A Report on
A) Ecological, Oceanographic and Modelling Studies in Lough Atalia and Renmore Lough, Inner Galway Bay in relation to their status as a Priority Habitat within the EU Habitats Directive and
B) The effects of the proposed Galway Harbour extension on the Lough Atalia and Renmore Lough.

Produced by

AQUAFACT International Services Ltd

On behalf of

Tobins Consulting Engineers

Issued

May 2013

AQUAFACT INTERNATIONAL SERVICES ltd
12 KILKERRIN park
TUAM rd
GALWAY city
www.aquafact.ie

info@aquafact.ie

tel +353 (0) 91 756812
fax +353 (0) 91 756888

Table of Contents

List of Figures

List of Tables

Appendices

Appendix I Current speed and direction data collected in Lough Atalia

Appendix II Salinity results from 21 locations in Lough Atalia on a selection of dates

Appendix III Salinity graphs collected by meters, March 2013

Appendix IV Mathematical model study

1. Introduction

Lough Atalia and Renmore Lough lie in the inner part of Galway Bay and are defined as "lagoons" within the EU Habitats Directive and lagoons are listed as priority habitats in this Directive. As these water bodies lie close to the site of a proposed extension of Galway Port, an assessment of the possible impact of the proposed development on the ecology of both water bodies was undertaken.

A review of existing salinity data and information collected as part of this study showed that recorded salinities ranged from 0.4 to 29.4 psu (practical salinity unit). The calculated full range of salinities is from zero to 30.0 psu. Initial results from a broad scale 2 dimensional hydrodynamic model indicated that salinities might decrease and for this reason, a fine scale 3 dimensional modelling study was carried out. This confirmed the out put of the 2 dimensional model and predicted that

i) the range of salinities within Lough Atalia will not change,

ii) the frequency of zero salinity will increase from 7 to 18 hours in an average year

and

iii) the median salinity will reduce by 1.29 psu or 10% of the present value.

This report describes the conservation status, morphology, bathymetry, current speeds and directions, salinity and biology of Lough Atalia and Renmore Lough. The species recorded in each water body are listed and are then discussed individually in terms of their salinity tolerances. The discussion at the end of the report comments on the likely effect the predicted temporal decreases in salinity may have on the conservation status of the water bodies.

2. Conservation Status

Both water bodies lie within Galway Bay candidate Special Area of Conservation (cSAC) and Lough Atalia only lies within the Galway Bay Special Protection Area (SPA) (see Figure 2.1). However, habitat quality in both is poor and in a review of Irish lagoons, Oliver (2007) states that "Lough Atalia is an "estuarine" lagoon and most of the bed of the lagoon appears to be bare, soft mud. It is also highly polluted, so that even on hard surfaces very few algal plants were found. Based on aquatic vegetation, the site is regarded as of **no conservation value** as a coastal lagoon." Oliver (*loc. cit.)* did not survey Renmore Lough.

The conservation objectives for Galway Bay cSAC and SPA were recently publish by National Parks and Wildlife and the section on lagoons in the cSAC is presented in the following table.

Annex I Habitat	**Coastal lagoons* [1150]**	
Measure : Hectares	**Attribute:** Habitat Area **Target:** Permanent habitat increasing or stable. Area stable, subject to slight natural variation. Favourable reference area 76.7ha. **Notes.** Areas calculated from spatial data derived from Oliver (2007). Site codes IL037, IL038, IL039, IL046, IL047, IL048, IL049, IL050, IL051, IL052. *N.B.* There may be more, as yet unmapped, lagoons within this cSAC.	No change to habitat area
Measure : Occurrence	**Attribute:** Habitat distribution **Target:** No decline, subject to natural processes. **Notes.** Site codes IL037, IL038, IL039, IL046, IL047, IL048, IL049, IL050, IL051, IL052 in Oliver (2007). *N.B.* There may be more, as yet unmapped, lagoons within this SAC.	No change to habitat distribution.
Measure : Practical salinity unit (psu)	**Attribute:** Salinity regime **Target:** Median annual salinity and temporal variation within natural ranges within natural ranges maintained. **Notes.** The lagoons in the site vary from oligohaline to euhaline. Lough Atalia and Renmore Lough are poikilohaline systems (see Table 4.1 for definitions).	Fluctuations on the existing variability possible though deemed not to have any impact on the functioning of the ecosystem.

