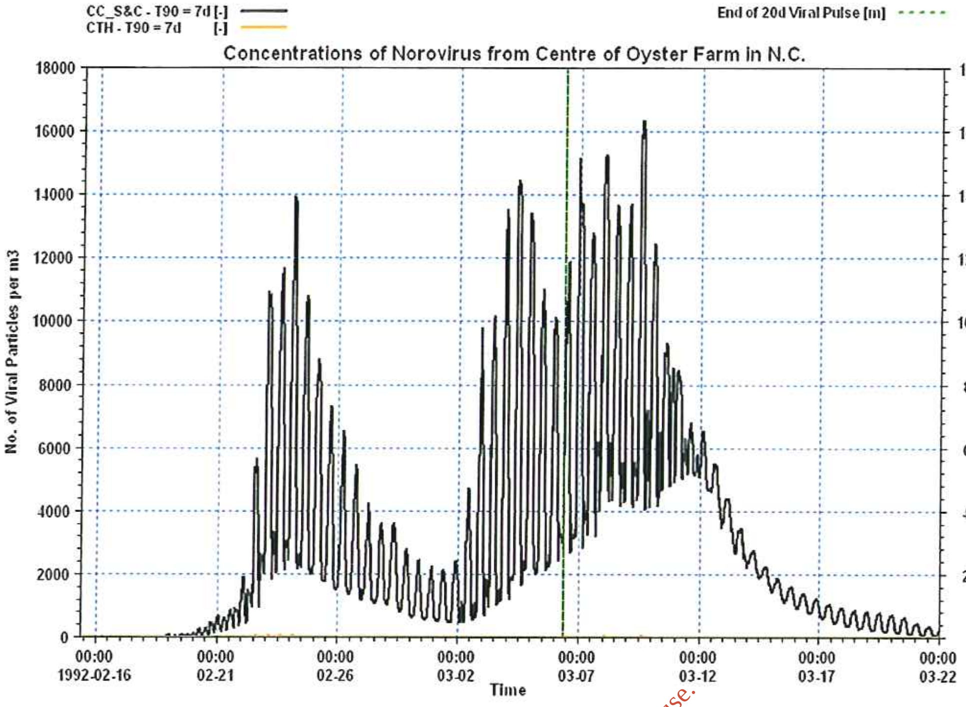

Fig. 5.22 CC_S&C and CTH. Summer conditions.

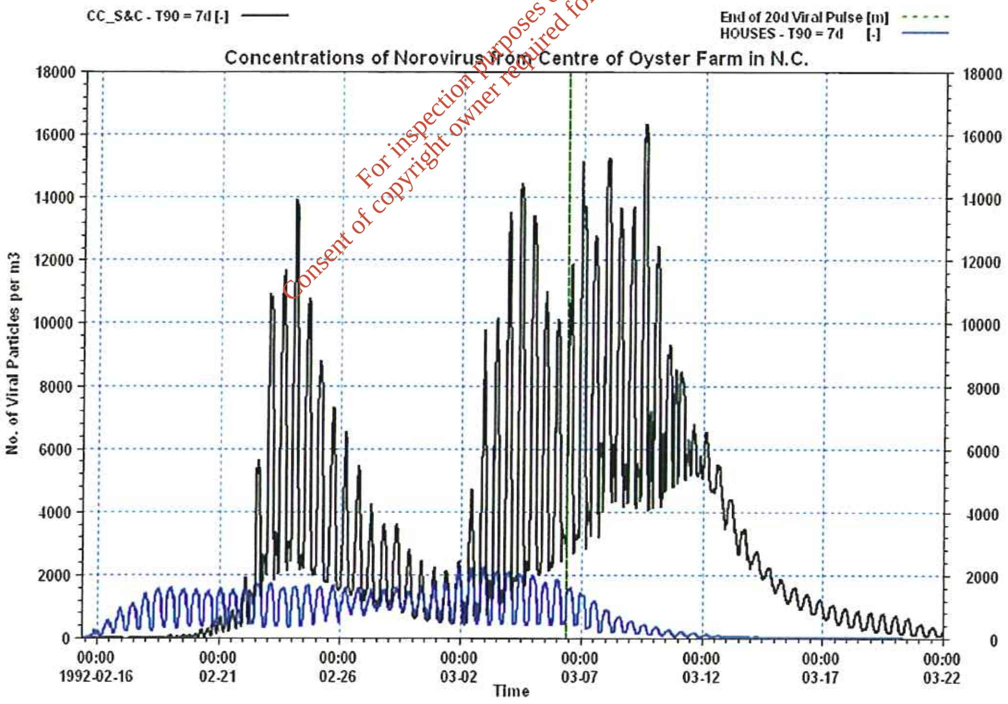

Fig. 5.23 CC_S&C and HOUSES. Summer conditions.

The concentrations from each of the outfalls are presented in Fig. 5.24. The contributions of CC_S&C and RC_S&C are easy to distinguish in the plot, but the rest are slightly unclear as they are all plotting on top of each other.

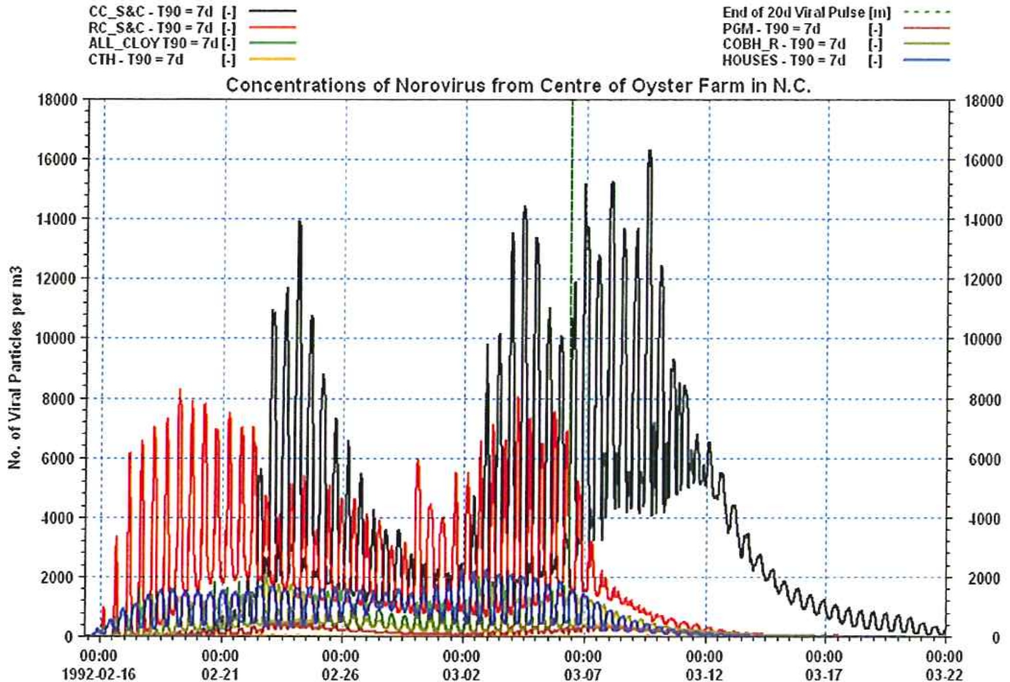

Fig. 5.24 All Outfalls at centre of Oyster Farm. Summer conditions.

The moving average timeseries of CC_S&C is presented in Fig. 5.25. We can see how the maximum and minimum values associated with the tide are filtered out. The moving average for all of the outfalls is shown in Fig. 5.26.

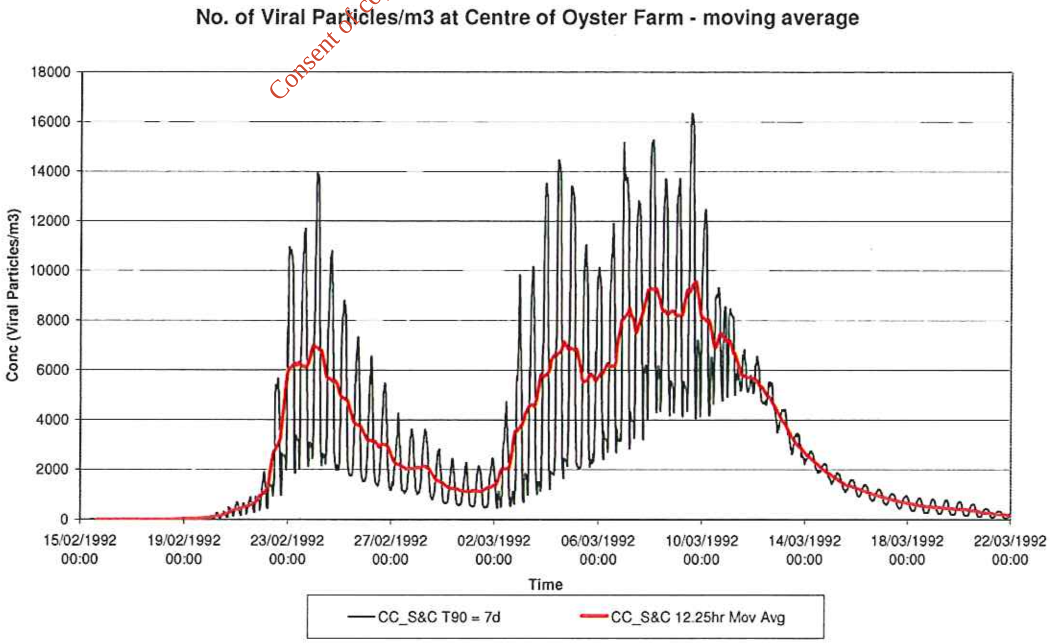

Fig. 5.25 CC_S&C – moving average of concentration. Summer conditions.

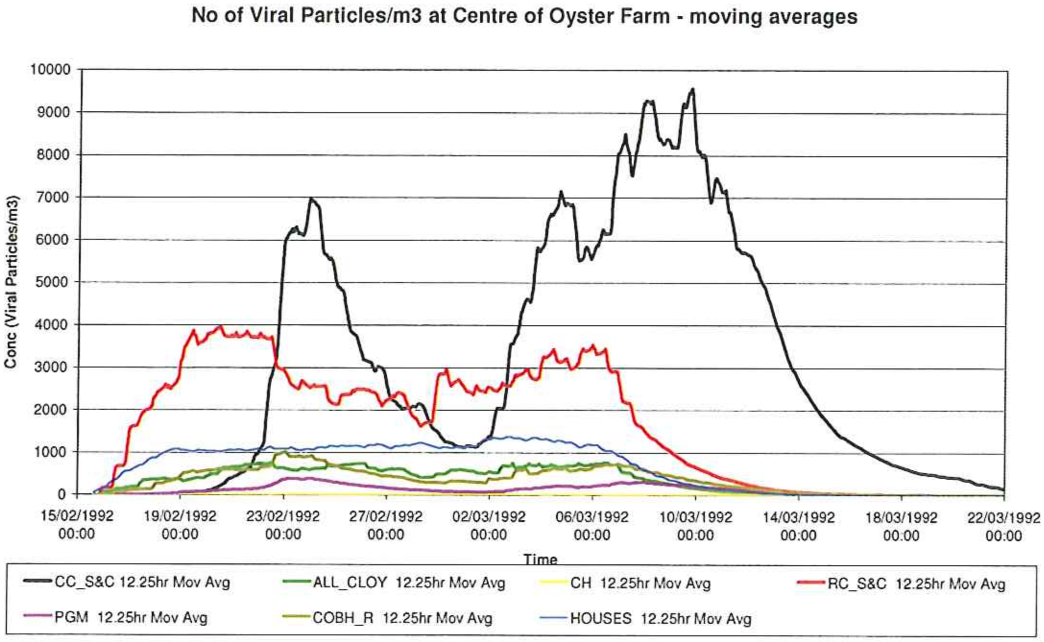

Fig. 5.26 Moving average for each outfall: Summer conditions.

When we look at Fig. 5.26 we can see that the averaged concentrations for CC_S&C resemble two large, but separate, individual peaks in concentration. As discussed the first of these is attributable to the wind blowing from the west on the 22nd of February. The second is also influenced by the wind but is considerably larger owing to the transport of *Norovirus* around Cobh Island. By the time of the second peak, *Norovirus* are being carried around Cobh Island and contaminating the model oyster farm by this route. This is more pronounced for winter conditions (described in the next section) when the *Norovirus* have a slower decay rate.

The relative contributions for the entire simulation period are presented in Fig. 5.27. We can see from the plot that at the very start of the simulation the houses are contributing 100% of the contamination at that particular moment. This is to be expected as they are the nearest source of *Norovirus* to the oyster farm. The concentrations at the start are extremely small so the houses are contributing 100% of a very small amount.

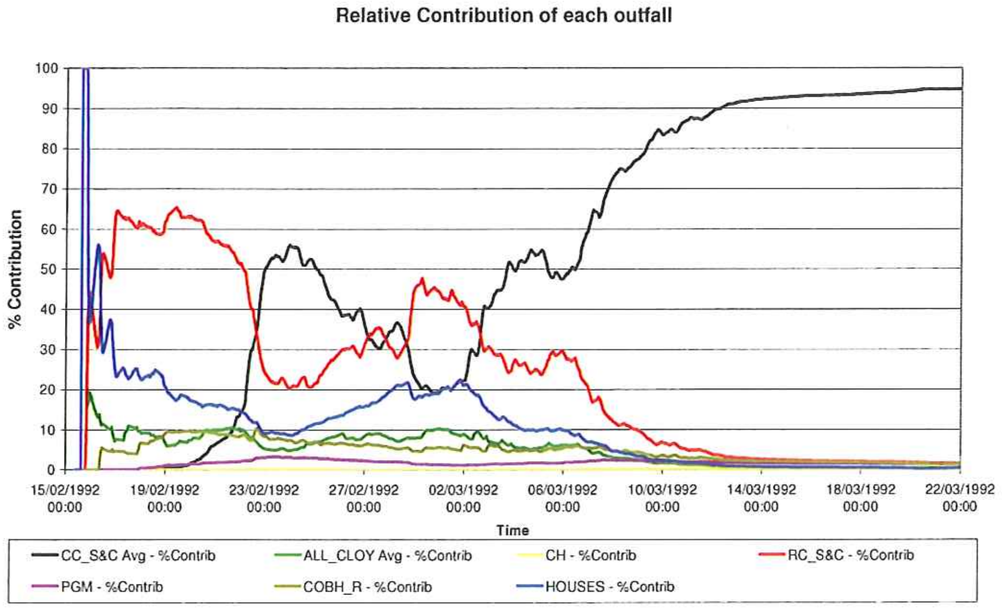

Fig. 5.27 Relative Contribution of each outfall for the entire simulation period. The y-axis is given as a percentage. At any moment the sum of the contributions of the individual outfalls equals 100%. Summer conditions.

It is therefore quite useful to plot the moving average of the total concentration on the secondary axis of this graph (pink line in Fig. 5.28). This allows us to examine the relative contributions when the total concentration at the oyster farm peaks. We can see a direct correlation between the contribution of CC_S&C and the total concentration in the plot. We can also see from the figure that after the westerly wind on the 22nd of February (described above), the relative contribution of CC_S&C increases to over 50% while RC_S&C decreases from 60% to 20%.

At any particular point along the time axis we can take a cross section and examine the relative contributions using a pie diagram. Fig. 5.29 presents a pie chart for midnight on the 2nd of March.

