Hydrological and Chemical survey of Cuskinny Lake,

Great Island, Cork Harbour, Co. Cork. April – June 2012.

Draft report prepared for Cork County Council, July 2012.

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Acknowledgements

Thanks to Birgit O'Driscoll, Conor O'Driscoll, Susan Lettice and Anna Aherne for help with the sampling, Dr. Debbie Chapman and Jim Wilson for felp and advice and Cork County Council through the Environmental Partnership Fund – LA 21, for the funding.

Cover: Photograph taken of the bridge over the inlet/outlet of Cuskinny Lake, Co. Cork taken on 11/10/2011, showing the milky-white colour of the water flowing from the lake (© J. Wilson).

Summary

An extreme eutrophication event occurred in Cuskinny Lake on 11th October 2011, which resulted in the water of the lagoon becoming milky white, giving off an unpleasant smell, and resulted in the death of probably most of the aquatic animals in the water column of the lake.

Water samples were collected from Cuskinny Lake on 4 occasions following the eutrophication event (18/10/2011, 21/01/2012, 20/3/2012, 24/5/2012) and compared with samples collected from other lagoons in the country as part of an EPA study into water quality in lagoons for compliance with the Water Framework Directive. Flow measurements were made in the main channel of the lagoon over tidal cycles during neap tides on 30th April and during spring tides on 23rd May 2012.

At the time of sampling it was calculated that seawater inflow on the neap tide represented 13% of the volume of the lagoon and over 50% of the lagoon water would be flushed in 2.5 days (5 tides). Seawater entering on the spring tide represented 51% of the volume of the lagoon, and over 98% of the lagoon water would be flushed in 3 days (6 tides). These calculations were made at a time of relatively low rainfall when freshwater inflow was equivalent to only 10% of the volume of seawater entering on an "average" spring tide.

During a period of high rainfall and weak tides, the percentage contribution of rainfall and runoff to the lagoon may well exceed that of tidal water, and be the major control on lagoon water levels. Under these conditions, the flushing effect of tidal water would be considerably less, but this is likely to occur during the winter months, when temperatures are lower, and the deoxygenation of the water less likely to be caused. Based on these calculations it can be concluded that Cuskinny Lake is very well flushed on most days of the year.

The lagoon has been referred to in the past as eutrophic, but this has usually been based on anecdotal information or subjective judgements. As a result of this water sampling in 2011 and then on three occasions in 2012, it was found that the nutrient levels in the lagoon were exceptionally high, with nitrate up to 1.9mg/L(N), ammonia up to 0.6 mg/L(N), nitrite up to 0.06 mg/L(N), and phosphate up to 0.05 mg/L. In most sampling periods nutrient levels in Cuskinny are far higher than any of the other 31 lagoon sites in the country that are being sampled as part of an on-going study by the EPA..

The only water quality data for Cuskinny before 2011 appears to be that of Galvin in 1991 who reported nitrate levels equivalent to 1.2 mg/L N and Van Heste in 2004 who

recorded exceptionally high levels of Nitrate, Ammonia and Phosphate in the water entering the lagoon. Nitrate levels in Cork Harbour are slightly elevated but are nothing like the values recorded in the lagoon or stream (R. Wilkes EPA, pers comm.) and it seems obvious that the nutrients are coming from the stream or from agricultural run-off in the catchment.

It is difficult to determine exactly what caused the extreme event in Cuskinny on 11th October, but the results of the water sample analyses **clearly indicate a nutrient overloading of lagoon**, and must be a major contributory factor involved, which together with a combination of additional factors resulted in the final event. This has existed for at least the last 25 years. The recent extreme event in October 2011 does not appear to be the result of an isolated occurrence of high nutrient loading as levels were exceptionally high in 1991 and 2004 and remain high in 2012.

There may have been some other external factor involved, such as work carried out by Eirgrid which was the final trigger for the event, but at this stage the most probable explanation of the extreme event that occurred in October 2011 **would appear to be that the nutrient over loading of the lagoon supported a proliferation of algae (probably *Ulva* sp.) which under unusually warm and calm conditions in October, died, de-oxygenated the water and resulted in the release of hydrogen sulphide, causing the water to become milky-white and giving off bad odours and probably killing all aquatic invertebrates.** This situation is likely to re-occur if the same combination of events occurs.

1. Introduction

An extreme eutrophication event occurred in Cuskinny Lake on 11th October 2011, which resulted in the water of the lagoon becoming milky white (see cover and Appendix I), giving off an unpleasant smell which local residents complained of, and resulted in the death of probably most of the aquatic animals in the water column of the lake. This lasted for several weeks and caused considerable concern to local residents and the committee of the Cuskinny Nature Reserve, which is managed on behalf of BirdWatch Ireland.

Cuskinny Lake is regarded by the National Parks and Wildlife Service as a "coastal lagoon", and is listed in the National Inventory of Irish Lagoons (Oliver 2007). Coastal lagoons are listed in the EU Habitats Directive as a "priority habitat" in need of special protection and it was decided that a survey should be carried out in an attempt to determine the cause of the disturbance to the lake. Funding for the survey was supplied by Cork County Council under the Local Agenda 21 (LA21) partnership fund to establish the cause of the acute eutrophication of the lagoon in order to establish a management plan to prevent possible future episodes.

2. Methods

Flow measurements were made in the main channel of the lagoon (Figure 1) during neap tides on 30th April and during spring tides on 23rd May 2012 using a flow meter (Ohio/Columbia Electronic Stream Flow Meter). Salinity, temperature and Oxygen measurements were made in situ using a conductivity meter (WTW Cond 315i) and Oxygen meter. Initially, flow measurements were made at 10, 20 and 30cm above the bed of the channel at 20cm intervals across the channel to measure variability of flow rate at different positions in the channel. One position was then chosen within the channel and the flow meter fixed at this position by clamping to a plank placed at right angles to the channel. This position was very close to the 0.6 depth position recommended in the users' manual (Jay

2000). Measurements made at this position were then multiplied by a correction factor to calculate the total flow through the channel. The depth of water across the channel at 20cm intervals was measured in order to measure the wetted perimeter and the cross-sectional area of the channel. The speed of flow in metres per second was then multiplied by the cross-sectional area in square metres to calculate the "discharge" of water entering and leaving the lake in cubic metres per second.

Discharge (Q) = Area of the Channel cross-section (X) x Flow velocity (V).

$Q = X.Vm^3/\text{second}$

The volume of water within the lagoon was calculated based on area and average depth of the lagoon. The amount of time water was entering and leaving the lagoon on each tide was measured in order to calculate the volume of water entering and leaving the lagoon on each tide in relation to the total volume of the lagoon.

Water samples were collected from Cuskinny Lake on 4 occasions following the eutrophication event (18/10/2011, 21/01/2012, 20/3/2012, 24/5/2012) and compared with samples collected from other lagoons in the country as part of an EPA study into water quality in lagoons in relation to the Water Framework Directive. These samples were analysed within 24 hours by Glan Uisce Teo (Furbo, Co. Galway) for Nitrate, Nitrite, Ammonia, Phosphate, BOD, and Chlorophyll. One sample was analysed for Sulphite following the eutrophication incident but no trace of sulphite was recorded. Water depth in the lake was recorded from the staff gauge installed near the "duck-feeding station" (Figure 2).

Figure 1. Main inlet/outlet channel where flow measurements were made in Cuskinny Lake during neap tides on 30th April and during spring tides on 23rd May 2012.

Figure 2. Staff gauge where water depth measurements were made in Cuskinny Lake during neap tides on 30th April and during spring tides on 23rd May 2012**.**

3. Results

3.1 Hydrology, Neap tide 30th April 2012. Tidal amplitude 2.2m.

A transect across the main inlet to Cuskinny Lake was selected on 30th April, 2012. Measurements were made from the water surface to the bed of the channel along this transect at 10 cm intervals (Table I) and a depth profile of the channel drawn (Figures 3a, b).

Table 1. Depth of water at 10cm intervals along transect across the main inlet channel at Cuskinny Lake, 30/4/2012

Distance from shoreline (cm)	0	10	20	30	40	50	60	70	80	90	100
Distance from surface of water to bed of channel (cm)	35.0	36.5	34.5	38.1	37.0	29.5	24.8	25.0	17.2	16.0	16.0

Distance from shoreline (cm)	110	120	130	140	150	160	170	180	190	195
Distance from surface of water to bed of channel (cm)	16.0	26.0	29.0	33.2	33.9	25.2	14.2	12.8	10.5	10.0

From the above measurements, width of the channel on this transect was 195 cm and the average depth of the channel was calculated to be 24.8cm.

Cross sectional area of channel = 24.8 x 195 = 4836 cm^2 = <u>0.484 m^2</u>

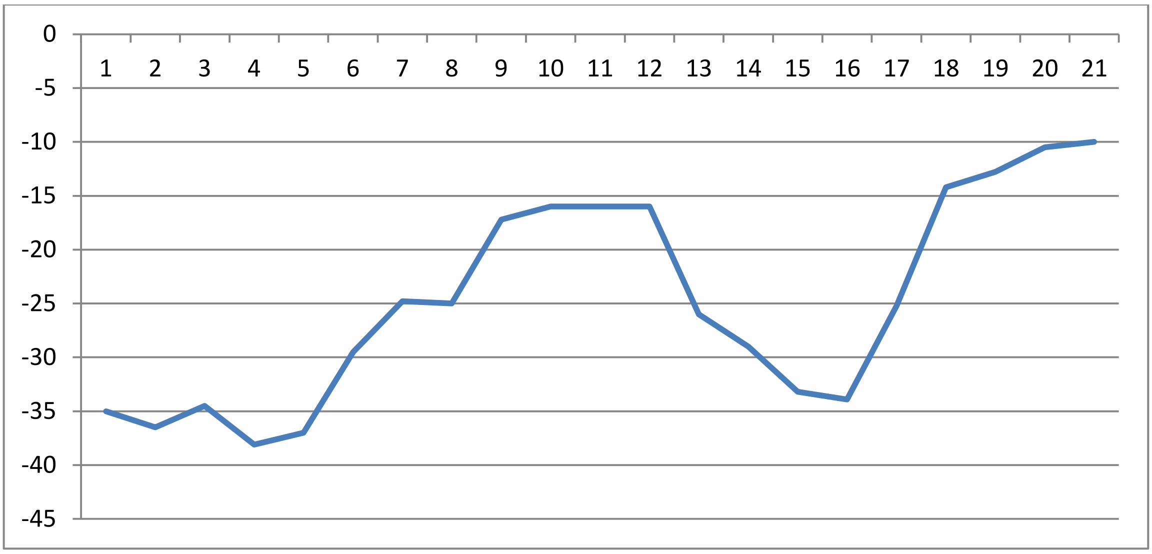


Figure 3a. Depth profile of channel where flow measurements were taken 30/4/2012.

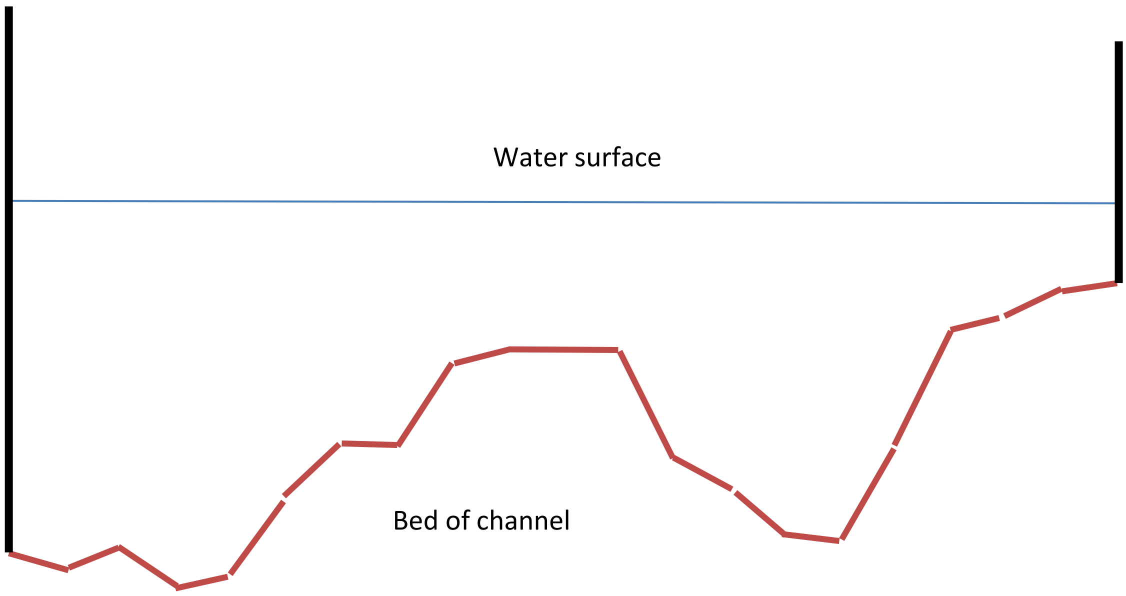


Figure 3a. Shape of channel bed where flow measurements were taken 30/4/2012.

Flow rates recorded on 30/4/2012.

From initial measurements made at 09.44 (Appendix II, Table I), the average **OUT** flow from the lagoon was calculated to be **0.04m/second**.

Discharge from the lagoon = Cross sectional area x Flow velocity

Outflow at low tide = **0.484 m^2 x 0.04m/sec** =

= **0.01936 m^3/second**

From a further series of measurements (Table 2, Appendix II), flow rates at 10cm, 20cm and 30cm depth were plotted across the channel at 20cm intervals across the channel to identify areas of high and low flow rates (Figure 4).

Table 2. Average taken from all readings with propeller blades at 10, 20 and 30cm above the bed and 20cm intervals across the channel during OUTFlow. (ow = propeller blades out of the water)

	Depth below surface (cm)		
Distance from "shoreline"(cm)	10cm	20cm	30cm
20	0.006	0.034	0.162
40	0.172	0.130	0.085
60	0.174	0.195	ow
80	0.201	ow	ow
100	0.132	ow	ow
120	0.000	0.000	ow
140	0.000	0.000	0.000
160	0.183	0.195	ow
180	0.184	ow	ow

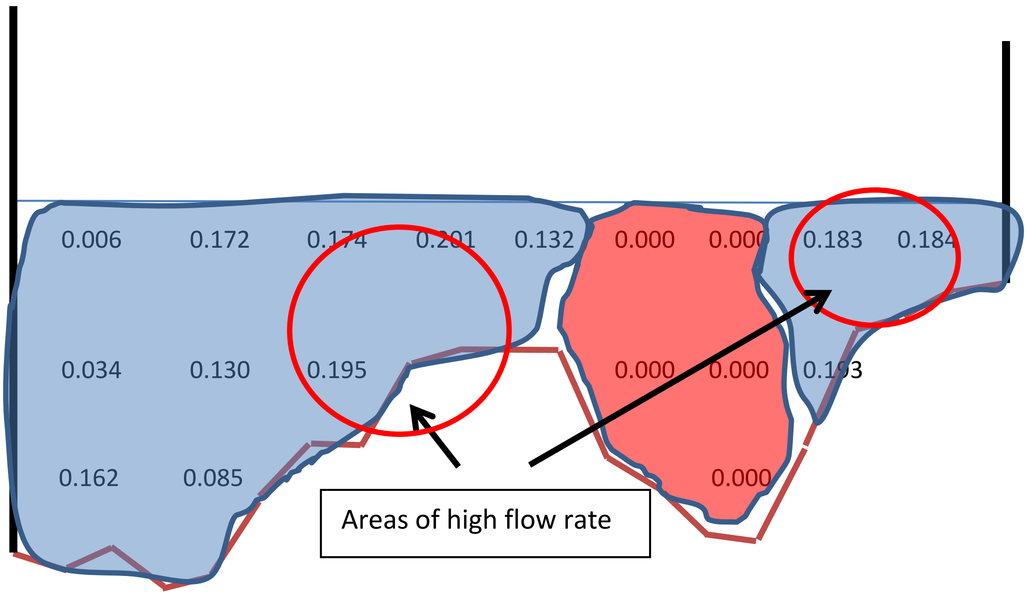


Figure 4. Areas of high and low flow rates in the channel of Cuskinny Lake, 30/4/2012. Red area is sheltered by up-stream rock. Blue area is main area of flow.

From these figures it was found that a large area in the middle of the channel was sheltered by a raised area of rock and mussel reef, where there was no flow of water at all, and areas of highest flow rates to the right and left of this area. Based on these figures using a larger, therefore more accurate data set, the average flow rate was calculated to be 0.103m/second .

At 10.27am average OUTflow = 0.103m/second compared with 0.04 m/sec measured earlier from a smaller data set.

