Chapter 8 Discussion and Conclusions

8.1 Discussion

The discharge of sewage effluent to coastal waters used for the cultivation of oysters poses a risk to human health. The primary pathogen in outbreaks of gastroenteritis following consumption of raw oysters is the *Norovirus* or "winter vomiting bug" (WVB), formerly known as Norwalk-like viruses.

The oyster farm in the North Channel in Cork Harbour, behind Cobh Island, has been closed for approximately five years due to outbreaks of gastroenteritis following consumption of its oysters. The outbreaks have been attributed to viral contamination. Regular assays for the presence of the *Norovirus* in oyster flesh have been found to be positive. In 2006 Cork County Council asked the lead author of this report to carry out an objective study of all the possible sources of contamination of the oyster farm. Each source has conceptualised in exactly the same way in the interests of equity.

Several computer models of the discharge, transport and decay of the *Norovirus* in Cork Harbour have been developed to determine the possible sources of contamination of the oyster farm. The models predict the changing concentrations of *Norovirus* averaged over the vertical depth of water on a horizontal grid of points that cover the whole Harbour under varying conditions of wind, tide and river flow. A number of assumptions have been made in the development of these models:

1. each and every person living within the catchments of the harbour experiences an identical attack of noroviral gastroenteritis
2. Each and every person living within the catchments of the harbour discharges the same large number of identical *Norovirus* particles to the nearest sewer at a constant rate for the duration of the outbreak. A constant *source concentration* of viruses, 50 million *Norovirus*, in each and every cubic meter of sewage has been assumed for each person

When the viruses enter the waters of the Harbour we have also assumed that each particle:

3. Is neutrally buoyant,
4. Is non-cohesive, and
5. Has the same fractional rate of decay, or inactivation, in each successive unit of time at every point in the Harbour

The assumptions regarding an epidemiological outbreak of *Norovirus* clearly do not correspond to any particular historical event, or set of events. How can they be justified?

We are not aware of any dynamic, spatio-temporal, epidemiological model of Winter Vomiting Bug outbreaks that would allow us to estimate the episodic loads from all discharges around the harbour. Even if such a model were available, the problem of calibration would remain.

No measurements of the discharge rates of *Norovirus* with a frequency that resolves the hourly, daily and seasonal variability in numbers *in water* have been made anywhere in the world. The only measurements of *Norovirus* with which we have been supplied are the results of the monthly assays for the presence or absence of the virus *in oysters* taken from the oyster farm in the North Channel. The numbers present in oyster tissue have not been determined. Since the minimum infective dose is one to ten viral particles, it is not necessary to determine the numbers present when food safety is the primary concern. In the scientific literature we know of only one comparison[98] with data when numbers in oyster tissue are available.

Oysters bio-accumulate viruses from their aquatic environment by a factor of 10 to 1,000. The associated ambient concentration may lie below the detection limit of the PCR method of measurement, the technique of choice at present among

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[98] Pommepuy, M. et al. "Fecal contamination in coastal waters: An engineering approach" Book chapter (p331-359) in Oceans and Health: Pathogens in the Marine Environment. Springer 2006. http://www.springerlink.com, http://www.ifremer.fr/docelec

environmental virologists. We know of no model comparison in the international literature against concentrations of *Norovirus* in ambient water.

In the absence of (a) epidemiological data, and (b) numbers bio-accumulated, a comparison of predicted concentrations of *Norovirus* with measured concentrations in either water or oyster tissue in Cork Harbour is not possible at this time.

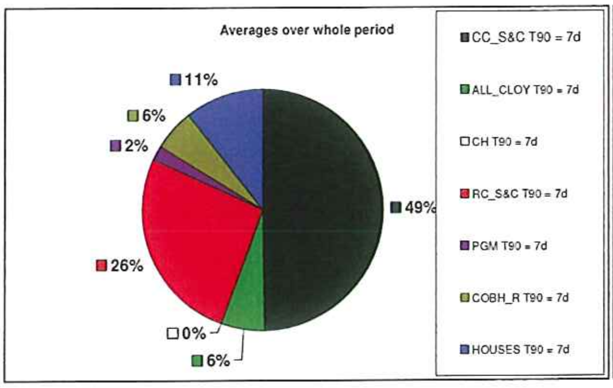
Consequently, our approach may be described as a method of thinking about the problem of relative contamination, starting from the simplest assumptions.

The two models presented in this report are the Roches Point (RP) model and the Old Head (OH) model. They are well calibrated against measurements of water level, current speed and direction for a number of locations within the harbour.

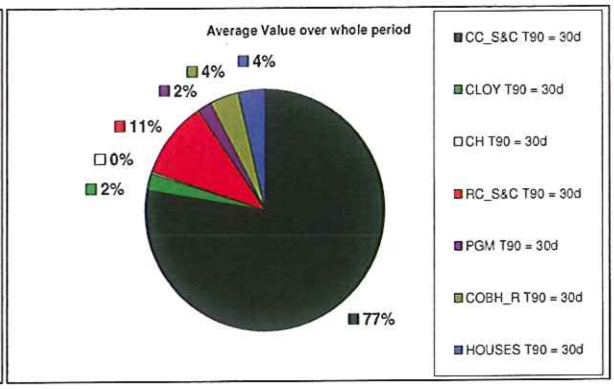
The models have been used to determine the relative contribution of eleven sources of contamination in the harbour. The twenty day pulses of *Norovirus* discharged at each location are independent of each other. In order to compare them they are shifted to a common time axis, where they are added together to determine the relative contribution of each irrespective of when they occur in winter or summer in each of the periods listed in the table below.

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

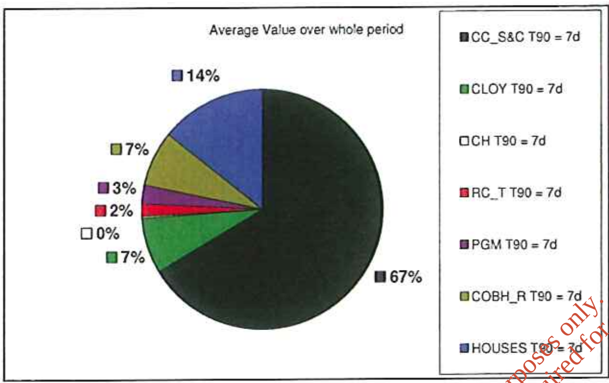
The pie charts illustrating the relative contributions for each of the six cases, as presented in Chapter 5, are shown on the next page.



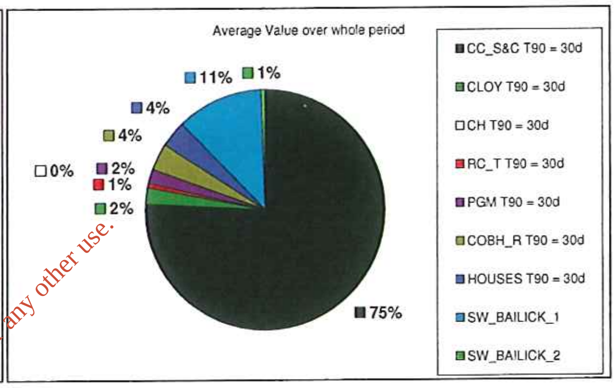
CASE 1 - summer



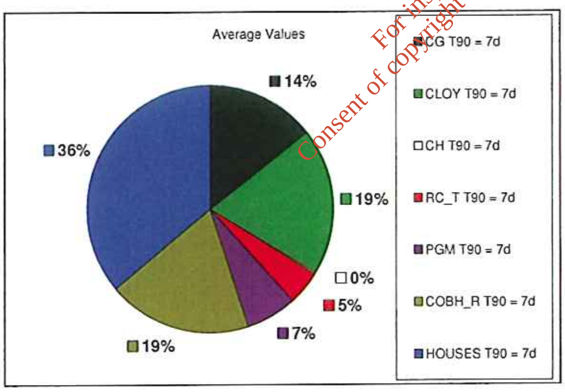
CASE 2 - winter



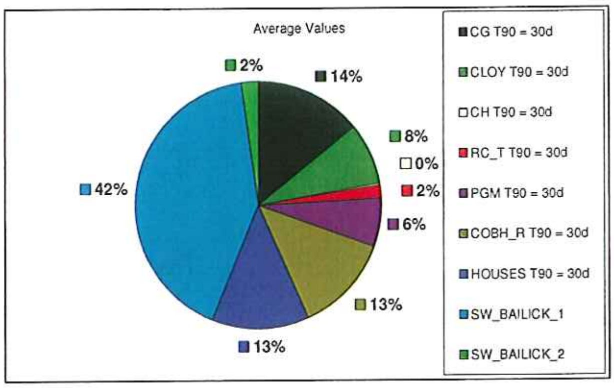
CASE 3 - summer



CASE 4 - winter



CASE 5 - summer



CASE 6 - winter

8.2 Conclusions

The conclusions 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 within the Harbour, from Cork City to the mouth at Roches Point, can contaminate the oyster farm with model viruses 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 wastewater treatment plants that serve Cork City and Midleton. In each period we distinguish between model winter conditions (T90 of 30 days and storm overflows) and model summer conditions (T90 of 7 days and NO storm overflows). 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 model oyster farm, through Belvelly Channel, especially under conditions of 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 our assumption that secondary treatment removes 95% of organic matter and consequently the same percentage of model viruses. 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 under winter conditions.

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 from Bailick 1 and Bailick 2 used in this report 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.

10. A sensitivity analysis of the model, varying the assumptions and parameters on which it depends, showed that the above conclusions remain unchanged, except

    a. During the model winter conditions i.e. slow decay of viruses and storm overflows from Midleton, the treated discharge from Carrigrennan can be comparable to the screened and diluted discharges from Bailick 1 and 2 in contaminating the model oyster farm [numerical result from model];

    b. During the model winter conditions, when a salinity feedback on momentum is included, the contributions from Cork City (both treated and untreated) to the contamination of the model oyster farm may increase, while the contribution of the untreated discharge at Rathcoursey (period 1) may remain the same [numerical result from model].

    c. When *Norovirus* is adsorbed on suspended sediment, discharges further away from the oyster farm may become less important because of possible sequestration of viruses in stationary bottom sediment; these processes are controlled by rates of sedimentation, resuspension, adsorption and desorption; insufficient data are available to make a secure model [qualitative statement].

11. The study underlines the importance of the civil works planned (1) to cater for a greater population in Midleton by increasing the capacity of the waste water treatment plant and, (2) reconstructing the sewers to ensure no infiltration of groundwater and very rare discharges of storm runoff.

8.3 Recommendations

We make the following recommendations.

1. An EAS (early alert system) system of the risk of *Norovirus* contamination of oysters in shellfish producing waters in Cork Harbour should be developed and deployed.
2. The real-time EAS (early alert system) should combine information from public-health authorities, hospitals, medical practitioners, infirmaries in institutions, etc., the Sanitary Services divisions of local authorities, meteorological and hydrological services, and appropriate computer models of sewers, treatment plants, outfalls and receiving waters. It should be continuously accessible on the web to all stakeholders.
3. The most important first step in the EAS (early alert system) is the confirmation and extension of the real-time ISO 14,001 SCADA (Supervisory Control and Data Acquisition) system that is used to monitor and control the secondary waste treatment plant at Midleton. It should be extended to cover
    a. each holding tank (water level) and pump (discharge) at Bailick 1, Bailick 2, and Ballinacurra,
    b. the tidal clock (on-off) and holding tank (water level) at the Ballinacurra diffuser and outfall,
    c. storm-water overflows that depend on storm run-off and infiltration of groundwater into sewers;
    d. the beneficial impact of future improvements to the Midleton sewerage system, such as the planned relining of the main sewer

to Bailick 1, the provision of additional storage for storm water, and the expansion of the treatment plant.

e. All SCADA measurements should be published on the EAS web-site every 15 minutes and subject to ISO 14,001 auditing and archiving.

4. The extended Midleton SCADA system should also include new telemetered measuring instruments. For example:

   a. Two meteorological stations measuring every 5 minutes, wind speed and direction, rainfall, temperature, short-wave radiation (UV band), at a station located at the sewage treatment plant, and at a second station located, for example at the potable water treatment plant,

   b. Digital piezometers measuring groundwater levels at three locations in the central low-lying area of Midleton in order to quantify infiltration into sewers (sampling interval to be determined),

   c. The discharge rate of the Balinacurra River,

   d. Tidal water level at the emergency overflow at Bailick 1,

   e. Water level, turbidity, temperature and salinity at two points at each end of the North Channel behind Cobh Island, and at the mouth of Cork Harbour.

5. The extended Midleton SCADA system, and the corresponding extended SCADA systems at the Carrigrennan Wastewater Treatment Plant and at the proposed Outer Harbour Wastewater Treatment Plant, should be integrated with appropriate computer models of sewers, treatment plants, pumping stations, outfalls and receiving waters to form a complete web-based EAS (early alert system) system of the risk of *Norovirus* contamination of oysters in shellfish producing and recreational waters in Cork Harbour.