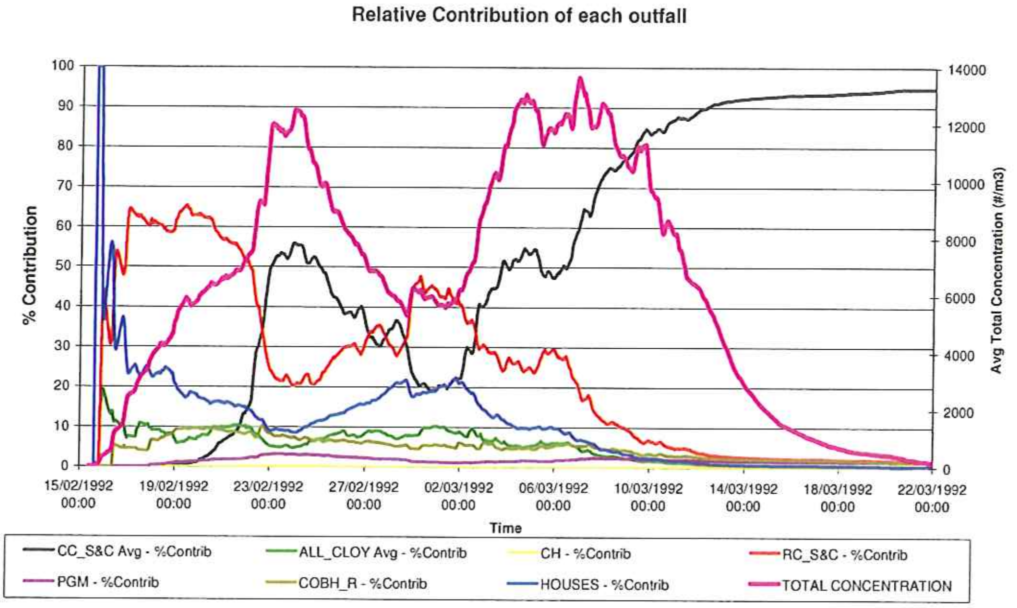

Fig. 5.28 Relative Contribution of each outfall for entire simulation period with the total moving average concentration superimposed. Summer conditions.

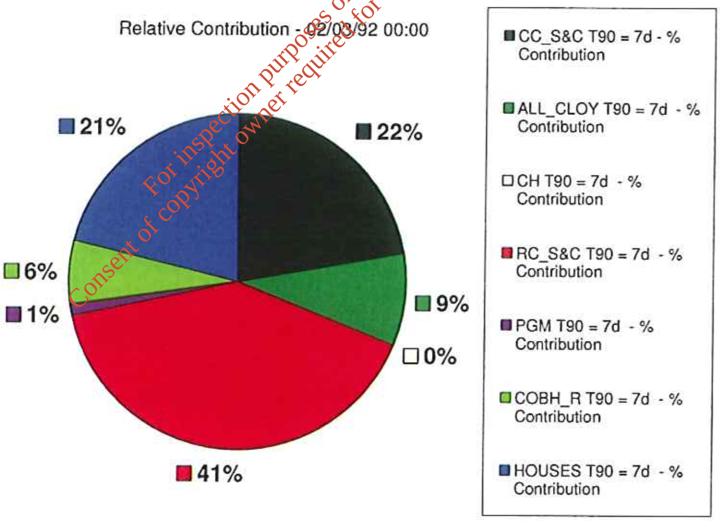

Fig. 5.29 Relative Contribution at Midnight on the 2nd of March. Summer conditions.

The peaks in concentration for each outfall (i.e. the maximum values attained over the course of the simulation) may be extracted and plotted on a pie chart (Fig. 5.30). The average concentration over the whole period may also be extracted and plotted in this way (Fig. 5.31)

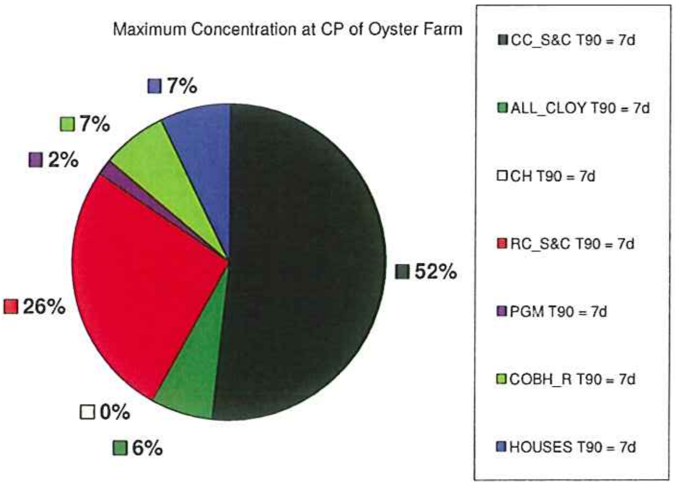

Fig. 5.30 Maximum concentrations – relative contributions. Summer conditions.

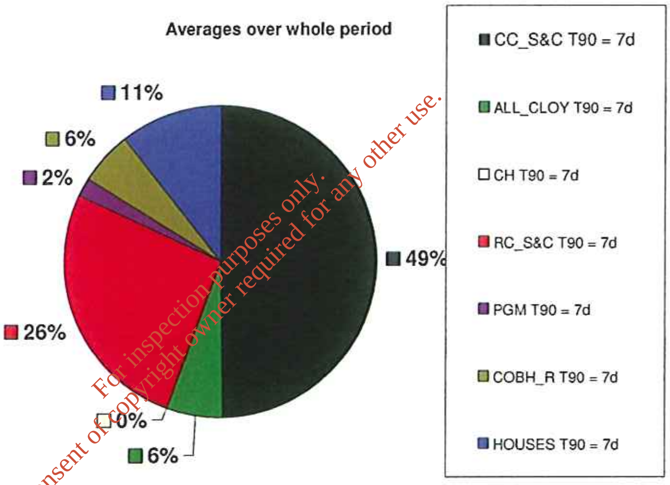

Fig. 5.31 Averages over entire period. Summer conditions.

The conclusion from both of the pie charts is the same. CC_S&C and RC_S&C are the biggest contributors to contamination of the oyster farm, and of the two, CC_S&C is contributing more.

5.4.2 CASE 2 - Winter conditions

The results of the second case are now presented.

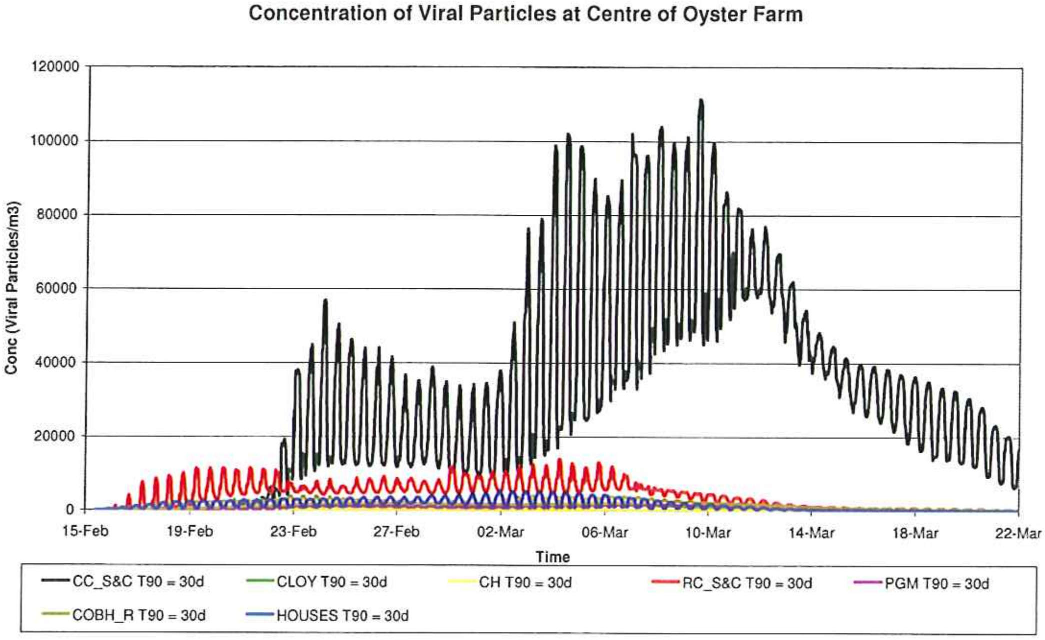

Fig. 5.32 CASE 2 –Timeseries of concentration for each outfall at oyster farm. Winter conditions.

Fig. 5.32 highlights the timeseries of extracted concentrations at the centre of the model oyster farm. We can see that the number of viral particles for this case is much greater. This is due to the much slower decay rate of the viruses in winter conditions. In the previous case the viruses had a T90 = 7 days whereas here it is 30 days. Once the viruses are released into the water they survive for a much longer period of time. Therefore the distance of each outfall to the oyster farm becomes much less of an issue as they survive for much longer periods and are advected throughout the harbour. The transport of *Norovirus* around Cobh Island also becomes more significant with the slower decay rate.

The relative contribution of CC_S&C is much greater in winter than in summer. This point is well illustrated if we plot the total moving averaged concentration for the summer and winter cases for this period (Fig. 5.33).

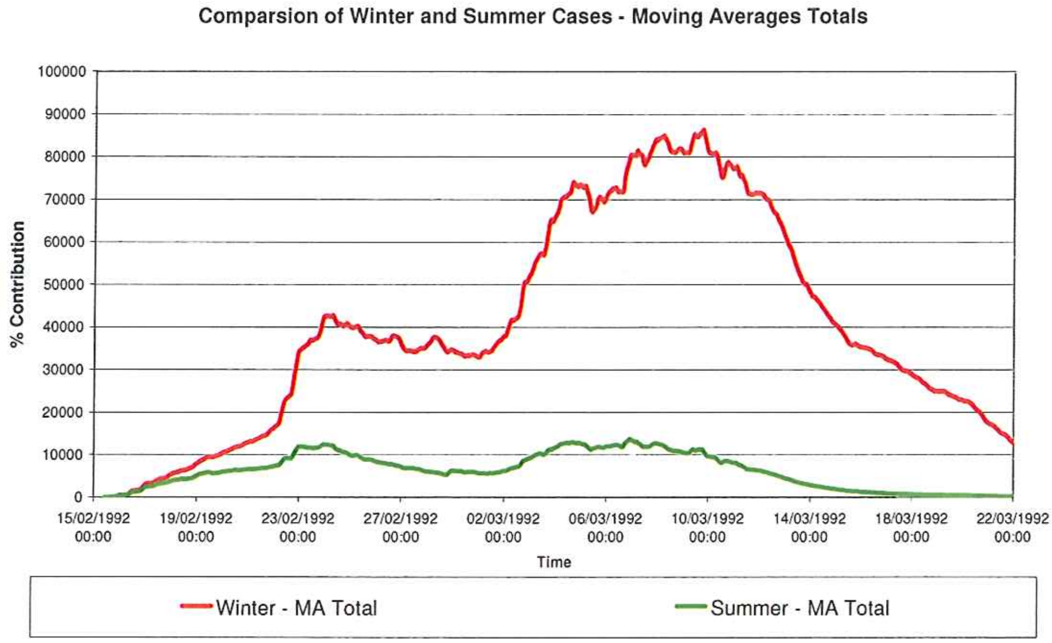

Fig. 5.33 Moving Averaged Totals – Winter and Summer Period One

We can see from Fig. 5.33 that the maximum averaged total for winter conditions is almost nine times greater than the summer case. If we look at the averaged concentrations for CC_S&C from summer and winter (Fig. 5.34) we can see that the winter case is over seven times greater than the summer case. But if we examine RC_S&C (Fig. 5.35) we can see that the winter case is only twice that of the summer case[81]. These graphs illustrate quite well the differences between winter and summer conditions. The contribution of RC_S&C in winter is double the contribution in summer. The contribution of CC_S&C is almost eight times larger than the contribution in summer. From this we can conclude that there is a strong correlation between the greater total number of viruses at the model oyster farm in winter and the greater number of viruses being contributed from CC_S&C in winter.

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[81] Please note the different scaling on the y-axis for CC_S&C and RC_S&C

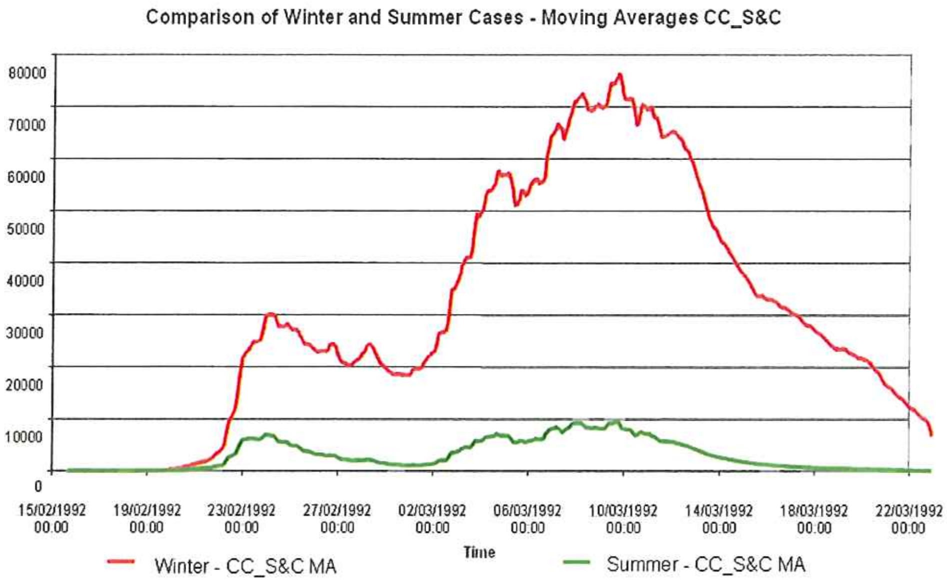


Fig. 5.34 CC_S&C Moving averages – Winter and Summer Period One

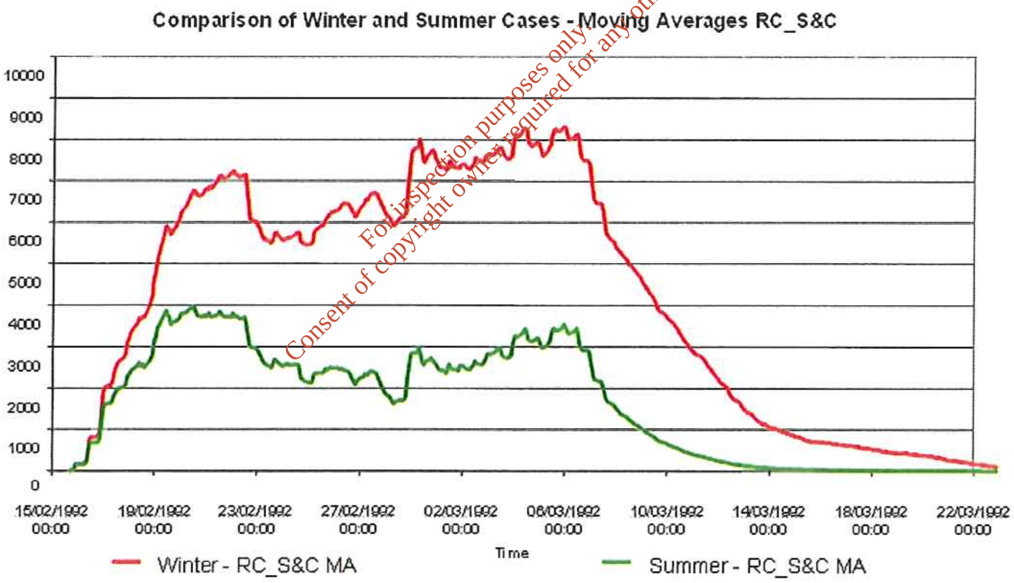


Fig. 5.35 RC_S&C Moving averages – Winter and Summer Period One

The moving averages for the second case considered as part of the study are presented in Fig. 5.36. We can see from the figure that CC_S&C is contributing the most to the contamination of the model oyster farm from the 22nd of February onwards. The relative contributions are plotted in Fig. 5.37. Please note that the pink line is the total averaged concentration. It is plotted on the second y-axis on the right-hand-side.