Predicted High Tide at Cobh on this date was 12.37pm. The flow of water changed direction at 11.16 am, when water started flowing into the lagoon 81 minutes before high tide on an "average" neap tide.

Water flowing into the lagoon on a rising tide.

Change of flow direction at 11.16 am, High Water at 12.37. Water flowing into lagoon 81 minutes before high tide on an "average" neap tide (tidal amplitude 2.2m). From a further series of measurements (Table 2, Appendix II, Tables 3a-c), flow rates at 10cm, 20cm and 30cm depth were again plotted across the channel at 20cm intervals to identify areas of high and low flow rates on a rising tide (Figure 5).

Table 2. Average taken from all readings at 10, 20 and 30cm depths and 20cm intervals across the channel during INFlow.

	At 10cm	At 20cm	At 30cm
	0.061	0.094	0.038
	0.245	0.257	0.303
	0.245	0.472	0.568
	0.228	0.370	0.340
	0.249	0.122	0.258
	0.083	0.152	
	0		
	0		
	0.113		
Mean	0.136	0.2445	0.301

Based on these measurements, again two areas of high flow rates were identified and average INflow through the channel was found to be 0.227 m/second

<u>Total mean INFlow = 0.227 m/sec</u>

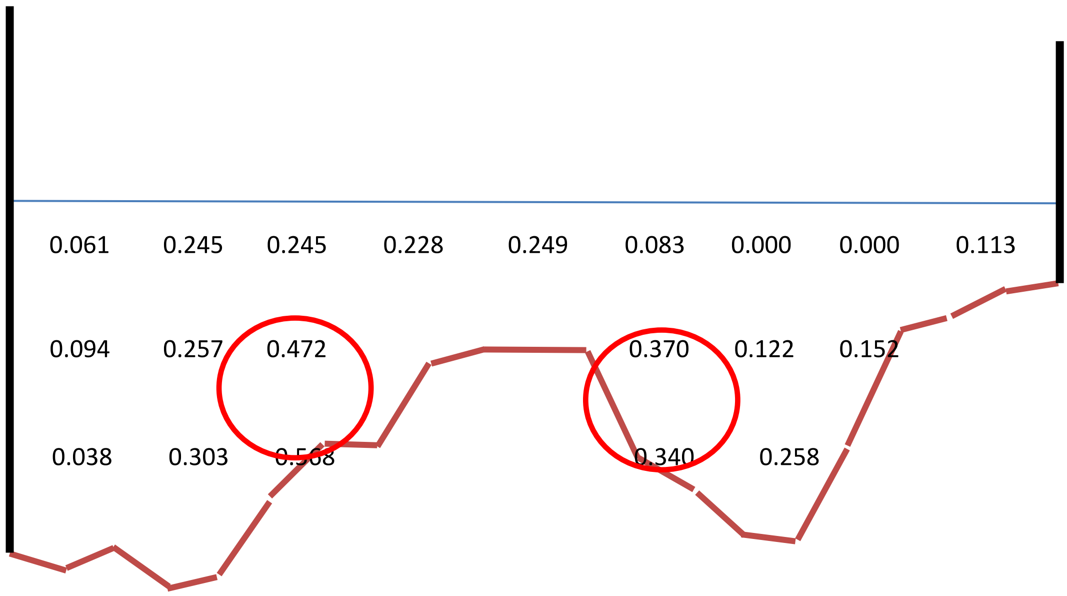


Figure 5. Areas of high and low flow rates in the channel of Cuskinny Lake, 30/4/2012. Red circle marks area of high flows where measurements were subsequently made.

At this time, (11.16am) water started flowing into the lagoon at a considerably higher rate. Water had been draining from the lagoon at 0.01 m/second, but was now flowing into the lagoon at 0.227 m/second.

Discharge on a falling tide = 0.484 m^2 x 0.01 m/sec = <u>0.00484 m^3/second</u>

Inflow on rising tide = 0.484 m^2 x 0.227 m/sec = <u>0.110 m^3/second</u>

Based on Figure 5, subsequent readings taken from an area of high flow rate, at 60cm from “shore” and 20cm depth (Table 3, Figure 6). On inflow at 11.16, average flow rate at this point was 0.472 m/sec. Average flow for whole cross sectional area is 0.227 m/sec. As an estimate of total volume of water entering lagoon the value for this point is multiplied by a correction factor of 0.472/0.227 = 0.48.

Water started flowing **OUT of the lagoon at 14.03**, 86 minutes after high tide.

Table 3. INflow rates at 20cm depth, 60 cm from shore with correction factor for mean total flow from 11.16am until 13.44

Time	11.16	12.14	12.21	12.25	12.29	12.34	12.39	13.08	13.18	13.23	13.27	13.38	13.44
Flow (m/sec)	0.47	0.72	0.81	0.87	0.87	0.86	0.86	0.79	0.76	0.69	0.65	0.57	0.49
X 0.48	0.23	0.35	0.39	0.42	0.42	0.41	0.41	0.38	0.36	0.33	0.31	0.27	0.24

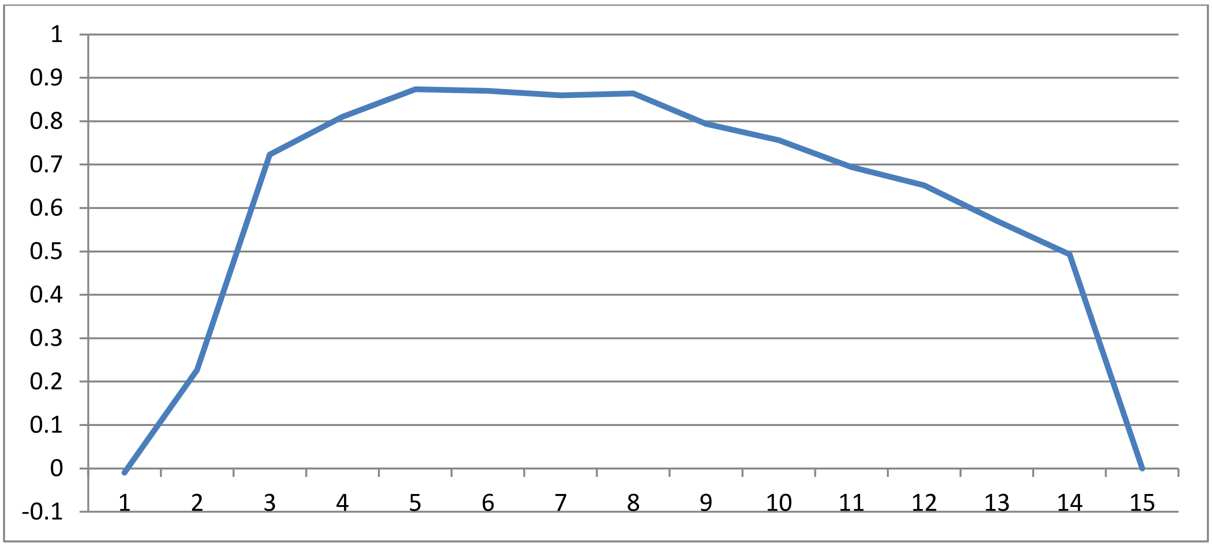


Figure 6. Flow rates at 60cm from "shore" and 20cm depth over incoming tide. 30/4/2012

Water flowing IN for a total of 167 minutes, at an average total flow of 0.36 m/second. During this time water level in the channel had risen by 12.5cm, so that the cross sectional area of the channel now measured **37.3 x 195 cm^2**

Cross sectional area of channel = 37.3 x 195 = 7273.5 cm^2 = **0.727 m^2**

Average flow rate = 0.36 m/second

Discharge =0.727 x 0.36 = 0.262 m^3/second

Vol. of water entering lagoon over tidal cycle = 0.262 x 60 x 167 = 2,622 m^3

Lagoon is approx.. 4 hectares and average depth of 0.5m

Volume of lagoon is approx. 200 x 200 x 0.5 m^3 = **20,000m^3**

Over one neap tide approx. 13% of lagoon volume is replaced

Assuming the tidal water circulates freely in the lagoon, with two tides a day, even on neap tides, more than 50% of the water in the lagoon would flushed from the lagoon in 3 days. In theory, this presumably would be mostly freshwater as the tidal water would be heavier than the fresh and sink (Figure 7). In a calm period most of the stream water entering the lagoon would tend to flow over the salt water and leave the lagoon. But maybe more mixing would occur in such a shallow lagoon.

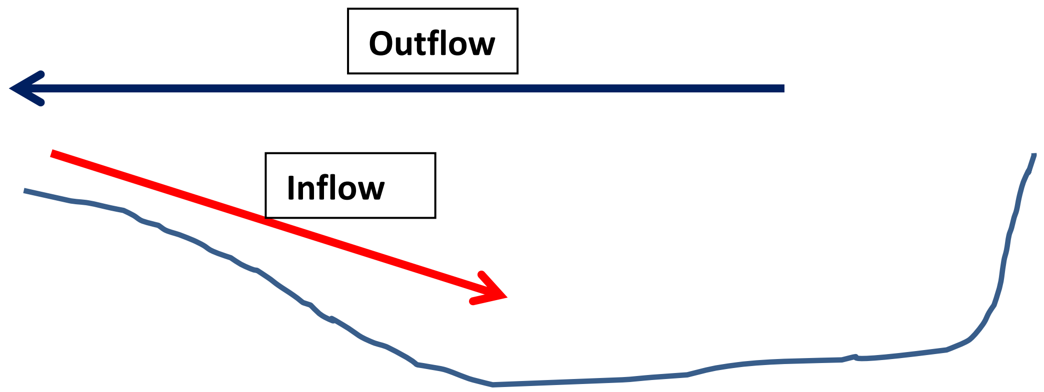


Figure 7. Without mixing, freshwater flowing into the lagoon would tend to flow over the denser seawater entering the lagoon.

Hydrology, Spring tide 23rd May 2012. Tidal amplitude 3.1m.

On 23rd May, high tide was at 07.35 and measurements started at 09.00. At this time, based on a series of measurements (Appendix III), mean INflow rate was **0.32 m/second**. At 09.15 the tide had dropped enough for water to be running from the lagoon, 100 minutes after predicted high tide from local tide tables.

Average OUTflow at 09.15 = -0.41 m/sec.

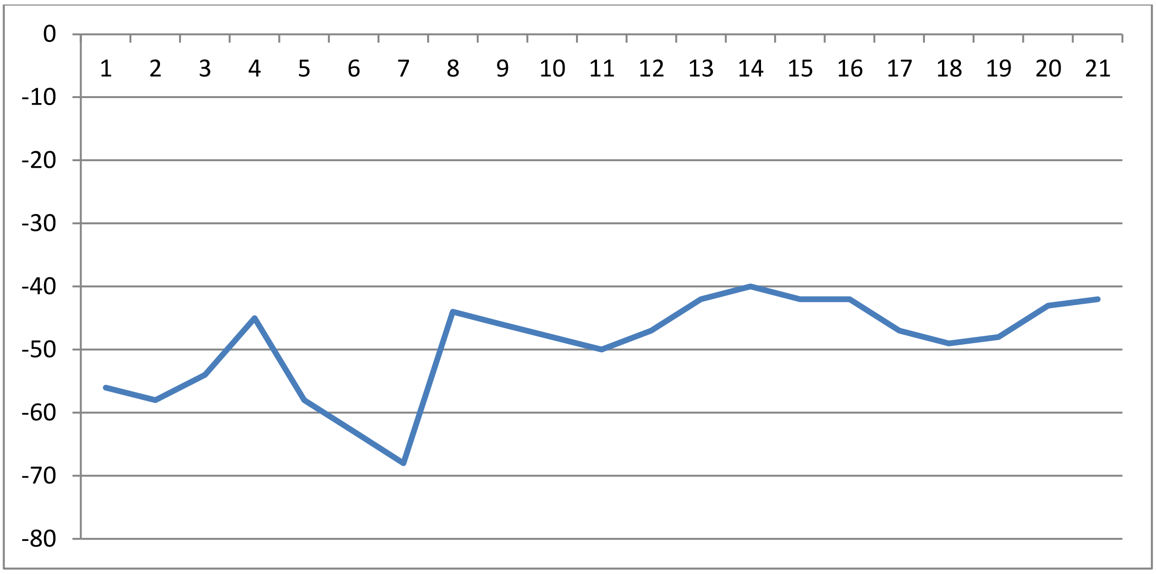


Figure 9. Depth profile of channel where flow measurements were taken 23/5/2012.

At 09.00 Average depth of channel = 49 cm

Width of channel = 210 cm

Cross-sectional area = 0.49m x 2.10m = 1.029 m^2

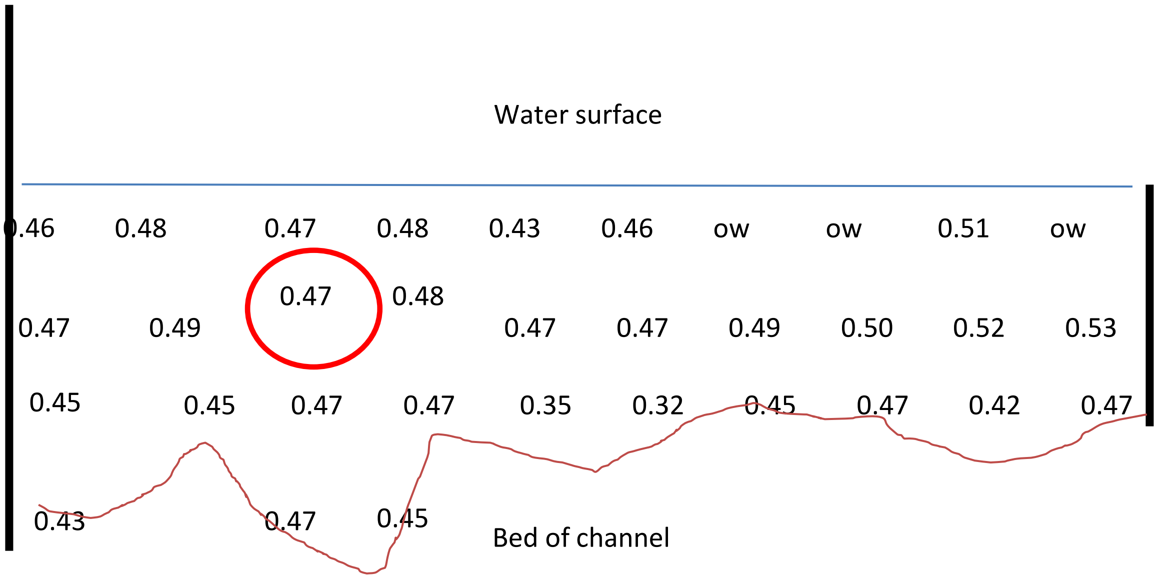


Figure 10. Flow measurements at 10, 20, 30 and 40cm below surface of water at 20cm intervals across channel on 23/5/2012. Measurements subsequently taken at the position of the red circle, 30cm off the bottom, 60cm from the “shore”.

Mean total flow rate at this time, 12.30 pm = 0.46 m/second

Flow rate where measurements taken = 0.47 m/second. This flow rate is very close to the total average flow rate, and no correction factor is needed.

Flow measurements were recorded at this position, 60cm from the “shoreline” and 30cm off the bed of the channel from 09.25 until 21.20 (Appendix 3, Table 4). Water flowed out of the lagoon until 09.15, then changed direction and flowed into the lagoon at an average flow rate of 0.4 m/second, until 18.04 when it started flowing in again at a much faster rate (mean = 0.88 m/second), then started flowing out again at 21.20.