6. The complete EAS (early alert system) will require telemetered instrumentation at a small number of locations in the harbour producing data *inter alia* on river inflows, temperature, salinity, turbidity, currents (speed and direction) and water level. A new bathymetric and sediment survey of the North Channel behind Great Island and the tidal reaches at Midleton will also be required.
7. In the event that the operational EAS, or modelling studies of the operation of a prospective EAS, advise against oyster harvesting for a substantial fraction of each year, or if there are episodes of *Norovirus* contamination when no alert is posted, further measures, such as containment of treated effluent in managed inter-tidal wetlands, should be evaluated.
8. The possible discharge of untreated sewage from the houses around the North Channel requires further examination.
9. The weekly setting and daily operation of the tidal clock at Rathcoursey should be subject to automatic audit and fail-safe operation.
10. High-frequency (every 30 to 40 minutes) water quality measurements should be made in the holding tank at Rathcoursey controlled by the clock.
11. Data, from 2000 to 2004, on the inactivation of indicator organisms by UV treatment at the Midleton WWTP show that it can be highly effective. However, this does not establish the efficiency of the UV apparatus for inactivation of *Norovirus* particles, which are of colloidal dimension. *Norovirus* particles, may be shaded from UV irradiation by the much larger bacteria, whether they are alive or dead. Appropriate model viruses, easily measured with PCR, would provide a more compelling estimate of inactivation efficiency.
12. Measure the actual numbers of *Norovirus* in oyster tissue, not simply presence or absence.
13. Collect epidemiological data on outbreaks of Winter Vomiting Disease.

14. Critically examine the current engineering paradigm for the disposal of treated effluent in coastal waters used for growing shellfish[99]: "dilution is the solution". This paradigm is optimal when the dose-response relationship is linear and the distribution of the affected organism is spatially uniform. This is not optimal when the dose-response relationship exhibits saturation, as is the case with *Norovirus,* and the distribution of the affected organism is spatially uniform. One alternative is the lazaretto paradigm: "containment is the solution".
15. The engineering works that are planned for the sewerage and treatment system for Midleton (1) to cater for the expansion of Midleton, and (2) to prevent the very large infiltration of groundwater, and stormwater runoff, into the sewers degrading the performance of the whole system, should be carried out as soon as possible.

[99] Or for water contact sports.

Appendix A Mathematical Equations

The mathematical equations used in MIKE 21 are described in this appendix.

A.1 MIKE 21 – Hydrodynamic module

The modelling system used in this study is MIKE 21. This professional engineering numerical modelling system simulates the hydrodynamics, water quality, waves and sediment transport of lakes, estuaries, coastal seas and other water bodies. The hydrodynamic (HD) module is the nucleus of the MIKE 21 modelling system and forms the basis for other modules which may simulate different phenomena such as Water Quality and the non-cohesive sediment transport. For this study the add-on Advection-Dispersion (AD) module has been used to simulate the release and advection of Norovirus in Cork Harbour.

MIKE 21 simulates the water level and unsteady free surface flow in two dimensions in response to a variety of forcing functions. The water levels and flows are resolved on a square or rectangular grid covering the area of interest. As with all two-dimensional models, MIKE 21 assumes that the fluid consists of a single layer (i.e. stratification of the body of water is neglected) with an average velocity throughout the depth of the water column of each individual grid square. It solves the full time-dependant non-linear equations of continuity and conservation of momentum. These equations are integrated over the vertical to describe the flow and are given as:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t}$$

Equation 8-1 Conservation of mass equation

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial x}$$

$$+\frac{gp\sqrt{p^2+q^2}}{C^2\cdot h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial x}(h\tau_{xx})+\frac{\partial}{\partial y}(h\tau_{xy})\right]-\Omega_q$$

$$-fVV_x+\frac{h}{\rho_w}\frac{\partial}{\partial x}(p_a) = 0$$

Equation 8-2 Conservation of momentum equation (x-direction)

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial y}$$

$$+\frac{gq\sqrt{p^2+q^2}}{C^2\cdot h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial y}(h\tau_{yy})+\frac{\partial}{\partial x}(h\tau_{xy})\right]+\Omega_p$$

$$-fVV_y+\frac{h}{\rho_w}\frac{\partial}{\partial y}(p_a) = 0$$

Equation 8-3 Conservation of momentum equation (y-direction)

where :

h(x,y,t) = water depth (m)

d(x,y,t) = time varying water depth (m)

ζ(x,y,t) = surface elevation (m)

p,q (x,y,t) = flux densities in x- and y-directions ($m^3/s/m$)

C(x,y) = Chezy Resistance ($m^{1/2}/s$)

g = acceleration due to gravity (m/s^2)

f(V) = wind friction factor

V, V_X, V_Y (x,y,t) = wind speed and components in x- and y-direction (m/s)

Ω (x,y) = Coriolius parameter, latitude dependent (s^{-1})

p_a(x,y,t) = atmospheric pressure ($kg/m/s^2$)

ρ_W = density of water (kg/m^3)

x,y = space coordinates (m)

t = time (s)

τ_{XX}, τ_{XY}, τ_{YY}, = components of effective shear stress

MIKE 21 utilises an Alternating Direction Implicit (ADI) finite difference scheme of second-order accuracy. This scheme results in a tridiagonal system of equations for each grid line in the model. The solution is obtained by inverting the tridiagonal matrix using the double sweep algorithms, an accurate form of Gauss Elimination.

A.2 MIKE 21 – Advection Dispersion Module

The Advection-Dispersion module solves the advection-dispersion equation for dissolved or suspended substances in two dimensions. This is in fact the mass conversation equation. Discharge quantities and compound concentrations at source and sink points are included together with a decay rate. The equation is given as:

$$\frac{\partial}{\partial t}(hc)+\frac{\partial}{\partial x}(uhc)+\frac{\partial}{\partial x}(vhc)=\frac{\partial}{\partial x}\left(h\cdot D_x\cdot\frac{\partial c}{\partial x}\right)$$

$$+\frac{\partial}{\partial y}\left(h\cdot D_y\frac{\partial c}{\partial y}\right)-F\cdot h\cdot c+S$$

Equation 8-4 The Advection-Dispersion equation

where :

c = compound concentration (arbitrary units)

u, v = horizontal velocity components in the x, y directions (m/s)

h = water depth (m)

D_X, D_Y = dispersion coefficients in the x, y directions (m^2/s)

F = linear decay coefficient (sec^{-1})

S = Q_S, (c_S-c)

Q_S = source/sink discharge ($m^3/s/m^2$)

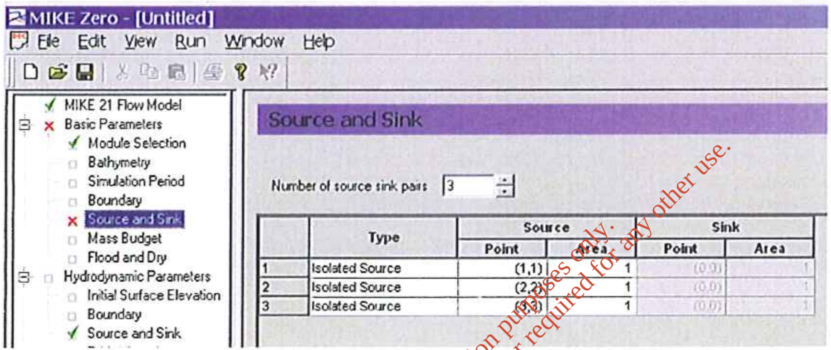
C_S = concentration of compound in the source/sink discharge

Information on u, v and h at each time step is provided by the hydrodynamic module.

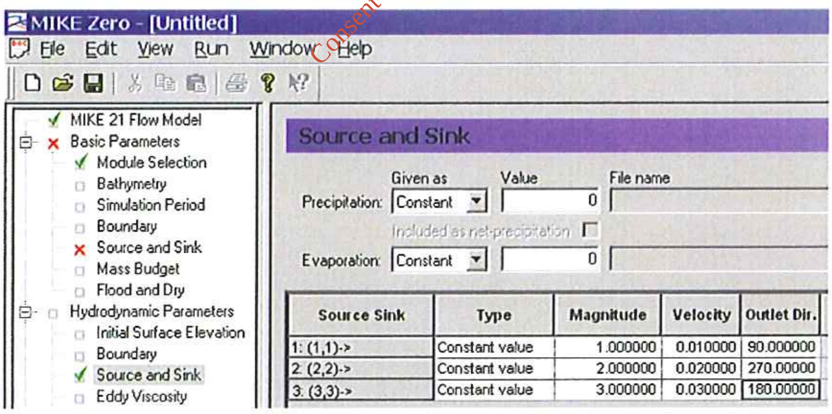
Appendix B Superposition

Testing Mike21 for superposition and scaling

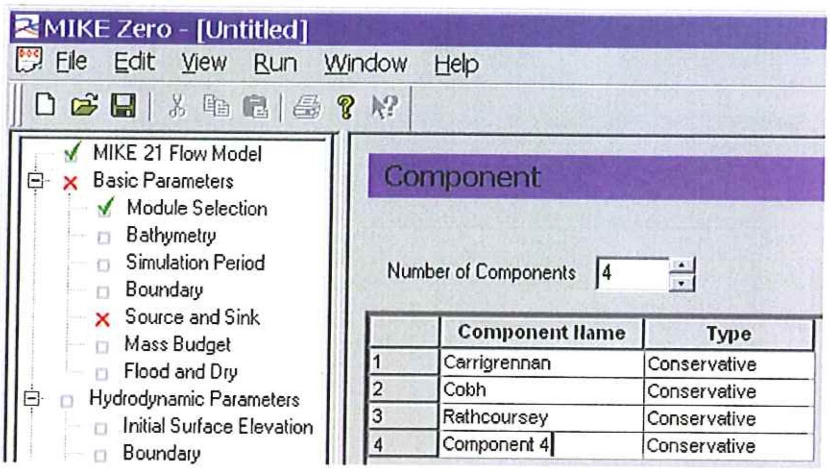
In the basic parameter section of the Mike21 input editor, we define three water sources, one for each of the three carrier flows. They are located at the model coordinates of the discharges from Carrigrennan, Cobh and Rathcoursey (untreated) respectively. In the picture below they are at coordinates (1,1), (2,2) and (3,3) for illustration.



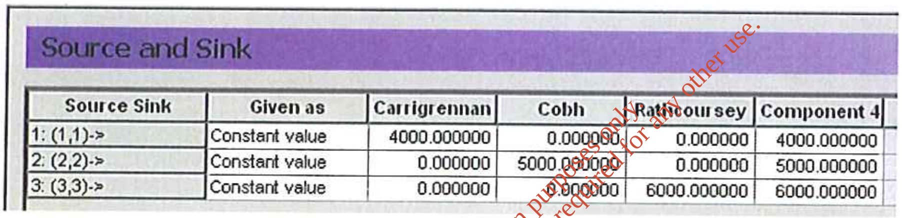
In the hydrodynamic parameters part we define the corresponding carrier flows, velocities and directions.



In the advection-dispersion parameters we define four water quality components.



In a separate window we give them their respective concentrations, for example, 4000, 5000 and 6000, at each outfall respectively. The first three components model each discharge in isolation. The fourth models their algebraic sum.


Source and Sink

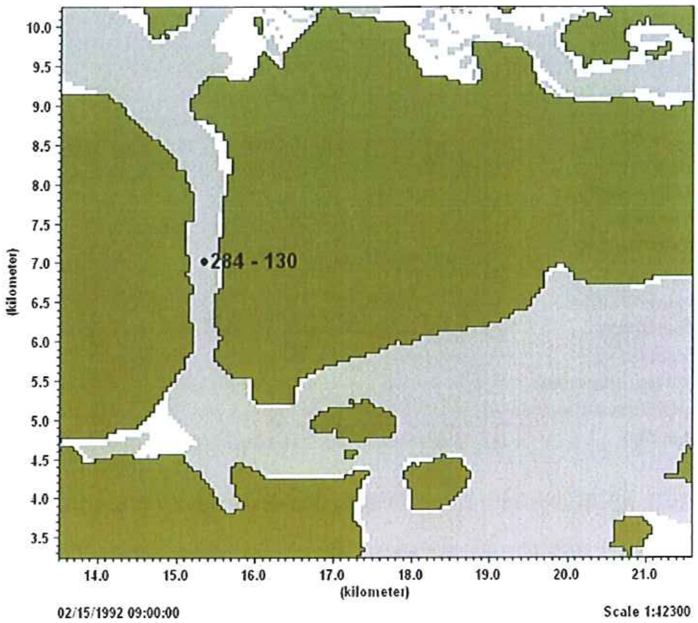
Source Sink	Given as	Carrigrennan	Cobh	Rathcoursey	Component 4
1: (1,1)->	Constant value	4000.000000	0.000000	0.000000	4000.000000
2: (2,2)->	Constant value	0.000000	5000.000000	0.000000	5000.000000
3: (3,3)->	Constant value	0.000000	0.000000	6000.000000	6000.000000

The calculations of the output time-series at all points in the model domain rely on the same, common underlying hydrodynamics.

The principle of superposition, based on the linearity of the advection-dispersion equation, asserts that component 4 will be found to equal the sum of the three components for Carrigrennan, Cobh and Rathcoursey, respectively, at all points and at all times in the model domain. It is also clear that scaling by an integer is a special case of superposition.

The following figures verify this universal result in a particular case with decay. The RP model, as presented in Chapter 5, is used to demonstrate Superposition with four separate discharges:

1. CG,
2. COBH_R,
3. RC_S&C,
4. CG + COBH_R + RC_S&C all together (i.e. similar to PGM in Chapter 5)



The extracted timeseries for the three separate outfalls are plotted in Fig. 8.1. We can see that CG and COBH_R have the highest concentrations while RC_S&C is only contributing a very small amount.