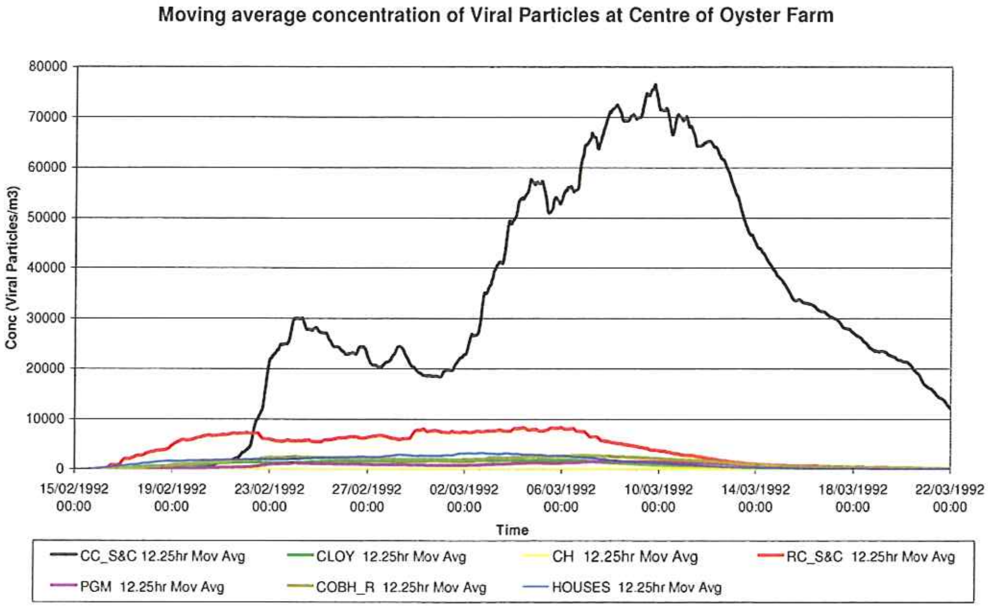


Fig. 5.36 CASE 2 – Moving averages of concentration

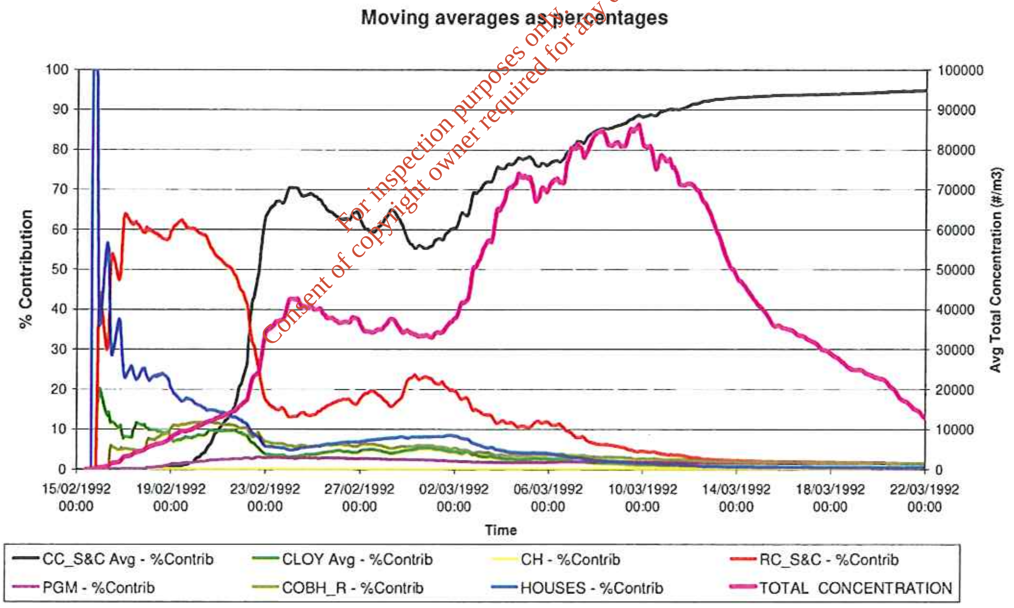


Fig. 5.37 CASE 2 – The relative contributions with the moving average total

As with the summer conditions we can see that the averaged concentrations for CC_S&C consist of two separate peaks in concentration. The second peak in winter is however, relatively speaking, much larger than the equivalent peak for summer conditions. This is due to the greater influence exerted by the transport around Cobh Island in winter conditions. The slower decay in winter ensures that a very large number of *Norovirus* will survive for longer periods and be carried around Cobh Island into the North Channel.

We can see from this figure the strong correlation between the increase in the total averaged number of viral particles in the model oyster farm and the relative contribution of CC_S&C. Between the 21st and the 23rd the relative contribution of CC_S&C increases from 10% to 70%. This particular increase is due to the westerly wind of over 10m/s that blows from the South-West as previously described. As the viruses decay at a much slower rate in winter than in summer the influence of the Westerly and South Westerly winds is felt for a much longer period after the wind has ceased to blow in this direction. Once the viruses are advected into the North Channel in winter their slow decay ensures that they survive for a much longer period. Because they are not flushed out by the tide they contribute a highly significant percentage of the total contamination of the model oyster farm.

From the 2nd of March onwards there is a noticeable increase on the number of *Norovirus* being contributed from CC_S&C. This is due to the transport of *Norovirus* around Cobh Island which is discussed in section 5.4.3.

The pie chart highlighting the maximum contributions is presented in Fig. 5.38. The averages are shown in Fig. 5.38. We can see from both figures that CC_S&C is the dominant contributor of *Norovirus* to the contamination of the oyster farm for the second case considered as part of this objective study.

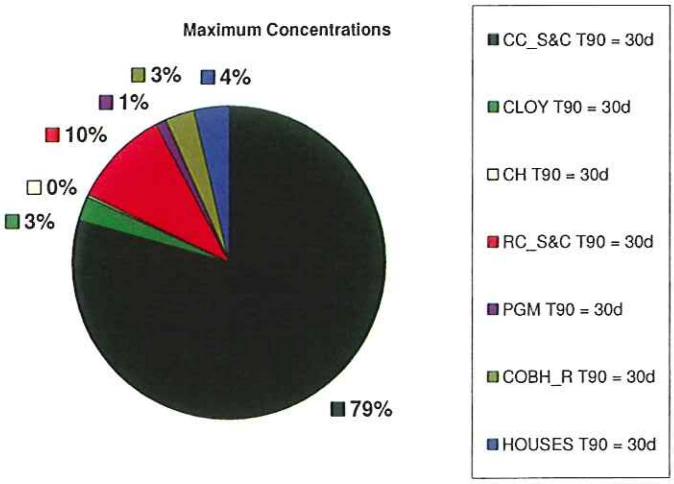


Fig. 5.38 CASE 2 – Maximum Concentrations – relative contributions

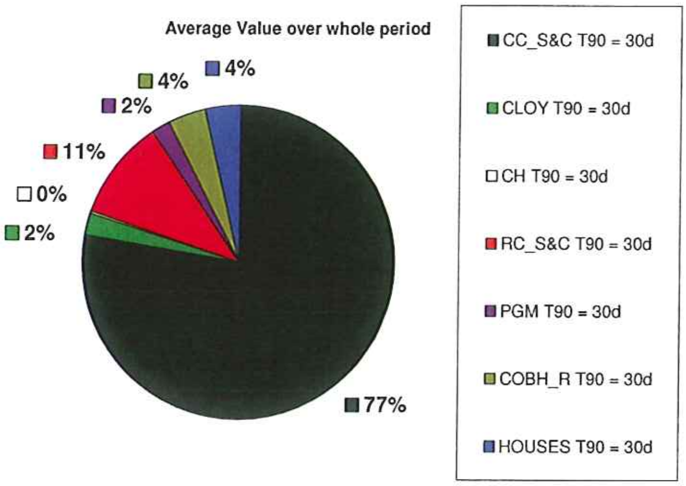


Fig. 5.39 CASE 2 – Averages over entire period

5.4.3 Transport of Viruses around Cobh Island

There are two routes by which *Norovirus* released from Cork City in Period 1 can make their way into the North Channel:

1. Through Belvelly Bridge
2. Around Cobh Island

The distance from the Kennedy Quay outfall to the oyster farm is approximately 17km through the Belvelly Channel. The equivalent distance around Cobh Island is approximately 28km.

In order to quantify the transport of Norovirus around Cobh Island it is useful to omit the influence of the wind. This allows a clearer interpretation of the results.

Fig. 5.41 presents three moving averaged timeseries of CC_S&C concentration for three separate points located around Cobh Island (Fig. 5.41). The influence of the wind has been omitted from the model run from which the timeseries are extracted. We can see from the figure that there is a dramatic increase in the averaged *Norovirus* concentration at Marloag Point at approximately 22:30 on the 2nd of March. This is due to the transport of *Norovirus* around Cobh Island. It takes approximately 16.5 days, with no wind blowing, for a significant number of *Norovirus* to be advected around Cobh Island in our model. There is a corresponding increase for the other two points with a time lag of approximately 24 hours.

It should be noted that *Norovirus* are carried into the North Channel in our model, via the outer harbour, before the 2nd of March. Within four days of the start of the simulation *Norovirus* from CC_S&C enter the North Channel via the outer harbour. But his contribution is much less than what is being contributed through the Belvelly Channel. However after 16.5 days (with no wind blowing) the contribution from the outer harbour is dominant and they enter the North Channel in significant numbers. The reader is referred to the animations included on the DVD accompanying this report.

When wind is included in the model the time it takes for *Norovirus* to be carried around Cobh Island may be increased or decreased depending on which way the wind is blowing.

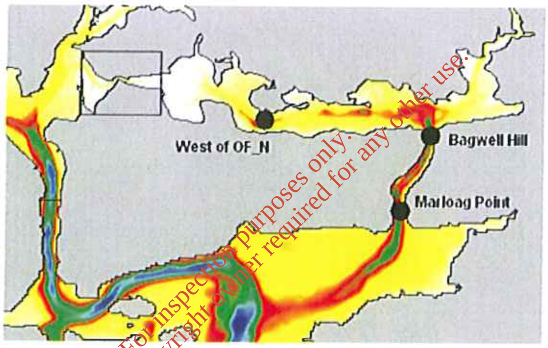


Fig. 5.40 Location of three points plotted in Fig. 5.41

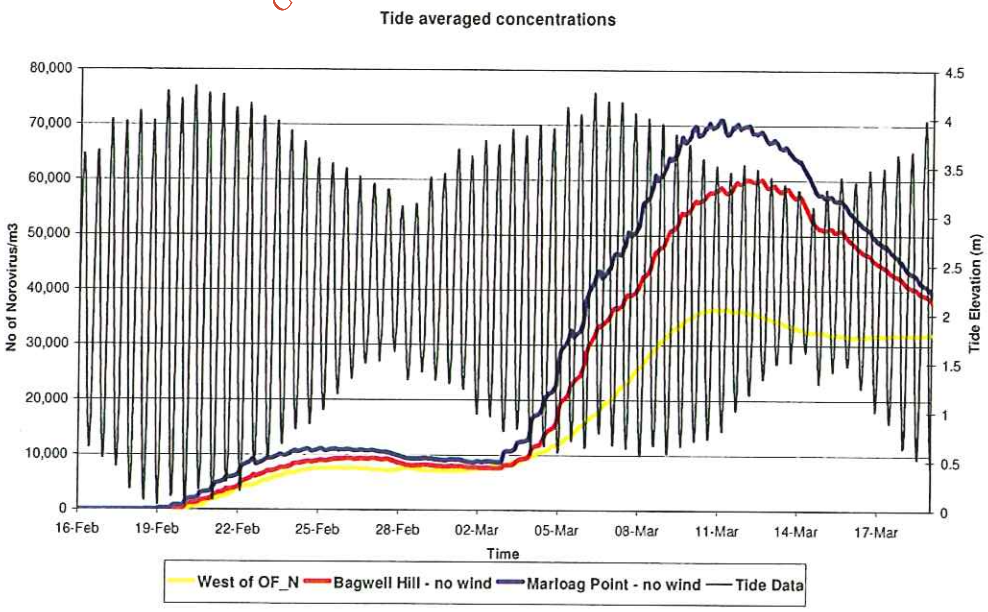


Fig. 5.41 Tide averaged concentrations for 3 points around Cobh Island

5.4.4 Transport of *Norovirus* through the Belvelly Channel

We saw in the previous section that when a reasonably strong wind from the west blows there is a significant increase in the number of *Norovirus* being carried through the Belvelly Channel. It should be noted however that even with no wind *Norovirus* from CC_S&C, in our model, are still transported through the Belvelly Channel. We can see this from the following series of plots.

The first plot (Fig. 5.43) presents the timeseries of *Norovirus* concentration for the two points shown in Fig. 5.42. These timeseries are taken from the model run in which the influence of the wind has been omitted. The second plot (Fig. 5.44) presents the equivalent timeseries for the case when the wind is acting. The left hand axis is the same in both plots.

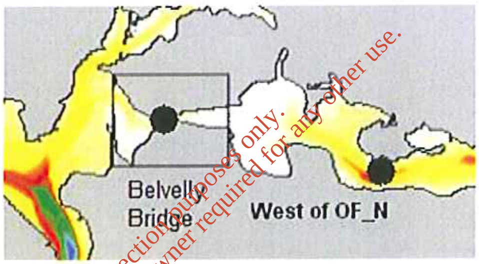


Fig. 5.42 Location of extracted points

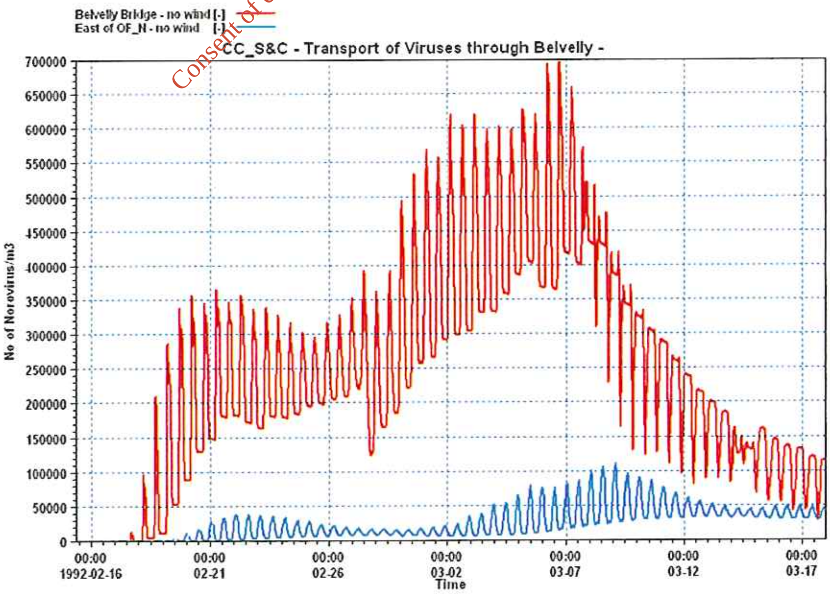


Fig. 5.43 Timeseries of concentration at Belvelly Bridge

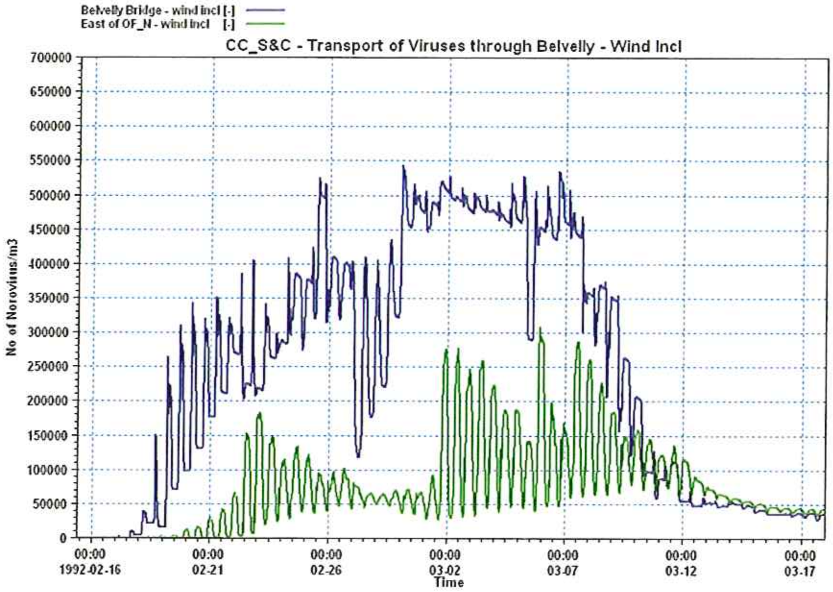


Fig. 5.44 Timeseries of concentration East of Belvelly Bridge

We can see from the plots that with no wind acting *Norovirus* are still being transported through the Belvelly Channel on the spring tides. The numbers are greatly reduced during neap tides. We can also see that on the 22nd of February when the wind is acting, there is up to four times the amount of *Norovirus* being carried through the Belvelly Channel. We can also see that on the 2nd of March when the wind is acting there is over 10 times the concentration of *Norovirus* to the west of the model oyster farm.