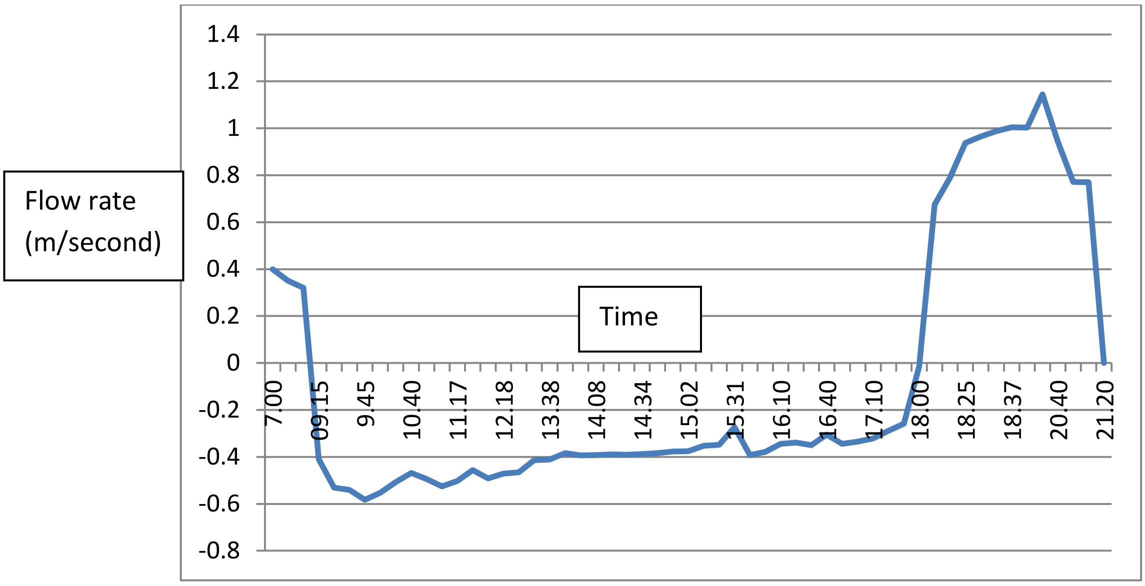


Figure 11. Flow rates of water flowing into and out of Cuskinny Lake over a tidal cycle on 23/5/2012.

On this occasion, seawater was flowing into the lagoon from 18.04 until 21.20 (3 hours 16 minutes) at an average flow rate of 0.88 m/second._Cross-sectional area of channel at 09.00 = 0.49m x 2.10m = 1.029 m^2. But depth of water over the tidal cycles changed by 23cm (Table 4).

Table 4. Variation in water depth where flow measurements were made at Cuskinny Lake on 23/5/2012.

Time	09.00	09.30	09.45	10.05	11.00	11.17	11.45	12.20	13.12
Water depth(cm)	60	55	53	52	50	49	48	46	44

Time	14.30	15.45	16.50		18.14	18.20	18.25	18.30	18.35
Water depth(cm)	41	39	37		40	41	42	42	44

Time	20.30	20.40	21.00
Water depth(cm)	55	57	58

Average depth of water in channel while water flowing into lagoon = 47.4 cm

Average cross-sectional area while water flowing INTO lagoon = 0.47m x 2.1m = 0.987 m^2

Average INflow to lagoon = 0.987 m^2 x 0.88 m/second = 0.869 m^3/second (52.11 m^3/min)

Over the 3h 16 minutes that water was flowing into lagoon:

Volume of water flowing into lagoon = 52.11 m^3/minute, = 3,126.8 m^3/hour

Volume of water flowing into lagoon between 18.04 and 21.20 = **52.11m^3 x 196 minutes**

= **10, 213.5 m^3**

Lagoon is approx.. 4 hectares and average depth of 0.5m

Volume of lagoon is approx. 200 x 200 x 0.5 m^3 = **20,000 m^3**

Over one spring tide over 50% of lagoon volume is replaced

Over one neap tide approx. 13% of lagoon volume is replaced

Residence time

If the seawater inflow on the neap tide represents 13% of the volume of the lagoon, over 50% of the lagoon water would be flushed in 2.5 days (5 tides, Table 5).

If seawater entering on the spring tide represents 51% of the volume of the lagoon, over 98% of the lagoon water would be flushed in 3 days (6 tides, Table 5).

Table 5. Percentage of volume of original lagoon water remaining after successive tides/days on the neap (30/4/2012) and spring tide (23/5/2012) at Cuskinny Lake, Co. Cork

	Day 1		**Day 2**		**Day 3**	
	Tide 1	**Tide 2**	**Tide 1**	**Tide 2**	**Tide 1**	**Tide 2**
Neap tide (13% replaced)	87	76	66	57	49	43
Spring tide (50.5% replaced)	49	24.01	11.76	5.76	2.82	1.38

Another, simpler way of calculating the volume of seawater flowing into the lagoon over a tidal cycle is simply to measure the change in depth of water on the staff gauge and relate this to the original volume of the lagoon.

During the spring tide on 23/5/2012 water depth measured on the staff gauge increased from 5cm at 18.00h just before water started flowing back in to 24cm at 21.05 just before water started flowing out again.

Volume of lagoon is approx. 200m x 200m x 0.5 m **= 20,000m^3**

Volume of water flowing into lagoon = 200m x 200m x 0.19m **= 7,600m^3**

Therefore over this one spring tidal cycle the volume of lagoon water replaced based on flow measurements is 51%, whereas the volume of lagoon water replaced based on staff gauge measurements is 38%.

However, part of the rise in water level within the lagoon is due to freshwater flowing in from the stream. On the following day (24/5/2012) that flow measurements were made during the spring tide, a quick attempt was made to measure this inflow.

On 24/5/2012, at approximately 10.00am:

Width of stream	=	**140cm**		
Average depth of water	=	**16.87cm**		
Average flow rate	=	**0.363 m/second**		
Cross-sectional area of the stream	=	**140 x 16.87 m^2**	=	**0.236 m^2**
Discharge of stream	=	**0.236m^2 x 0.363 m/second**	=	**0.857 m^3/second**
			=	**5.14 m^3/minute**

On the previous day, seawater was flowing into the lagoon for 195 minutes.
During this time, if flowing at the same rate, the amount of fresh water entering the lagoon would have been:

Amount of freshwater entering at same time as seawater inflow

= 5.14 x 195 = 1,002.3 m^3

So, the amount of freshwater entering at the same time as the seawater would be approximately 10% of the volume of seawater entering.

3.2 WATER CHEMISTRY

Following the extreme event at Cuskinny on the 11/10/2012, water samples were collected and analysed together with samples collected from a range of lagoon types from around the country which were being sampled as part of an ongoing study for the E.P.A. in relation to compliance with the Water Framework Directive (Appendix IV).

Samples were collected from Cuskinny at the "duck-pond" and at the southern end of the lagoon, close to the sea inlet. In these initial samples, the concentration of nitrates, nitrite and ammonia were all higher than any of the other 31 lagoon sites sampled at this time, including some of those regarded as being extremely eutrophic such as Inch Lough, Lough Donnell, and the North Slob (Figures 12a,b,c).

Water samples were taken from Cuskinny again on 21st January and 20th March and compared with samples from other lagoons collected in December 2011 and January 2012 (Appendix IV). And again nitrate and nitrite concentrations are exceptionally high (Figures 13a & b). Finally, samples were taken from Cuskinny and other lagoons in May and June 2012, and again nitrate and nitrite levels are very high in both the lagoon and in the stream flowing under the bridge, approximately 200m north of the lagoon. And also, Phosphate levels are very high in the stream and similar to values from North Slob West and Tacumshin West. (Figures 14 (a-c).

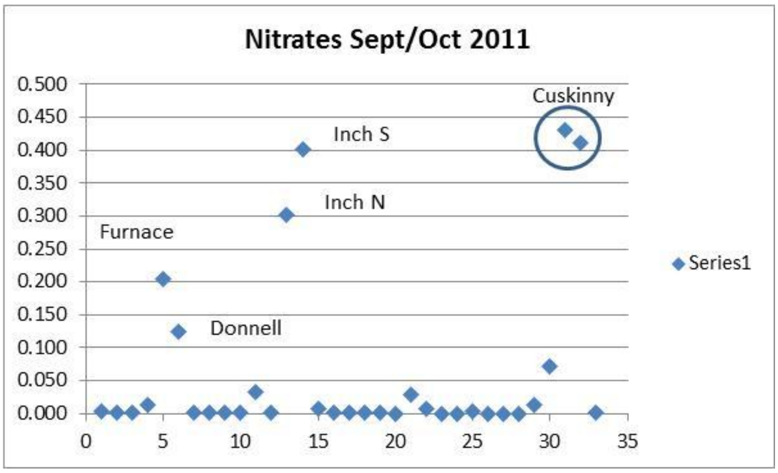


Figure 12(a). Concentration of NitrateN (mg/L) in water samples from 31 lagoon sites in Ireland, September and October 2011.

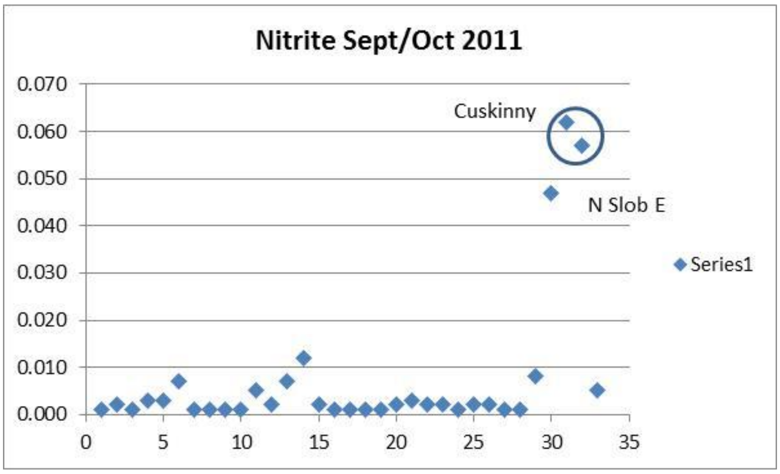


Figure 12(b). Concentration of NitriteN (mg/L) in water samples from 31 lagoon sites in Ireland, September and October 2011.

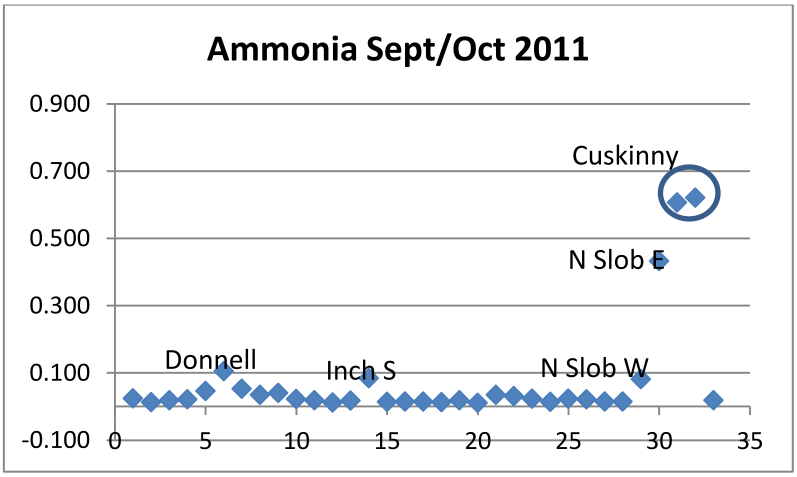


Figure 12(c). Concentration of AmmoniaN (mg/L) in water samples from 31 lagoon sites in Ireland, September and October 2011.

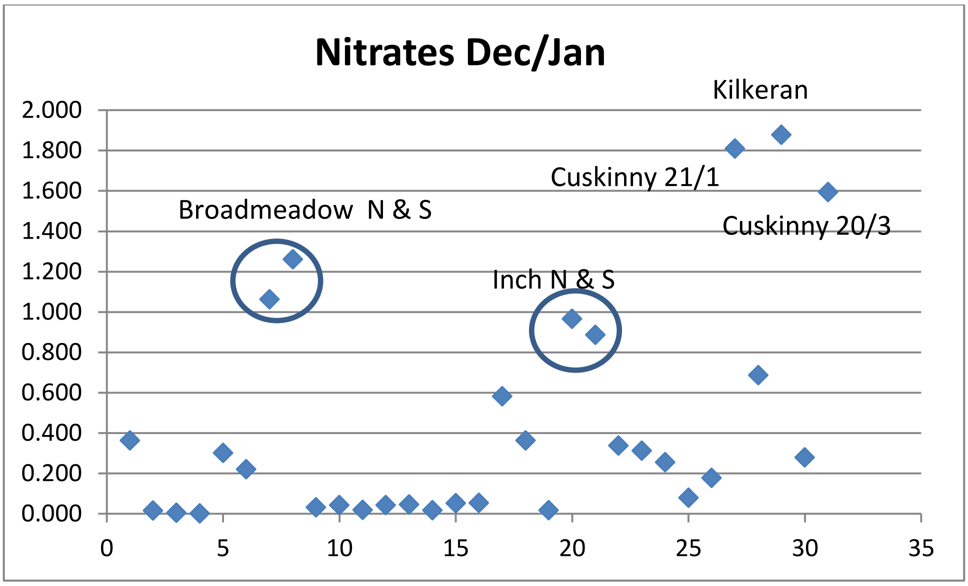


Figure 13(a). Concentration of NitrateN (mg/L) in water samples from 31 lagoon sites in Ireland, December 2011 and January 2012 with an additional sample from Cuskinny from 20th March /2012.

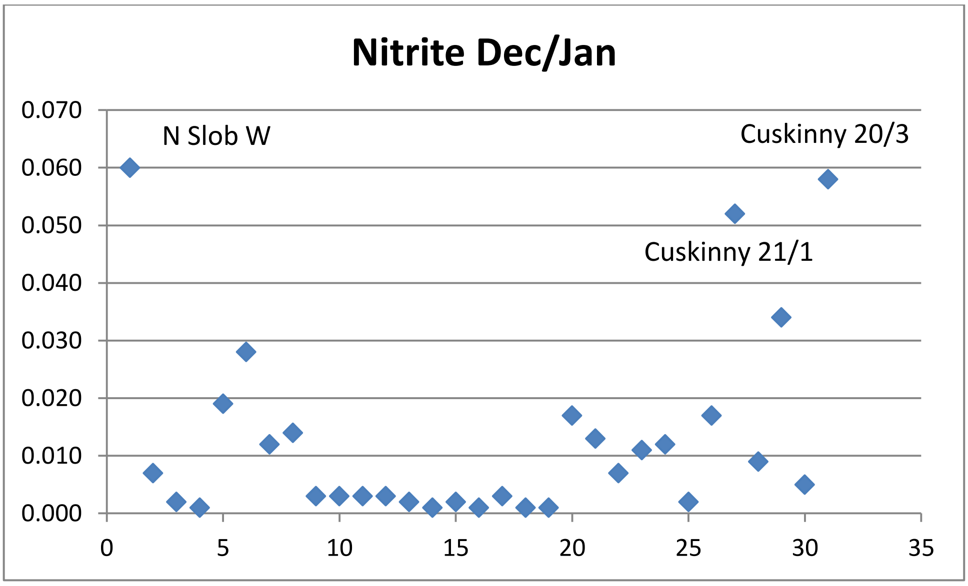


Figure 13(b). Concentration of NitriteN (mg/L) in water samples from 31 lagoon sites in Ireland, December 2011 and January 2012 with an additional sample from Cuskinny from 20th March /2012.

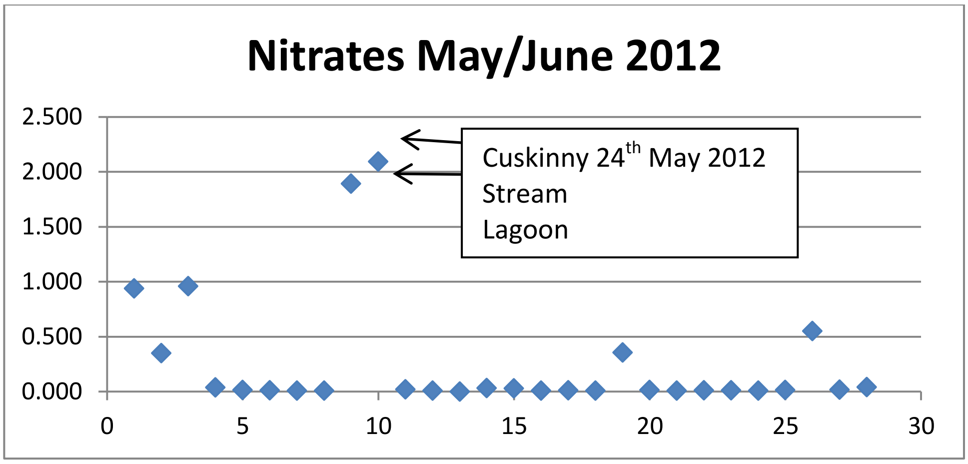


Figure 14(a). Concentration of NitrateN (mg/L) in water samples from 31 lagoon sites in Ireland, May and June 2012.