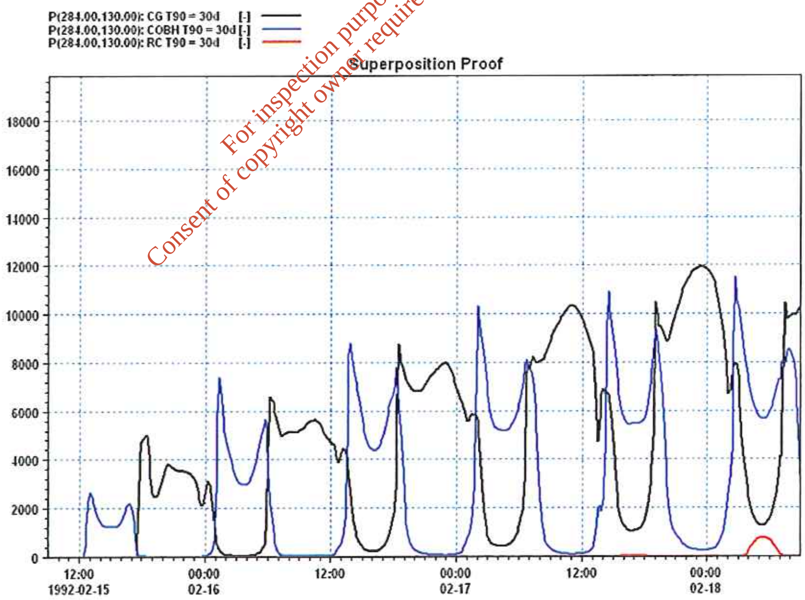


Fig. 8.1 No of Viral Particles for the 3 individual components

If these timeseries are exported to a spreadsheet they may be added together as a single timeseries. This is plotted, with the three individual timeseries, in Fig. 8.2.

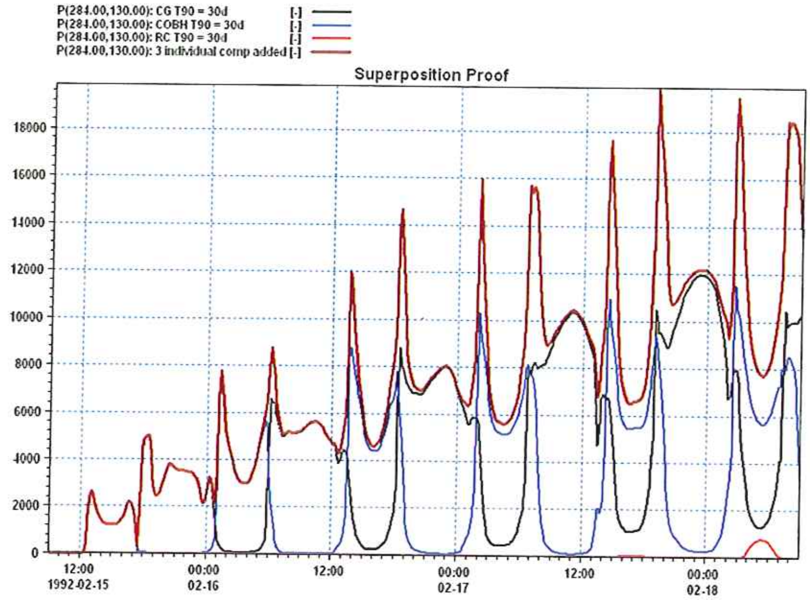


Fig. 8.2 Three individual components added together

If we then extract a timeseries of concentration from the same point of component 4 (which is the sum of CG, RC_S&C and CC_S&C) we find that the plot appears to contain a single timeseries (Fig. 8.3). There are however two timeseries contained in this figure but they appear as one because they are equal. This demonstrates the principle of superposition: the combined effect of many discharges acting together is identical to the sum of their individual effects when they are regarded separately. If we zoom in on the graph (Fig. 8.4) we can distinguish between the two timeseries. We can see that the difference is approximately 0.009%

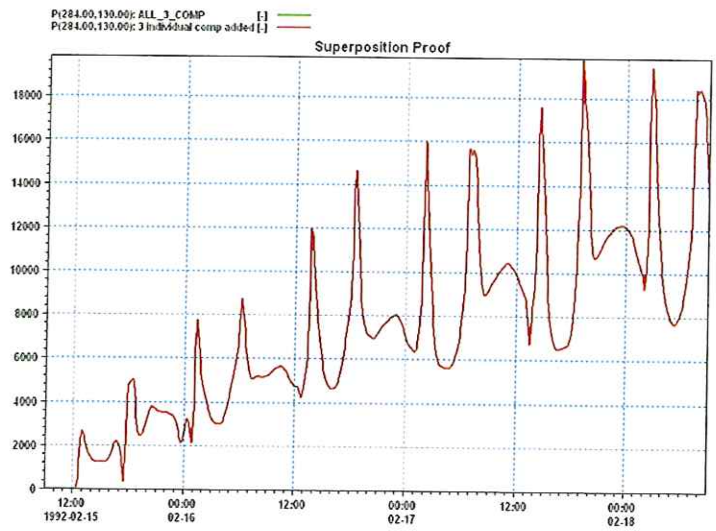


Fig. 8.3 Single Component and the added timeseries plotted together

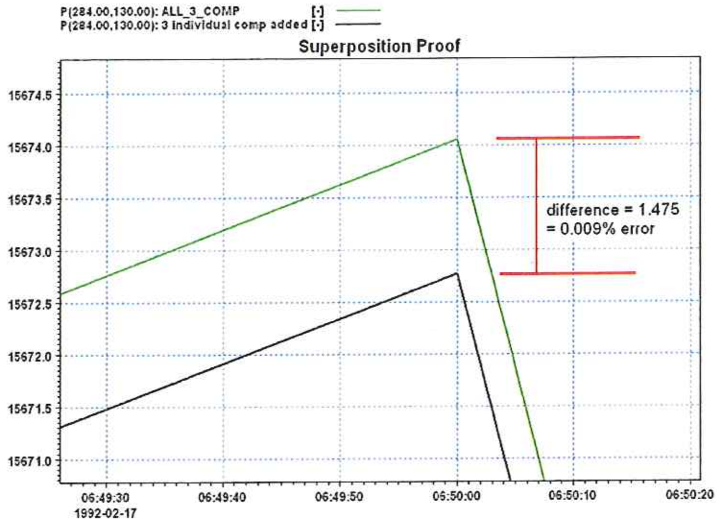


Fig. 8.4 Difference in timeseries

In a similar manner we can verify scaling with a factor, which is not an integer. This is illustrated in the following figures.

We can demonstrate it by extracting the timeseries of concentration from a component with a reduced number of viral particles (in this case CG with 16,666,666 viral particles).

This timeseries may be exported to a spreadsheet and multiplied by 3. Both of these timeseries are plotted in (Fig. 8.6)

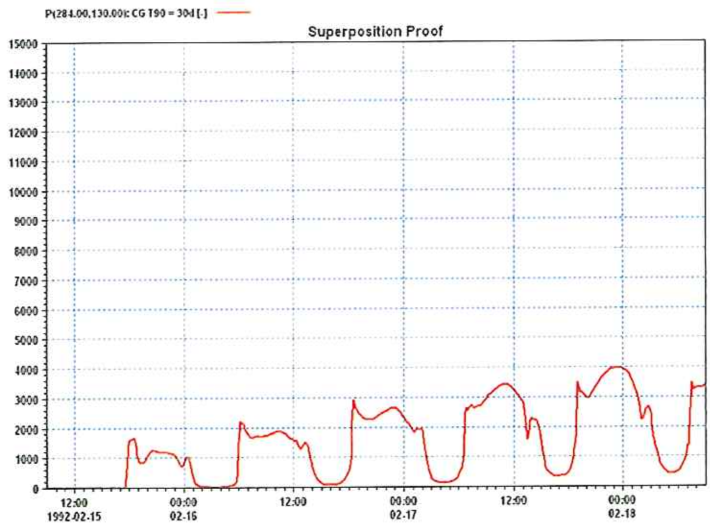


Fig. 8.5 CG timeseries – 16,666,666 viral particles per cubic metre of sewage

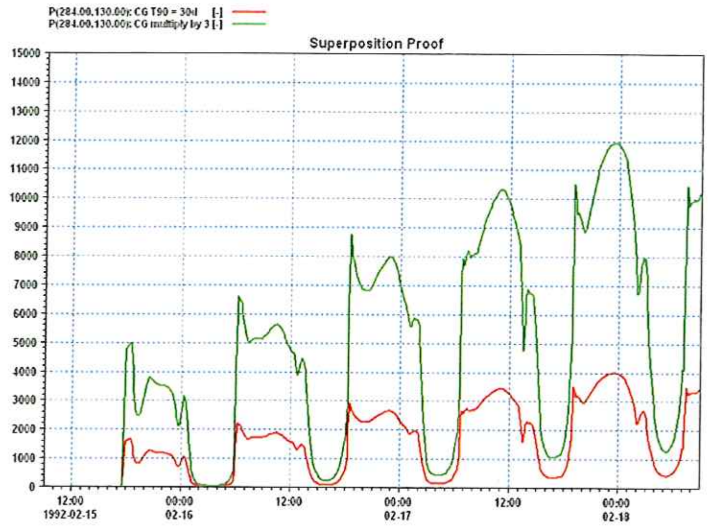


Fig. 8.6 CG – input divided by 3 and rescaled by multiplying with 3

If we then plot the timeseries which has been multiplied by 3 against the original CG we can see that they are identical (Fig. 8.7). This demonstrates the scaling property of superposition: the effect of multiplying, or scaling, any individual discharge by a constant positive number, x, is x times the concentration of viruses in the Harbour due to that discharge before scaling *i.e.* when x is one.

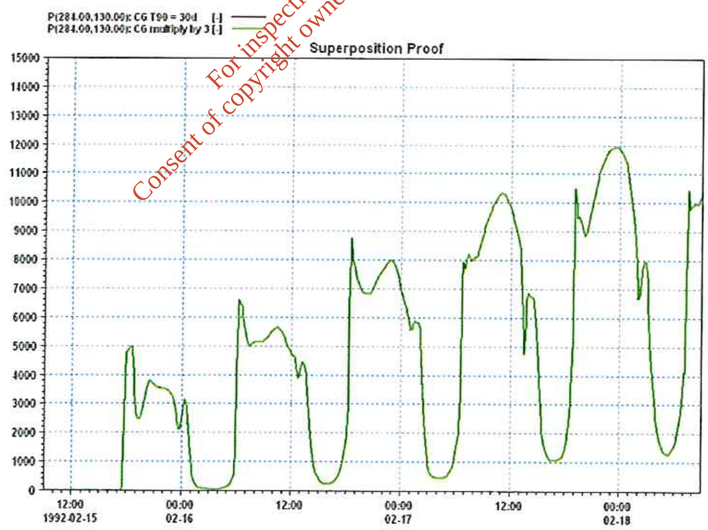
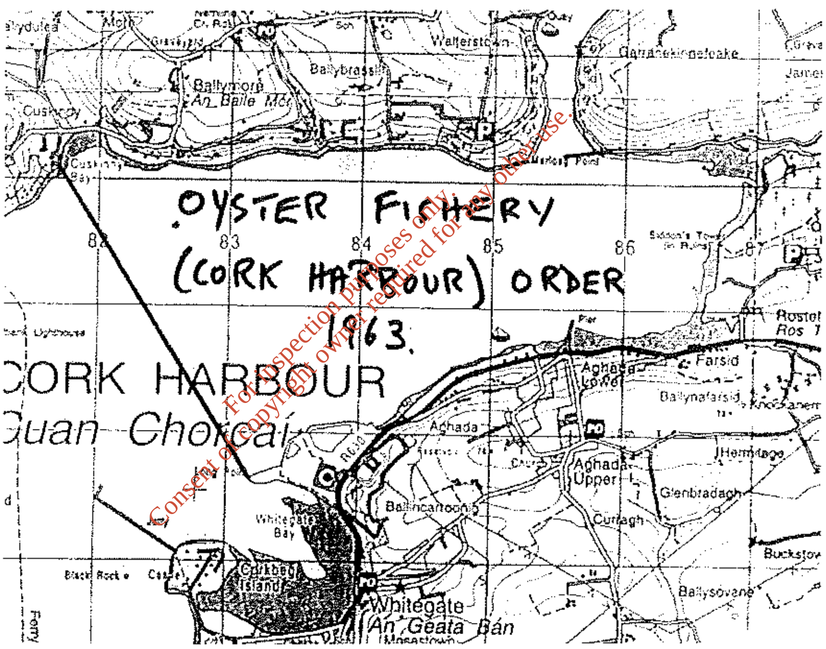


Fig. 8.7 Rescaled CG and Original plotted together

Appendix C The Outer Harbour

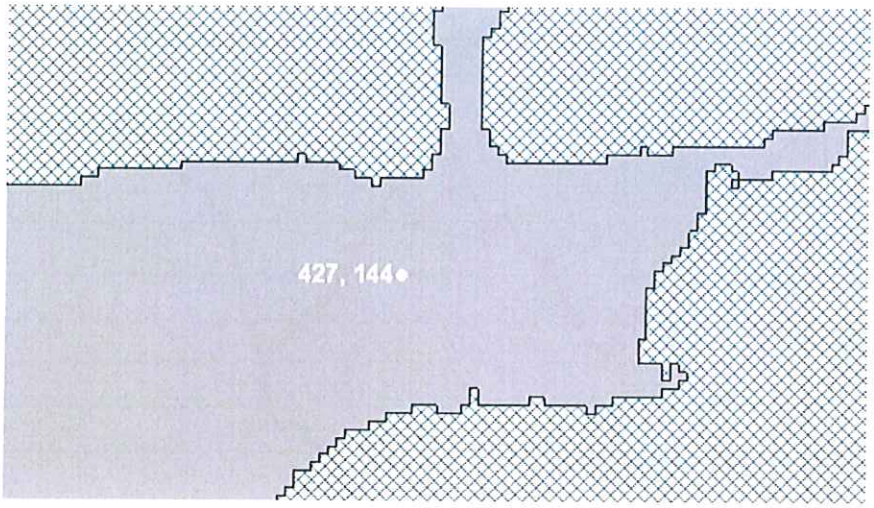
The extent of the concession in the outer harbour is described as "all that water to the East of a line from Long Point to Cuskinny House on Cobh. There are two groups of Trestles in the outer harbour. The first is at Saleen and the second are along the eastern shore of the harbour south of Siddons Tower (see figure below). Between the two sets there are 13km of trestles and coming off the Rostellan shore west for about a kilometre are underwater beds of native oysters[100]."