5.5 Period Two

The summer and winter conditions of Period two are now considered. The difference between this and the last period is that now all of the waste from Midleton is being treated at the Waste Water Treatment Plant in Midleton. The location of the outfall is the same as in period one. The pulsing of the treated waste is also the same. We have assumed that no storm water overflows from Bailick 1 and Bailick 2 occur during summer conditions. They are however included in the winter conditions.

We have assumed that there is a 95% removal efficiency of *Norovirus* in Midleton (and Carrigrennan) WWTP. This is discussed further in Appendix D.

5.5.1 CASE 3 - Summer Conditions

The time-series of concentration of viral particles from the centre of the concession for this case are presented in Fig. 5.45. The untreated waste from Rathcoursey has now been replaced by the treated waste. As we have assumed a 95% reduction in the number of *Norovirus* after treatment there is a corresponding 95% reduction in the number of viral particles from Rathcoursey.

The untreated waste from Cork City is now the main contributor of viral particles to the oyster farm. The moving averages are plotted in Fig. 5.46.

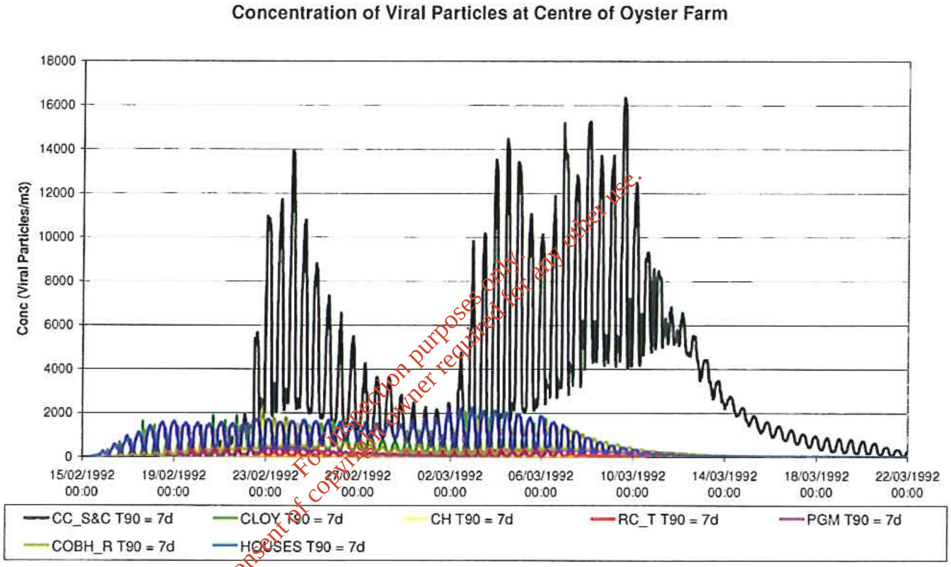


Fig. 5.45 CASE 3 - Timeseries of concentration for each outfall at oyster farm. Period 2 summer conditions.

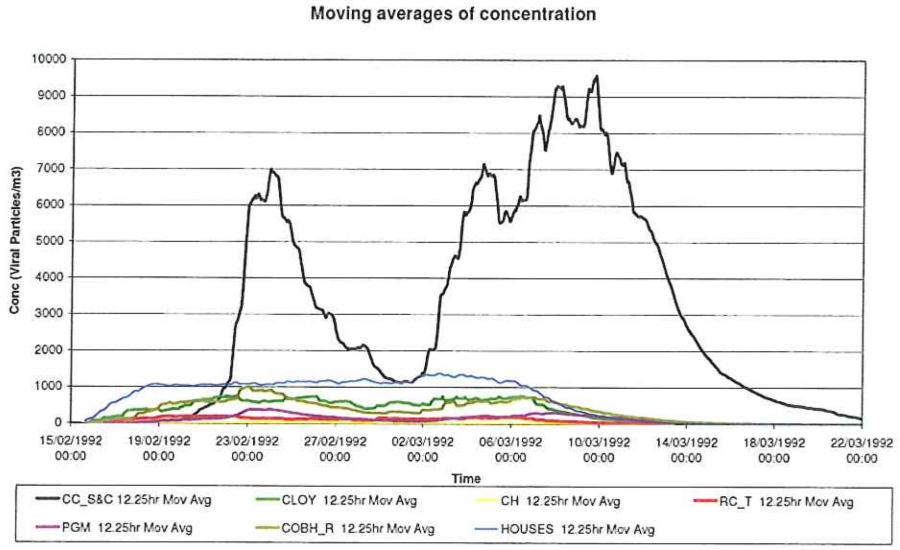


Fig. 5.46 CASE 3 – Moving averages of concentration. Period 2 summer conditions

We can see from Fig. 5.46 that CC_S&C that the Houses around the model harbour are now the second biggest contributor of viral particles to the model oyster farm. The amount they contribute however is significantly less than that of CC_S&C with the exception of a period around the 2nd of March. The relative contributions are plotted in Fig. 5.47 and Fig. 5.48(with the total concentrations added)

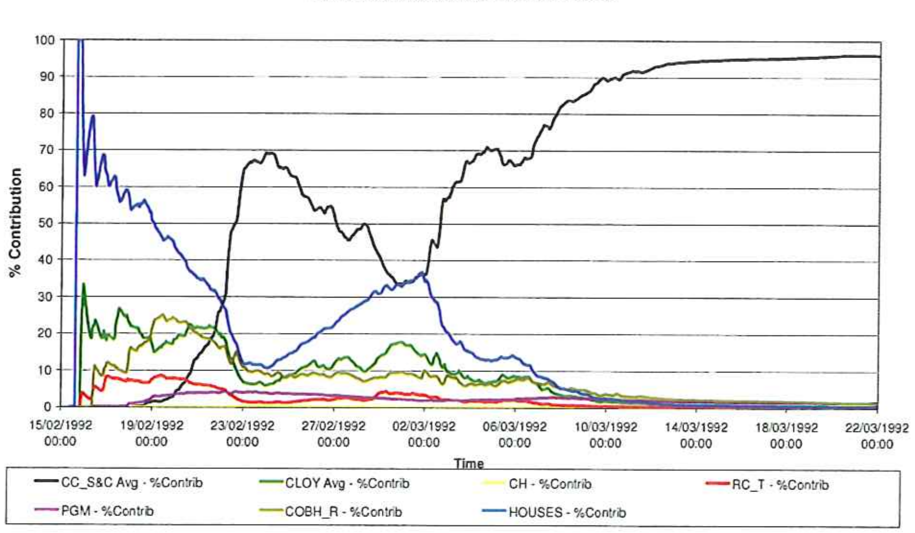


Fig. 5.47 CASE 3 – The relative contributions. Period 2 summer conditions.

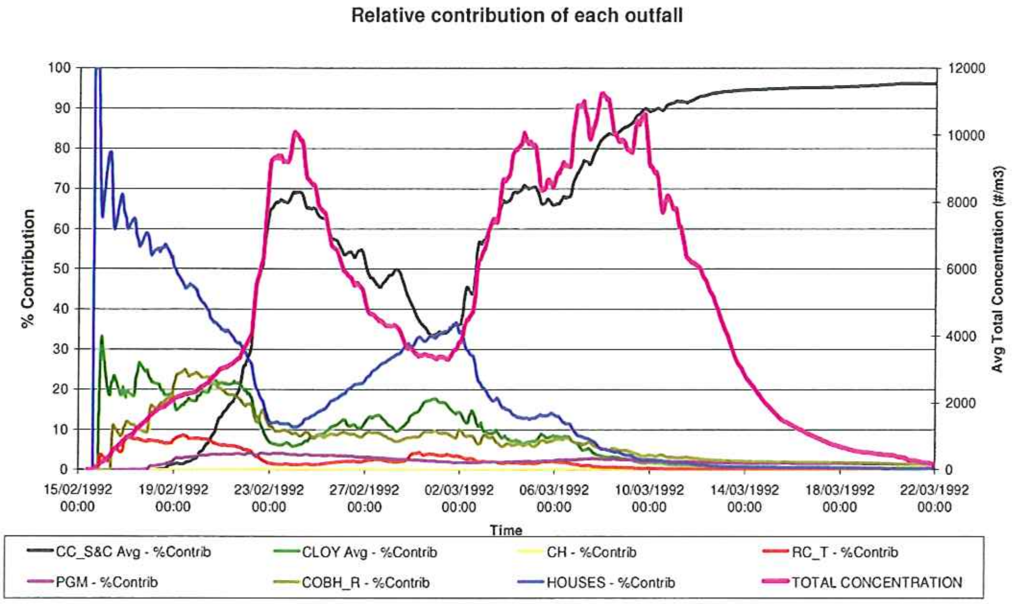


Fig. 5.48 – CASE 3 - The relative contributions with the total concentration plotted on the secondary axis. Period 2 summer conditions.

We can see from Fig. 5.47 that CC_S&C is the main contributor of viral particles to the model oyster farm. There is a reasonably significant increase in the contribution of the houses from the 24th of February to the 2nd of March. This is not due to an increase in the number of viral particles coming from the houses but rather is due to the reduction in the number of viral particles from CC_S&C. From Fig. 5.48 we can see the very strong correlation in the model between the averaged total number of viral particles (plotted with the pink line on the secondary axis) and the relative contribution of CC_S&C. The pie charts of the maximum and averaged contribution are shown in Fig. 5.49 and Fig. 5.50. From these figures we can clearly see that CC_S&C is the main contributor of viral particles to the model oyster farm.

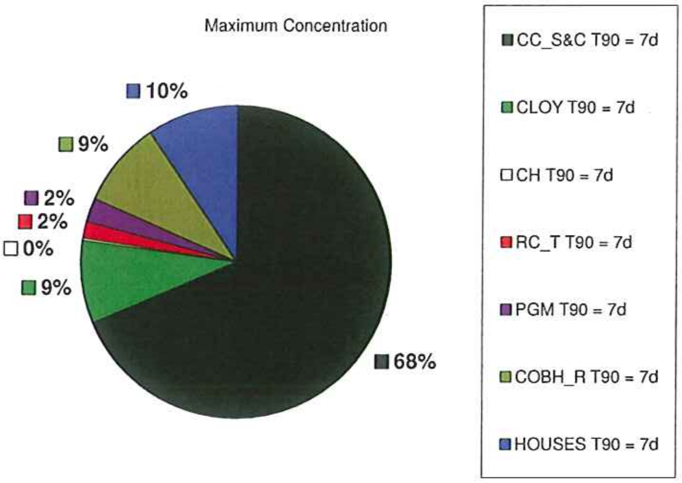


Fig. 5.49 CASE 3 – Maximum Concentrations. Period 2 summer conditions

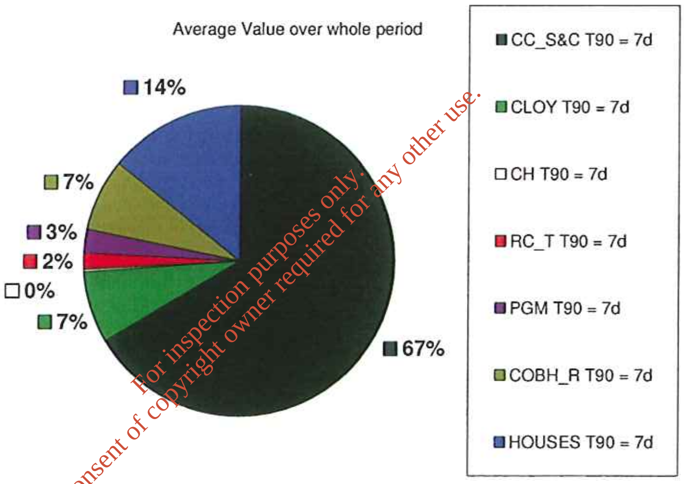


Fig. 5.50 CASE 3 - Average Concentrations – the relative contributions. Period 2 summer conditions

5.5.2 Case 4 - Winter Conditions

The winter conditions for period two are now presented. This is the first case where storm water overflows from Bailick 1 and Bailick 2 are included in the model. The time series of concentration extracted from the centre of the concession are shown in Fig. 5.51. We can see from the figure that as before CC_S&C is the main source of contamination of the oyster farm. The second biggest contribution is now the storm water overflows from Bailick 1. From this plot we can see how the other contributions are, relatively speaking, minor in comparison the two main sources of *Norovirus* in the model.

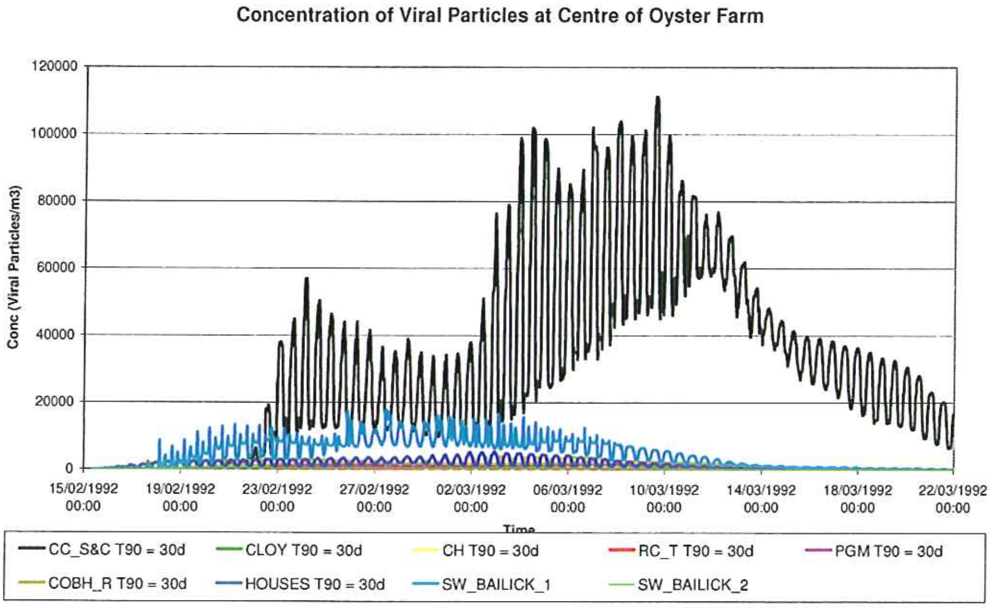


Fig. 5.51 CASE 4 – Time series of Concentration at the model Oyster Farm. Period 2 winter conditions

The moving averages are shown in Fig. 5.52 and the relative contributions in Fig. 5.53. We can see from the figures that after the 22nd of February the untreated waste from Cork is the main contributor of viral particles to the model oyster farm. The maximum contribution from the overflows at Bailick 1 is 50%. This value is slightly misleading as the total concentration at this moment on the graph is approximately 1/9th of the maximum that is reached later on in the simulation. We can see this from Fig. 5.54 where the relative contributions are plotted against the averaged total concentrations.

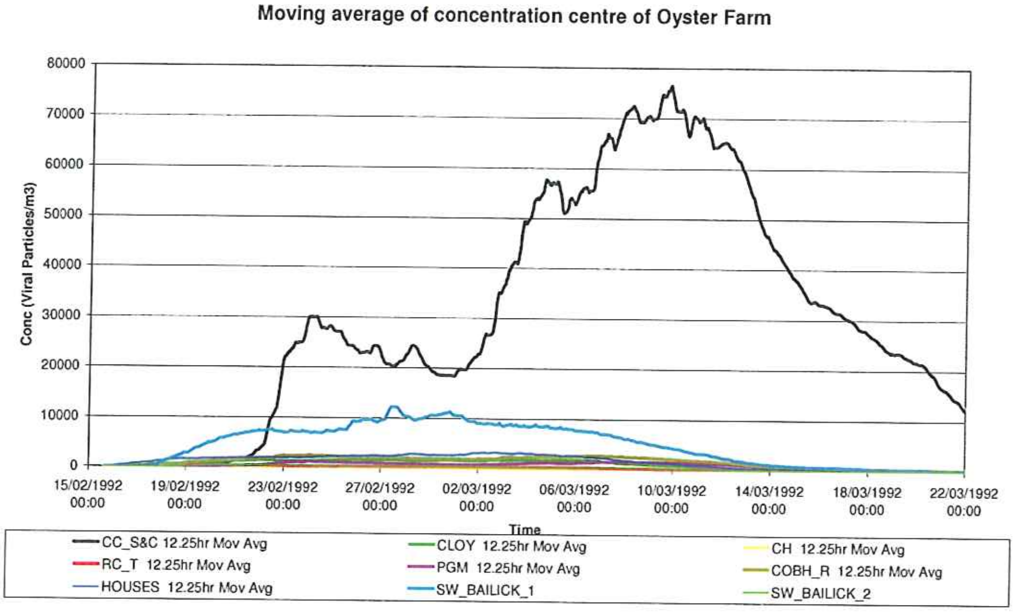


Fig. 5.52 CASE 4 - Moving Averages of Concentration at the model Oyster Farm. Period 2 winter conditions.

