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1 Introduction

This technical note has been prepared in response to a request from David Hugh-Jones of Atlantic Shellfish concerning a report prepared in July 2019 by Irish Hydrodata (IH):

- Rathcoursey Outfall. Investigation of the Impact of Treated Wastewater Discharges arising from the DairyGold Mogeely Plant to Cork Harbour.

I have been asked to comment on the aspects of the above report that deal with the flushing characteristics of the North Channel (section 4.9: Estuary Tidal Flushing). The North Channel is the home of oyster beds owned by Atlantic Shellfish.

2 Flushing

2.1 Tidal prism method

Section 4.9 of the IH report deals with flushing within Cork Harbour. Flushing is described based on an analysis of tidal prism data. The tidal prism method is based on the following formula:

$$T = \frac{(P + V)}{P}$$

Where: T is tidal cycles

P is the tidal prism volume

V is the volume of water left in the estuary at low water

Such a method provides a first estimate of the flushing time. However, the method assumes there is complete mixing within the estuary and that water leaving the estuary on the ebb tide will not re-enter the estuary on the flood tide. These assumptions are never completely met in real estuaries. Therefore, the flushing time derived from the tidal prism method represents the shortest possible time that an estuary can be flushed.

Using the tidal prism method IH estimated the flushing time above Rathcoursey Point was approximately two tidal cycles (just over one day). IH addressed some of the shortcomings in the tidal prism method by assuming an exchange rate on each tide 0.35. This extended the flushing time to just over three days. However, that assumption assumes any water exchanged on one tide is not re-exchanged on one of the subsequent tides. Therefore, even with making assumptions about the exchange rate, the method is still likely to underestimate the flushing time for the estuary.

Even making allowances for shortcomings in the tidal prism method it still produces a single estimate of the time it takes to flush an estuary. That estimate though is not necessarily representative for the time required to flush all parts of the estuary. Many estuaries such as Cork Harbour have a complicated topography, which includes isolated depressions and secluded embayments with little water exchange. While most areas of the harbour may be flushed in the time estimated using the tidal prism method, there can remain pockets of stagnant water with much longer flushing times.

An alternative method for estimating flushing times within an estuary is the use of numerical models that simulate hydrodynamics and advection-dispersion processes. IH have such a model because earlier sections of their report described how it had been used to simulate the movement of BOD and nutrients around Cork Harbour. Such a model could have been used to

derive flushing times for every location in Cork Harbour. There has been no explanation as to why this approach was not adopted.

2.2 Residence times

A study of phytoplankton dynamics in Cork Harbour was conducted:

- Nash, Hartnett and Dabrowski. Modelling phytoplankton dynamics in a complex estuarine system. ICE Water Management Volume 164. January 2011

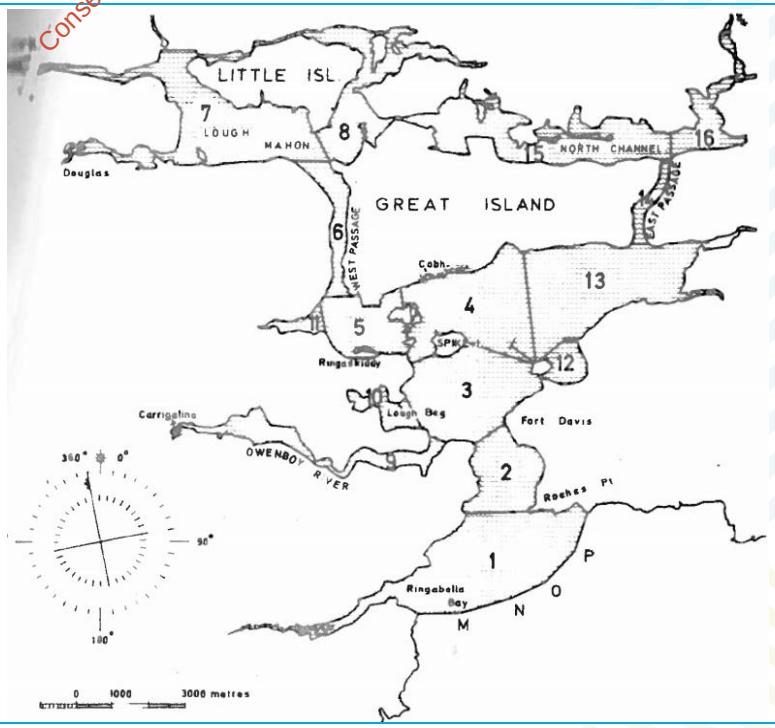
The study considered the residence times across the harbour. As part of the study residence times were plotted across the harbour. The plots show that residence times in the North Channel are at their greatest just to the east of Belvelly (22-days). Residence times to the west of Belvelly (up to 6-days) are less than the residence times at Rathcoursey (up to 9-days), the eastern end of the North Channel. These residence times are considerably greater than those estimated by IH using the tidal prism method, indicating that the exchange rate assumed by IH of 0.35 was too high. There is a clear step change in the residence times at a point just to the west of Belvelly presumably at the null point where the incoming tides from the east and the west meet at high water.