Concession in the Outer Harbour

The relative contribution of contamination in this region of the harbour is now presented. Data has been extracted from grid point (427, 144) in the 54m grid (see figure on following page). The presentation of the results follows the same format at in chapter 5.

[100] Personal Communication with the owner of the Oyster Farm



Location of grid point 427, 144 in the 54m grid

Period One, Summer Conditions

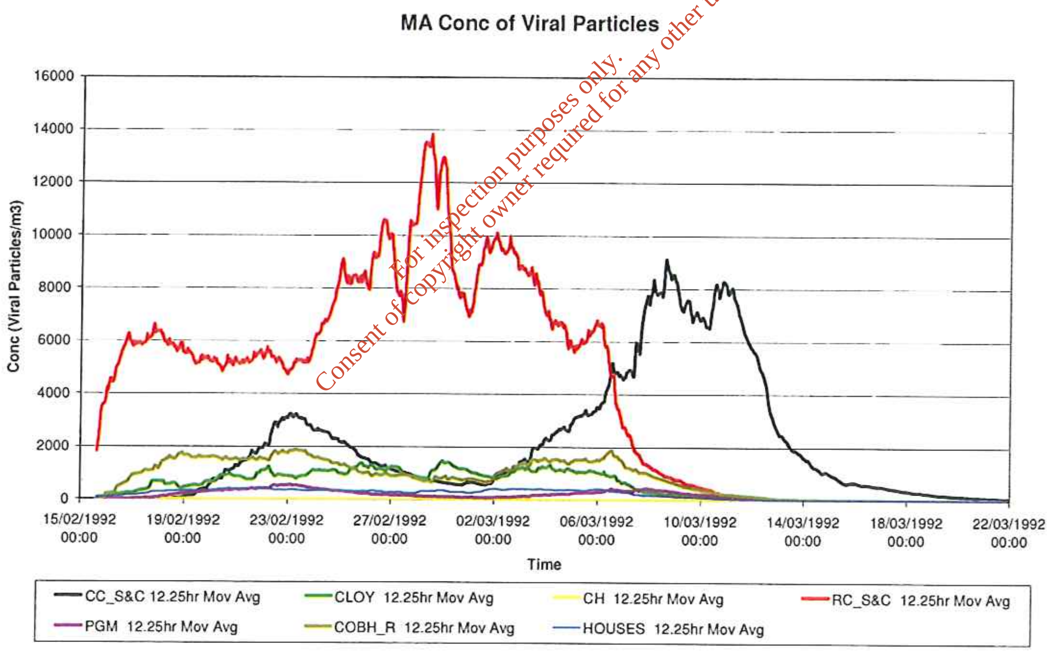


Fig. 8.8 CASE 1 - Moving Averages of Concentration

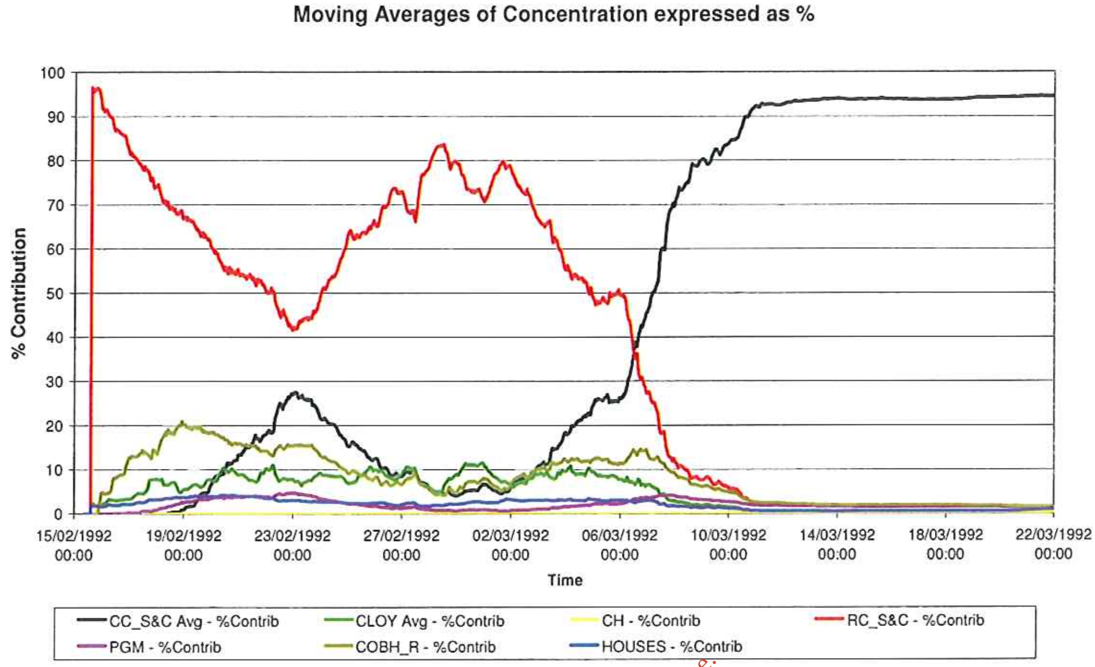


Fig. 8.9 CASE 1 – The Relative Contributions

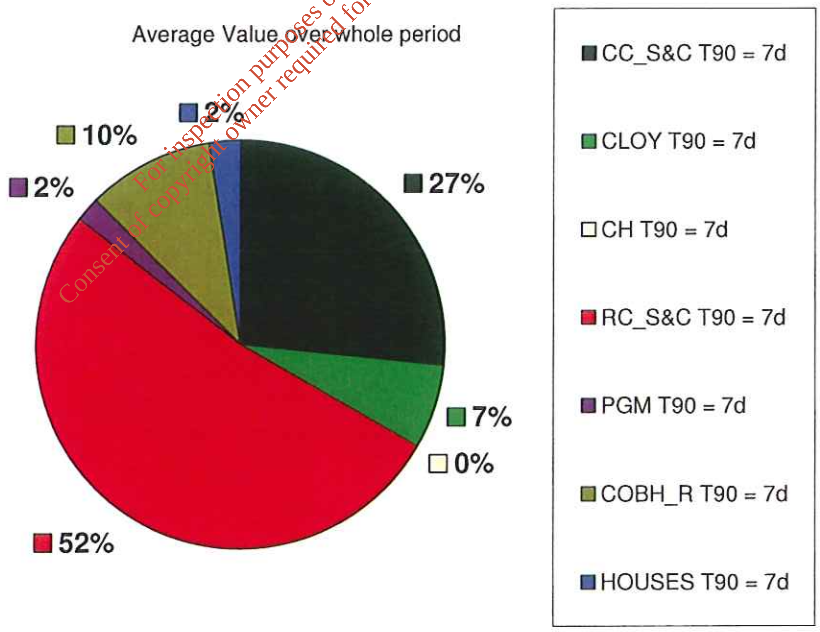


Fig. 8.10 CASE 1 – Average Concentrations – The Relative Contributions

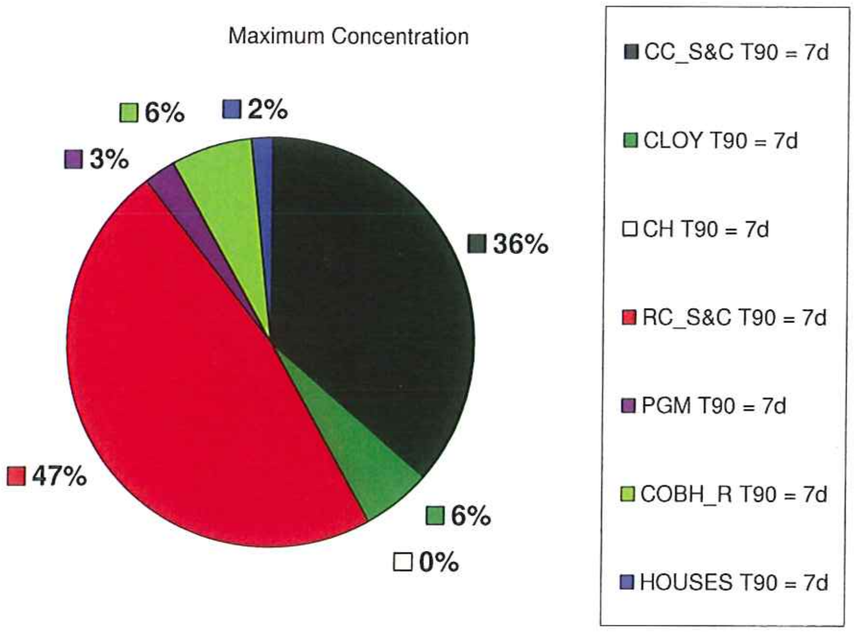


Fig. 8.11 CASE 1 – The Maximum Contributions

8.3.2 Case 2 – Period 1, Winter Conditions

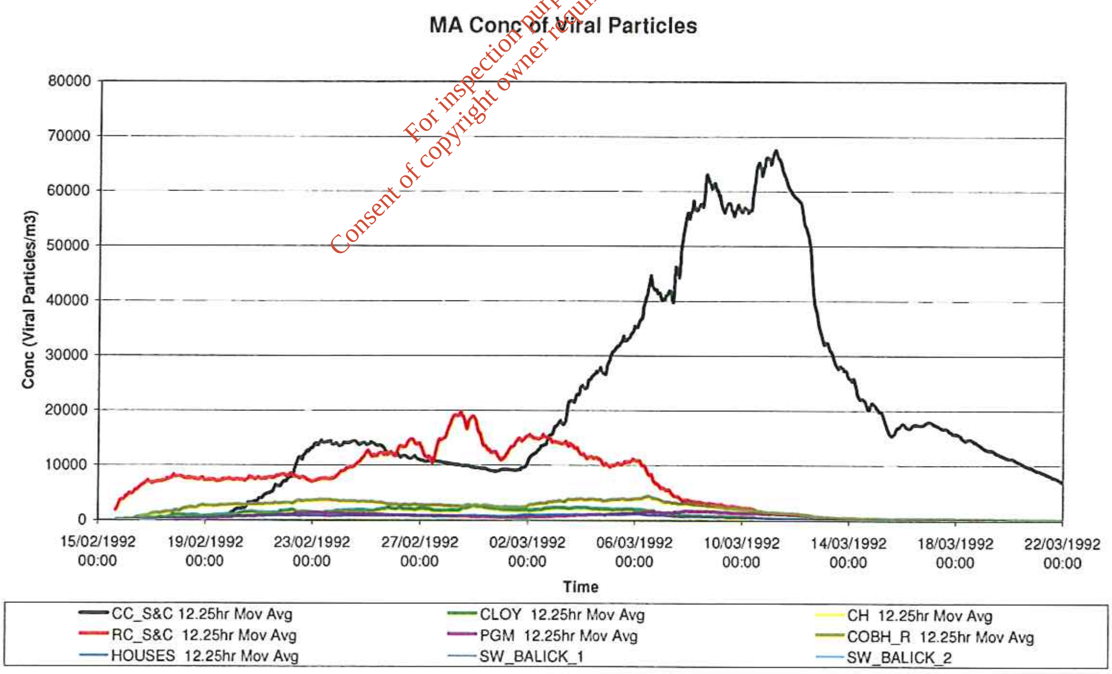


Fig. 8.12 – CASE 2 Moving Averages of Concentration

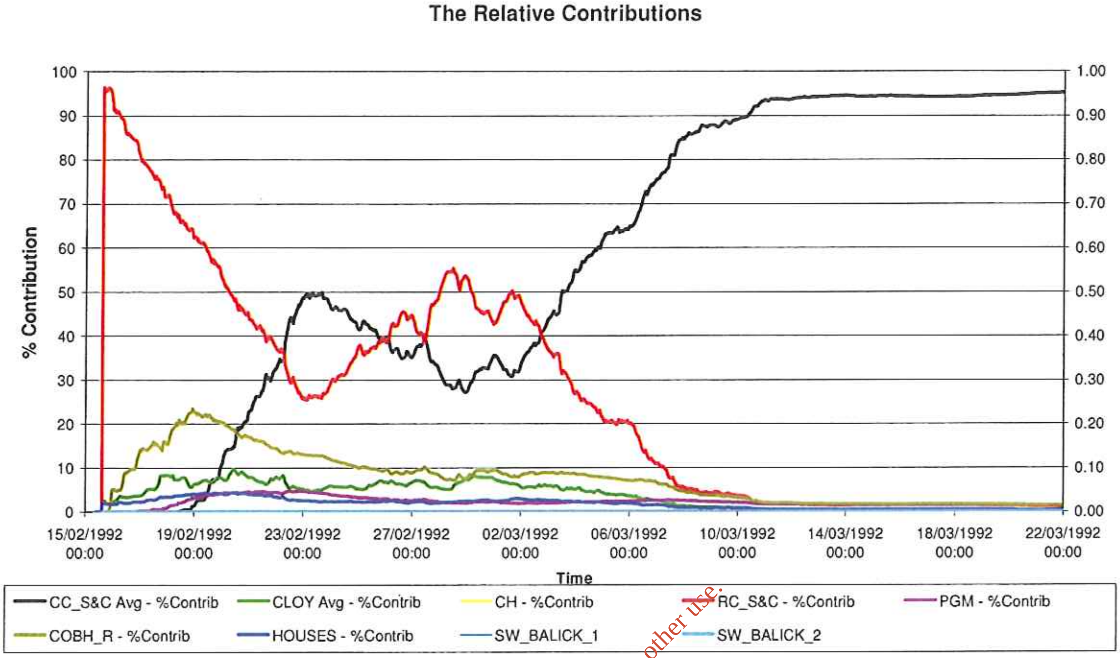


Fig. 8.13 CASE 2 – The Relative Contributions

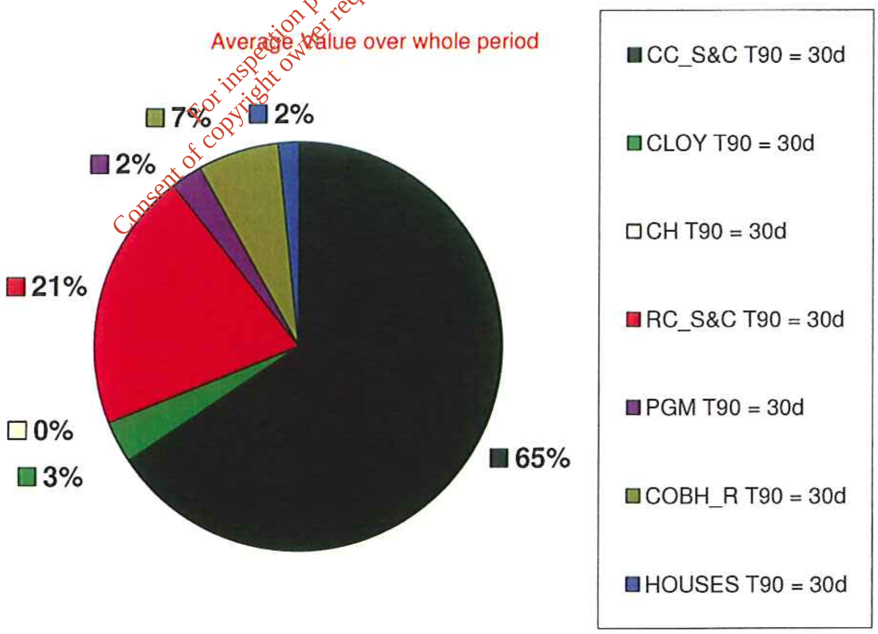


Fig. 8.14 CASE 2 – Average Concentrations – The Relative Contributions

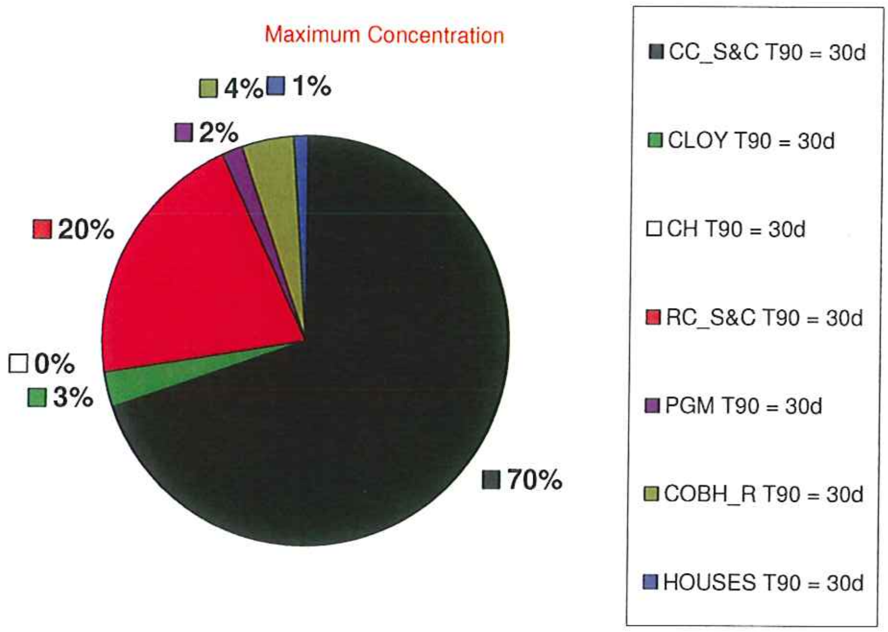


Fig. 8.15 CASE 2 – The Maximum Contributions

8.3.3 Case 3 – Period 2, Summer Conditions