Annex I Habitat	**Coastal lagoons* [1150]**	
Measure: Water depth	**Attribute:** Hydrological regime **Target:** Current annual water level fluctuations and minima maintained within natural ranges. **Note.** Most of the lagoons listed for the site are considered to be shallow; however, Aughinish and Lough Atalia do have deeper (at least 3m) parts.	Water levels will be maintained and will not be altered by the development.
Measure: Barrier	**Attribute:** Barrier **Target:** Permeability of barrier maintained. Appropriate hydrological connections between lagoons and sea, including where necessary, appropriate management. **Notes.** The lagoons within this site exhibit a variety of barrier types including cobble/shingle, karst and artificial embankment/causeway. Several are recorded as having sluices.	There will be no impact on the barrier/sill.
Measure: Chlorophyll a	**Attribute:** Water Quality (Chlorophyll a) **Target:** Annual median chlorophyll a reduced within natural ranges and less than 5µg/l. **Note.** Target based on Roden and Oliver (2010).	There will be no impact on chlorophyll a.
Measure: Phosphorous	**Attribute:** Water Quality (MRP: Molybdate reducing Phosphorous) **Target:** Annual median MRP reduced within natural ranges 0.1mg/l. **Note.** Target based on Roden and Oliver (2010).	The development will not alter MRP levels.
Measure: Nitrogen	**Attribute:** Water Quality (DIN; dissolved inorganic Nitrogen) **Target:** Annual median DIN a reduced within natural ranges and less than 0.15mg/l. **Note.** Target based on Roden and Oliver (2010).	The development will not alter DIN level.

Annex I Habitat	Coastal lagoons* [1150]	
Measure: Macrophytic growth	**Attribute:** Depth of Macrophyte Colonisation **Target:** Increase colonization to maximum depth. **Note.** Macrophyte colonisation at least 2m depth.	Development will not alter macrophyte communities
Measure: Floral diversity	**Attribute:** Typical Plant Species **Target:** Maintain number and extent of listed lagoonal specialists, subject to natural variation. **Note.** Species listed in Oliver (2007).	The development will not alter floral lagoonal specialists.
Measure: Faunal diversity	**Attribute:** Typical Animal Invertebrate Species **Target:** Maintain listed lagoon specialists, subject to natural variation. **Note.** Species listed in Oliver (2007).	The development will not alter faunal lagoonal specialists.
Measure: Negative indicator species	**Attribute:** Negative Indicator Species **Target:** Negative indicator species absent or under control. **Note.** Low salinity, shallow water and elevated nutrient levels increase the threat of accelerated encroachment by reed beds.	The development will not alter negative indicator species.

Table 2.1. Conservation Objectives for lagoons in Galway Bay cSAC.

Turbidity is not listed in the conservation objectives as an attribute. However, sediments suspended during the dredging operations have the potential to enter the lagoon on flooding tides. As a result of the oceanographic conditions within the lagoon, this sediment will not be remobilised and will be retained within it. The result will be the loss of water depth *(ca* 10mm) in the northeastern section of the lagoon. This will be mitigated by permitting dredging only under ebbing tides.