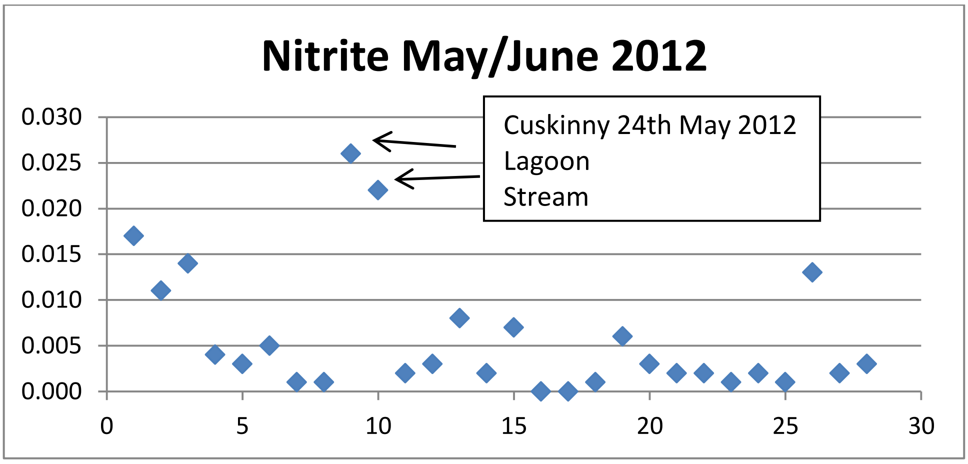


Figure 14(b). Concentration of NitriteN (mg/L) in water samples from 31 lagoon sites in Ireland, May and June 2012.

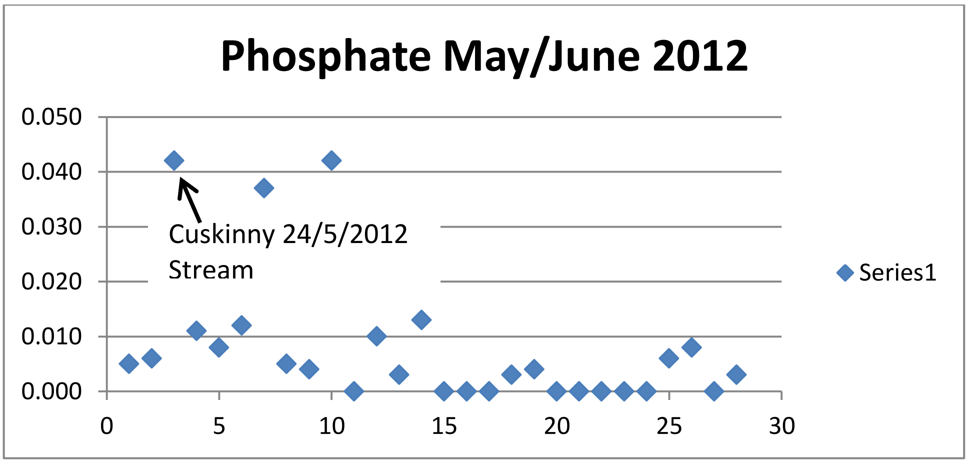


Figure 14(c). Concentration of PhosphateP (mg/L) in water samples from 31 lagoon sites in Ireland, May and June 2012.

Salinity, Temperature and Dissolved Oxygen

Salinity, Temperature and Dissolved Oxygen were measured on 23rd May 2012 between 09.30 am and 18.20 pm (Table 15, Appendix V).

Salinity remained between 27 and 29 psu for the first few hours when tidal water was flowing from the lagoon, then gradually declined as the freshwater inflow from the stream had more effect, then increased again sharply as tidal water started flowing into the lagoon.

Temperature increased slightly during the day, then decreased slightly with the inflow of water from the Bay.

Dissolved oxygen gradually increased from 8.1 to 10.7mg/L during the day.

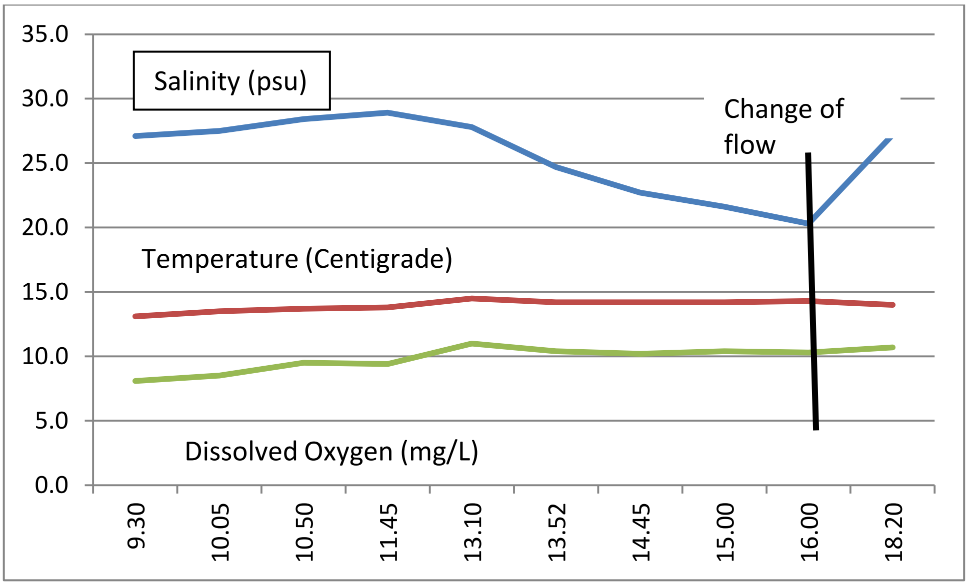


Figure 15. Salinity, Temperature and Dissolved Oxygen in the inlet/outlet channel of Cuskinny Lake, 23rd May 2012.

It looks like the lagoon is well flushed, but the main problem would appear to be the high nutrient loading entering the lagoon. This is all very preliminary but the main form of management would appear to be the need to reduce the amount of nutrients entering the lagoon, perhaps by creation of additional ponds or filter beds (or reducing the initial inputs !?).

Historical nutrient levels

A study of leukemia-like conditions in the cockle population (*Cerastoderma edule*) in Cuskinny Bay in the late 1980s noted that general eutrophication produces large blooms of algae in Cuskinny Bay (Twomey,1987). Large amounts of algae were seen on the beach in 2011 and 2012 and this seems to be an almost permanent feature. Nitrate levels in Cork Harbour are slightly elevated but nothing like the values recorded in the lagoon or stream (R. Wilkes EPA, pers comm.). Galvin reported high nitrate levels in 1991 (Galvin 1992, Table 6 from RPS 2000), equivalent to 1.2 mg/L Nitrate N. Van Heste recorded exceptionally high levels of Nitrate, Ammonia and Phosphate in the water entering the lagoon, and the effect of the pond in reducing these nutrient levels before water entered the lagoon (Figure 16).

Table 6. Environmental parameters recorded by Galvin in 1991 (Galvin 1992) in Cuskinny Lake, Co. Cork. (from RPS 2000)

Parameter	Southern end	Northern end	
	summer	winter	summer
Colour	clear	clear	clear
Temperature	23.1	8.6	23.9
pH	8.26	7.81	8.07
Dissolved Oxygen (%)	123	74	89
Dissolved Oxygen (mg/L)	11.1	9.4	7.8
BOD	10.5	4.8	7.5
Chlorophyll a (µg/L)	106.3	10.4	74.5
Organic content (of sediment)(%)	12.7	-	9.9
Ammonia (µg-at//L)	0	14.42	0
Nitrite (µg-at//L)	2.33	2.38	3.15
Nitrate (mg/L)	0	5.40	0
Phosphate (µg-at//L)	0	1.07	0
N/P	-	5062.4	-
Silica (µg-at//L)	16.1	47.3	7.9

Table 7. Nutrient levels recorded by Van Heste in 2004 (Van Heste 2004) from the stream and pond north of Cuskinny Lake, Co. Cork and then the lake itself. (data converted to mg/L N and P).

	Into pond	In pond	Out of pond	In stream	In lagoon	In channel
Nitrate N (mg/L)	17.1	9.2	10.4	4.9	2.6	2.2
Ammonia N (mg/L)	0.39	0.39	0.39	0.01	0.01	0.01
Phosphate P (mg/L)	1.20	0.73	0.94	0.30	0.00	0.01

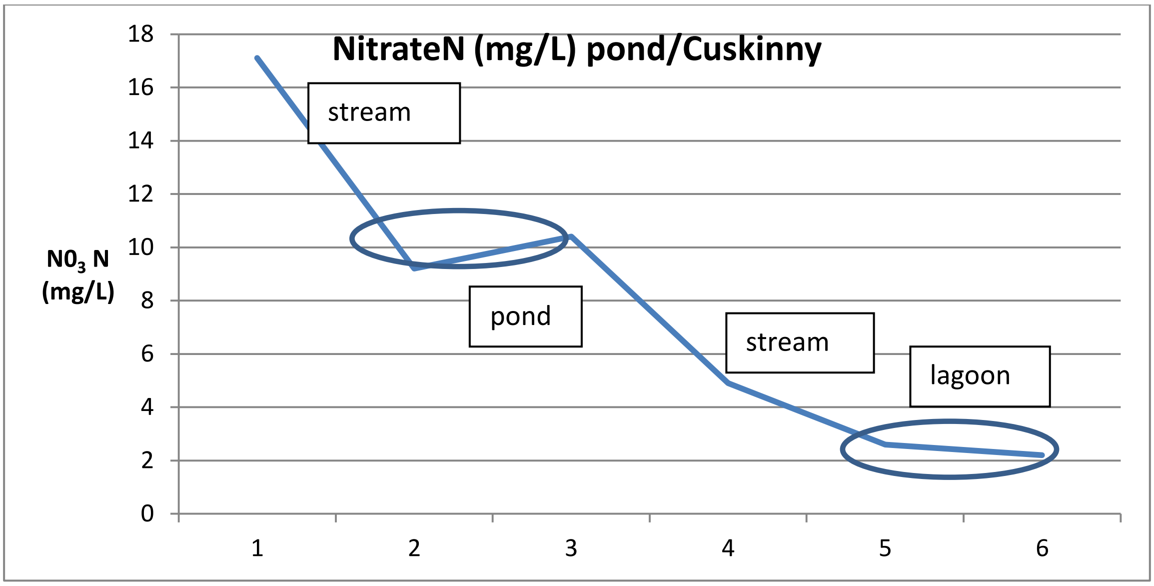


Figure 16. Nitrate levels coming into the lagoon from the stream, and "filter effect" of small pond (from Van Heste 2004)

There is obviously a nutrient problem in Cuskinny, which has existed for at least the last 25 years. The situation was summarised in the Conservation Status of Irish Lagoons (Oliver 2007a) as *"Moderate eutrophication from surrounding farmland and domestic housing but significant tidal flushing. Unfavourable-Inadequate."* The recent extreme event in October 2011, does not appear to be the result of an isolated occurrence of high nutrient loading as levels were exceptionally high in 2004 and remain high in 2012. In 1993, the management plan for Cuskinny suggested the creation of additional ponds above the lagoon, as wildlife habitat. In the subsequent management plan (RPS 2002) it is stated that "the lake appears to suffer from eutrophication" and the suggestion of creating more ponds was repeated and also suggested by Van Heste in 2004.

There may have been some other external factor such as work carried out by Eirgrid which was the final trigger for the event, but at this stage the most probable explanation of the extreme event that occurred in October 2011 would appear to be that the nutrient over loading of the lagoon supported a proliferation of algae (probably *Ulva* sp.) which under unusually warm and calm conditions in October, died, de-oxygenated the water and resulted in the release of hydrogen sulphide, causing the water to become milky-white and giving off bad odours and probably killing all aquatic invertebrates. This situation is likely to re-occur if the same combination of events occur.

Reducing the nutrient loading may not have an immediate effect as the sediment within the lagoon is probably very high in accumulated nutrients, but it would appear to be an essential part of the management plan, either to reduce the loading at source, or to reduce it by filtering through ponds.

It appears that the farmer was happy to dig the first pond, and in order reduce the likelihood of such an extreme event occurring again, he may be very happy to create more ponds, even at the expense of losing grassland needed to support his dairy cattle. Cuskinny is managed as a nature reserve and all attempts should be made to prevent the annihilation of the fauna which forms the base of the food chain in the lagoon.

4. Discussion

Hydrology

The bed of the channel is very irregular and presumably dynamic as it is covered largely by stones and a living mussel reef, which is likely to change shape. In a uniform channel it would be advisable to mark a transect where any future measurements can be made, but in this particular channel that would appear to be impractical. The manual recommends measuring the flow rate at 0.6 depth of the channel, but flow rates vary considerably in different parts of the cross-sectional area of this irregular channel, and it is important to measure these rates and select a position at which to anchor the flow meter. The rates measured at this point can then be used as an index on which to base calculations for total mean flow. This was particularly important on the neap tide when there was less water in the channel and flow rates within the cross-sectional area varied considerably.

However, a much simpler, and possibly more accurate method of calculation, would be simply to record the change in water levels on the staff gauge over a tidal cycle. Over the one spring tidal cycle on the 23rd May 2012, the volume of lagoon water replaced based on flow measurements is 51%, whereas the volume of lagoon water replaced based on staff gauge measurements is 38%. The discrepancy between the two values may be partly due to the fact that the last measurement on the staff gauge was made 10 minutes before the water stopped flowing into the lagoon, but also due to the fact that results are based on average flow rates and average water depths. Averages are used because the flow rates are different in different parts of the cross sectional area, and water depth and flow rates are changing throughout this time. The accuracy of this calculation could be improved by taking more measurements more frequently but calculations based on staff gauge measurements would be far easier and possibly more accurate.

According to the management plan of 2000 (RPS 2000), water level fluctuations with the tide is not precisely known, but it is believed to be no more than ± 10 cm. Obviously it is much more than this as on 23rd May the water level changed by at least 19cm and this was on a relatively weak spring tide with a tidal amplitude of 3.1 metres. Tidal amplitude at Cobh can be up to 4.4m, or even greater in certain weather conditions. With these higher tides, flushing rates would be even greater. Whichever method of calculation is used this is a very high percentage of the volume of the lagoon, meaning that up to 98% of the lagoon water would be replaced in 3 days.

However, an important part of this calculation is the volume of water in the lagoon before seawater starts to flow in and only a crude estimate of the area of the lagoon and the average depth was used to calculate this volume. Any future studies should include an accurate measurement of depths in the lagoon in relation to water depths recorded on the staff gauge. A graph could then be drawn of the volume of water in the lagoon in relation to depths recorded on the staff gauge.

The depth of the lagoon was measured by a local school, Colaiste Muire, Cobh, and according to their measurements, depths ranged from 0.50m to 0.75m with a mean depth of 0.59 (s.e. = 0.02m). Average water level measured on the staff gauge near the "dick-feeding station" from January – October 1992 was around 0.49m (RPS 2000, from Jim Wilson) with a maximum of 0.84m. Lake water levels were recorded from November 1991 – June 1997 during January – February, May – June and September – December in conjunction with recording of rainfall by by Scoil Iósaef Naofa. The maximum range in water level was 0.81m but 90% were within the range of 20cm. Visual comparison of the lake water level graphs with rainfall graphs indicate that rainfall explains a large proportion of the variation in lake water levels and rainfall was considered to be the principal influence on lake water levels rather than tides.

The day of sampling on 23rd May 2012, followed a period of relatively low rainfall and was chosen to coincide with a spring tide. On this day the water level rose by 19cm of which only 10% was due to the inflow of freshwater. During a period of high rainfall and weak tides, the percentage contribution of rainfall and runoff to the lagoon may well exceed that of tidal water, and be the major control on lagoon water levels. Under these conditions, the flushing effect of tidal water would be considerably less, but this is likely to occur during the winter months, when temperatures are lower, and the deoxygenation of the water less likely to be caused.

Some of the estimates used in the calculations, especially those for the volume of water in the lagoon, may not be very accurate, but it is clear that for most of the year large amounts of seawater enter the lagoon twice a day and flush a high percentage of the water from within the lagoon. No attempt was made on this occasion to investigate the circulation of tidal water within the lagoon, and it is possible that certain parts such as distant corners, or areas behind the old submerged embankments, may not get the benefit of this flushing especially in calm periods, but the lagoon is small and shallow, and it is assumed that the combined effects of tides and winds is enough to circulate the water sufficiently.

Water chemistry

Cuskinny has been referred to in the past as eutrophic, but this has usually been based on anecdotal information or subjective judgements. Twomey (1987) referred to "a general eutrophication…. in Cuskinny Bay". Galvin analysed water samples in 1991, and among other parameters, reported high nitrate levels equivalent to 1.2 mg/L Nitrate N (Galvin 1992). The lagoon was described by RPS (2000) as hyper-eutrophic based on Galvin's 1991 data, as evidenced by summer chlorophyll a levels, and that winter nutrient levels indicated that the lake was being enriched by agricultural run-off, but that in summer these nutrients were being taken up by the algae, and the lake was nutrient limited. Also that, the dissolved oxygen level at the southern end of the lake in summer may indicate excessive daytime photosynthesis which would be followed by depletion during the hours of darkness. Both low oxygen and super-saturation may be injurious to fish and other aquatic organisms. In the summary of factors which may influence the important features of the reserve, they say agricultural run-off may be harmful to aquatic fauna and risk impacts to bird populations and intertidal flora and fauna.