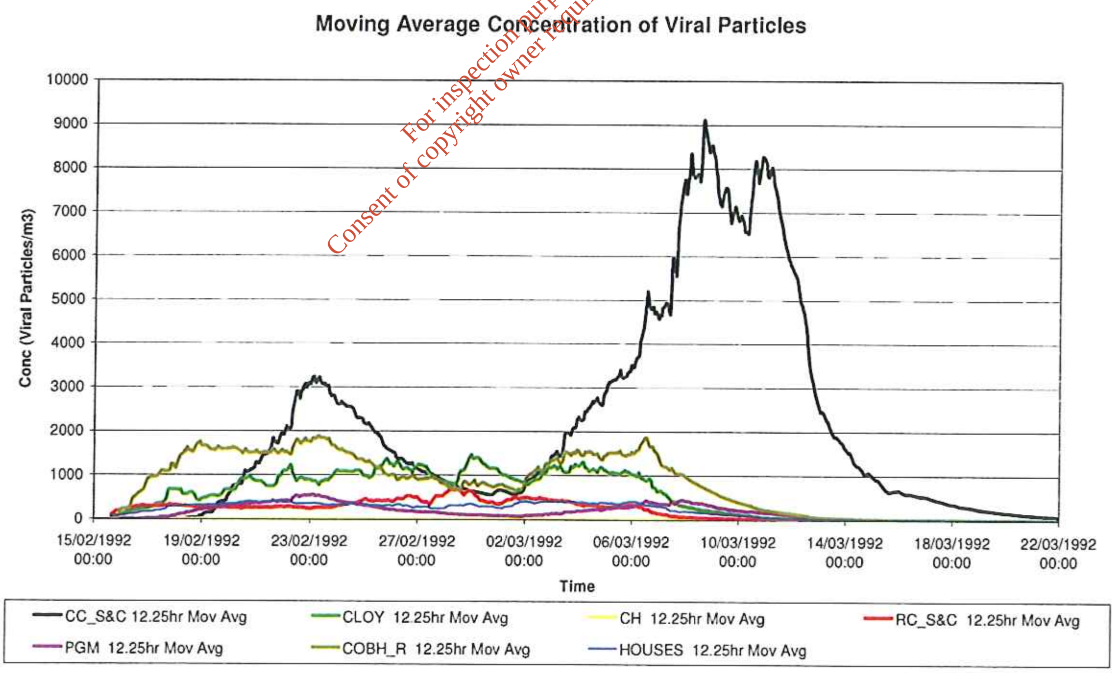


Fig. 8.16 CASE 3 – Moving Averages of Concentration

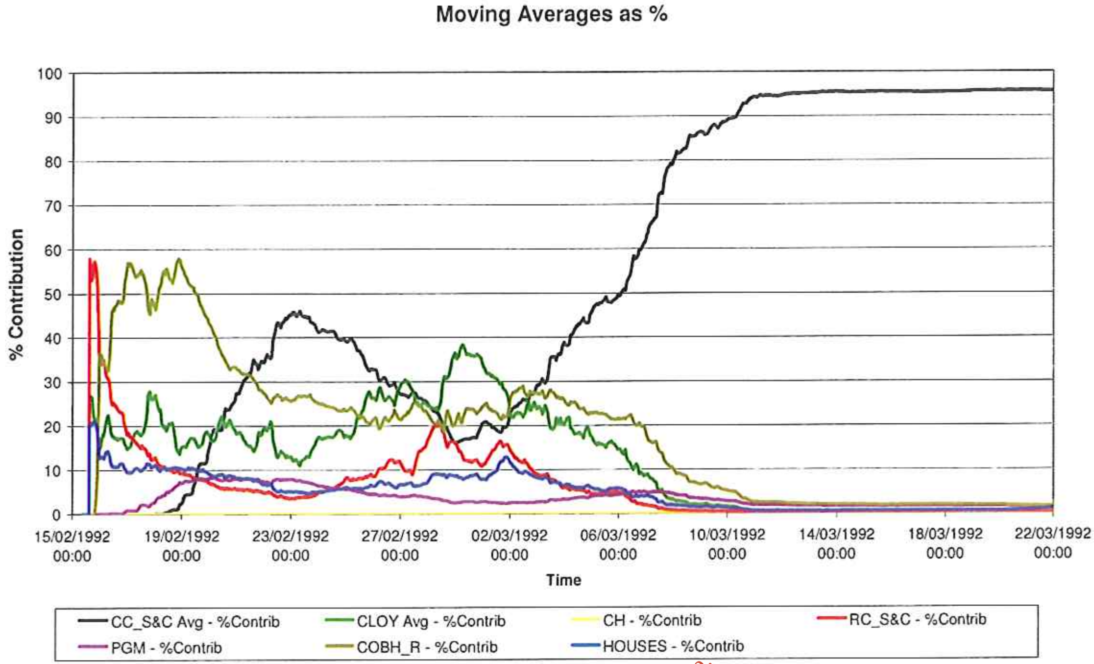


Fig. 8.17 CASE 3 – The Relative Contributions

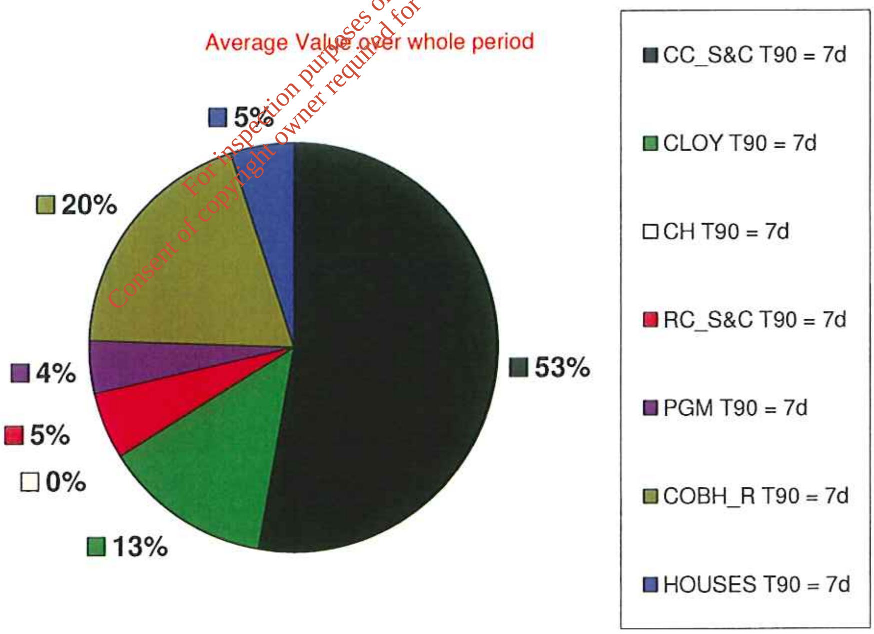


Fig. 8.18 CASE 3 – Average Concentrations – The Relative Contributions

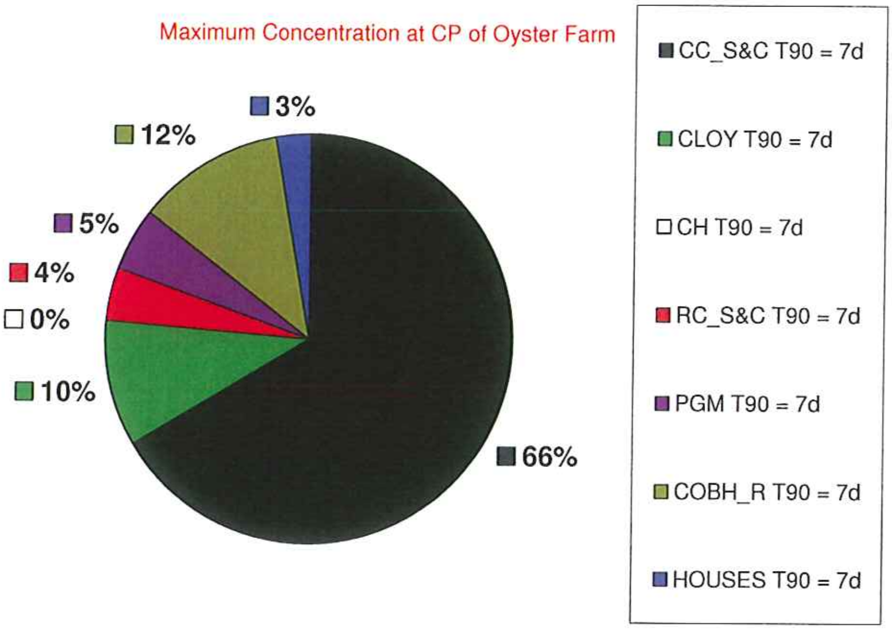


Fig. 8.19 CASE 3 – The Maximum Contributions

8.3.4 Case 4 – Period 2, Winter Conditions

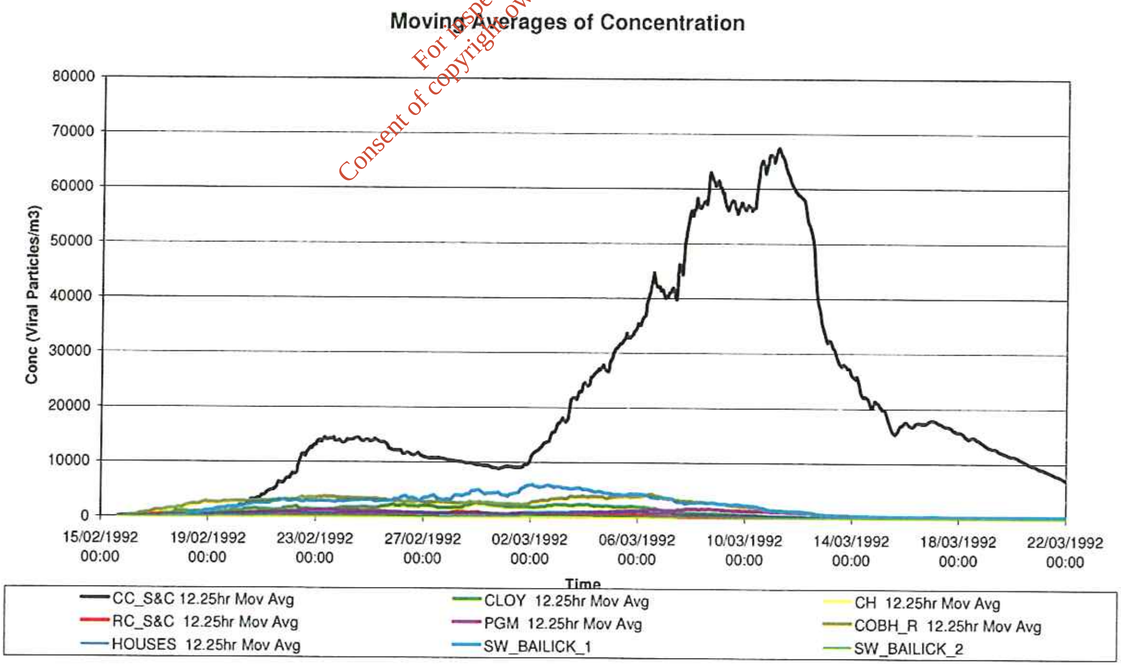


Fig. 8.20 Moving Averages of Concentration

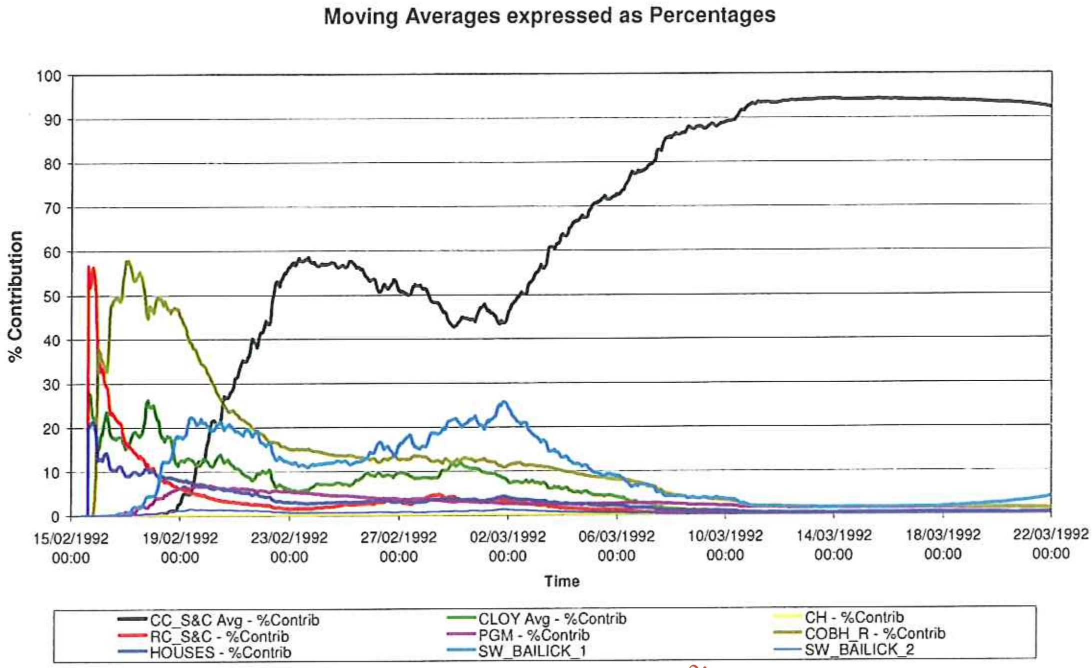


Fig. 8.21 The Relative Contributions

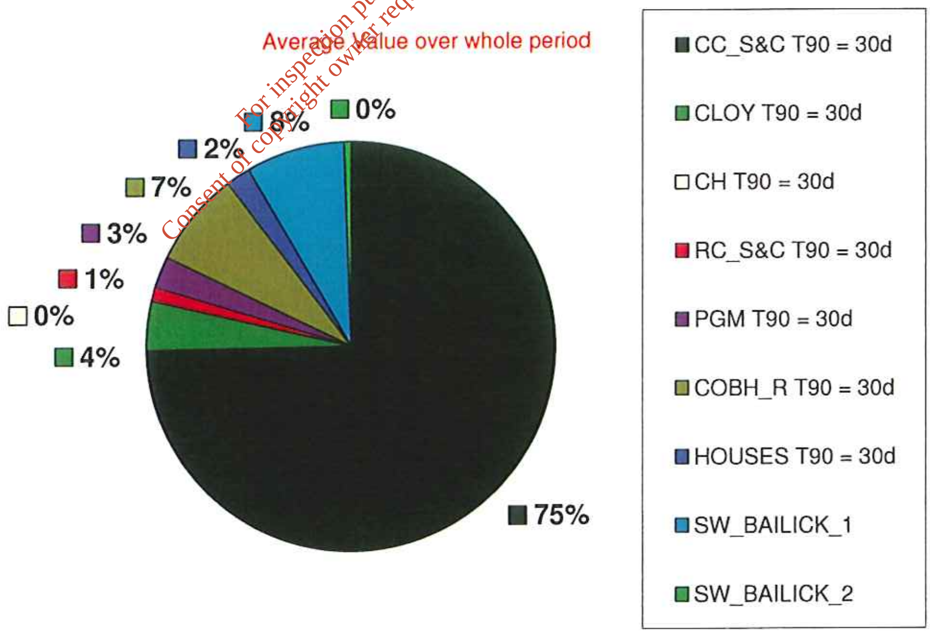


Fig. 8.22 Averages Concentrations – The Relative Contributions

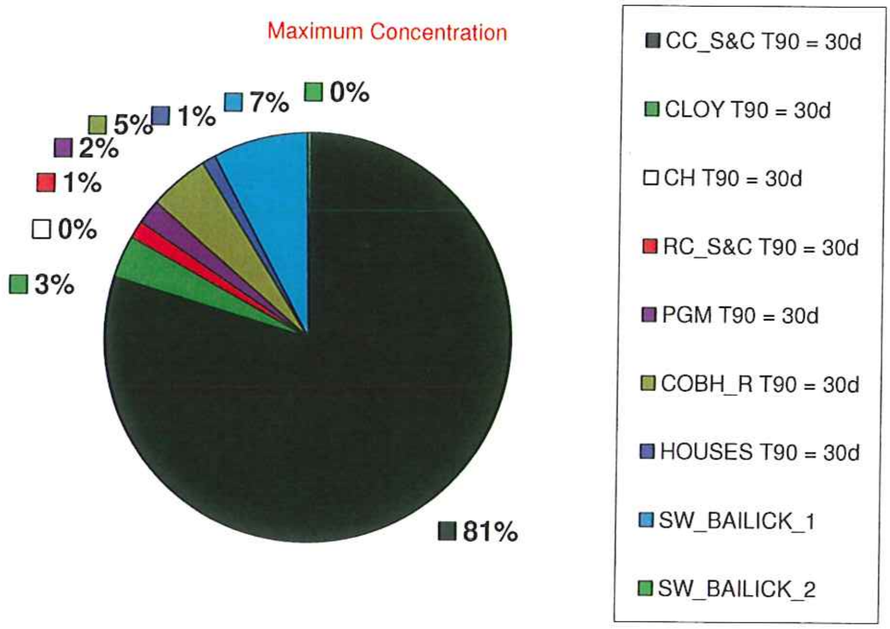


Fig. 8.23 Maximum Concentrations – The Relative Contributions

8.3.5 Case 5 – Period 3, Summer Conditions

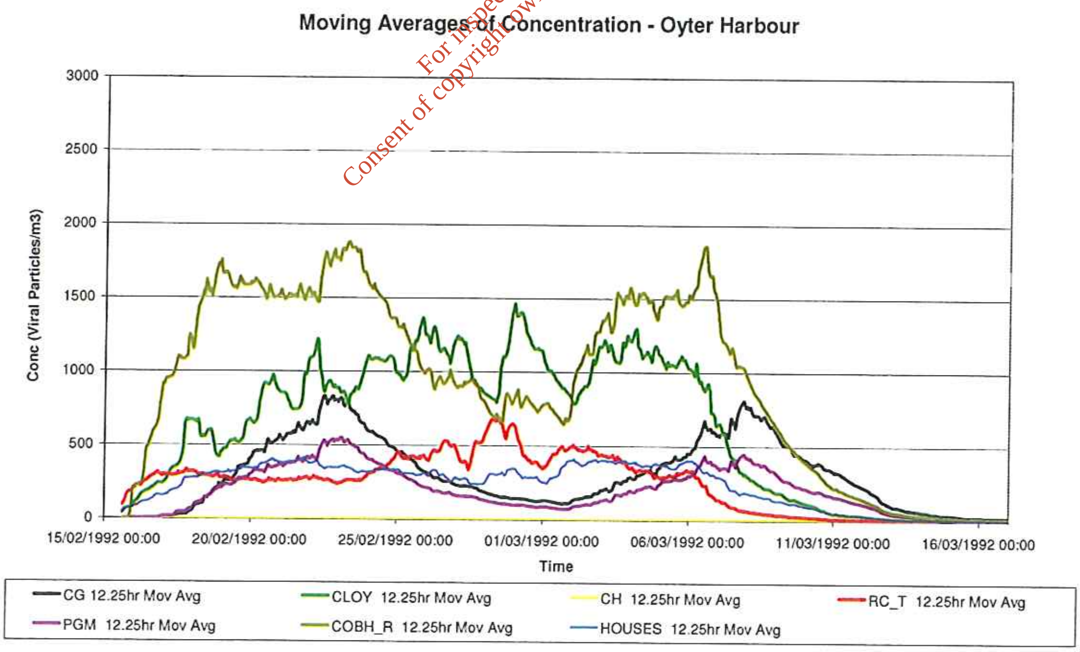


Fig. 8.24 CASE 5 – Moving Averages of Concentration

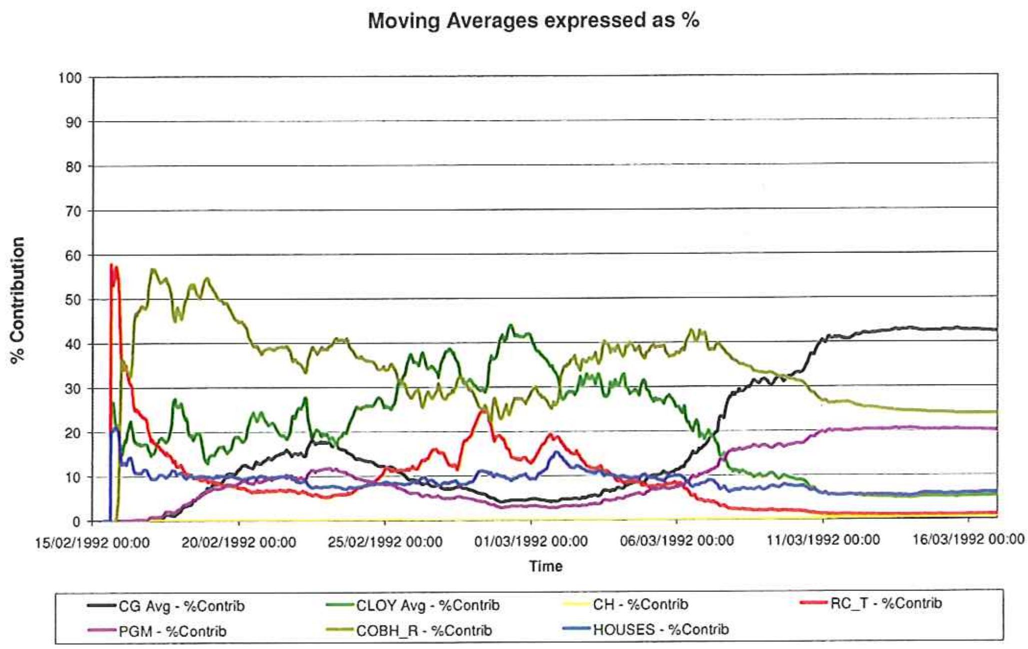


Fig. 8.25 CASE 5 – The Relative Contributions

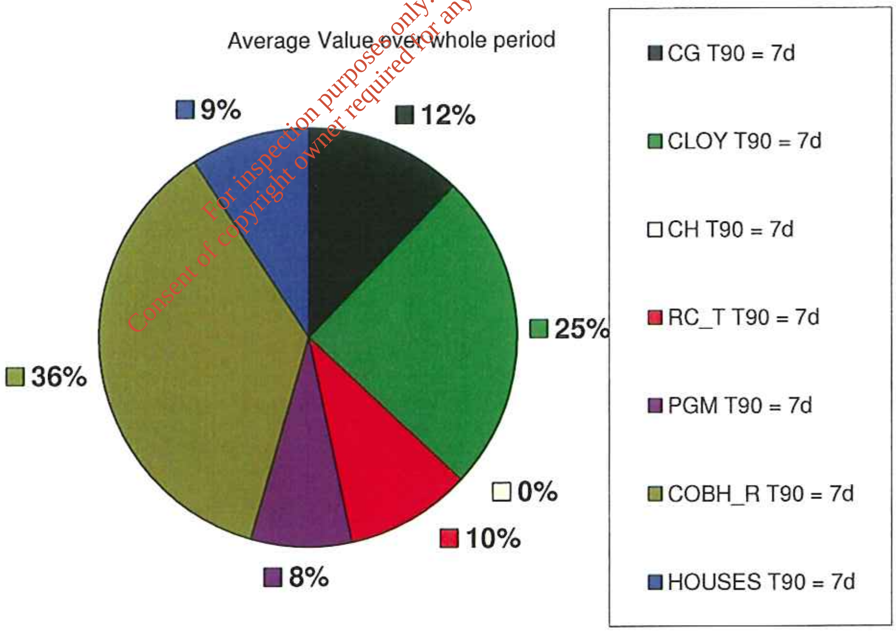


Fig. 8.26 CASE 5 – Average Concentrations – The Relative Contributions

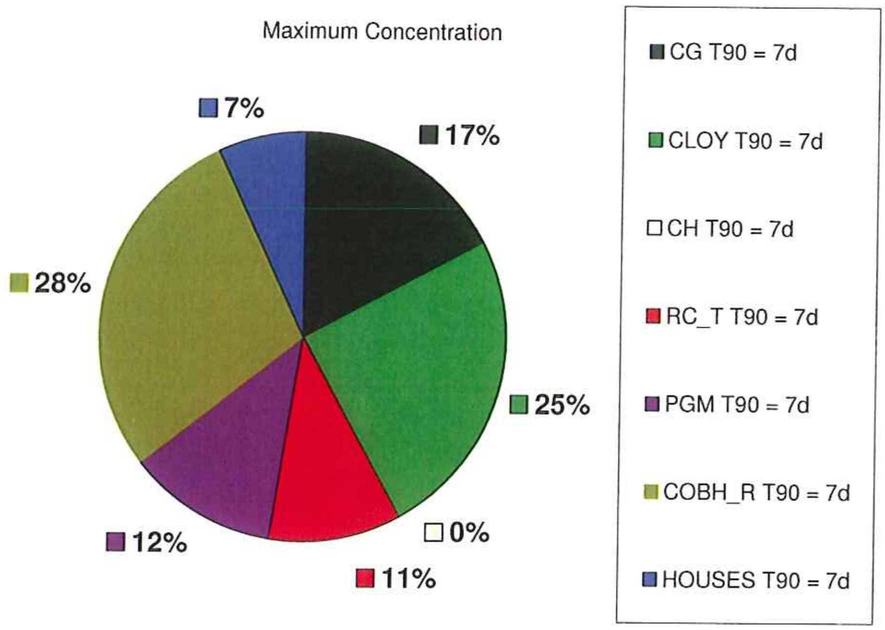


Fig. 8.27 CASE 5 – The Maximum Contributions

8.3.6 Case 6 – Period 3, Winter Conditions