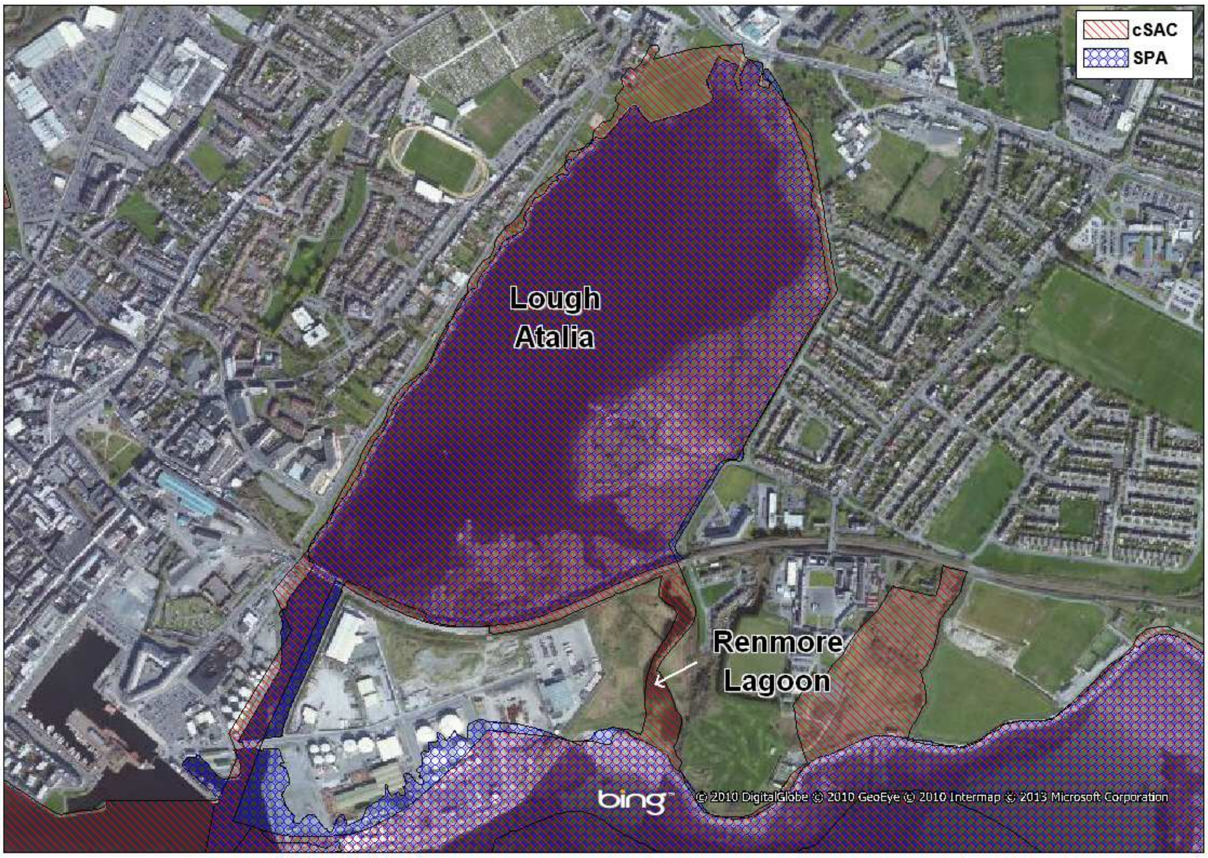


Figure 2.1: Lough Atalia and Renmore Lough within the cSAC and SPA.

3. Description of Lough Atalia and Renmore Lough.

Lough Atalia and its small off-shoot, Renmore Lough comprises an area of *ca* 40 ha of Inner Galway Bay (see Figure 3.1). Given the presence of at least 3 lagoonal specialists in the Lough Atalia/Renmore Lough water body, the wide variability in salinities and the fact that it only partially empties, this habitat falls within the definition of a lagoon. Lagoons are listed in Annex I of the Habitats Directive as a priority habitat, 'Coastal Lagoons' (Natura 2000 Code 1150).

Figure 3.1. Lough Atalia and Renmore Lough

Lough Atalia has a narrow channel to the south-west connecting it with Inner Galway Bay (see Figure 3.1). There is a shallow sill at the entrance to the lough (see Figure 3.2) which restricts full tidal flow into it. This corresponds to the characterisation by Healy (2003) of lagoons being at least partially separated from, while still having exchange of water, with the sea. The presence of the sill in Lough Atalia leads to an asymmetrical tide of *ca* nine hours ebb and three hours flood. The sill also acts to retain water at low tide with approximately 80% of the lough remaining inundated at low tide (Oliver, 2007). Such asymmetrical tides are typical of water bodies with significant sills and other examples in Co. Galway are Curanroo, Lough Rusheen, several other Lough Atalias in Connemara and Salt Lake, Clifden. Some systems *e.g.* Inverbeg and Loch Aneera, both in Kilkieran Bay, only receive salt water on equinoctial Spring tides. This denser water sinks underneath the lighter freshwater and lies on the lake bed where it becomes anoxic. However, due to the significant flows into and out of Lough Atalia, anoxia in the water column does not occur. The intertidal, muddy area in the northern part of Lough Atalia is relatively small in comparison to the large area of water retained.

The access channel (Figure 3.1) has undergone a number of changes in the last *ca* 150 years. It was partially narrowed as part of the construction of the railway line into Galway City in the 1860s by the building of an abutment on the eastern side and two piers to support the rail bridge. Further alterations occurred in the 1960s and 90s when the sides of the channel (between the railway bridge and a newly constructed road bridge to the south allowing access to the Galway Enterprise Park and southwards) were straightened. Other changes include the construction of storm water overflows at the northern and eastern end of the lough. There is a freshwater well on the western side of the lough and there has been some conjecture that the Terryland River may rise in Lough Atalia but this has never been proven.