In the action plans of the 2000 management plan RPS suggest the extension of the existing pond and creation of new ponds, but this is entirely for nature conservation and educational objectives. Although they do go on to describe the lake as polluted based on existing data (from Galvin, 1992) and advise good land management practises to reduce pollution from agricultural run-off.

In 2004, Van Heste recorded exceptionally high levels of Nitrate, Ammonia and Phosphate in the water entering the lagoon, and the effect of the pond in reducing these nutrient levels before water entered the lagoon. Following this, Van Heste suggested creating more ponds, specifically be used as "water treatment plants" in order to reduce the nutrient loading of the lagoon. However, these ponds could also result in the creation of valuable wildlife habitat.

The situation was summarised in the Conservation Status of Irish Lagoons (Oliver 2007a) as *"Moderate eutrophication from surrounding farmland and domestic housing but significant tidal flushing. Unfavourable-Inadequate," but* this was based more on an overall impression rather than on any intrinsic evidence.

The only water quality data for Cuskinny before 2011 appears to be that of Galvin in 1991 and Van Heste in 2004.

Following the extreme event at Cuskinny on the 11/10/2012, water samples were collected and analysed together with samples collected from a range of lagoon types from around the country which were being sampled as part of an on-going study for the E.P.A. in relation to compliance with the Water Framework Directive. As a result of this water sampling in October, following the event, then in January, March and May of 2012, it was found that the nutrient levels in the lagoon remain exceptionally high, and in most sampling periods are higher than any of the other 25 lagoon sites in the country.

Nitrate levels in Cork Harbour are slightly elevated but are nothing like the values recorded in the lagoon or stream (R. Wilkes EPA, pers comm.) and it seems obvious that the nutrients are coming from the stream or from agricultural run-off in the catchment.

There is obviously a nutrient problem in Cuskinny, which has existed for at least the last 25 years. The recent extreme event in October 2011 does not appear to be the result of an isolated occurrence of high nutrient loading as levels were exceptionally high in 2004 and remain high in 2012.

What happened on 11th October 2012?

Following the event on 11/10/2012, various hypotheses have been proposed in order to explain the cause. Jim Wilson, the manager of the Cuskinny Nature Reserve on behalf of BirdWatch Ireland thought that the situation may have arisen as a result of work carried out by Eirgrid while laying an electricity cable. Mr Wilson had put in a detailed response to their EIA in which he had stated that above all, the hydrology of the lake must not be affected through silting of the culvert or interference with the tidal flap itself. It now seems less likely that this event had anything to do with work carried out by Eirgrid, although it seems possible that work that was carried out may have allowed more seawater to percolate through the causeway into the lagoon.

However, considering the amount of flushing the lagoon receives, it seems unlikely that a **change in the hydrology**, especially an increase in the flushing rate, could cause such a catastrophic event. However, Ambrose Furey of C.I.T. spoke to a local resident who thought that water was moving much more slowly than usual (from the lagoon) and that the sluice was **partially blocked with silt**, and he (Mr Furey) believed that this would cause the water to partially stagnate and that this would account for H2S production. However, Jim Wilson walked up the culvert following the incident and checked the sluice position and it appeared to be in the same position as it was before the Eirgrid work was carried out and there appeared to be no obvious signs of fresh work in the sluice area.

In an email to Dave Suddaby (Reserves Manager BWI) on 11th October, Jim Wilson stated that the water quality division of Cork County Council and staff from the Inland

Fisheries Board had examined the site and taken samples (pending). The inland fisheries representative suggested that the "whiteness was an algal bloom and may have been caused by **bird droppings** in the lake. This is known to have happened in other lakes but as a result of a build-up of nutrients in "closed systems" which again is unlikely to happen in a lake with tidal inflows twice a day.

What happened in the lagoon reminded Jim Wilson of Ballycotton Lake where seaweed rots under fresh/brackish water and Dr. Debbie Chapman of U.C.C. agreed that it could be due to a freak acute episode of eutrophication/gas liberation from **decomposing seaweed** as a result of the recent warm spell. The rotting of large amounts of seaweed in a lagoon can often occur, especially following storms when large amounts of marine seaweed is deposited in the lagoon by high tides and strong winds resulting in overtopping of the lagoon barrier. This has been witnessed on several occasions in lagoons such as Lough Murree, Co. Clare. Lough Cowragh, Aranmore and Lough Bofin, Inish Bofin. However, on this occasion, the temperature was unseasonally high but weather conditions were not stormy (quite the opposite). Jim Wilson reports seeing large amounts of *Ulva* in the lake at the time of the incident and in the months leading up to it. Ulva blooms during the summer have occurred on the lake on many occasions in the past (photo from 1976 showing one such bloom).

Ambrose Furey of C.I.T. took water samples on the Sunday and the pH of the water ranged from pH 6.5 to pH 7. The milky white colour disappeared from the water once sampled which led him to believe that the milky colour was being producing through the release of hydrogen sulphite from the decomposition of organic matter within the sediment and water column of the marsh. "H2S gas can cause a milky appearance in water when reaching atmospheric pressure. As H2S dissolves in water, it increases the S ion which can force sulphate formation. H2S can result in a decline in the natural pH of water which can actually force dissolved minerals out of solution, creating a discoloration in water".

In an email from John O'Halloran to Jim Wilson it appeared that the C.O.D. of water samples collected in Cuskinny by Ger Morgan and Ambrose Furey were "huge" (>150 mg/L).

Meanwhile, Jim Wilson wrote to Mauro Lenzi who specialises in the **eutrophication** of Mediterranean lagoons (see refs) describing the condition of Cuskinny and remarking on the **exceptionally hot weather** in late October with air temperatures up to 20 degrees Celsius. Mr Lenzi replied that similar situations are common in Mediterranean non-tidal lagoons and are caused by **sulphate reduction due to bacterial activity** due to the accumulation of organic matter on the bed of the lagoon.

Paraphrased from M. Lenzi: *"In the less extreme climate of Ireland* ***sulphate reduction*** *occurs gradually and rarely occurs in such a striking and dramatic manner. This was surely supported by the* ***accumulation of organic matter*** *and happened in a synchronic and homeostatic manner due* ***to temperature and (probably) the humidity*** *which prevented a sufficient heat to the air-water interface at night. The mechanism is triggered when the sediment capacity to buffer the hydrogen sulfide is exhausted".*

So, according to Lenzi, the situation was caused by a combination of factors. This may have included the accumulation of seaweed, the silting up of the sluice, and the exceptional weather conditions.

However, the results of the water sample analyses **clearly indicate a nutrient overloading of lagoon**, and must be a major contributory factor involved, which together with a combination of additional factors resulted in the final event.

It looks like the lagoon is well flushed, but the main problem would appear to be the high nutrient loading entering the lagoon. This is all very preliminary but the main form of management would appear to be the need to reduce the amount of nutrients entering the lagoon, perhaps by creation of additional ponds or filter beds (or reducing the initial inputs !)

There may have been some other external factor involved, such as work carried out by Eirgrid which was the final trigger for the event, but at this stage the most probable explanation of the extreme event that occurred in October 2011 **would appear to be that the nutrient over loading of the lagoon supported a proliferation of algae (probably *Ulva* sp.) which under unusually warm and calm conditions in October, died, de-oxygenated the water and resulted in the release of hydrogen sulphide, causing the water to become milky-white and giving off bad odours and probably killing all aquatic invertebrates.** This situation is likely to re-occur if the same combination of events occurs.

5. Suggestions for further work.

1. Make more flow measurements over a range of tidal conditions in order to refine the calculation of the amount of seawater entering the lagoon and overall water budget.

2. Make more measurements of the amount of freshwater entering the lagoon from streams (and possibly groundwater). Calculate the amount of freshwater entering the lagoon based on average rainfall and catchment area.

3. Refine the calculation of relative amounts of tidal and freshwater inputs to the lagoon affecting residence time of the water and flushing rates.

4. Make accurate measurements of water depth in the lagoon in relation to water level measured on the staff gauge, in order to calculate the volume of water in the lagoon under different water level regimes.

5. Measure the amount of algae growing within the lagoon and record seasonal changes in species, percentage cover and biomass.

6. Record the amount of marine algae entering the lagoon under normal tidal conditions and on extreme tidal and storm conditions.

7. Monitor changes in the invertebrate community by regular sampling.

8. Carry out more water sampling, perhaps monthly, to monitor the amount of nutrients within the lagoon and in the stream.

9. Identify the source of nutrient inputs to the lagoon.

Some of the above suggestions may be very time- consuming, labour-intensive and expensive if carried out entirely by professionals. However, many of these suggestions would make very good student projects, which could involve local volunteers under professional guidance.

Appendix I. Photographs of Cuskinny Lake, Great Island, Co. Cork taken on the 11/10/2011, following an extreme eutrophication event.

Figure 1. Dead prawns floating in the entrance channel to Cuskinny Lake, Co. Cork taken on 11/10/2011 (© J. Wilson). (Based on the length of the rostrum, these prawns appear to be *Palaemon serratus*).

Figure 2. Milky-white water flowing from Cuskinny Lake, Co. Cork close to the inlet/outlet of the lake taken on 11/10/2011 (© J. Wilson).

Appendix I cont.. Photographs of Cuskinny Lake, Great Island, Co. Cork taken on the 11/10/2011, following an extreme eutrophication event.

Figure 3. Milky-white water flowing from Cuskinny Lake, Co. Cork taken from the bridge over the inlet/outlet taken on 11/10/2011 (© J. Wilson).

Figure 4. Milky-white water flowing from Cuskinny Lake, Co. Cork over the beach, taken on 11/10/2011 (© J. Wilson).

Appendix I cont.. Photographs of Cuskinny Lake, Great Island, Co. Cork taken on the 11/10/2011, following an extreme eutrophication event.

Figure 5. Milky-white water in Cuskinny Lake, Co. Cork, taken at the "duck-feeding station" on 11/10/2011 (© J. Wilson).

Figure 6. Milky-white water in Cuskinny Lake, Co. Cork, taken at the "duck-feeding station" with staff gauge on 11/10/2011 (© J. Wilson).

Appendix II. Flow measurements of water entering and leaving Cuskinny Lake, Great Island, Co. Cork during a neap tide on 30th April 2012.

Initial measurements made at 09.44

Table 1. INFlow rates 10cm above bottom at 4 positions across the channel. Every 10 seconds

	1	2	3	4
1	0.053	0.059	0.053	0.017
2	0.082	0.029	0.047	0.017
3	0.047	0.023	0.053	0.011
4	0.071	0.011	0.011	0.023
5	0.077	0.017	0.017	0.017
6	0.071	0.011	0.035	0.017
7	0.082	0.017	0.041	0.023
8	0.077	0.017	0.047	0.017
9	0.118	0.017	0.041	0.017
10	0.072	0.017	0.017	0.011
Average	0.075	0.022	0.036	0.017
SD	0.02	0.014	0.0157	0.004
	0.08	0.022	0.0362	0.017
	0.04			

Table 2a. OUT flow rates at 10.27 at 10cm depth across the channel in 20cm intervals

At 10 cm depth 10.27 am

	20	40	60	80	100	120	140	160	180
	0.011	0.017	0.189	0.195	0.1	0	0	0.13	0.171
	0.005	0.183	0.183	0.189	0.077	0	0	0.118	0.201
	0.011	0.183	0.183	0.195	0.066	0	0	0.171	0.183
	0	0.201	0.159	0.213	0.13	0	0	0.195	0.171
	0.011	0.189	0.154	0.201	0.183	0	0	0.189	0.177
	0.011	0.183	0.148	0.225	0.159	0	0	0.183	0.177
	0	0.177	0.183	0.195	0.171	0	0	0.201	0.183
	0	0.177	0.189	0.201	0.177	0	0	0.207	0.189
	0.005	0.201	0.177	0.189	0.124	0	0	0.213	0.207
	0.005	0.213	0.177	0.207	0.136	0	0	0.219	0.183
	0.006	0.172	0.174	0.201	0.132	0.000	0.000	0.183	0.184

At 20 cm depth 10.27 am

	20	40	60	80	100	120	140	160	180
	0.005	0.094	0.195	ow	ow	0	0	0.231	ow
	0.029	0.13	0.201	ow	ow	0	0	0.248	ow
	0.041	0.124	0.207	ow	ow	0	0	0.207	ow
	0.059	0.136	0.201	ow	ow	0	0	0.189	ow
	0.023	0.13	0.171	ow	ow	0	0	0.183	ow
	0.042	0.118	0.201	ow	ow	0	0	0.213	ow
	0.029	0.13	0.207	ow	ow	0	0	0.159	ow
	0.041	0.142	0.183	ow	ow	0	0	0.165	ow
	0.047	0.154	0.195	ow	ow	0	0	0.159	ow
	0.023	0.142	0.189	ow	ow	0	0	0.177	ow
Average	0.034	0.130	0.195	#DIV/0!	#DIV/0!	0.000	0.000	0.193	######

At 30cm depth at 10.27 am

At 30 cm depth 10.27 am

20	40	60	80	100	120	140	160	180
0.88	0.077	ow	ow	ow	ow	0	ow	ow
0.094	0.065	ow	ow	ow	ow	0	ow	ow
0.077	0.065	ow	ow	ow	ow	0	ow	ow
0.094	0.094	ow	ow	ow	ow	0	ow	ow
0.071	0.106	ow	ow	ow	ow	0	ow	ow
0.082	0.088	ow	ow	ow	ow	0	ow	ow
0.088	0.094	ow	ow	ow	ow	0	ow	ow
0.071	0.1	ow	ow	ow	ow	0	ow	ow
0.077	0.088	ow	ow	ow	ow	0	ow	ow
0.088	0.077	ow	ow	ow	ow	0	ow	ow
0.162	0.085	######	#DIV/0!	#DIV/0!	#DIV/0!	0.000	#DIV/0!	######

Table 3a. INFlow rates at 10cm depth at 11.16 am

	20	40	60	80	100	120	140	160	180
	0.006	0.236	0.236	0.231	0.189	0.142	0	0	0.77
	0.112	0.219	0.219	0.236	0.26	0.142	0	0	0.065
	0.118	0.225	0.225	0.231	0.242	0.077	0	0	0.023
	0.106	0.248	0.248	0.254	0.231	0.112	0	0	0.017
	0.088	0.272	0.272	0.278	0.248	0.118	0	0	0.029
	0.047	0.29	0.29	0.236	0.266	0.059	0	0	0.041
	0.029	0.201	0.201	0.213	0.284	0.047	0	0	0.071
	0.017	0.272	0.272	0.171	0.272	0.041	0	0	0.041
	0.029	0.242	0.242	0.219	0.242	0.047	0	0	0.047
		0.248	0.248	0.213	0.254	0.041	0	0	0.023
Mean	0.061	0.245	0.245	0.228	0.249	0.083	0.000	0.000	0.113

Table 3b INflow rates at 20 cm depth 11.16

	20	40	60	80	100	120	140	160	180
	0.059	0.124	0.595	ow	ow	0.307	0.189	0.171	ow
	0.035	0.201	0.331	ow	ow	0.349	0.183	0.189	ow
	0.041	0.272	0.475	ow	ow	0.39	0.077	0.148	ow
	0.071	0.231	0.521	ow	ow	0.408	0.118	0.142	ow
	0.039	0.331	0.421	ow	ow	0.402	0.124	0.159	ow
	0.41	0.308	0.533	ow	ow	0.337	0.094	0.124	ow
	0.035	0.284	0.367	ow	ow	0.355	0.112	0.154	ow
	0.035	0.278	0.385	ow	ow	0.349	0.147	0.135	ow
	0.154	0.272	0.568	ow	ow	0.414	0.071	0.163	ow
	0.065	0.266	0.527	ow	ow	0.385	0.1	0.136	ow
Mean	0.094	0.257	0.472	#DIV/0!	#DIV/0!	0.370	0.122	0.152	######

Table 3c. INFlow rates at 30cm depth at 11.16

	20	40	60	80	100	120	140	160	180
	0.035	0.201	0.414	ow	ow	ow	0.313	0.177	ow
	0.047	0.361	0.598	ow	ow	ow	0.304	0.254	ow
	0.082	0.355	0.635	ow	ow	ow	0.395	0.183	ow
	0.029	0.207	0.636	ow	ow	ow	0.313	0.29	ow
	0.027	0.331	0.616	ow	ow	ow	0.317	0.254	ow
	0.035	0.308	0.592	ow	ow	ow	0.337	0.325	ow
	0.027	0.355	0.462	ow	ow	ow	0.343	0.385	ow
	0.029	0.343	0.509	ow	ow	ow	0.331	0.255	ow
	0.035	0.279	0.55	ow	ow	ow	0.379	0.246	ow
	0.029	0.29	0.663	ow	ow	ow	0.371	0.208	ow
Mean	0.038	0.303	0.568	#DIV/0!	#DIV/0!	#DIV/0!	0.340	0.258	######

Table 4. Average taken from all readings at 10, 20 and 30cm depths and 20cm intervals across the channel during OUTFlow.