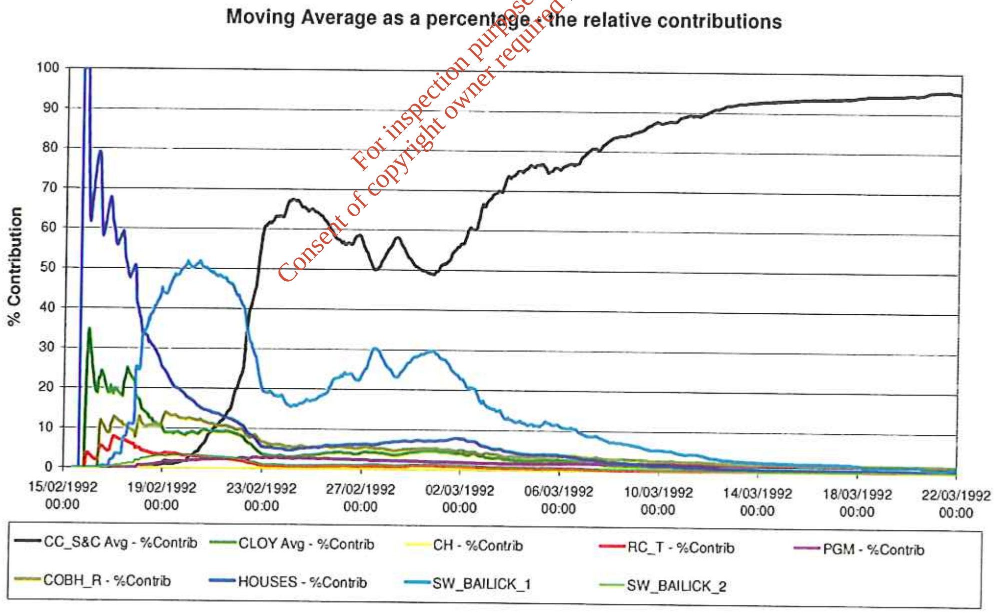


Fig. 5.53 CASE 4 - Moving Average as a percentage – The Relative Contributions. Period 2 winter conditions.

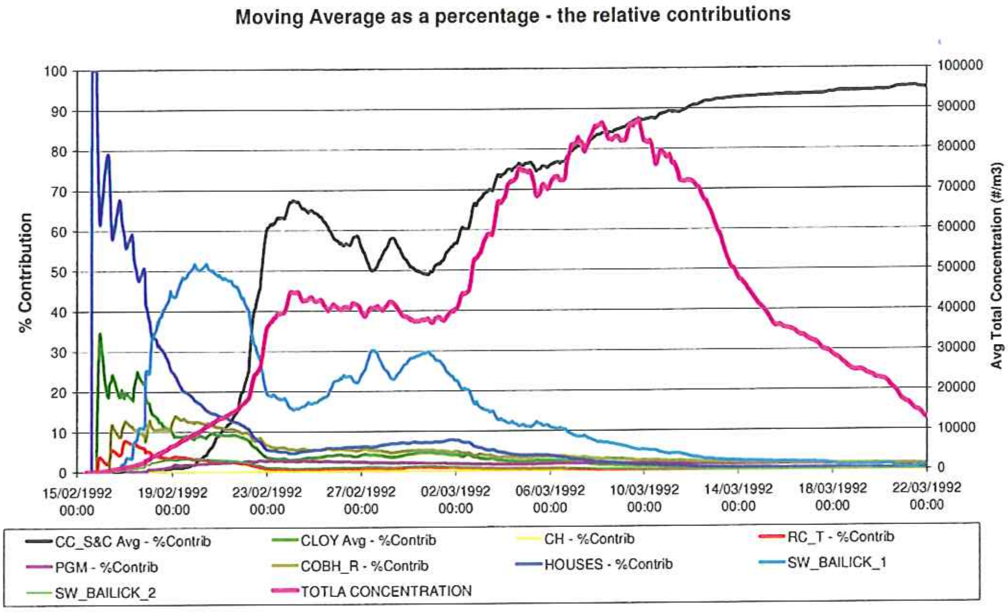


Fig. 5.54 The Relative Contributions with the Averaged Total Concentration. Period 2 winter conditions.

We can also see from the diagrams that the contribution of Bailick 1 is much greater than that of the treated waste from Rathcoursey.

The pie diagrams of the maximum and averaged concentrations are shown in the following two figures. From these we can see that CC_S&C is contributing the largest portion of viral particles to the model oyster farm. We can also see that the contribution of viral particles from Bailick 1 is 10 times greater than that from RC_T.

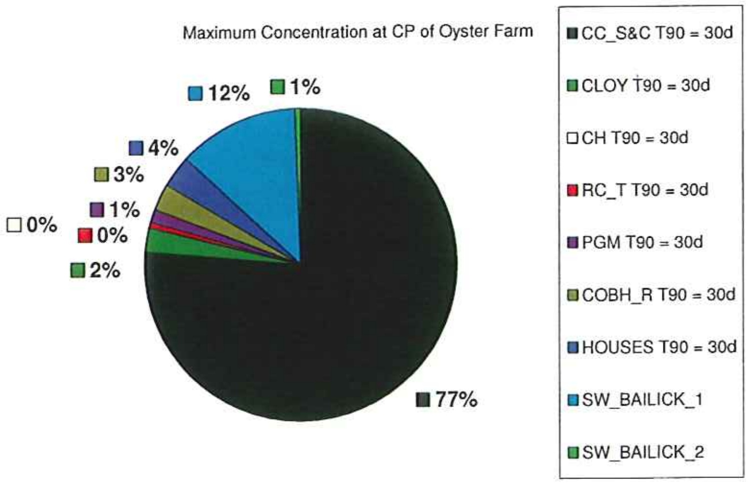


Fig. 5.55 The maximum contributions. Period 2 winter conditions

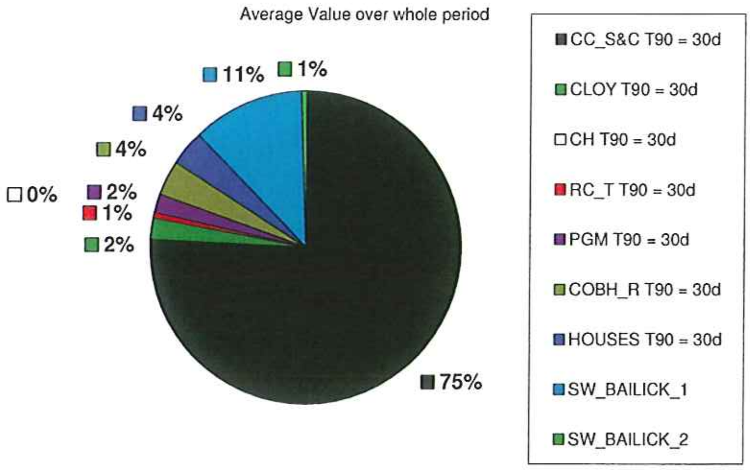


Fig. 5.56 The Average Concentrations – Relative Contributions. Period 2 winter conditions.

5.6 Period Three

The summer and winter conditions of period three are now presented. For this period all of the waste from Cork City is being treated at the Waste Water Treatment Plant at Carrigrennan. The location of the outfall from Carrigrennan is closer to the oyster farm than the outfalls at Kennedy Quay. There is however an assumed 95% reduction in the number of viral particles being discharged. This 95% assumption of the removal of *Norovirus* is discussed further in Appendix D.

5.6.1 CASE 5 - Summer Conditions

The time series of concentration extracted from the model oyster farm for case 5 is presented in Fig. 5.57. We can see clearly from the figure that the houses around the harbour are the main contributor of viral particles at the model oyster farm. The secondary treatment plant at Carrigrennan has lead to significant improvements in the total concentration in viral particles at the model oyster farm. The moving averages are presented in Fig. 5.58 and the relative contributions are highlighted in Fig. 5.59. We can see from the figures that unlike previous cases there in no single outfall which is contributing a significantly higher percentage of viral particles than the others.

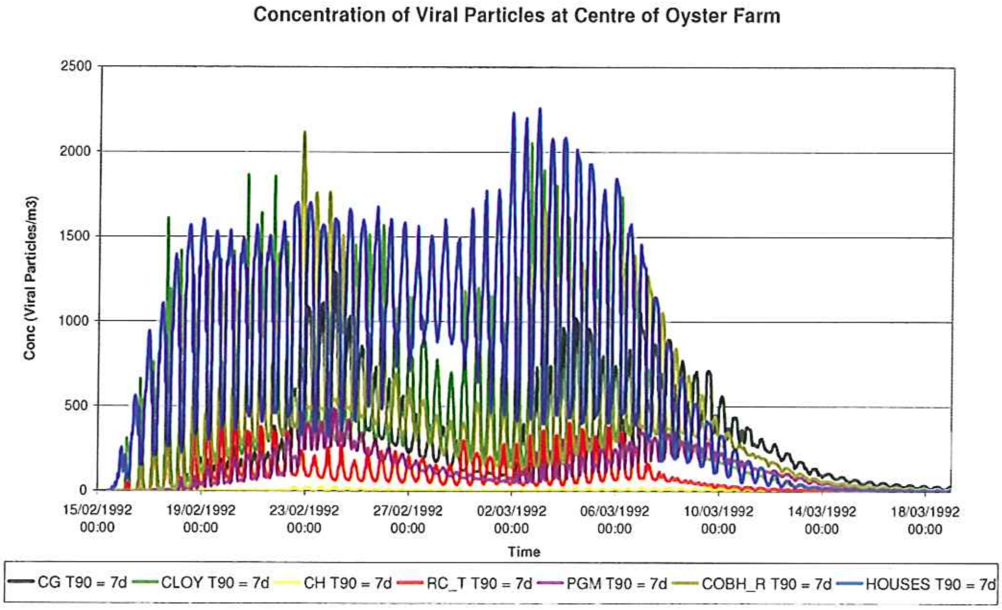


Fig. 5.57 CASE 5 – Concentrations at the centre of the model oyster farm. Period 3 Summer Conditions

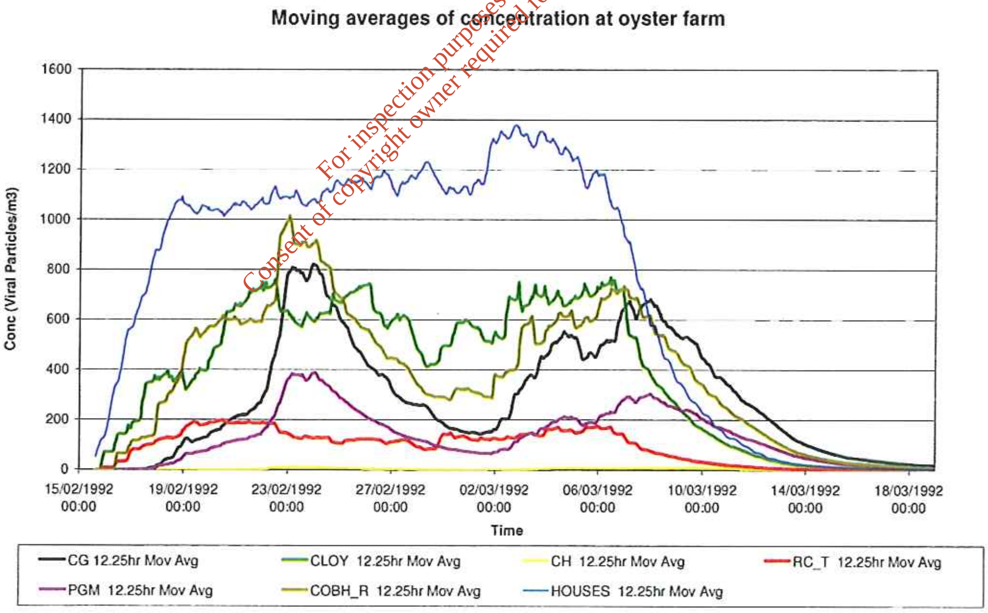


Fig. 5.58 CASE 5 - Moving averages of concentration. Period 3 summer conditions

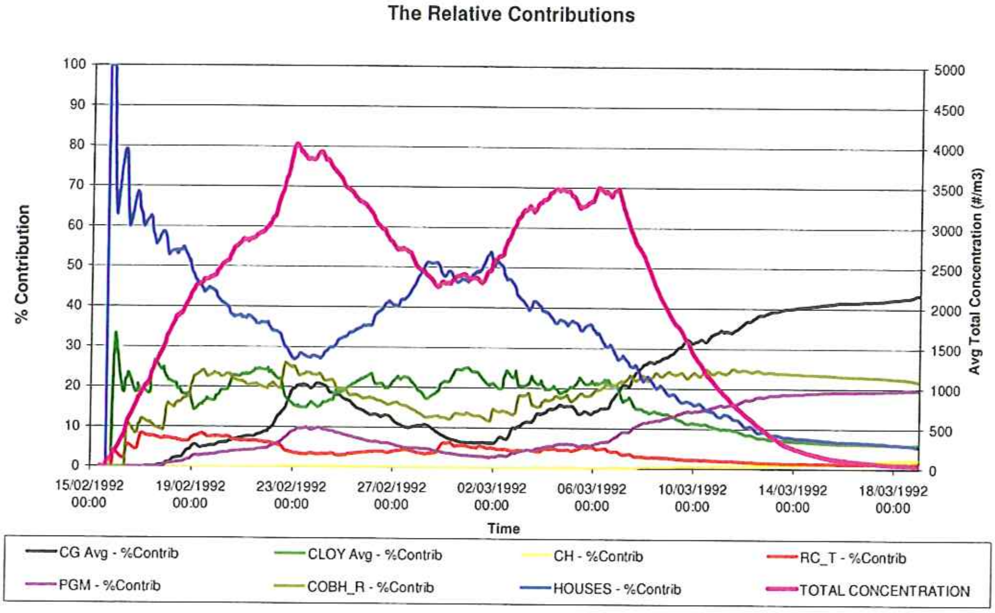


Fig. 5.59 CASE 5 - The Relative Contributions and the Total Concentration. Period 3 summer conditions.

The pie charts for the maximum and averaged contributions are shown in figures Fig. 5.60 and Fig. 5.61. We can see from the figures that the houses around the harbour are contributing the most to the contamination of the oyster farm. Cloyne, Cobh and Carrigrennan are all approximately equal.

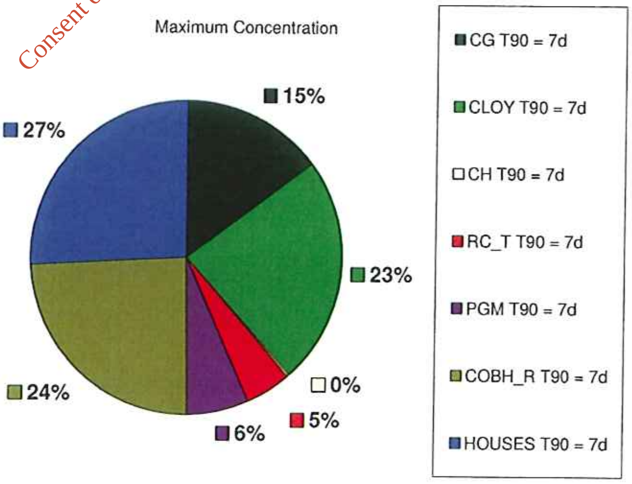


Fig. 5.60 CASE 5 – Maximum Concentrations. Period 3 summer conditions.