Renmore Lough (Figure 3.1) is connected to the south-east of Lough Atalia via a cut channel under the railway. It was historically connected to Lough Atalia by a natural channel but this was closed up when the railway line was built and a small channel was opened *ca* 100m to the west of the original access point and this goes under the railway line to join the main body of Lough Atalia (Figure 3.1). The water level in Renmore Lough is *ca* 1 m higher than the top of the culvert under the railway line (marked on Figure 3.1 as "New Connection"). This indicates that sea water rarely accesses Renmore Lough from Lough Atalia.

3.1. Bathymetry

A bathymetric survey of Lough Atalia was carried out using a Precision SonarMite Echo Sounder in conjunction with a Trimble® GeoXT™ to record depths within Lough Atalia. Depths are mostly shallow (less that 1 m) but there is a deeper area towards the south-western section of the mouth with depths of up to *ca* 4m and which can reach >5.5m at high water (see Figure 3.2). This figure also shows a blow up of the access channel into Lough Atalia from the open sea. Its narrow width, shallow depths and sill (coloured in gold) all restrict ingress of water into Lough Atalia and give rise to the asymmetrical tides noted above.

Depths of Renmore Lough, taken at a neap low water 14/03/2012 ranged between 0.15-0.85 and for this reason, a vessel-based bathymetric survey was not possible.