At 10cm	At 20cm	At 30cm
0.06	0.094	0.038
0.25	0.257	0.303
0.25	0.472	0.568
0.23	0.37	0.34
0.25	0.122	0.258
0.08	0.152	
0		
0		
0.11		
0.136	0.2445	0.3014

0.2273

Table 5. Flow rates at 20cm depth, 60 cm from shore

Time	12.14	12.21	12.25	12.29	12.34	12.39	13.08	13.18	13.23	13.27	13.38	13.44	14.03
	0.681	0.776	0.875	0.875	0.812	0.848	0.764	0.746	0.710	0.722	0.556	0.485	
	0.598	0.802	0.861	0.861	0.855	0.888	0.746	0.776	0.699	0.687	0.592	0.473	
	0.781	0.809	0.881	0.796	0.868	0.888	0.789	0.764	0.681	0.669	0.544	0.521	
	0.740	0.855	0.868	0.848	0.881	0.861	0.796	0.740	0.693	0.657	0.568	0.527	
	0.824	0.796	0.875	0.861	0.809	0.855	0.815	0.752	0.704	0.544	0.574	0.462	
	0.645	0.720	0.888	0.894	0.802	0.848	0.783	0.764	0.716	0.633	0.562	0.503	
	0.728	0.855	0.868	0.861	0.848	0.855	0.789	0.722	0.683		0.58	0.491	
	0.752	0.861	0.868	0.901	0.914	0.881	0.809	0.764	0.687		0.604	0.488	
	0.746	0.783	0.848	0.888	0.901	0.868	0.822	0.758	0.681		0.539	0.485	
	0.734	0.842	0.901	0.914	0.907	0.848	0.829	0.776	0.687		0.586		
Mean	0.723	0.810	0.873	0.870	0.860	0.864	0.794	0.756	0.694	0.652	0.571	0.493	0

Appendix III. Flow measurements of water entering and leaving Cuskinny Lake, Great Island, Co. Cork during a neap tide on 23rd May 2012.

High tide at 07.35. Start time 09.00.

Table 1. Variation in water depth where flow measurements were made at Cuskinny Lake on 23/5/2012.

Time	09.00	09.30	09.45	10.05	11.00	11.17	11.45	12.20	13.12
Water depth(cm)	60	55	53	52	50	49	48	46	44

Time	14.30	15.45	16.50		18.14	18.20	18.25	18.30	18.35
Water depth(cm)	41	39	37		40	41	42	42	44

Water depth on the staff gauge at 12.20 m 22cm.

Table 2a. Inflow rates across the channel at 20cm above the bottom, and 20cm intervals.

	20	40	60	80	100	120	140	160	180	195
	0.379	0.622	0.639	0.663	0.610	0.130	0.313	0.302	0.260	0.213
	0.343	0.627	0.693	0.669	0.426	0.082	0.278	0.385	0.189	0.154
	0.373	0.622	0.586	0.675	0.420	0.088	0.319	0.361	0.213	0.254
	0.438	0.622	0.651	0.681	0.396	0.100	0.278	0.373	0.248	0.231
	0.343	0.633	0.663	0.663	0.361	0.100	0.331	0.355	0.213	0.213
mean	0.38	0.63	0.65	0.67	0.44	0.10	0.30	0.36	0.22	0.21
SD sample	0.04	0.00	0.04	0.01	0.10	0.02	0.02	0.03	0.03	0.04

Table 2b INFlow rate across channel at 40cm above bottom, 20cm intervals

	20	40	60	80	100	120	140	160	180	200
	0.236	0.367	0.402	0.402	0.331	0.165	ow	0.077	0.053	0.047
	0.420	0.390	0.414	0.361	0.231	0.189	ow	0.088	0.071	0.041
	0.402	0.402	0.408	0.355	0.248	0.231	ow	0.106	0.077	0.017
	0.361	0.414	0.396	0.343	0.266	0.148	ow	0.041	0.071	0.000
	0.373	0.367	0.402	0.355	0.231	0.106	ow	0.035	0.077	0.000
mean	0.36	0.39	0.40	0.36	0.26	0.17		0.07	0.07	0.02
SD sample	0.07	0.02	0.01	0.02	0.04	0.05		0.03	0.01	0.02

Table 3. OUTFlow rate across channel at 20cm above bottom, 20cm intervals

	20	40	60	80	100	
	0.331	0.385	0.379	0.296	0.438	0
	0.367	0.402	0.390	0.396	0.426	0
	0.355	0.396	0.408	0.450	0.438	0
	0.361	0.379	0.426	0.444	0.444	0
	0.367	0.408	0.420	0.438	0.432	0
mean	0.36	0.39	0.40	0.40	0.44	
SD sample	0.01	0.01	0.02	0.06	0.01	

Average OUTflow at 09.15 = -0.41 m/sec

Flow rates 10cm off bottom at 20cm intervals across the channel at 12.30pm

Distance from "shore" (cm)	20	40	60	80	100	120	140	160	180	200
	0.373	0.396	0.408	0.408	0.432	0.325	0.349	0.462	0.467	0.414
	0.414	0.419	0.414	0.462	0.319	0.349	0.497	0.473	0.408	0.491
	0.438	0.473	0.402	0.473	0.319	0.325	0.473	0.479	0.402	0.462
	0.45	0.473	0.408	0.462	0.342	0.325	0.462	0.462	0.42	0.503
	0.45	0.479	0.414	0.462	0.331	0.296	0.485	0.462	0.42	0.485
Mean	0.425	0.448	0.473	0.4534	0.3486	0.324	0.4532	0.4676	0.4234	0.471

Flow rates 20cm off bottom at 20cm intervals across the channel at 12.30pm

Distance from "shore" (cm)	20	40	60	80	100	120	140	160	180	200
	0.313	0.462	0.367	0.361	0.467	0.426	0.467	0.456	0.497	0.515
	0.467	0.497	0.45	0.485	0.479	0.491	0.497	0.503	0.515	0.544
	0.485	0.509	0.491	0.503	0.473	0.485	0.491	0.515	0.521	0.527
	0.479	0.497	0.473	0.497	0.479	0.479	0.485	0.509	0.527	0.533
	0.485	0.509	0.479	0.503	0.467	0.479	0.503	0.515	0.515	0.539
Mean	0.4458	0.4948	0.473	0.4698	0.473	0.472	0.4886	0.4996	0.515	0.5316

Flow rates 30cm off bottom at 20cm intervals across the channel at 12.30pm

Distance from "shore" (cm)	20	40	60	80	100	120	140	160	180	200
	0.473	0.467	0.467	0.462	0.331	0.438	ow	ow	0.432	ow
	0.467	0.456	0.42	0.467	0.438	0.467	ow	ow	0.521	ow
	0.473	0.485	0.467	0.473	0.432	0.473	ow	ow	0.527	ow
	0.467	0.491	0.467	0.479	0.467	0.462	ow	ow	0.539	ow
	0.473	0.485	0.462	0.467	0.479	0.456	0w	0w	0.521	0w
Mean	0.4706	0.4768	0.473	0.4696	0.4294	0.4592	ow	ow	0.508	ow

Table 4. Measurements then taken at 30cm above the bottom and 60 cm from the "shore"

	Measurements					
Time	M1	M2	M3	M4	M5	Mean
9.25	0.539	0.521	0.533	0.527	0.533	0.53
9.35	0.539	0.533	0.544	0.533	0.539	0.54
9.45	0.580	0.574	0.586	0.580	0.592	0.58
10.05	0.550	0.562	0.539	0.562	0.550	0.55
10.22	0.503	0.509	0.503	0.509	0.515	0.51
10.40	0.473	0.467	0.473	0.462	0.467	0.47
10.50	0.477	0.503	0.491	0.503	0.497	0.49
11.00	0.521	0.533	0.521	0.533	0.521	0.53
11.17	0.503	0.497	0.503	0.509	0.497	0.50
11.30	0.456	0.450	0.456	0.462	0.456	0.46
11.45	0.497	0.491	0.485	0.497	0.485	0.49
12.18	0.473	0.467	0.473	0.467	0.473	0.47
13.10	0.462	0.473	0.467	0.462	0.467	0.47
13.27	0.408	0.420	0.408	0.414	0.420	0.41
13.38	0.414	0.414	0.408	0.408	0.414	0.41
13.50	0.396	0.379	0.379	0.379	0.385	0.38
14.00	0.390	0.390	0.390	0.402	0.396	0.39
14.08	0.390	0.396	0.390	0.390	0.396	0.39
14.16	0.390	0.385	0.390	0.396	0.385	0.39
14.25	0.396	0.385	0.390	0.396	0.385	0.39
14.34	0.390	0.379	0.396	0.390	0.385	0.39
14.42	0.390	0.379	0.373	0.390	0.385	0.38
14.52	0.367	0.373	0.367	0.373	0.402	0.38
15.02	0.373	0.379	0.373	0.379	0.373	0.38
15.12	0.301	0.367	0.361	0.373	0.361	0.35
15.24	0.349	0.355	0.343	0.355	0.343	0.35
15.31	0.201	0.213	0.302	0.349	0.302	0.27
15.41	0.385	0.390	0.396	0.385	0.402	0.39
16.00	0.373	0.385	0.379	0.385	0.373	0.38
16.10	0.343	0.349	0.343	0.343	0.343	0.34
16.20	0.337	0.343	0.337	0.343	0.337	0.34

Table 4. Measurements then taken at 30cm above the bottom and 60 cm from the "shore"
Time M1 M2 M3 M4 M5 Mean

16.30	0.349	0.355	0.349	0.349	0.349	0.35
16.40	0.302	0.308	0.302	0.308	0.302	0.30
16.50	0.319	0.396	0.337	0.331	0.337	0.34
17.00	0.343	0.325	0.337	0.331	0.337	0.33
17.10	0.308	0.331	0.319	0.331	0.319	0.32
17.41	0.278	0.290	0.296	0.308	0.272	0.29
17.45	0.254	0.260	0.260	0.254	0.266	0.26
18.00	0.005	0.000	0.000	0.005	0.059	0.01
18.04	**TIDE TURNED. INFLOWING**					
18.14	0.675	0.687	0.669	0.681	0.663	0.68
18.20	0.860	0.770	0.734	0.776	0.802	0.79
18.25	0.940	0.927	0.980	0.934	0.907	0.94
18.30	1.013	0.973	0.934	0.967	0.940	0.97
18.35	0.927	1.013	0.986	1.019	0.993	0.99
18.37	1.013	0.999	1.013	1.006	0.993	1.00
18.50	1.026	0.980	1.006	0.986	1.019	1.00
20.30	1.114	0.960	1.326	1.319	1.006	1.15
20.40	0.986	0.940	0.967	0.914	0.907	0.94
20.50	0.720	0.861	0.752	0.722	0.802	0.77
21.00	0.734	0.835	0.783	0.802	0.699	0.77
21.20	OUT Tide flowing out again at 21.20.					OUT
Inflow for 2h 15mins						

Appendix IV. Lagoon Chemistry Sept 2009 - June 2012

Site no.	Date	Site	Salinity	BOD mg/l	Chlorophyll ug/l	Ammonia mg/l N	Nitrate mg/l N	Nitrite mg/l N	phosphate mg/l P	total P mg/l P
September 2009. 23 sites										
1	18.09.09	Inch 1	0.4	3.1	8.64	0.085	0.019	0.003	0.008	0.049
2	18.09.09	Inch 2	0.0	<2.0	2.02	0.026	1.057	0.020	0.010	0.021
3	18.09.09	Durnesh	1.2	<2.0	<1.00	0.008	0.017	0.002	0.006	0.014
4	22.09.09	Shannon	0.3	2.6	2.59	0.062	0.010	0.002	0.005	0.028
5	22.09.09	L Donnell	24.4	5.3	25.63	0.008	0.007	0.002	0.004	0.057
6	23.09.09	Furnace	8.7	<2.0	1.73	0.029	0.092	0.007	0.011	0.014
7	24.09.09	Athola	33.8	<2.0	<1.00	0.016	0.017	0.006	0.005	0.010
8	24.09.09	Aibhnín	26.9	2.1	<1.00	0.018	0.017	0.003	0.003	0.010
9	24.09.09	Tanaí	23.6	2.1	<1.00	0.038	0.014	0.003	0.003	0.003
10	24.09.09	Ahalia	6.6	<2.0	6.62	0.014	0.012	0.005	0.005	0.009
11	24.09.09	North Slob W	4.2	6.8	4.87	0.014	0.007	0.002	0.067	0.090
12	24.09.09	North Slob E	22.7	10.9	1.33	0.018	0.007	0.002	0.026	0.089
13	24.09.09	Tacumshin W	0.1	2.3	<1.00	0.034	0.031	0.002	0.070	0.100
14	24.09.09	Tacumshin E	2.4	3.6	4.90	0.026	0.007	0.002	0.056	0.099
15	24.09.09	Lady's Isl N	9.9	9.4	39.36	0.015	0.031	0.006	0.006	0.223
16	24.09.09	Lady's Isl S	10.2	7.7	33.74	0.012	0.008	0.005	0.005	0.230
17	25.09.09	Muree	8.6	2.5	1.15	0.053	0.010	<0.001	<0.003	0.020
18	25.09.09	Bridge	23.7	5.1	39.17	0.006	0.006	0.001	<0.003	0.048
19	29.09.09	L Gill	0.7	3.1	3.17	0.098	0.006	0.001	0.003	0.024
20	29.09.09	Drongawn	25.9	2.8	4.90	0.006	0.005	<0.001	<0.003	0.019
21	29.09.09	Kilkeran	4.3	7.2	53.57	0.197	1.299	0.068	0.003	0.100
22	02.10.09	Broadmeadow N	29.1	6.7	26.50	0.006	0.021	<0.001	0.037	0.247
23	02.10.09	Broadmeadow S	29.9	5.0	15.55	0.005	0.007	<0.001	0.028	0.093
October/November 2009. 23 sites										
1	23.10.09	Lough Gill	1.9	2.1	1.73	0.019	0.141	0.004	0.006	0.012
2	23.10.09	Drongawn	24.1	2.2	5.47	0.006	0.010	0.001	0.007	0.022
3	26.10.09	Ahalia	6.1	2.1	1.73	0.012	0.025	0.003	<0.003	0.011
4	26.10.09	Tanaí	27.6	<2.0	1.44	0.018	0.007	0.002	<0.003	0.015
5	26.10.09	Aibhnín	20.7	<2.0	<1.00	0.012	0.008	0.002	0.003	0.006
6	26.10.09	Athola	31.3	<2.0	2.02	0.010	0.005	0.002	<0.003	0.003
7	25.10.09	Lough Donnell	4.2	<2.0	3.17	0.034	0.115	0.007	0.011	0.038
8	26.10.09	Shannon	1.2	2.7	17.28	0.007	0.005	0.002	<0.003	0.024
9	28.10.09	Bridge	24.4	8.5	116.20	0.012	0.010	0.003	0.011	0.102
10	28.10.09	Murree	10.3	4.9	14.98	0.013	0.011	0.001	0.003	0.017
11	29.10.09	N Slob W	2.0	4.2	12.96	0.518	0.228	0.042	0.231	0.306
12	29.10.09	N Slob E	24.0	2.7	7.49	0.082	0.017	0.003	0.031	0.062
13	29.10.09	Lady's Isl N	8.8	8.4	25.34	0.085	0.262	0.026	0.013	0.172
14	29.10.09	Lady's Isl S	9.3	8.0	30.40	0.191	0.106	0.025	0.005	0.174
15	29.10.09	Tacumshin W	0.0	7.3	1.15	0.078	0.019	0.005	0.194	0.257
16	29.10.09	Tacumshin E	5.8	2.8	20.74	0.032	0.011	0.002	0.042	0.083
17	30.10.09	Inch 1	0.3	3.6	4.03	0.154	0.456	0.018	0.005	0.058
18	30.10.09	Inch 2	0.6	2.4	4.61	0.155	0.654	0.021	0.010	0.038
19	30.10.09	L Durnesh	3.0	2.3	6.91	0.014	0.034	0.001	<0.003	0.014
20	01.11.09	Kilkeran	1.7	4.0	26.50	0.088	1.721	0.055	0.025	0.106
21	01.11.09	Malahide N	22.2	4.4	**25.92**	0.026	0.262	0.009	0.014	0.075
22	01.11.09	Malahide S	14.6	4.9	22.22	0.348	0.973	0.014	0.157	0.303
23	04.11.09	L Furnace	2.5	<2.0	<1.00	0.023	0.085	0.002	0.003	0.003