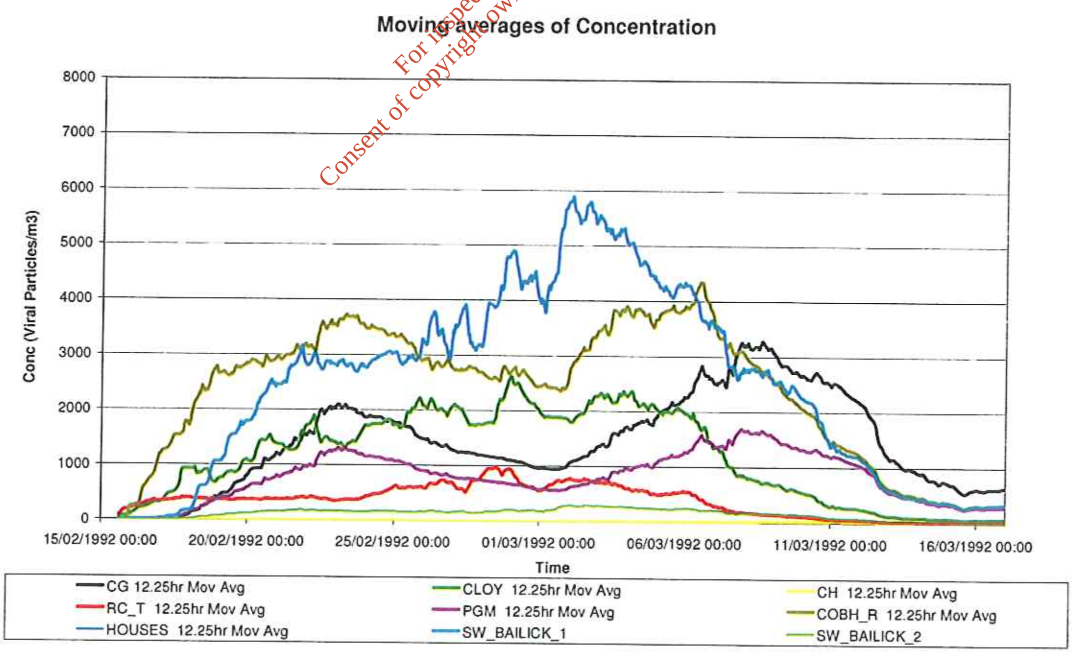


Fig. 8.28 Moving Averages of Concentrations

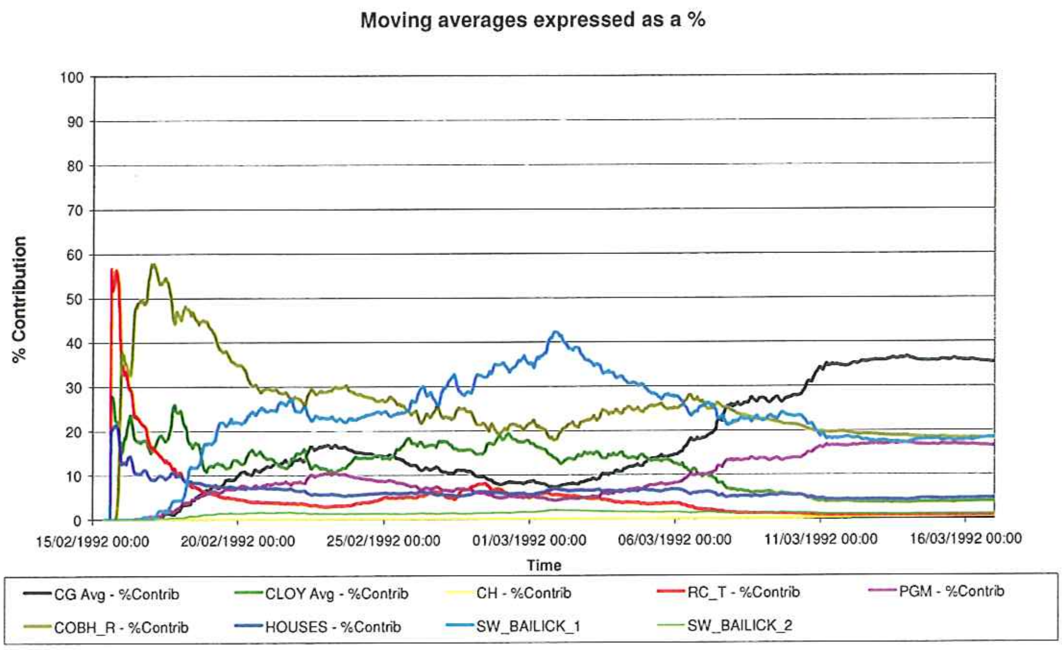


Fig. 8.29 The Relative Contributions

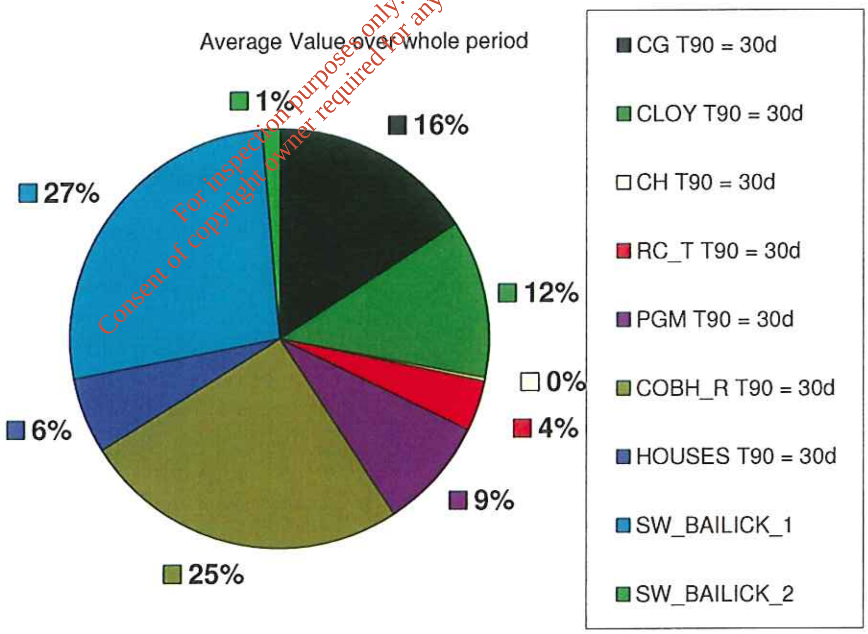


Fig. 8.30 Average Concentrations – The Relative Contributions

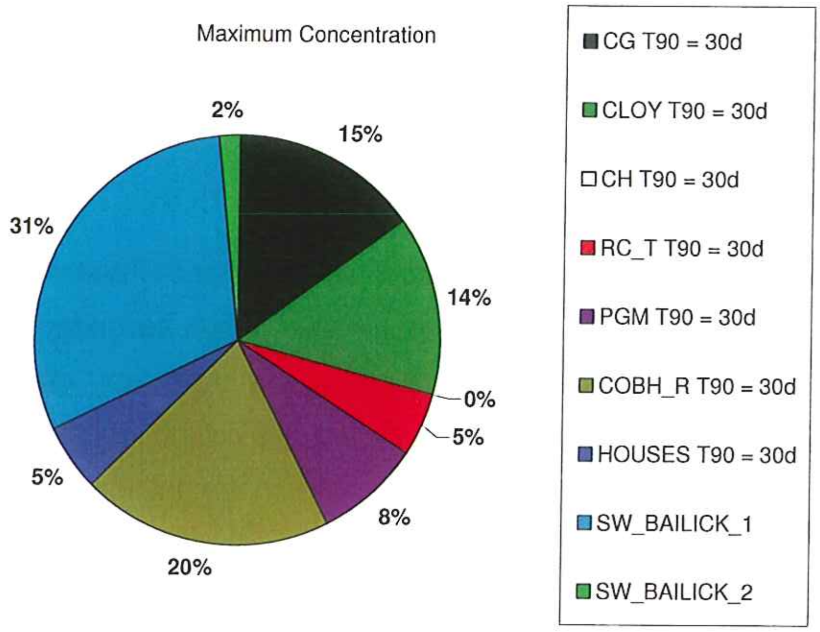


Fig. 8.31 The Maximum Concentrations in the outer harbour

Appendix D The removal efficiency of the treatments plants at Midleton and Carrigrennan

The concentration of *Total Coliform* and *Faecal Coli.* bacteria have been measured in (a) the influent to the Midleton secondary waste treatment plant, (b) the effluent from the plant before UV treatment, and (c) the effluent from the plant after UV treatment, during the period from 2000 to 2004. In addition, concentrations were also measured in the holding tank at Bailick 1.

We have not used these data to estimate the removal efficiency for *Norovirus* for the following reasons:

Total *Coliform* and *Faecal Coli.* bacteria are indicator bacteria that indicate the presence of faecal micro-organisms from warm blooded animals. They are universally present in the intestines of humans. In contrast, *Norovirus* is only present when there is an outbreak of Winter Vomiting Disease in the population served by the treatment plant. To the best of our knowledge high frequency measurement of *Norovirus* in sewage effluent has not yet been achieved anywhere in the world.

Let $b_i(t)$ and $b_{out}(t)$, and $n_i(t)$, and $n_{out}(t)$ be the concentrations of indicator bacteria and *Norovirus* in the influent and effluent respectively. If the removal efficiencies for indicator bacteria and *Norovirus* are constant and identical, the ratios $b_{out}(t)/b_i(t)$ and $n_{out}(t)/n_i(t)$ are equal at all points in time. We have one equation and four quantities; to find $n_{out}(t)$ we must know $b_{out}(t)$, $b_i(t)$, and $n_i(t)$. But this is not so! When there is no outbreak of Winter Vomiting Disease the ratio $n_{out}(t)/n_i(t)$ is indeterminate, zero divided by zero. We do not know when this occurs, since medical data on the timing, strength and duration of such outbreaks are not available. When there is an outbreak, $n_i(t)$ grows from zero to a maximum and then falls again to zero in a manner that bears no relationship to $b_i(t)$ the time-varying concentration of indicator bacteria that are continuously discharged in sewage. Consequently, we cannot determine from $b_i(t)$ and $b_{out}(t)$, the value of the ratio $n_{out}(t)/n_i(t)$ and we conclude that the two ratios are independent of each other.