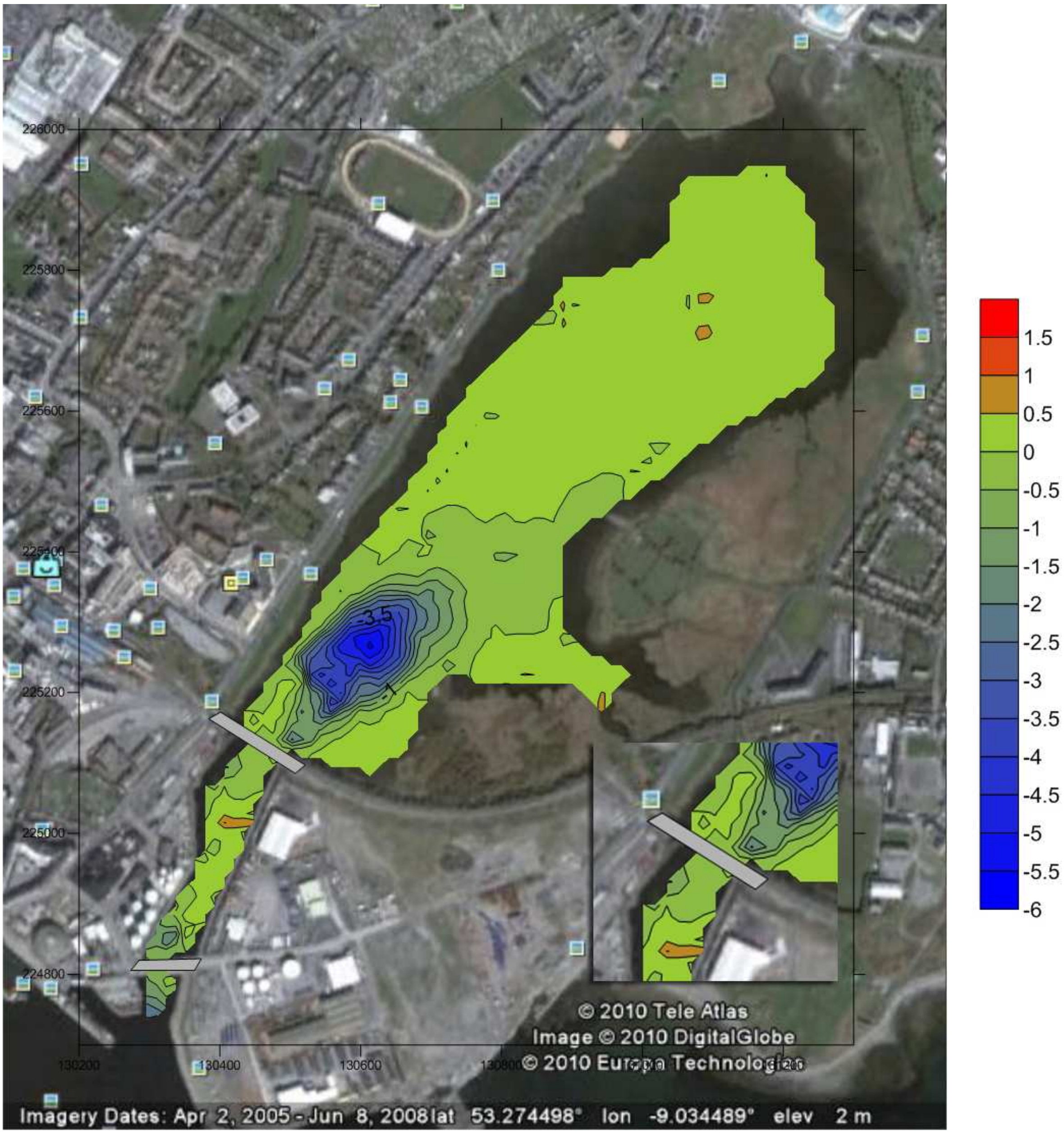


Figure 3.2. Bathymetry of Lough Atalia.

3.2. Current speeds and directions

Current flow at the mouth of Lough Atalia was measured by deploying a continuous recording current meter between 8 January and 1 February 2013 and for a second period between 11 March and 25 March 2013 (see Figure 3.5 for location and Appendix I for graphical representation of data).

There is greater water flow near the south-western mouth of the lough compared to its north-eastern head. The increased velocity of water at the mouth is caused by water movement over the sill and these forces are less in waters towards the north-eastern end. Hydrodynamic model output shows Lough Atalia to have greater and more variable velocities during spring tides. Velocities around the mouth vary from 0.15 - 3m/s with lower velocities in the rest of the lough often at the minimum of 0m/s but sometimes rising to 0.05m/s in the centre. Weak water currents compared to those of estuaries are a characteristic of lagoons (Healy, 2003). The water velocity patterns result in the sediment at the mouth comprising gravel, compared to the soft muds found towards the north-eastern end. All current graphs can be found in Appendix I.

Directions of flow are northeast on a rising tide and southwest on a falling tide.

Water from Lough Atalia flows into Renmore Lough at high water during Spring tides. Run off and seepage from land, flows into Renmore Lough in accordance with rain fall. Because Renmore Lough is perched (+1m above mean high water neap), water flows out of it into Lough Atalia for a much longer period than water flows into it (see Figure 3.3 for cross sections from the sea into Lough Atalia and from Lough Atalia in to Renmore Lough). It is only under highest astronomical Spring tides that sea water can access Renmore Lough.