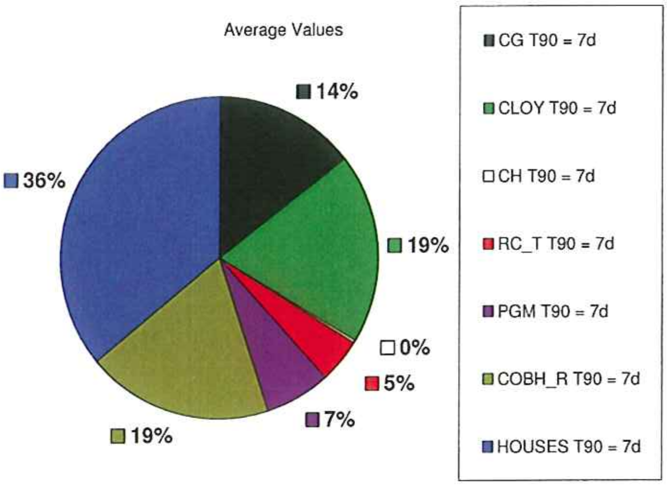


Fig. 5.61 CASE 5 – Average Contributions. Period 3 summer conditions

5.6.2 CASE 6 - Winter Conditions

The winter conditions for the third period are now presented. From Fig. 5.62 we can see that the storm water overflows from Bailick 1 are the largest source of viral particles at the oyster farm.

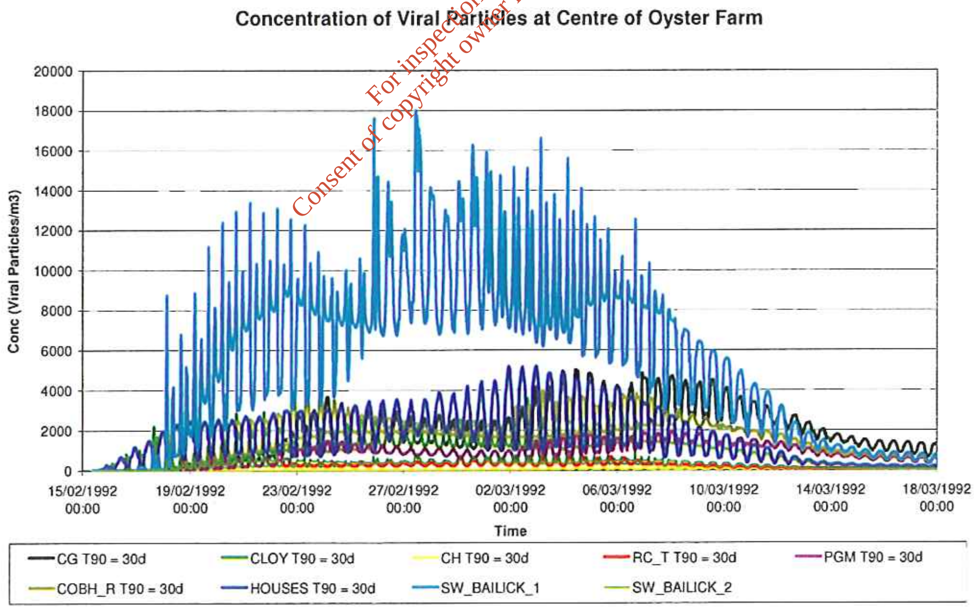


Fig. 5.62 CASE 6 – Timeseries of Concentration at the model Oyster Farm. Period 3 winter conditions

The moving averages of concentration are presented in Fig. 5.63. From this we can see that the averaged maximum contribution from Bailick 1 is approximately three times greater than any other source of viral particles. From the plot of the relative contributions we can see that Bailick 1 is contributing up to 50% of the total concentrations for a significant period of time. This contribution decreases as the influence of Carrigrennan increases.

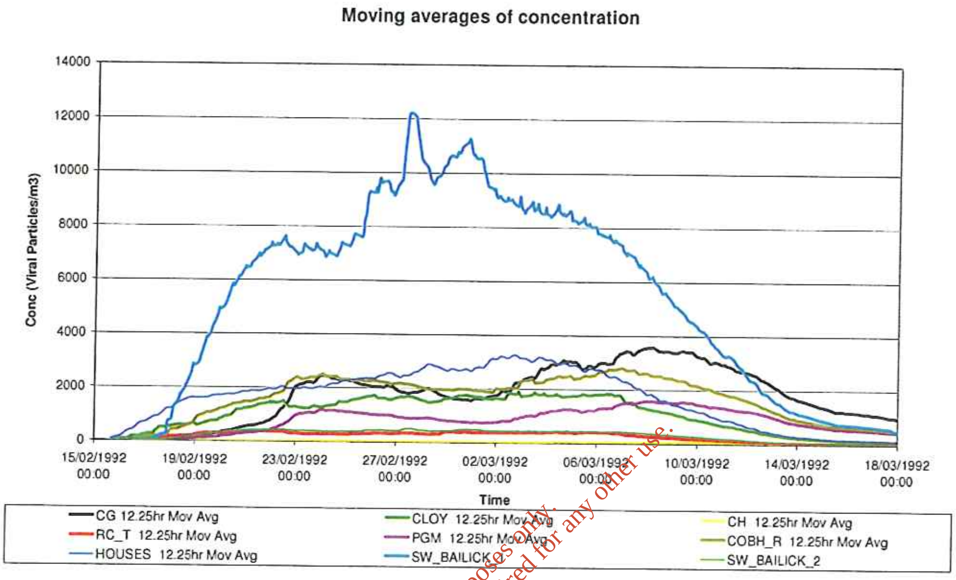


Fig. 5.63 Moving Averages of Concentration. Period 3 winter conditions

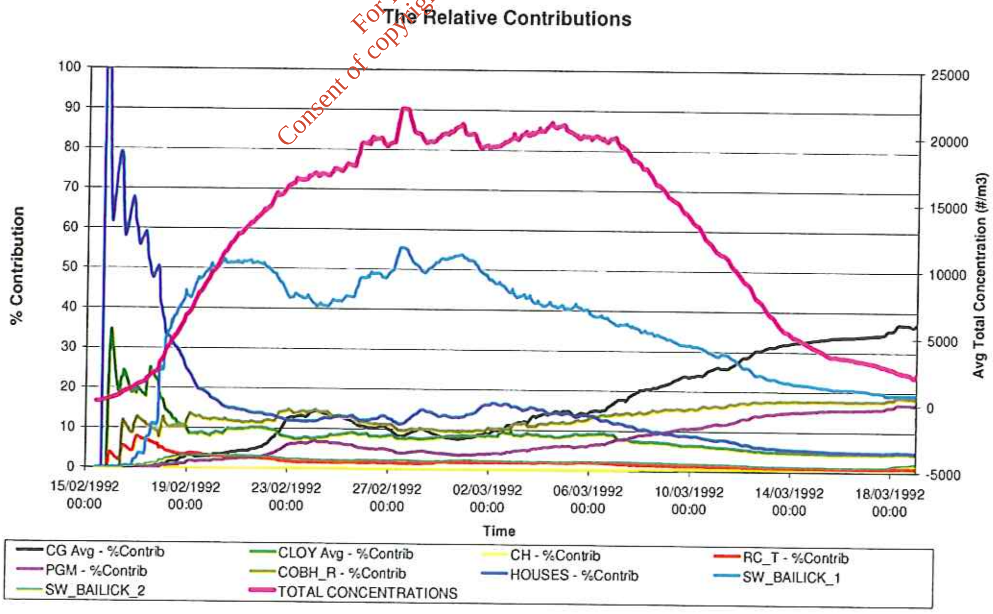


Fig. 5.64 The Relative Contributions and the Total Concentrations. Period 3 winter conditions

The pie charts highlighting the maximum and averaged concentrations are presented in the following two figures. We can see from the plots that Bailick 1 is the main source of viral particles at the model oyster farm. It is contributing up to 20 times the amount from RC_T.

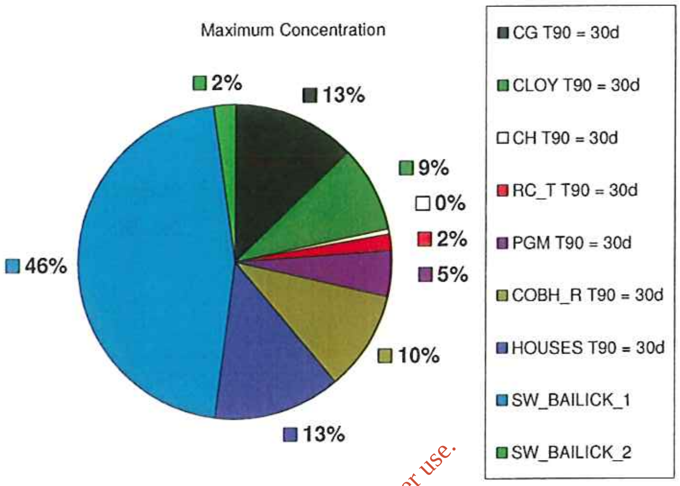


Fig. 5.65 The Maximum Contributions. Period 3 winter conditions.

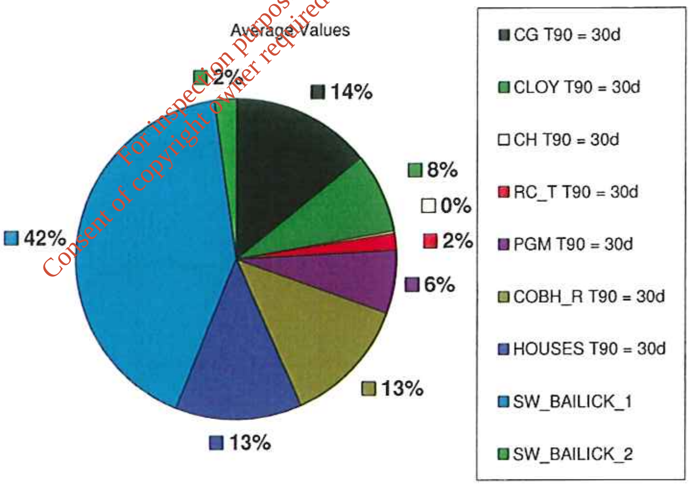


Fig. 5.66 Average Concentrations – The Relative Contributions. Period 3 winter conditions.

5.7 Variation across the Oyster Farm

The detailed results presented in the previous section were extracted from a point that corresponds to the centre of the concession of the model oyster farm in the North Channel. From the plots of maximum concentration presented in section 5.2 we can see that the concentrations of viral particles vary across the entire model harbour for each outfall. This section considers the east-west variation in concentration across the concession, a distance of approximately 1.7km. Two pie diagrams are presented side by side for each of the six cases considered as part of the study. The diagram on the left shows the averaged relative contribution for the entire period for the point (1056, 105) on the 18m grid. This corresponds to the most westerly point of the concession. The diagram on the right shows the averaged relative contribution for the entire period for the point (1145, 107)) on the 18m grid. This corresponds to the most easterly point of the concession. By examining these diagrams side by side we can determine the variation in the relative contributions of concentration across the model oyster farm.

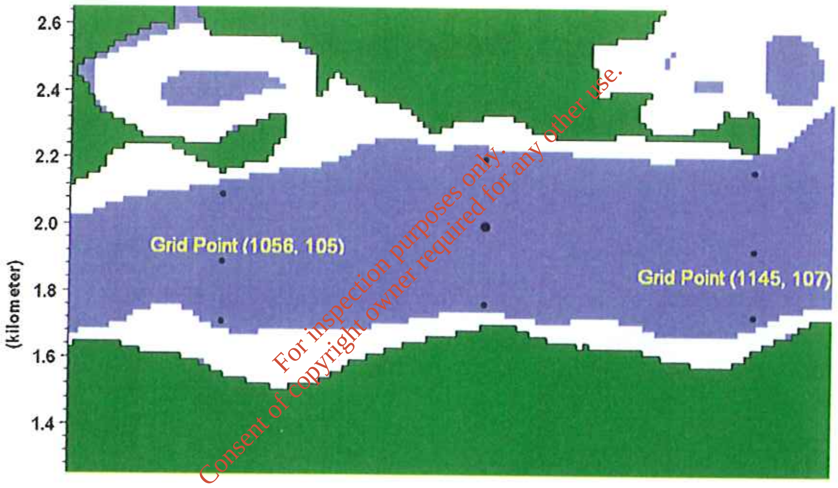
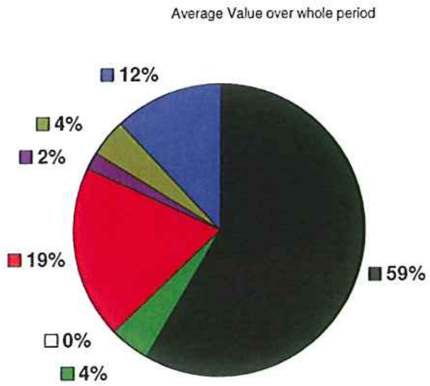


Fig. 5.67 Location of the grid points at either end of the concession. There are 11 grid points at 18m intervals between the ends (198m).

5.7.1 CASE 1 – Period 1, Summer Conditions

We can see from the plots below that there is a change in the relative contributions of concentration across the model oyster farm. The contribution of RC_S&C is greater on the eastern side as it lies closer to the outfall at Rathcoursey.



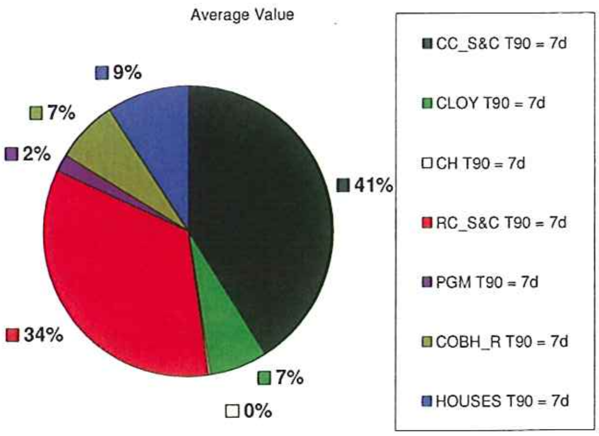
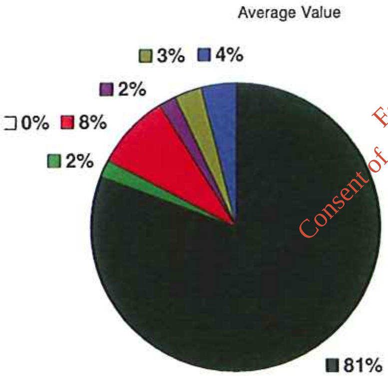


Fig. 5.68 Easterly Point

Fig. 5.69 Westerly Point

5.7.2 CASE 2 – Period 1, Winter Conditions.

The relative contributions for the winter case do not vary as much for the summer conditions.



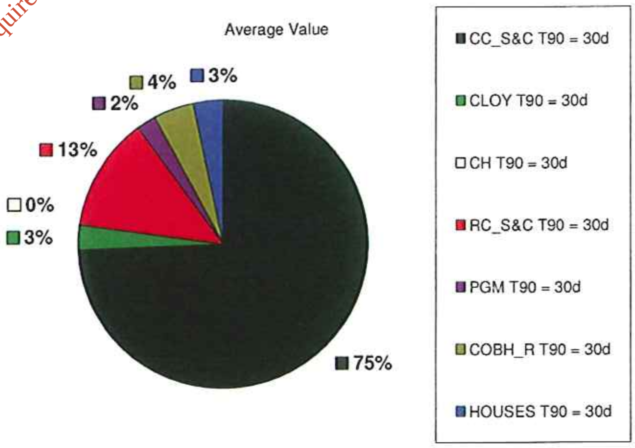


Fig. 5.70 Easterly Point

Fig. 5.71 Westerly Point

5.7.3 Period 2, Summer Conditions

The relative contributions for the third case are presented below. We can see that, as before, there is a variation across the model oyster farm.

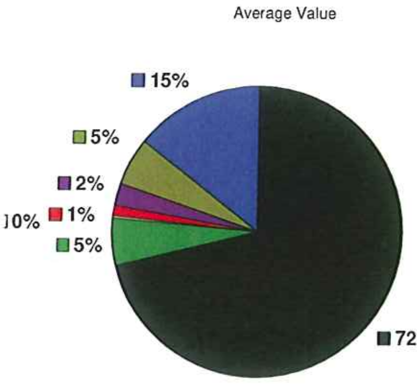


Fig. 5.72 Easterly Point

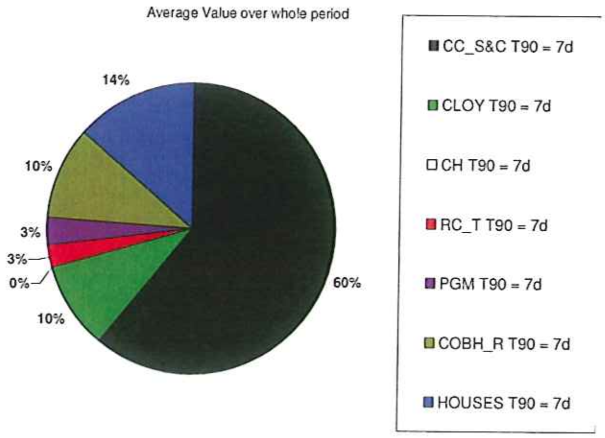


Fig. 5.73 Westerly Point

5.7.4 CASE 4 – Period 2, Winter Conditions

The relative contributions for the fourth case are presented below. We can see from the figures that there is a minor variation in the relative contributions across the model oyster farm.