2.3 Mixing conditions in the North Channel

The North Channel, particularly to the east of Belvelly is recognised as having relatively little water movement. Evidence for poor flushing of the North Channel is available in the form of tidal prism volumes for Cork Harbour:

- Vol XIV. Cork Harbour Pollution Report. Physical Study. Dye Survey Analysis. 1977.

Figure 2-1: Sub-areas of Cork Harbour



The data comprises tables for the low water volume and tidal prism volume of different sub areas of Cork Harbour (see Figure 2-1).

By analysing that data, it was possible to calculate the relative flushing that takes place in each sub-area due to the tide. The amount of flushing is the volume of water that flows into the area during a tidal cycle (the volume of the tidal prism for the area and further into the harbour) divided by the total volume of water in the area (low water volume plus tidal prism volume). Table 2-1 summarises the analysis.

Table 2-1: Estimated flushing in sub-areas of Cork Harbour

Sub-area number	Sub-area name	Average flushing
1	Outer Harbour	127.6%
2	Forts Sound	305.3%
3	Curlane	235.3%
4	Spit Bank	175.3%
5	Ringaskiddy	184.4%
6	West Passage	165.1%
7	Lough Mahon	61.6%
8	Fota	84.3%
9	Owenboy River	55.2%
10	Lough Beg	96.7%
11	Monkstown Creek	96.5%
12	Whitegate Bay	85.2%
13	East Channel	92.4%
14	East Passage	260.3%
15	North Channel	59.5%
16	Ballinacurra	84.9%

There will be more flushing of sub areas closer to the sea and less flushing of areas deeper into the harbour. The calculations bear this out and show that the sub areas of Cork Harbour with the least amount of tidal flushing are the Owenboy River (Area 9), the North Channel (Area 15) and Lough Mahon (Area 7). The average tidal flushing of these areas is: 55%, 59% and 61% respectively.

It should be noted that these figures only look at tidal flushing (albeit with the shortcomings described in section 2.1 and so will overestimate the flushing). Furthermore, the calculations do not account for the effect of river flow through each section which will tend to increase the flushing of Lough Mahon (due to the Lee River) and the Owenboy River. The North Channel has no similar direct river input.

The sub-areas with the next lowest amount of flushing are: Fota (Area 8), Ballinacurra (Area 16) and Whitegate Bay (Area 12). The average tidal flushing in these areas is: 84%, 85% and 85% respectively. The analysis shows that the tidal flushing of the Fota and Ballinacurra areas is considerably greater than that for the North Channel which lies immediately between those two bodies of water and illustrates that the North Channel has poorer mixing than other parts of Cork Harbour.

3 Dye plumes

Two dye tracing exercises have been undertaken in the East Passage and Owenacurra Estuary areas of Cork Harbour. These are:

- Dye releases from Rathcoursey in 1977 (Vol XIV. Cork Harbour Pollution Report. Physical Study. Dye Survey Analysis. 1977)
- Dye releases from Rathcoursey, Ballinacurra and Green Point in 1993 (Midleton Sewage Treatment Plant. Environmental Impact Statement. Technical Appendices. November 1996)

3.1 Dye releases in 1977

Two dye releases were undertaken:

- Intermittent discharge from Rathcoursey for the period 17 to 22 August 1977. Dye traced up to 29 August 1977.
- Continuous release from Rathcoursey for the period 13 to 18 September 1977. Dye traced up to 28 September 1977.