November/December 2009. 23 sites

Site no.	Date	Site	Salinity	BOD mg/l	Chlorophyll ug/l	Ammonia mg/l N	Nitrate mg/l N	Nitrite mg/l N	phosphate mg/l P	total P mg/l P
1	29.11.09	Drongawn	19.2	3.1	5.47	0.007	0.039	0.003	<0.003	0.022
2	29.11.09	Lough Gill	0.0	2.8	2.30	0.031	0.448	0.007	0.008	0.030
3	30.11.09	Shannon	0.1	3.5	16.70	0.015	0.010	0.001	0.013	0.050
4	01.12.09	Lough Donnell	5.6	2.3	<1.00	0.059	0.296	0.003	0.011	0.036
5	02.12.09	Bridge	4.5	2.6	1.15	0.452	0.435	0.010	0.010	0.010
6	02.12.09	Muree	6.1	2.9	<1.00	0.020	0.315	0.006	<0.003	<0.003
7	04.12.09	Aibhnín	19.9	2.1	<1.00	0.015	0.028	0.001	<0.003	<0.003
8	04.12.09	Tanaí	13.9	2.4	<1.00	0.016	0.019	0.001	<0.003	<0.003
9	04.12.09	Ahalia	1.5	2.7	3.46	0.021	0.044	0.001	<0.003	0.003
10	04.12.09	Ahalia	28.3	2.5	<1.00	0.010	0.019	0.001	<0.003	<0.003
11	05.12.09	Kilkeran	1.7	<2.0	2.59	0.061	1.908	0.014	0.055	0.055
12	08.12.09	Tacumshin West	0.0	3.7	2.02	0.022	0.225	0.008	0.079	0.103
13	08.12.09	Tacumshin East	2.2	3.1	10.66	0.011	0.706	0.006	0.049	0.057
14	08.12.09	North Slob West	0.9	5.2	<1.00	0.257	0.436	0.017	0.087	0.135
15	08.12.09	North Slob East	19.6	2.3	<1.00	0.399	0.089	0.007	0.064	0.113
16	08.12.09	Lady's Island N	5.2	5.8	3.74	0.202	1.667	0.084	0.085	0.221
17	08.12.09	Lady's Island S	28.5	3.5	12.38	0.121	0.303	0.026	0.031	0.079
18	10.12.09	Inch 1	0.0	2.4	1.73	0.165	0.820	0.009	0.023	0.027
19	10.12.09	Inch 2	0.4	<2.0	1.15	0.131	0.943	0.013	0.020	0.031
20	10.12.09	Durnesh	1.3	<2.0	<1.00	0.114	0.539	0.017	0.012	0.014
21	10.12.09	Furnace	0.1	2.4	<1.00	0.010	0.083	0.004	0.004	0.004
22	17.12.09	Broadmeadow N	26.6	<2.0	7.78	0.231	0.601	0.020	0.047	0.047
23	17.12.09	Broadmeadow S	14.4	2.6	6.34	0.504	1.476	0.025	0.146	0.176

January 2010. 23 sites

Site no.	Date	Site	Salinity	BOD mg/l	Chlorophyll ug/l	Ammonia mg/l N	Nitrate mg/l N	Nitrite mg/l N	phosphate mg/l P	total P mg/l P
1	31.12.09	Lough Gill	0.0	4.6	105.60	0.108	0.201	0.611	0.010	0.044
2	31.12.09	Drongawn	22.8	2.4	4.03	0.013	0.055	0.001	0.003	0.003
3	13.01.10	Muree	5.3	3.3	2.88	0.118	0.195	0.003	0.003	0.003
4	13.01.10	Bridge	3.9	4.1	3.74	0.014	0.118	0.002	0.003	0.003
5	14.01.10	Ahalia	4.1	<2.0	<1.00	0.049	0.063	0.002	0.005	0.006
6	14.01.10	Aibhnín	23.7	<2.0	<1.00	0.073	0.041	0.002	0.017	0.017
7	14.01.10	Tanaí	17.9	2.5	2.88	0.034	0.013	0.002	0.004	0.008
8	14.01.10	Ahalia	29.7	<2.0	1.73	0.021	0.014	0.001	0.004	0.004
9	19.01.10	Kilkeran	0.9	2.6	2.88	0.074	1.929	0.012	0.051	0.065
10	20.01.10	Lady's Island N	8.5	5.8	14.98	0.068	1.517	0.027	0.021	0.046
11	20.01.10	Lady's Island S	14.3	4.8	17.64	0.010	0.706	0.022	0.004	0.010
12	20.01.10	North Slob West	0.4	2.9	1.15	0.091	0.736	0.016	0.095	0.144
13	20.01.10	North Slob East	14.3	2.3	1.44	0.444	0.154	0.017	0.071	0.105
14	21.01.10	Tacumshin West	0.0	<2.0	1.15	0.011	0.106	0.009	0.047	0.047
15	21.01.10	Tacumshin East	0.1	2.4	2.59	0.005	1.992	0.007	0.022	0.022
16	21.01.10	Malahide N	12.0	2.0	2.30	0.447	1.607	0.016	0.085	0.173
17	21.01.10	Malahide S	21.2	<2.0	1.73	0.334	1.034	0.015	0.056	0.080
18	22.01.10	Furnace	1.1	2.3	1.15	0.018	0.099	0.003	0.004	0.005
19	22.01.10	Shannon	0.8	3.3	5.18	0.059	0.015	0.002	0.003	0.009
20	22.01.10	Donnell	0.0	2.5	1.73	0.032	0.343	0.006	0.013	0.018
21	25.01.10	Inch N	0.2	5.0	16.70	0.235	0.872	0.015	0.014	0.026
22	25.01.10	Inch S	0.3	3.4	<1.00	0.178	1.161	0.013	0.010	0.010
23	25.01.10	Durnesh	4.4	3.9	2.30	0.111	0.432	0.008	0.006	0.008

June 2010. 26 sites

Site no.	Date	Site	Salinity	BOD	Chlorophyll	Ammonia	Nitrate	Nitrite	phosphate	total P
				mg/l	ug/l	mg/l N	mg/l N	mg/l N	mg/l P	mg/l P
1	22.06.10	Tacumshin W	0.1	2.3	5.76	0.043	0.005	0.003	0.044	0.064
2	22.06.10	Tacumshin E	6.0	4.9	5.76	0.034	0.001	0.003	0.092	0.118
3	22.06.10	North Slob W	6.1	3.5	6.34	0.024	<0.001	0.004	0.125	0.160
4	22.06.10	North Slob E	31.2	3.3	15.55	0.169	0.002	0.003	0.005	0.012
5	22.06.10	Lady's Island N	23.4	3.1	3.46	0.022	0.001	0.003	0.007	0.007
6	22.06.10	Lady's Island S	23.7	3.1	1.73	0.017	0.002	0.002	0.003	0.006
7	23.06.10	Broadmeadow N	29.6	5.1	12.67	0.028	0.001	0.003	0.099	0.099
8	23.06.10	Broadmeadow S	32.8	6.4	36.86	0.022	0.002	0.002	0.068	0.099
9	24.06.10	L Muree	10.7	2.7	<1.00	0.022	0.001	0.002	0.007	0.008
10	24.06.10	Bridge	35.4	33.6	**103.68**	0.040	0.002	0.002	0.019	0.028
11	24.06.10	Rincarna	45.1	6.1	167.00	0.015	<0.001	0.005	0.026	0.101
12	25.06.10	Ahalia	16.0	<2.0	<1.00	0.022	0.002	0.001	0.004	0.005
13	25.06.10	Aibhnín	34.0	<2.0	<1.00	0.023	0.002	0.001	0.006	0.011
14	25.06.10	Tanaí	32.0	<2.0	<1.00	0.023	<0.001	0.002	<0.003	0.005
15	25.06.10	Lettermullen	35.7	<2.0	<1.00	0.026	0.001	0.001	0.003	0.012
16	25.06.10	Athola	36.3	2.5	3.84	0.021	0.001	0.001	0.004	0.007
17	27.06.10	Inchydoney	33.3	2.4	**3.17**	0.031	0.012	0.003	0.028	0.029
18	27.06.10	Kilkeran	1.4	5.5	29.95	0.025	0.004	0.001	0.008	0.044
19	27.06.10	Drongawn	31.3	<2.0	2.02	0.017	0.002	0.001	0.004	0.005
20	28.06.10	L Gill	0.3	<2.0	1.15	0.030	<0.001	0.003	0.010	0.011
21	28.06.10	Inch 1	2.4	2.5	2.59	0.061	0.003	0.001	0.018	0.026
22	28.06.10	Inch 2	0.1	2.9	2.69	0.019	0.002	0.002	0.007	0.017
23	28.06.10	Durnesh	22.7	2.6	6.91	0.017	0.003	0.001	0.004	0.005
24	28.06.10	Furnace	11.7	2.2	2.59	0.020	0.002	0.002	0.003	0.003
25	30.06.10	Shannon	1.3	6.1	12.67	0.074	0.002	0.002	0.010	0.064
26	30.06.10	Donnell	1.6	2.3	6.91	0.014	0.002	0.001	<0.003	0.023
July 2010. 26 sites										
1	12.07.10	Athola	33.9	3.0	4.61	0.031	<0.001	0.004	<0.003	0.006
2	12.07.10	Ahalia	14.4	<2.0	1.44	0.034	<0.001	0.005	<0.003	<0.003
3	12.07.10	Tanaí	29.7	<2.0	2.02	0.020	<0.001	0.005	<0.003	<0.003
4	12.07.10	Aibhnín	32.7	<2.0	<1.00	0.021	0.001	0.003	<0.003	<0.003
5	12.07.10	Lettermullen	30.3	<2.0	<1.00	0.023	<0.001	0.005	<0.003	<0.003
6	13.07.10	Muree	11.0	2.4	1.15	0.088	<0.001	0.005	0.006	0.006
7	13.07.10	Rincarna	35.2	20.0	49.54	0.026	<0.001	0.006	0.019	0.088
8	13.07.10	Bridge	32.3	65.3	370.53	0.038	<0.001	0.007	0.056	0.076
9	16.07.10	Inch 1	2.0	5.6	57.60	0.038	0.002	0.002	0.179	0.250
10	16.07.10	Inch 2	0.0	2.0	2.02	0.030	0.003	0.001	0.006	0.025
11	16.07.10	Durnesh	20.0	<2.0	**4.32**	0.024	0.001	0.001	<0.003	0.006
12	16.07.10	Furnace	10.0	<2.0	**6.34**	0.015	0.001	0.001	<0.003	0.006
13	19.07.10	Lady's Island N	20.2	7.8	28.80	0.052	0.002	0.001	0.009	0.047
14	19.07.10	Lady's Island S	22.3	7.4	31.30	0.021	0.001	0.001	<0.003	0.025
15	19.07.10	North Slob W	4.0	3.2	**6.91**	0.049	0.019	0.005	0.675	0.806
16	19.07.10	North Slob E	22.8	<2.0	3.46	0.167	0.009	0.004	0.037	0.067
17	19.07.10	Tacumshin W	0.1	<2.0	2.88	0.087	0.033	0.003	0.129	0.151
18	19.07.10	Tacumshin E	8.2	2.4	2.30	0.086	0.005	0.002	0.044	0.090
19	19.07.10	Broadmeadow N	21.1	6.8	**144.00**	0.029	0.001	0.004	0.099	0.360
20	19.07.10	Broadmeadow S	31.9	2.6	37.40	0.018	0.001	0.001	0.039	0.072
21	27.07.10	Drongawn	25.9	2.6	<1.00	0.058	0.002	0.002	0.008	0.008
22	27.07.10	L Gill	0.1	2.3	4.03	0.042	0.001	0.003	0.003	0.006
23	27.07.10	Inchydoney	30.2	2.2	2.88	0.052	0.034	0.003	0.046	0.048
24	27.07.10	Kilkeran	2.4	5.9	120.96	0.023	1.075	0.076	0.006	0.033
25	29.07.10	Donnell	0.1	3.7	17.05	0.041	0.013	0.004	0.007	0.012
26	29.07.10	Shannon	0.5	2.9	5.18	0.047	0.006	0.002	0.003	0.006

	Date	Sample	Salinity	BOD mg/l	Chlorophyll ug/l	Ammonia mg/l N	Nitrate mg/l N	Nitrite mg/l N	phosphate mg/l P	total P mg/l P
August 2010. 26 sites										
1	13.08.10	Durnesh	16.3	<2.0	2.02	0.033	0.002	0.001	0.003	0.003
2	13.08.10	Inch North	2.1	3.8	20.16	0.015	<0.001	0.002	0.119	0.153
3	13.08.10	Inch South	0.4	4.3	8.96	0.026	0.001	0.003	0.024	0.055
4	16.08.10	Shannon	0.6	3.6	14.98	0.031	<0.001	0.003	<0.003	0.011
5	16.08.10	Donnell	13.0	4.7	14.40	0.014	<0.001	0.004	0.015	0.021
6	18.08.10	Tacumshin W	5.1	<2.0	2.02	0.110	0.022	0.003	0.298	0.371
7	18.08.10	Tacumshin E	8.4	<2.0	1.73	0.014	0.005	0.002	0.012	0.024
8	19.08.10	Lady's Island N	23.1	4.9	20.16	0.008	0.005	0.002	0.003	0.032
9	19.08.10	Lady's Island S	22.6	5.9	43.20	0.024	0.010	0.002	0.004	0.046
10	19.08.10	North Slob W	7.5	4.9	39.74	0.014	0.005	0.002	1.055	1.144
11	19.08.10	North Slob E	29.4	<2.0	47.23	0.049	0.010	0.002	0.011	0.010
12	27.07.10	Muree	13.8	<2.0	1.15	0.026	0.002	0.001	0.003	0.003
13	27.07.10	Bridge	30.3	43.5	**233.90**	0.014	0.001	0.003	0.042	0.080
14	29.08.10	Ahalia	8.8	<2.0	6.34	0.012	<0.001	0.002	<0.003	0.004
15	29.08.10	Aibhnín	8.7	<2.0	<1.00	<0.010	0.001	0.002	<0.003	0.003
16	29.08.10	Tanaí	25.0	<2.0	<1.00	0.011	0.001	0.002	<0.003	0.003
17	29.08.10	Lettermullen	30.5	<2.0	<1.00	<0.010	0.002	0.001	<0.003	0.003
18	30.08.10	Rincarna	32.2	2.6	69.12	<0.010	0.001	0.002	0.013	0.098
19	30.08.10	Lough Gill	0.6	2.7	2.02	0.007	0.001	0.001	<0.003	0.007
20	30.08.10	Inchydoney	34.3	<2.0	3.17	0.024	0.020	0.002	0.013	0.014
21	30.08.10	Drongawn	30.7	2.3	4.32	<0.010	0.001	0.002	<0.003	0.005
22	30.08.10	Kilkeran	5.4	7.3	112.32	0.011	0.033	0.200	<0.003	0.033
23	31.08.10	Broadmeadow N	32.0	2.5	1.44	0.018	0.001	0.004	0.048	0.064
24	31.08.10	Broadmeadow S	31.5	4.6	7.49	0.010	0.001	0.001	0.048	0.084
25	3.09.10	Furnace	1.2	<2.0	4.32	0.022	0.002	0.005	0.003	0.010
26	4.09.10	Athola	35.3	<2.0	1.73	0.035	0.001	0.002	<0.003	0.010
August 2011. 27 sites										
1	15.08.11	Lettermullen	32.8	<2.0	1.15	0.036	0.011	0.002	<0.003	0.32
2	15.08.11	Aibhnín	31.0	<2.0	<1.00	0.029	0.013	0.001	<0.003	0.89
3	15.08.11	Tanaí	29.0	<2.0	1.15	0.029	0.010	0.002	<0.003	1.76
4	15.08.11	Ghadaí	12.4	2.2	3.17	0.038	0.007	0.002	<0.003	0.72
5	16.08.11	Furnace	1.8	<2.0	1.73	0.023	0.044	0.004	<0.003	0.65
6	16.08.11	Inchydoney	34.0	<2.0	<1.00	0.046	0.027	0.003	0.013	0.66
7	17.08.11	Drongawn	30.8	<2.0	2.30	0.019	0.013	0.001	<0.003	0.38
8	17.08.11	L Gill	0.9	3.1	5.76	0.020	0.009	0.001	0.006	2.57
9	17.08.11	Kilkeran	1.1	8.1	111.36	0.023	0.009	0.002	0.009	10.50
10	19.08.11	Inch N	1.0	5.0	16.12	0.049	0.013	0.003	0.005	7.52
11	19.08.11	Inch S	0.0	3.6	5.76	0.026	0.027	0.006	0.007	5.71
12	20.08.11	Durnesh	6.4	<2.0	1.73	0.022	0.007	0.001	0.006	1.03
13	22.08.11	Shannon	0.7	3.1	4.11	0.022	0.009	0.002	<0.003	0.82
14	22.08.11	Donnell	0.9	2.4	6.34	0.012	0.005	0.004	0.004	2.15
15	23.08.11	Muree	13.5	<2.0	1.73	0.015	0.008	0.001	<0.003	0.60
16	23.08.11	Rincarna	31.8	5.6	17.28	0.019	0.009	0.001	<0.003	0.73
17	23.08.11	Bridge	30.8	6.1	9.79	0.014	0.007	0.002	0.003	3.16
18	26.08.11	Ahalia	32.4	3.3	1.73	0.029	0.004	0.001	<0.003	0.88
19	26.08.11	tSáile	0.6	<2.0	2.02	0.016	0.001	0.002	0.003	0.48
20	26.08.11	Aconeera	5.7	<2.0	1.15	0.013	0.001	0.001	<0.003	0.74
21	29.08.11	Tacumshin W	10.1	3.2	14.98	0.013	0.001	0.003	0.182	3.80
22	29.08.11	Tacumshin E	15.0	2.9	2.30	0.018	<0.001	0.002	0.085	1.33
23	29.08.11	Ladies' Isle N	31.6	8.9	14.40	0.012	<0.001	0.002	0.022	6.85
24	29.08.11	Ladies' Isle S	33.4	7.7	34.56	0.020	<0.001	0.002	0.069	12.70
25	30.08.11	N Slob W	10.0	4.9	19.01	0.031	0.001	0.002	1.190	3.77
26	30.08.11	N Slob E	22.8	3.8	4.11	0.258	0.006	0.005	0.025	15.60