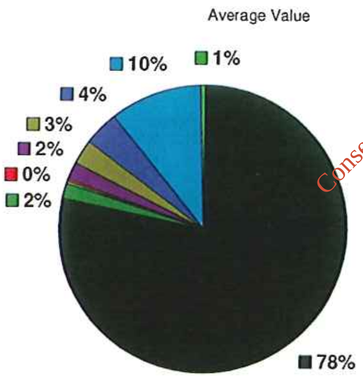


Fig. 5.74 Easterly Point

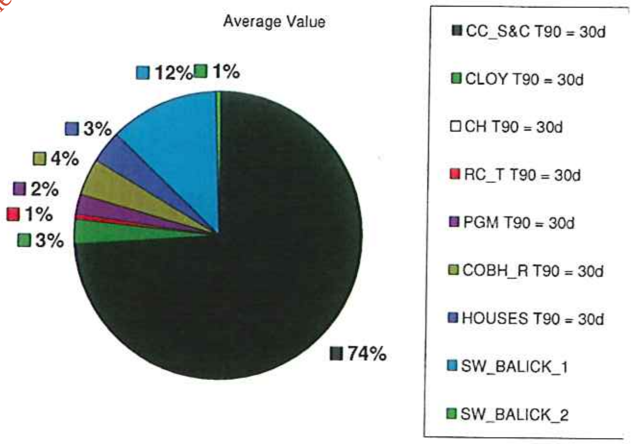


Fig. 5.75 Westerly Point

5.7.5 CASE 5 – Period 3, Summer Conditions

The relative contributions for the fifth case are presented below. We can see from the figures that there is a minor variation in the relative contributions across the model oyster farm. The influence of the houses is stronger on the left hand side.

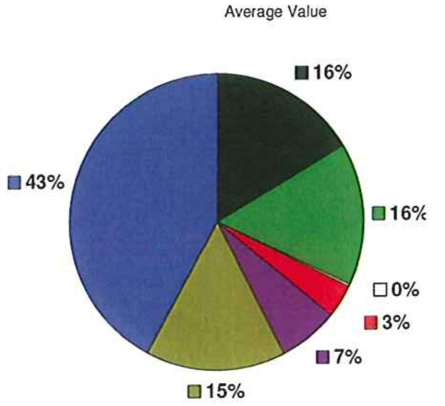


Fig. 5.76 Easterly Point

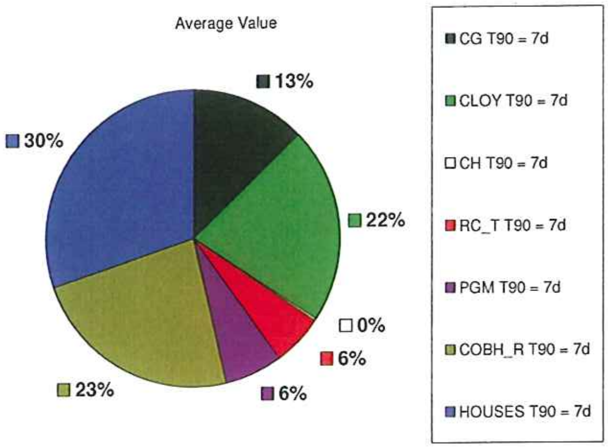


Fig. 5.77 Westerly Point

5.7.6 CASE 6 – Period 3, Winter Conditions

The relative contributions for the fourth case are presented below. We can see from the figures that there is a minor variation in the relative contributions across the model oyster farm.

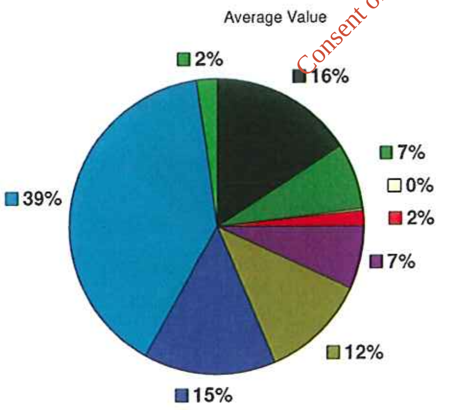


Fig. 5.78 Easterly Point

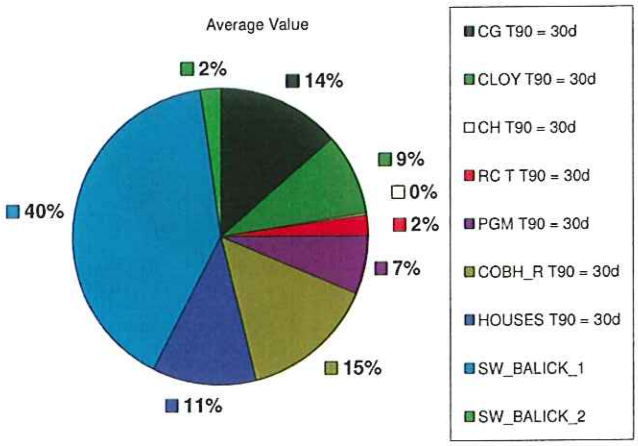


Fig. 5.79 Westerly Point

5.8 Differences between the three periods

All of the results presented so far in this chapter have been categorised into three separate periods of time. This section looks at the differences between these periods. The total number of viral particles in each period has been successively reduced with the construction of the waste water treatment plants at Midleton and Carrigrennan. All of the time series in this section are extracted from the centre point of the concession in the North Channel.

5.8.1 Summer Conditions

The averaged total number of viral particles, for each of the three periods for summer conditions, is plotted in Fig. 5.80. We can see the effect that each of the secondary waste water treatment plants has had on the viral load at the model oyster farm. The averages are presented in Fig. 5.81.

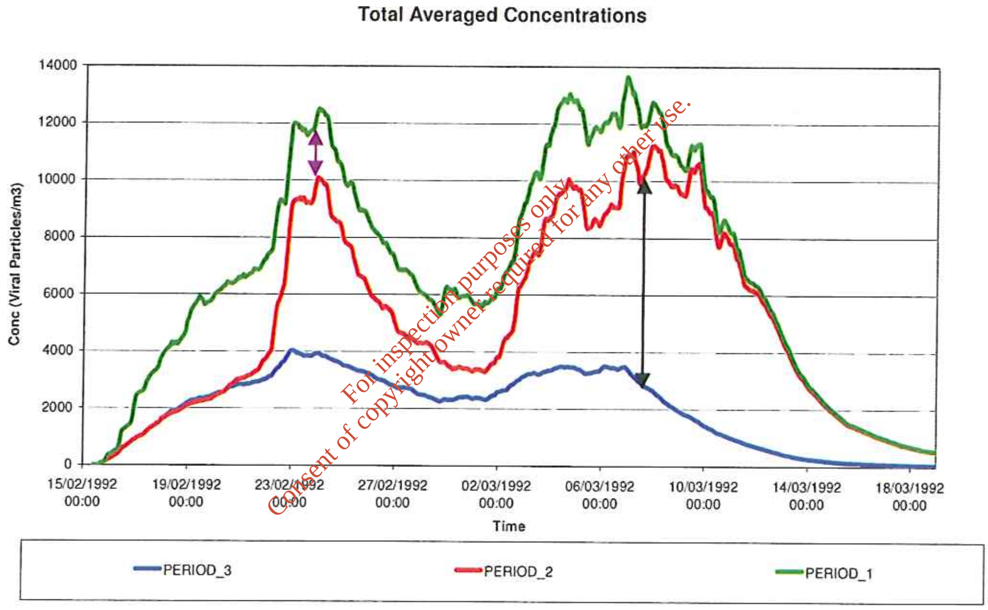


Fig. 5.80 Comparison between the three periods for Summer Conditions – Averaged Concentrations at the model oyster farm with all discharges combined. The wine coloured arrow indicates the improvement due to the construction of Midleton WWTP. The black arrow indicates the improvement due to the construction of Carrigrennan WWTP.

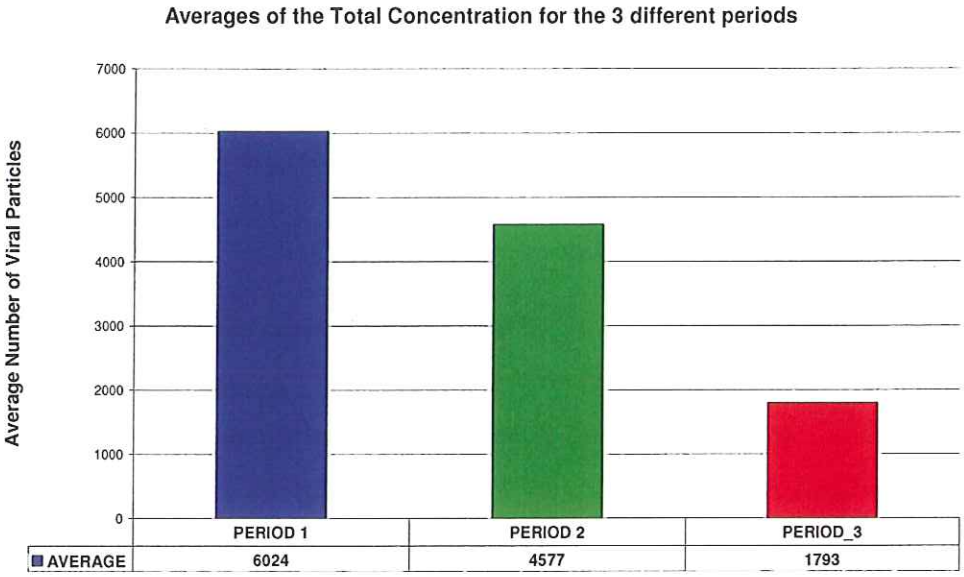


Fig. 5.81 Average summer concentrations for the three periods at the model oyster farm with all discharges combined

The following two figures highlight the reduced concentrations at the centre of the model oyster brought about by the construction of the secondary waste water treatment plants at Cork and Midleton.

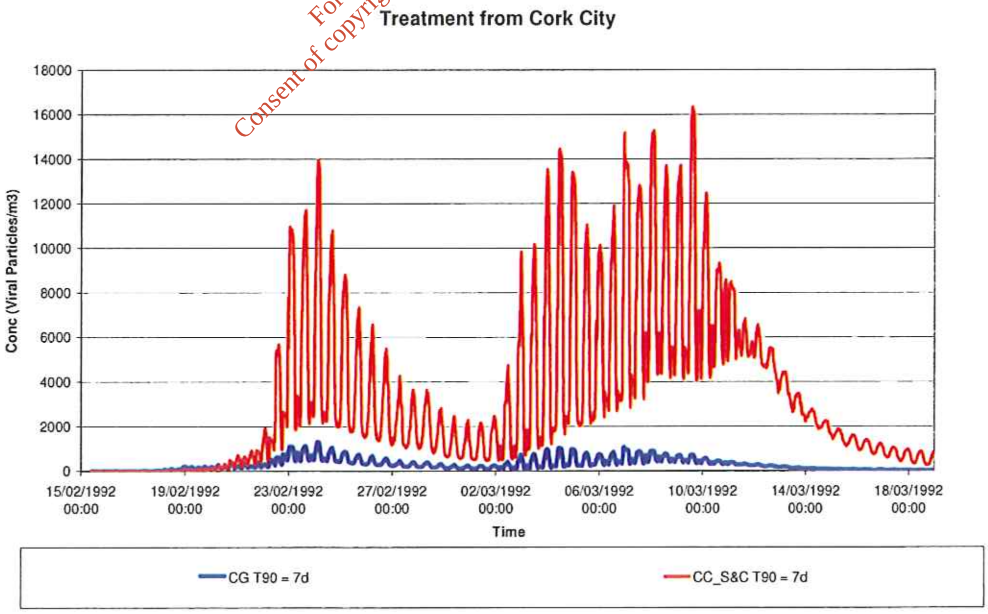


Fig. 5.82 Cork City loading on its own before and after the construction of Carrigrennan WWTP – SUMMER CONDITIONS

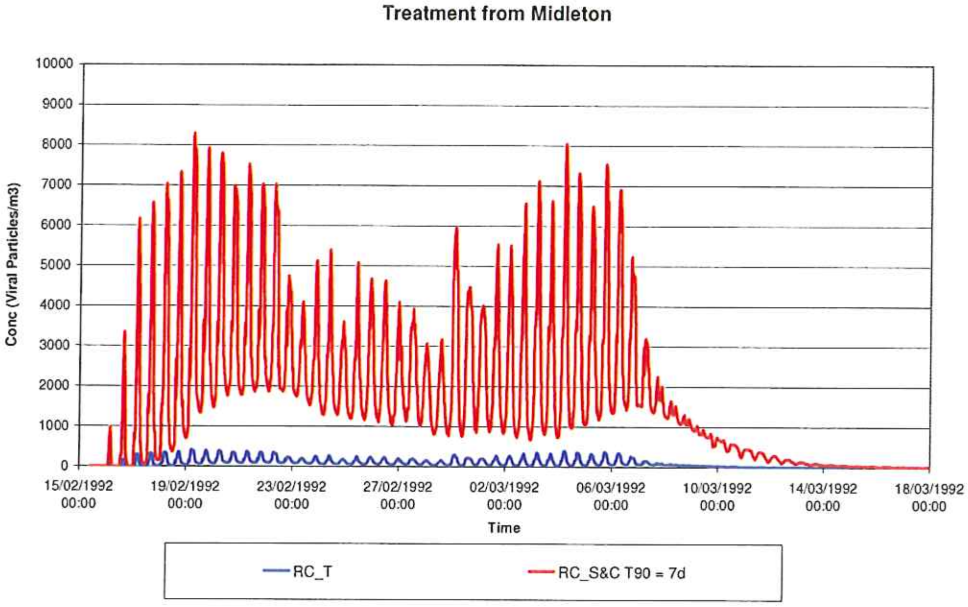


Fig. 5.83 Rathcoursey loading on its own before and after the construction of Midleton WWTP – SUMMER CONDITIONS

5.8.2 Winter Conditions

The winter conditions are now presented in the following set of figures. We can see from Fig. 5.84 that there is virtually no difference between the averaged concentrations at the centre of the model oyster farm for periods 1 and 2. There is a significant reduction for period 3 with the construction of the treatment plant at Carrigrennan.

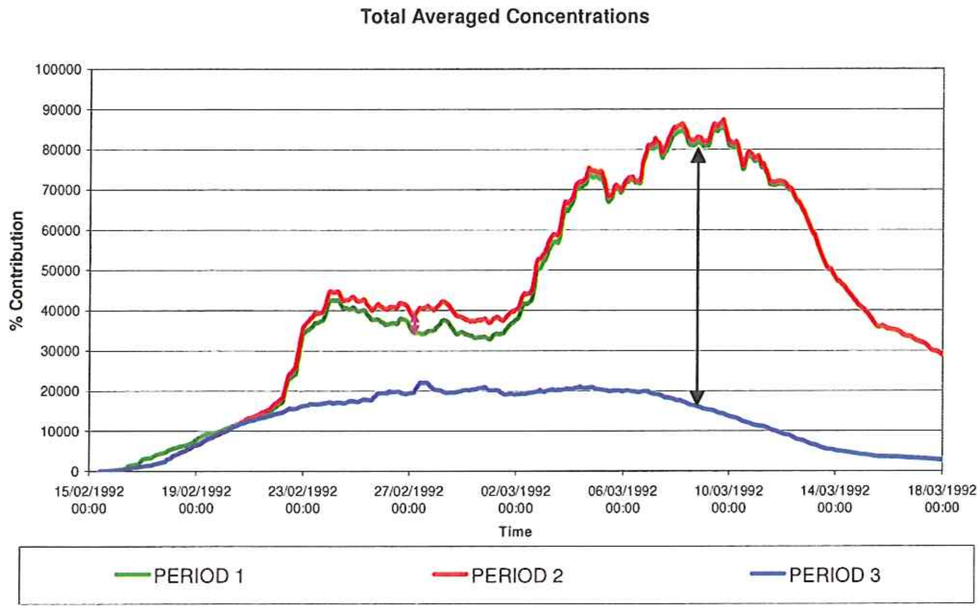


Fig. 5.84 Comparison between the three periods for Winter Conditions – Averaged Concentrations at the model oyster farm with all discharges combined. The wine coloured arrow indicates the improvement due to the construction of Midleton WWTP. The black arrow indicates the improvement due to the construction of Carrigrennan WWTP.