The results of the survey were presented as contour plots of the dye plumes at high and low water throughout the period of measurements.

The intermittent release of dye at Rathcoursey took place between one and four hours after high water. The contour plots at low water show the dye was transported down the East Passage and into the outer harbour. Plots at high water show that despite there being no release of dye during the flood tide, dye was carried back up the East Passage and into the North Channel and the Owenacurra Estuary. Traces of dye were measured in the North Channel within 12-hours of the start of the exercise. The concentrations of dye measured in the North Channel were generally lower than those measured in the outer harbour.

For the continuous release at Rathcoursey the low water plots show dye spread along the East Passage into the Outer Harbour. At high water dye was transported back up the East Passage into the North Channel and Owenacurra Estuary. The first dye patches were observed 25-hours after the start of the test when dye was observed at low water around the head of the East Passage. 31-hours after the start of the test dye was observed at high water in the North Channel and Owenacurra Estuary. As the test progressed some dye was seen to linger in the North Channel and Owenacurra Estuary even at low water. Generally higher dye concentrations were measured in the North Channel and Owenacurra Estuary than were found in the outer harbour.

The dye releases from 1977 illustrate that even using an intermittent discharge from Rathcoursey dye was still seen to enter and be detected in the North Channel up to six days after the intermittent release had stopped. For the continuous release, dye was detected in the North Channel up to nine days after the release had stopped.

These durations indicate that the flushing time for the eastern end of the North Channel at Rathcoursey is greater than the three days estimated by IH using the tidal prism method. Flushing times for water further west in the North Channel will be even greater. This is further evidence that the exchange rate of 0.35 used by IH was too high.

3.2 Dye releases in 1993

In 1993, IH conducted dye tracking studies. Four dye releases were undertaken:

- Dye Release from Rathcoursey (10.5-hour release on the 14 September 1993)
- Dye release from Ballinacurra (12.75-hour release on the 21 September 1993)
- Dye release from Green Point (12.75-hour release on the 8 October 1993)
- Dye release from Rathcoursey (Discrete release three hour before high water on the 11 October 1993)

The dye tests show the behaviour of dispersion in the Owenacurra Estuary, North Channel and down the East Passage into the Outer Harbour.

During the ebb tide, the dye plume from Rathcoursey travelled down the East Passage and into the Outer Harbour. Two hours after low water, the dye plume was observed in the North Channel and four hours after low water the plume was spread across the oyster beds in the North Channel.

The plume of dye released from Ballinacurra travelled down the Owenacurra Estuary and into the East Passage during the ebb tide. The dye plume was observed to be spread across the North Channel oyster beds three hours after low water.

The dye release from Green Point behaved in a similar manner to that released from Ballinacurra. The main difference was that an easterly wind was blowing and some dye instead of being transported down the East Passage entered the North Channel during the ebb tide.

Within 1.5-hours of the discrete dye release at Rathcoursey the dye patch was observed over the eastern end of the oyster beds in the North Channel.