Because indicator bacteria are primarily an indication of the presence or absence of sewage, microbiological procedures measure their concentration to within a factor of 10. If, for example, the uncertainty in the concentration in the input lies between 10^6 to 10^7 bacteria per cc, and if the uncertainty in the concentration in the output is between 10^4 to 10^5 per cc, the uncertainty in the removal efficiency of 99% [i.e. a reduction from 10^7 to 10^5, or from 10^6 to 10^4] lies between 90% [i.e. a reduction from 10^6 to 10^5] to 99.9% [i.e. a reduction from 10^7 to 10^4]. Consequently, removal efficiency is very uncertain when it is based on the ratio of concentrations of bacteria measured in the conventional manner.

There are strong diurnal, daily and weekly components in the chemical and bacterial quality of the influent to municipal wastewater treatment plants. The accurate identification of these components and the removal efficiency of the plant require a sampling frequency that resolves the highest frequency, namely, one measurement every 20 to 30 minutes. The available data were measured at a frequency of roughly twice per week; the resulting time-series are severely aliased by the hidden high-frequency components.

We have chosen instead to use an indicative removal efficiency of 95% for both treatment plants with a sensitivity analysis of the case when the efficiency is reduced to 85% for whatever reason e.g. overload during storms that decrease the residence time in the plant and consequently bacterial activity. Since the model is linear any other removal efficiency can be found by rescaling the results.

SECTION G: PROGRAMMES OF IMPROVEMENTS

Advice on completing this section is provided in the accompanying Guidance Note.

G.1 Compliance with Council Directives

Provide details on a programme of improvements to ensure that emissions from the agglomeration or any premises, plant, methods, processes, operating procedures or other factors which affect such emissions will comply with, or will not result in the contravention of; the Dangerous Substances Directive 2006/11/EC, the Water Framework Directive 2000/60/EC, the Birds Directive 79/409/EEC, the Groundwater Directives 80/68/EEC & 2006/118/EC, the Drinking Water Directives 80/778/EEC, the Urban Waste Water Treatment Directive 91/271/EEC, the Habitats Directive 92/43/EEC, the Environmental Liabilities Directive 2004/35/EC and the Bathing Water Directive 76/160/EEC.

Attachment G.1 should contain the most recent programme of improvements, including a copy of any approved funding for the project and a timeframe for the completion of the necessary works to take place.

Attachment included	Yes	No
	✓	

G.2 Compliance with Water Quality Standards for Phosphorus Regulations (S.I. No. 258 of 1998).

Provide details on a programme of improvements, including any water quality management plans or catchment management plans in place, to ensure that improvements of water quality required under the Water Quality Standards for Phosphorous Regulations (S.I. No. 258 of 1998) are being achieved. Provide details of any specific measures adopted for waste water works specified in Phosphorus Measures Implementation reports and the progress to date of those measures. Provide details highlighting any waste water works that have been identified as the principal sources of pollution under the P regulations.

Attachment G.2 should contain the most recent programme of improvements and any associated documentation requested under Section G.3 of the application.

Attachment included	Yes	No
	Not Applicable	**Not Applicable**

G.3 Impact Mitigation

Provide details on a programme of improvements to ensure that discharges from the agglomeration will not result in significant environmental pollution.

Attachment G.3 should contain the most recent programme of improvements, including a copy of any approved funding for the project and a timeframe for the completion of the necessary works to take place.

Attachment included	**Yes**	**No**
	✓	

G.4 Storm Water Overflow

Provide details on a programme of improvements to ensure that discharges other than the primary and secondary discharges comply with the definition of 'storm water overflow' as per Regulation 3 of the Waste Water Discharge (Authorisation) Regulations, 2007.

Attachment G.4 should contain the most recent programme of improvements, including a copy of any approved funding for the project and a timeframe for the completion of the necessary works to take place.

Attachment included	**Yes**	**No**
	✓	

Foreshore Licence & Current Discharge Standards

The current treatment standards that the WWTP is operating to is contained within Cork County Councils application to the Department of the Marine & Natural Resources for a Foreshore licence in April 1998 which states the Midleton WWTP shall achieve a final effluent standard of:-

- BOD 20mg/l
- SS 30mg/l
- TN 15mg/l

In addition the application states that UV disinfection will also be installed on the final effluent that will have the effect of reducing the faecal coliform numbers in the discharge by a factor of 10,000 over that presently discharging (prior to the construction of the WWTP).

A Memorandum of Agreement dated 22nd September 1999 was signed between the Minister for the Marine & Natural Resources and Cork County Council to lay, use and maintain foreshore crossings, domestic rising main, outfall pipes, pumping station storm water outfall and overflow pipes in connection with the Midleton Sewerage Scheme.

THE LICENCE STATES *"THE LICENSEE SHALL PROVIDE A LEVEL OF TREATMENT, INCLUDING ULTRA-VIOLET TREATMENT, WHICH SHALL ENSURE THE FOLLOWING EFFLUENT QUALITY AT THE INSPECTION CHAMBER IN THE CHANNEL DOWNSTREAM OF THE TREATMENT PLANT OF A GEOMETRIC MEAN OF FAECAL COLIFORMS PER 100ML OF EFFLUENT MUST BE 250 FC OR LESS. THIS LIMIT CAN BE REVIEWED IN THE EVENT OF EFFLUENT INPUTS. COMPLIANCE WITH THIS CLAUSE SHALL BE MEASURED ON THE BASIS OF A 50 SAMPLE ROLLING PROGRAMME AS APPLICABLE. 95% OF ALL SAMPLES SHALL BE LESS THAN 1000FC/100ML. IN THE EVENT OF A RESULT OF OVER 1,000FC/100ML, THE LICENSEE SHALL IMMEDIATELY CONTACT THE DEPARTMENT OF THE MARINE AND NATURAL RESOURCES TO AGREE THE NECESSARY ACTION."*

Assessment of Relevant Legislation Applicable to Midleton WWTP

The following assesses the relevant European Union Directives and Irish Statutory Legislation that is applicable to the discharge standards from the Midleton WWTP.

The Urban Waste Water Treatment Directive 91/271/EEC and amendment Directive 98/15/EEC

The Urban Waste Water Treatment Regulations, (S.I. 254 of 2001) gives effect to provisions of the Urban Wastewater Treatment Directive (91/271/EEC). The 2001 Irish Regulations cover various requirements in relation to the collection and treatment of urban wastewater.

Article 4 (1) (c) states that '*In the case of urban waste water entering collecting systems, a sanitary authority shall provide treatment plants which provide for secondary treatment or an equivalent treatment by 31 December 2005, in respect of all discharges to freshwaters and estuaries from agglomerations with a population of between 2,000 and 10,000*.

The **Second Schedule (Part 1)** of the 2001 Regulations states that the Treated Effluent should have the characteristics shown in **Table 1.1** below.

Table 1.1 Treated Effluent Characteristics

Parameter	Concentration		Minimum % of Reduction
BOD_5	25.0	mg/l O_2	70-90
SS	35.0	mg/l	90
COD	125	mg/l 0_2	75

The **Third Schedule** of the 2001 Regulations gives a list of sensitive areas which in accordance with Article 4 (2) (a) for population equivalent above 10,000PE in sensitive areas require phosphorus and nitrogen consents in accordance the **Second Schedule (Part 2)**. The Owenacurra River/Estuary is not identified as a sensitive area and current the plant is design for a PE of 10,000 therefore this part of the regulation does not apply.

The **Fifth Schedule** of the 2001 Regulations gives a methodology for monitoring the final effluent from the WWTP. Item 3 states the minimum number of samples shall be taken according to the size of the treatment plant. For PE of between 10,000 to 49,999 12 samples shall be taken each year.

The sampling technique used should be flow proportional sampling and the Table in the **Fifth Schedule** of the 2001 Regulations stipulates the maximum permitted number of samples which can fail to conform in any given year; for example if 365 samples analysed over a one year period, 25 are permitted to fail, and the plant is still considered to be in compliance with the Regulations.

Bathing Water Directive

Council Directive 76/160/EEC 1975 concerning bathing water quality and the associated Bathing Water Regulations (SI No 177 of 1998) lay down quality requirements for inland and coastal waters designated bathing areas. The quality standards rely predominantly on microbiological parameters. The Ballyancorra River/Estuary is not designated as a bathing water (nearest bathing water is at Fountainstown approximately 5 miles down stream of the final effluent outfall). Therefore there are no further refinements of the treated effluent characteristics listed in **Table 1.1** above arising from the Bathing Water Directive.

EU Shellfish Waters Directive (79/923/EEC); and EU Directive on Health Conditions and the Placing on the Market of Live Biovalve Molluscs (91/67/EEC) and associated amendments

There are two main EU directives relating to Shellfish Waters. These are the Shellfish Directive (79/923/EEC) as implemented by the Quality of Shellfish Waters Regulations 2006 (SI No 268 of 2006), and the Directive on Health Conditions and the placing on the market of Live Biovalve Molluscs (91/67/EEC) and its associated amendments.

The Ballyancorra River/Estuary is not designated, "Shellfish Waters", under the Quality of Shellfish Waters Regulations 2006. However the Ballyancorra River/Estuary flows to Cork Harbour, which is a licensed aquaculture area. The

Department of Communications, Marine, and Natural Resources Live Bivalve Mollusce (Production Areas) Designation 2006 has confirmed that Cork Harbour, into which the Ballyancorra River/Estuary flows, is a licensed area for the cultivation of shellfish such as oysters as detailed in **Table 1.2** below.

Table 1.2 Designated Bivalve Mollusc Production Areas in Ireland - October 2006

Production Area	Boundaries	Bed Name	Species	Previous Classification	Current Classification
Cork Harbour	Between 8°16.4' W and 8° 15.6' W.	North Channel West	Oysters	B	B
	Between 8°14.6'W and 8°13.2'W.	North Channel East	Oysters	B	B
	Ahada Pier to Gold Point	Rostellan	Oysters	B	B

In accordance with the Live Bivalve Molluscs (Production Areas) Designation 2006 and Council Directive 91/492/EEC, Cork Harbour has a Category B status which means that shellfish from this area have to be treated in a purification centre or a relay bed before they can be placed on the market for human consumption. The water quality standards for Shellfish in Category B Waters is summarised in **Table 1.3** below. The status of the shellfish waters is monitored on a monthly basis by the National Marine Institute.

Table 1.3 Requirements for Faecal Coliform levels for Live Bivalve Molluscs in Accordance with EEC Directive 91/492/EEC

Category of Waters	Faecal Coliforms /100g of Flesh	Compliance of Samples	Further Treatment
A- Immediate Human Consumption	<300	100% <300	Not Required
B- Human Consumption After Treatment	**300 - 6,000**	**90% < 6,000**	**Purification after Relaying**
C-Human Consumption After Treatment	6,000 - 60,000	100% < 60,000	Relaying for long period -Intensive Purification

Summary of Discharge Standards

Table 1.4 below summaries the treatment standards that the Midleton WWTP is required to achieve to comply with European and Irish legislation and compares them to the standards adopted within the Foreshore Licence Application and the Memorandum of Agreement dated 22nd September 1999 which was signed between the Minister for the Marine and Natural Resources and Cork County Council.

Table 1.4 Summary of Discharge Standards

Parameter	European & Irish Legislation Standards & CEFAS Findings for Faecal Coliforms	Foreshore Licence Application & Memorandum of Agreement	Comments
BOD_5	25mg/l	20mg/l	Foreshore licence is a higher standard than EU/Irish Standards
SS	35mg/l	30mg/l	Foreshore licence is a higher standard than EU/Irish Standards
COD	125mg/l	-	Not stated on Foreshore licence but there is a relationship between BOD&COD
Total Nitrogen	-	15mg/l	>10,000PE in Sensitive areas or in areas of poor water exchange
faecal coliforms per 100ml of effluent	<300 faecal coliforms/100ml in 75% of all Samples	Geometric mean of <250 faecal coliforms/100ml and 95% of all Samples<1000 faecal coliforms/100ml	Foreshore licence is a higher standard than CEFAS findings

It can be concluded from the above that the standards set within the foreshore licence and the Memorandum of Agreement for Midleton WWTP are more stringent than the treatment standards set in European and Irish Legislation.

SECTION H: DECLARATION

Declaration

I hereby make application for a waste water discharge licence/revised licence, pursuant to the provisions of the Waste Water Discharge (Authorisation) Regulations, 2007 (S.I. No. 684 of 2007).

I certify that the information given in this application is truthful, accurate and complete.

I give consent to the EPA to copy this application for its own use and to make it available for inspection and copying by the public, both in the form of paper files available for inspection at EPA and local authority offices, and via the EPA's website.

This consent relates to this application itself and to any further information or submission, whether provided by me as Applicant, any person acting on the Applicant's behalf, or any other person.

Signed by :______________________________ **Date :**____________
(on behalf of the organisation)

Print signature name: ____

Position in organisation:____

SECTION I: Joint DECLARATION

Joint Declaration [Note1]

I hereby make application for a waste water discharge licence/revised licence, pursuant to the provisions of the Waste Water Discharge (Authorisation) Regulations, 2007 (S.I. No. 684 of 2007).

I certify that the information given in this application is truthful, accurate and complete.

I give consent to the EPA to copy this application for its own use and to make it available for inspection and copying by the public, both in the form of paper files available for inspection at EPA and local authority offices, and via the EPA's website.

This consent relates to this application itself and to any further information or submission whether provided by me as Applicant, any person acting on the Applicant's behalf, or any other person.

Lead Authority

Signed by :______________________________ **Date :**____________
(on behalf of the organisation)

Print signature name: ____

Position in organisation:____

Co-Applicants

Signed by :______________________________ **Date :**____________
(on behalf of the organisation)

Print signature name: ____

Position in organisation:____

Signed by :______________________________ **Date :**____________
(on behalf of the organisation)

Print signature name: ____

Position in organisation:____

Note 1: In the case of an application being lodged on behalf of more than a single water services authority the following declaration must be signed by all applicants.