Appendix IV. Lagoon Chemistry Sept 2009 - June 2012

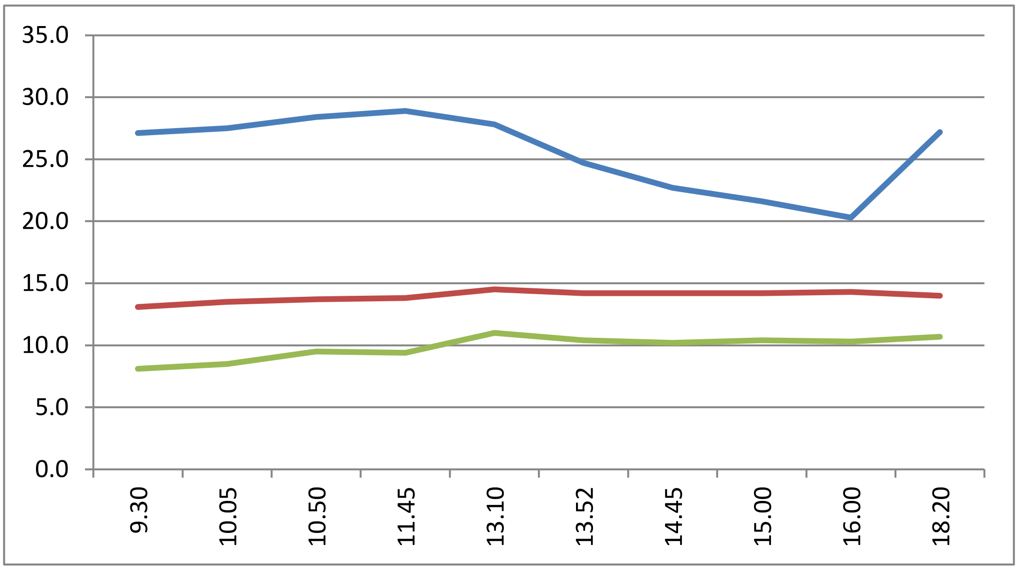
	Date	Site	Salinity	BOD	Chlorophyll	Ammonia	Nitrate	Nitrite	phosphate	turbidity
August 2011. 27 sites cont.				mg/l	ug/l	mg/l N	mg/l N	mg/l N	mg/l P	NTU
26	30.08.11	Broadmdw N	32.9	2.2	2.30	0.016	0.002	0.002	0.027	8.32
27	30.08.11	Broadmdw S	32.3	3.0	8.06	0.021	0.022	0.003	0.043	4.53
Sept/Oct 2011. 33 sites										
1	11.09.11	Aibhnín	27.6	<2.0	<1.00	0.024	0.004	0.001	<0.003	0.59
2	11.09.11	Ghadaí	13.3	<2.0	5.18	0.012	0.001	0.002	<0.003	2.86
3	11.09.11	Tanaí	20.5	<2.0	<1.00	0.018	0.001	0.001	<0.003	0.66
4	11.09.11	Lettermullen	28.4	2.6	2.30	0.021	0.014	0.003	0.003	7.29
5	14.09.11	Furnace	2.3	<2.0	1.15	0.046	0.204	0.003	0.008	1.72
6	18.09.11	Donnell	0.0	<2.0	4.03	0.105	0.125	0.007	0.010	4.38
7	18.09.11	Muree	13.4	<2.0	3.46	0.052	0.002	0.001	<0.003	0.92
8	18.09.11	Bridge	24.6	2.6	1.44	0.034	0.002	0.001	<0.003	1.70
9	18.09.11	Rincarna	29.7	3.1	<1.00	0.040	0.001	0.001	0.022	1.23
10	18.09.11	Malahide N	33.2	2.1	4.90	0.022	0.002	0.001	0.017	2.43
11	18.09.11	Malahide S	31.1	3.3	8.64	0.018	0.033	0.005	0.022	9.17
12	22.09.11	Durnesh	2.2	<2.0	4.03	0.011	0.001	0.002	0.013	2.15
13	22.09.11	Inch N	0.1	3.2	26.88	0.017	0.301	0.007	0.005	4.34
14	22.09.11	Inch S	0.0	2.5	5.76	0.084	0.402	0.012	0.026	7.98
15	22.09.11	tSáile	0.6	<2.0	2.59	0.013	0.008	0.002	<0.003	0.86
16	22.09.11	Aconeera	6.2	<2.0	1.15	0.014	0.002	0.001	<0.003	0.68
17	22.09.11	Athola	30.4	<2.0	2.88	0.014	0.002	0.001	<0.003	1.73
18	23.09.11	Shannon	0.7	2.4	2.47	0.012	0.001	0.001	<0.003	10.30
19	24.09.11	An Chara	7.2	3.2	5.04	0.018	0.001	0.001	<0.003	2.09
20	24.09.11	Chorrúch	6.9	5.3	20.16	0.010	<0.001	0.002	0.053	1.61
21	26.09.11	Inchydoney	31.5	<2.0	8.06	0.034	0.028	0.003	0.020	1.26
22	26.09.11	Kilkeran	4.2	<2.0	302.40	0.030	0.008	0.002	0.003	6.69
23	27.09.11	L Gill	0.8	2.7	6.91	0.023	<0.001	0.002	<0.003	2.13
24	27.09.11	Drongawn	28.0	<2.0	4.61	0.013	<0.001	0.001	<0.003	1.14
25	30.09.11	Tacumshin W	9.3	2.4	17.28	0.023	0.003	0.002	0.225	2.11
26	30.09.11	Tacumshin E	23.4	3.2	7.20	0.021	<0.001	0.002	0.130	3.44
27	30.09.11	Lady's Island N	31.4	4.9	38.40	0.014	<0.001	0.001	0.006	6.79
28	30.09.11	Lady's Island S	32.0	4.6	61.71	0.014	<0.001	0.001	0.044	11.10
29	05.10.11	North Slob W	9.9	7.0	72.58	0.081	0.013	0.008	0.612	5.44
30	05.10.11	North Slob E	25.4	6.6	9.60	0.432	0.071	0.047	0.010	119.00
31	18.10.11	Cuskinny Inlet	20.4	2.6	1.73	0.606	0.431	0.062	0.052	2.23
32	18.10.11	Cuskinny Feed Station	23.4	2.4	1.15	0.621	0.412	0.057	0.050	3.78
33	20.10.11	Inishbofin	10.8	6.6	54.72	0.018	0.002	0.005	0.007	10.70
Dec 2011/Jan 2012. 32 sites										
1	26.11.11	Furnace	4.4	<2.0	2.88	0.033	0.053	0.003	0.006	0.74
2	01.12.11	North Slob W	4.3	4.4	7.68	8.459	0.363	0.060	0.020	44.20
3	01.12.11	North Slob E	31.6	<2.0	2.88	0.761	0.016	0.007	0.041	3.00
4	01.12.11	Lady's Island N	26.2	4.5	28.80	0.413	0.004	0.002	0.007	14.80
5	01.12.11	Lady's Island S	26.6	3.8	28.80	0.045	0.001	0.001	0.007	11.20
6	01.12.11	Tacumshin W	5.0	<2.0	2.30	0.045	0.301	0.019	0.073	3.80
7	01.12.11	Tacumshin E	16.4	4.3	15.84	0.165	0.220	0.028	0.021	16.80
8	04.12.11	Broadmeadow S	24.5	2.4	<1.00	0.062	1.062	0.012	0.041	4.78
9	04.12.11	Broadmeadow N	22.3	2.0	4.32	0.074	1.260	0.014	0.040	4.66
10	09.12.11	Ghadaí	2.8	2.1	1.73	0.018	0.031	0.003	0.004	4.24
11	09.12.11	Aibhnín	16.4	<2.0	1.73	0.052	0.042	0.003	0.003	2.14
12	09.12.11	Tanaí	6.9	2.2	1.73	0.057	0.018	0.003	0.003	2.82
13	09.12.11	Lettermullen	26.4	<2.0	<1.00	0.026	0.042	0.003	0.008	0.62
14	10.12.11	tSáile	0.0	2.3	3.74	0.026	0.046	0.002	0.004	2.48
15	10.12.11	Athola	23.7	<2.0	1.73	0.010	0.017	0.001	0.003	1.09

Appendix IV. Lagoon Chemistry Sept 2009 - June 2012

	Date	Site	Salinity	BOD mg/l	Chlorophyll ug/l	Ammonia mg/l N	Nitrate mg/l N	Nitrite mg/l N	phosphate mg/l P	turbidity NTU
Dec 2011/Jan 2012. 32 sitescont.										
16	10.12.11	Aconeera	7.0	<2.0	<1.00	0.021	0.052	0.002	0.003	0.72
17	18.12.11	Drongawn	15.9	<2.0	<1.00	0.030	0.054	0.001	0.003	0.69
18	18.12.11	Gill	0.2	<2.0	10.70	0.010	0.581	0.003	<0.003	5.70
19	20.12.11	Donnell	0.0	<2.0	1.44	0.030	0.363	0.001	0.012	2.61
20	20.12.11	Shannon	0.3	2.2	3.60	0.010	0.017	0.001	0.003	0.89
21	30.12.11	Inch N	0.0	2.1	3.46	0.154	0.965	0.017	0.016	22.00
22	30.12.11	Inch S	0.0	2.2	1.73	0.083	0.886	0.013	0.015	22.30
23	30.12.11	Durnesh	1.0	<2.0	2.30	0.097	0.337	0.007	0.005	3.79
24	10.01.12	Bridge	7.1	<2.0	8.06	0.069	0.312	0.011	0.005	1.48
25	10.01.12	Muree	7.5	3.5	25.92	0.363	0.255	0.012	0.005	4.86
26	11.01.12	An Cara	3.0	2.1	7.78	0.031	0.079	0.002	0.003	0.87
27	11.01.12	Cabhrach	3.9	7.2	101.95	0.012	0.178	0.017	0.392	5.36
28	21.01.12	Cuskinny	7.6	2.6	24.19	0.129	1.810	0.052	0.007	19.20
29	21.01.12	Inchydoney	29.1	<2.0	1.15	0.065	0.686	0.009	0.023	5.15
30	21.01.12	Kilkeran	1.4	5.6	132.48	0.018	1.877	0.034	0.003	6.83
31	25.01.12	Rincarna	23.1	<2.0	4.32	0.084	0.279	0.005	0.004	1.52
32	20.03.12	Cuskinny	18.6	2.2	4.99	0.058	1.593	0.058	0.006	1.85
May/June 2012. 28 sites.										
1	13.05.12	Broadmeadow N	21.8	4.1	14.40	0.052	0.937	0.017	0.005	4.63
2	13.05.12	Broadmeadow S	27.9	4.5	6.34	0.030	0.348	0.011	0.006	5.08
3	23.05.12	Tacumshin W	0.2	<2.0	9.79	0.085	0.958	0.014	0.042	4.29
4	23.05.12	Tacumshin E	4.8	<2.0	6.91	0.009	0.037	0.004	0.011	20.10
5	23.05.12	Lady's Island N	17.3	6.2	49.92	0.019	0.013	0.003	0.008	15.70
6	23.05.12	Lady's Island S	16.6	7.0	46.08	0.014	0.010	0.005	0.012	17.20
7	23.05.12	North Slob W	4.6	3.8	12.10	0.016	0.008	0.001	0.037	10.90
8	23.05.12	North Slob E	14.2	6.0	21.89	0.017	0.009	0.001	0.005	9.73
9	24.05.12	Cuskinny	14.7	4.9	8.64	0.027	1.891	0.026	0.004	3.71
10	24.05.12	Cuskinny Stream	0.0	<2.0		0.026	2.092	0.022	0.042	3.57
11	28.05.12	Muree	9.6	4.4	20.74	0.023	0.020	0.002	<0.003	4.99
12	28.05.12	Bridge	32.1	22.0	42.48	0.034	0.009	0.003	0.010	8.30
13	28.05.12	Rincarna	36.1	10.5	15.55	0.013	<0.001	0.008	0.003	3.40
14	30.05.12	Inchydoney	33.2	<2.0	2.88	0.040	0.031	0.002	0.013	1.98
15	30.05.12	Kilkeran	1.0	4.0	2.30	0.306	0.028	0.007	<0.003	7.36
16	04.06.12	Drongawn	29.3	2.3	4.80	0.014	0.009	<0.001	<0.003	1.07
17	04.06.12	Gill	2.1	3.3	8.64	0.014	0.010	<0.001	<0.003	2.08
18	06.06.12	Shannon	0.3	4.0	1.92	0.014	0.009	0.001	0.003	1.95
19	06.06.12	Donnell	0.0	4.3	<1.00	0.042	0.356	0.006	0.004	6.41
20	13.06.12	Ahalia	1.4	<2.0	2.02	0.022	0.014	0.003	<0.003	0.59
21	13.06.12	Athola	33.1	2.7	2.59	0.014	0.009	0.002	<0.003	0.60
22	13.06.12	Lettermullen	29.2	2.0	<1.00	0.015	0.010	0.002	<0.003	0.65
23	13.06.12	Aibhnín	29.6	<2.0	1.15	0.018	0.010	0.001	<0.003	0.42
24	13.06.12	Tanaí	24.5	<2.0	1.44	0.016	0.009	0.002	<0.003	0.37
25	25.06.12	Durnesh	8.1	2.1	3.83	0.022	0.014	0.001	0.006	1.19
26	25.06.12	Inch S	0.1	3.0	5.75	0.053	0.550	0.013	0.008	2.53
27	25.06.12	Inch N	0.9	4.4	12.96	0.010	0.018	0.002	<0.003	2.75
28	27.06.12	Furnace	2.0	<2.0	2.88	0.031	0.039	0.003	0.003	1.01

Appendix V. Salinity, Temperature and Dissolved Oxygen, Cuskinny, Co. Cork, 23rd May 2012

Date	Time	Salinity psu	Temperature degrees C	Dissolved Oxygen Mg/L
23/05/2012	9.30	27.1	13.1	8.1
23/05/2012	10.05	27.5	13.5	8.5
23/05/2012	10.50	28.4	13.7	9.5
23/05/2012	11.45	28.9	13.8	9.4
23/05/2012	13.10	27.8	14.5	11.0
23/05/2012	13.52	24.7	14.2	10.4
23/05/2012	14.45	22.7	14.2	10.2
23/05/2012	15.00	21.6	14.2	10.4
23/05/2012	16.00	20.3	14.3	10.3
23/05/2012	18.20	27.2	14.0	10.7



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