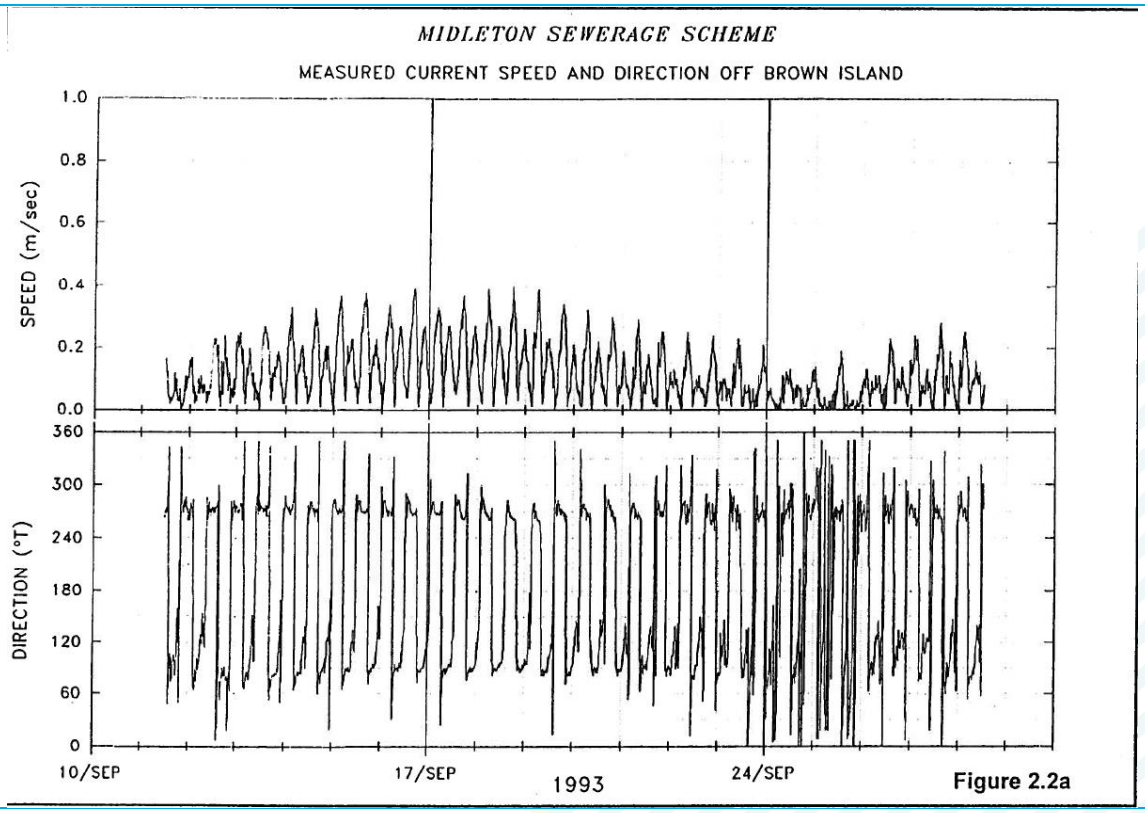
4 North Channel currents

In 1993, current observations in the North Channel were made at Brown Island and Bagwell Hill during September of that year. The data was presented as plots of current speed and direction.

- Midleton Sewage Treatment Plant. Environmental Impact Statement. Technical Appendices. November 1996

Figure 4-1 shows the plots for the site at Brown Island (which is really sited further west towards Brick Island).

Figure 4-1: 1993 current meter measurements at Brown Island



For most of the observation period, the currents at Brick Island show distinct ebb (easterly) and flood (westerly) tide currents. That pattern breaks down for a short period (24 to 25 September) but then re-establishes itself. This would be expected because the site is in the deeper part of the North Channel and unlikely to be significantly affected by eddies. A distinctive feature of the observed currents at Brick Island is that the peak flood tide currents exceed those observed on the ebb tide. This suggests there is a residual current in the North Channel that flows from east to west. The residual current is the current averaged over a whole tidal cycle and shows the overall movement of water at the site once the tidal signal has been removed.

Atlantic Shellfish, with the help of BIM, attempted to replicate the data of the 1993 IH survey over two whole spring/neap tidal cycles in late 2019. However, the equipment failed on that occasion. They plan to carry out the recording again in the New Year to calculate the strength

of any residual current and hence estimate the resulting water movement to the west on each tide. IH should be able to calculate the residual current from the current meter data they hold from 1993.

5 Conclusions

The main conclusions from this investigation are:

- By their nature, tidal prism calculations will tend to under-estimate flushing times for estuarial waters.
- The use of hydrodynamic models, including advection-dispersion processes, enables a better calculation of flushing times because they take account the harbour topography and the effect of embayments on flushing.
- Even using tidal prism calculations, the North Channel is one of the least flushed areas of water in Cork Harbour.
- Using tidal prism calculations IH estimated flushing times for the North Channel of approximately three days, based on an exchange rate of 0.35 per tide.
- Reported modelling studies of residence times in the North Channel and observed dye releases from Rathcoursey indicate flushing times for the North Channel are of the order of weeks not days. This indicates that the exchange rate for the North Channel is probably approximately 0.05, nearly an order of magnitude less that that used by IH.
- Long term measurements of tidal currents in 1993 indicate there is a residual current along the North Channel from east to west. Such currents will tend to increase residence times in the North Channel by holding water in the North Channel that can only escape via the narrow bridge at Belvelly.