The contribution of the untreated waste from Rathcoursey (Period 1) is plotted with the contribution from the overflows at Bailick 1 and Bailick 2 (Period 2 and Period 3) in Fig. 5.85. We can see from the figure that the contribution from Bailick 1 in period 2 is as significant as that of the untreated waste from Rathcoursey in period 1 at the model oyster farm. The moving averages are presented in Fig. 5.85 where the contribution of Bailick 1 and Bailick 2 has been added together since Bailick 2 is very small.

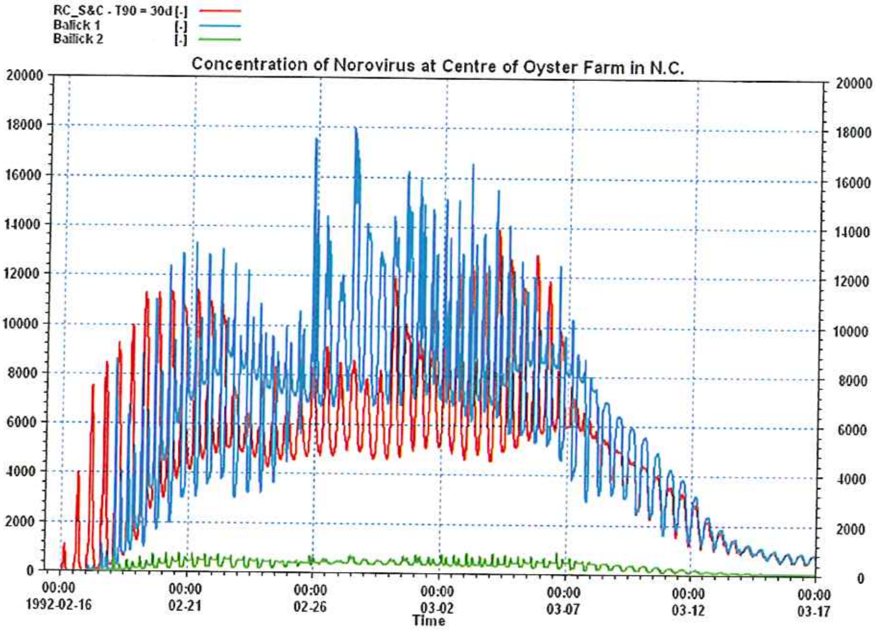


Fig. 5.85 Comparison of RC_S&C (period 1) and Bailick 1 and Bailick 2 (same for period 2 & 3). Winter conditions.

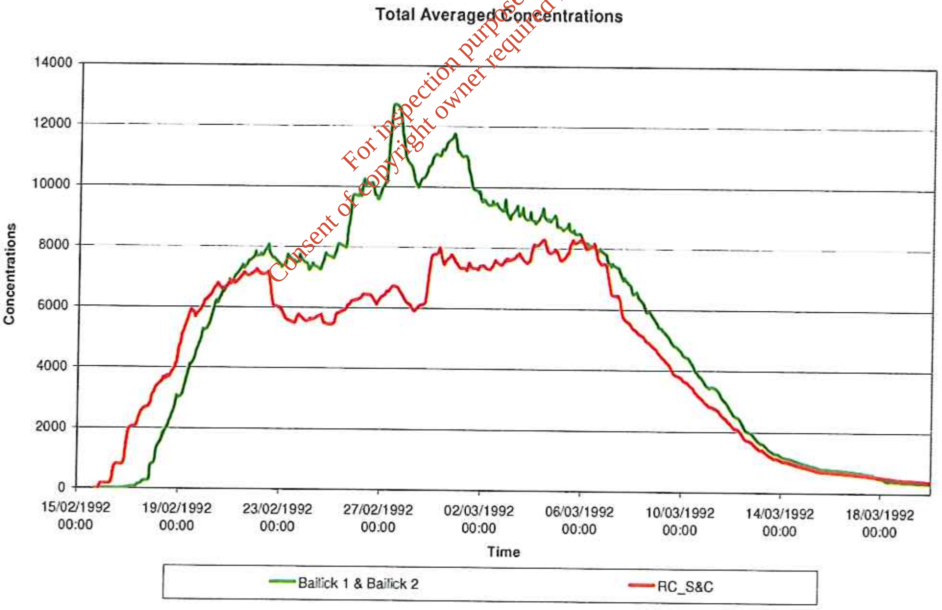


Fig. 5.86 Comparison of moving averages of RC_S&C (period 1) and the sum of Bailick 1 and Bailick 2 (same for period 2 & 3). Winter conditions.

If no stormwater overflows were to occur in winter in period 2 we can see from a comparison of Fig. 5.84 and Fig. 5.87 that there would only be a minor reduction in the total averaged concentrations of viral particles at the model oyster farm. This is due to the very large number of viral particles contributed from CC_S&C.

The relative contributions, as presented earlier in the chapter for case 4 (Fig. 5.56), as shown again in Fig. 5.88, illustrate this point.

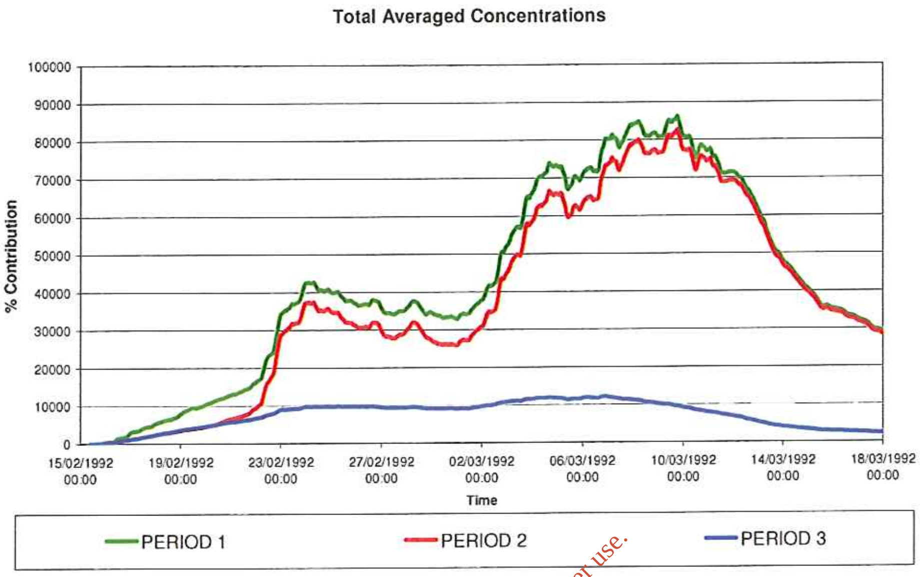


Fig. 5.87 Comparison between the three periods for Winter Conditions – Averaged Concentrations at the model oyster farm with the SW overflows removed.

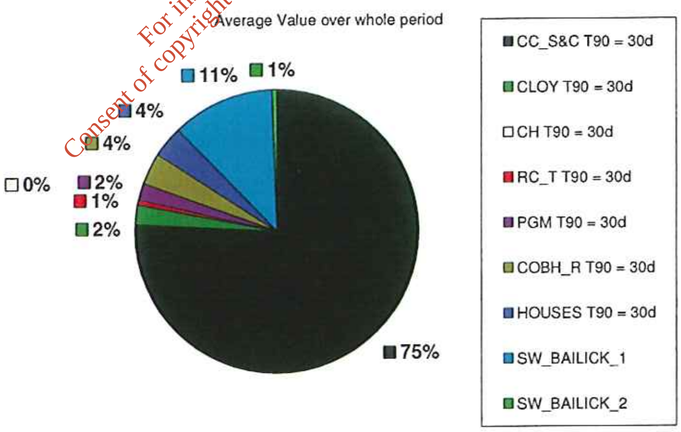


Fig. 5.88 The Average Concentrations – Relative Contributions. Period 2 winter conditions (As presented in Chapter 5).

The average for the three different periods is presented in the following figure (Fig. 5.89) for winter conditions including storm water overflows. The average for the three different periods in winter with the overflows from Bailick 1 and Bailick 2 removed is presented in Fig. 5.90.

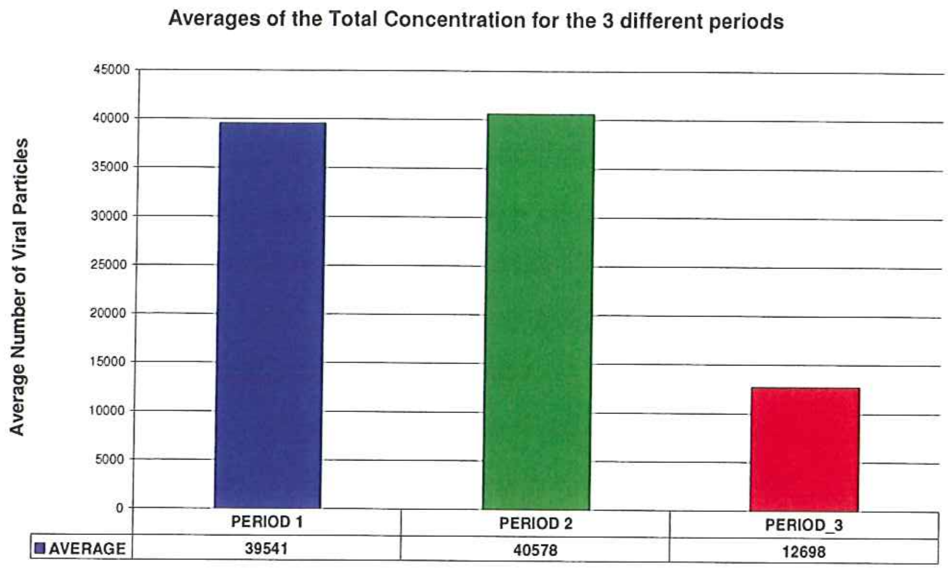


Fig. 5.89 Comparison between the three periods. Winter conditions.

The same figures are now presented from winter conditions with no overflows occurring.

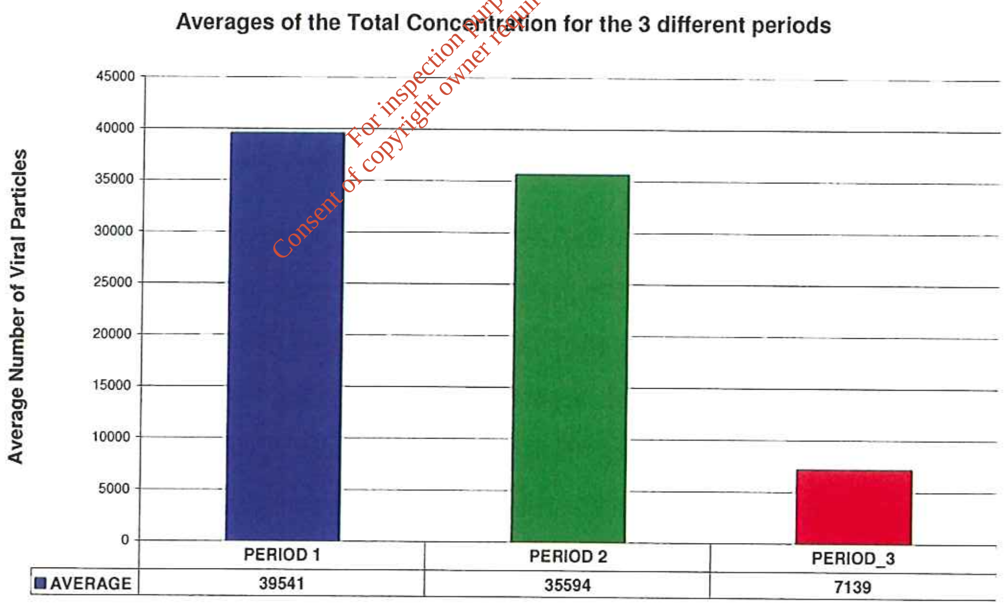


Fig. 5.90 Comparison between the three periods. Winter conditions and **NO** storm water overflows

5.9 Conclusions

The conclusions to be drawn from this are the following.

1. Because Cork Harbour is a macro-tidal lens of shallow water, one thousand times as wide as it is deep, the twice daily variation of 2m (Neaps) to 4m (Springs) in water level implies a corresponding oscillatory horizontal motion of 5km (Neaps) to 10km (Springs) approximately. Consequently, long-lived, non-cohesive, neutrally buoyant, particles, such as our model *Norovirus,* are dispersed very widely by water movement throughout the harbour. Our model says all discharges of such viruses can contaminate the oyster farm to a greater or lesser extent.
2. We have used our well-calibrated model to examine in detail the relative contributions of all significant sources in their historical context. We have divided the historical examination into three periods defined by the dates of commissioning of the two waste water treatment plants that serve Cork City and Midleton. In each period we distinguish between winter and summer conditions. The six cases tell the story of the changing contamination of the model oyster farm.
3. Because the potential burden of *Norovirus* from Cork City is the largest, it is of singular importance, even though it is the furthest away of all the sources. The model viruses from Cork have two routes to contaminate the oyster farm, through Belvelly Channel, especially under conditions of strong westerly wind, and more circuitously around Cobh Island, with the assistance of southerly winds through East Passage into the North Channel.
4. The potential sources of *Norovirus* closest to the oyster farm are (a) the isolated houses close to the shore of the North Channel, and (b) the treated and untreated discharges of sewage from Midleton. The relative importance of these sources changes in each of the three periods and under winter and summer conditions.

5. The construction of the secondary waste water treatment plants at Carrigrennan, serving Cork City, and at Midleton, have reduced both average and peak concentrations of *Norovirus* at the model oyster farm in the North Channel behind Cobh Island. This follows from the assumption that secondary treatment removes 95% of organic matter and consequently the same percentage of model viruses (this assumption is discussed in Appendix D) . Secondary treatment is planned for the sources around the Outer Harbour with a further reduction in contamination

6. As more and more treatment is applied, intermittent discharges of untreated sewage during storms become significant. This is already the case in Midleton where the discharges of screened and diluted sewage from the Bailick 1 and 2 pumping stations are currently the most important source of contamination of the model oyster farm.

7. The discharges of screened and diluted sewage from Bailick 1 and 2 in periods 2 and 3 (winter conditions) i.e. after the construction of the Midleton secondary waste treatment plant, contaminate the model oyster farm to roughly the same extent as the previous discharge of all Midleton's untreated sewage at Rathcoursey Point during period 1 (winter conditions).

8. The reference storm overflows used in the simulation occurred in December 2002/January 2003. The data from the current year, winter 2006/2007, show that there has been a further disimprovement in the Midleton sewerage system: more frequent, longer lasting, and intense overflows to the river. Consequently, our model results for storm overflows at Bailick 1 and Bailick 2 underestimate for the current year - 2007. On the other hand, when more viruses are discharged to the river, there is a matching reduction in the number of viruses entering the treatment plant during the reference 20-day pulse of *Norovirus.* At the same time, the treatment plant is operating above its maximum design loading, and the range of uncertainty in the removal of model viruses is increased. In the absence of (a) a calibrated model of the

treatment plant, and (b) any measurements of viral particles, we are content to use the range from 95% to 85%, for the removal or inactivation of *Norovirus*. We have used the same range of uncertainty for the much larger Carrigrennan WWTP even though no UV treatment is present there. We do not imply that the removal efficiencies are the same in both cases.

9. The discharges of untreated domestic sewage from the houses around the North Channel are the largest contributor to the contamination of the model oyster farm for the current summer conditions (period 3). During current winter conditions the discharges from Bailick 1 and 2 are dominant.