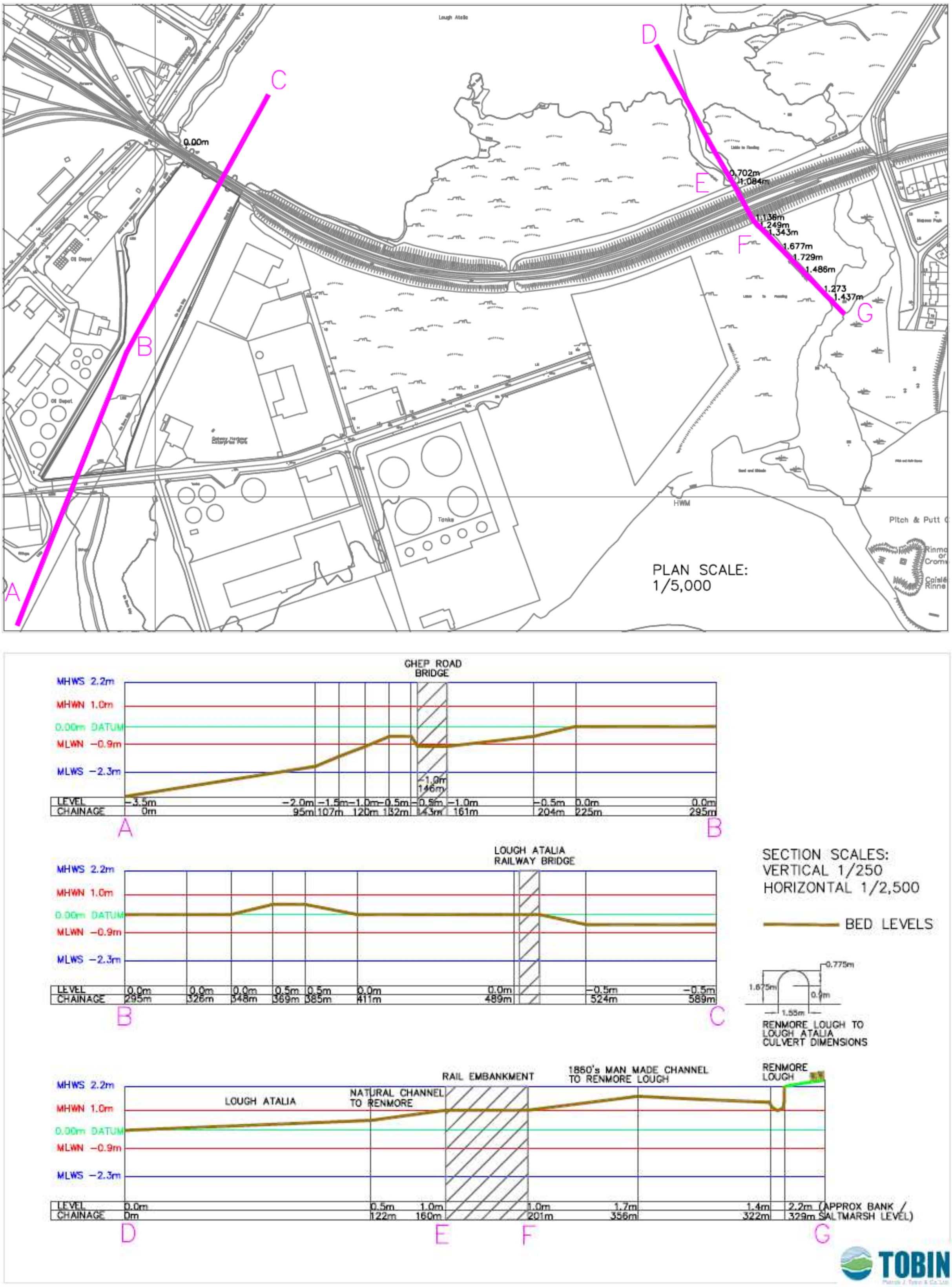


Figure 3.3. Cross section

3.3. Salinity

Existing data reported by Sotillo *et al.* (2011) and data collected by AQUAFACT were used to describe the salinity conditions in both Lough Atalia and Renmore Lough. Sotillio *et al.* (2011) used a field probe to record values at different depths and locations while the AQUAFACT surveys included both a field probe deployed along the shoreline (surface readings only) and from a boat (at 50 cms depth intervals) and salinity recording meters deployed for extended periods of time. The different survey types and durations are listed below. Figure 3.4 shows the initial location of 21 profile stations used to describe salinity in profile while Figure 3.5 shows the locations of the reduced 10 profiling stations. Appendix II and III presents the data in graphical form.

<u>Shore Surveys</u>

- In August 2011, salinity measurements were taken at 4 stations on the western shore of Lough Atalia.
- Between 12 September 2011 and 29 November 2011, salinity measurements were recorded at Renmore Lough, on 5 separate occasions. Further salinity measurements were recorded at Renmore Lough between 5th March 2012 and 2nd May 2012 on 14 separate occasions. A salinity measurement was also taken at a site located on the NE shore of Lough Atalia, as part of the 2012 surveys.
- Between 14th January 2013 and 24th January 2013, salinity measurements were recorded at the south and north ends of Renmore Lough.
- On the 6th March 2013, salinity measurements were taken at the bridge over the mouth of Lough Atalia, between 9am and 5pm, at 15 minute intervals, with readings recorded at surface, 0.5m, 1m, 1.5m, and 2m depth.

<u>Boat Surveys</u>

- In August 2011, 7 vertical salinity profiles were taken along a transect from south to north Lough Atalia.
- In March 2012, depth measurements were taken in Renmore Lough in a transect from north to south.

- At 21 stations located in Lough Atalia, salinity measurements were taken by boat on 5 separate occasions, between 4th April 2012 and 4th May 2012.
- At 10 stations in Lough Atalia, salinity was measured by boat on 8 separate occasions, between 4th December 2012 and 24th January 2013. Fauna and sediment samples for PSA/OCA were taken at these 10 stations on the 4th December 2012.

Continuous current and salinity recordings

- Current metering using a bottom mounted, upward looking Acoustic Doppler Current Profiler, (ADCP) and salinity readings were recorded between 8 January 2013 and 1 February 2013, and for a second period between 11 March 2013 and 25 March 2013. Figure 3.5 shows how these meters were deployed. Readings were recorded every 30 minutes.

Figure 3.4. Figure showing the 21 stations where salinity profiles were recorded with a probe.

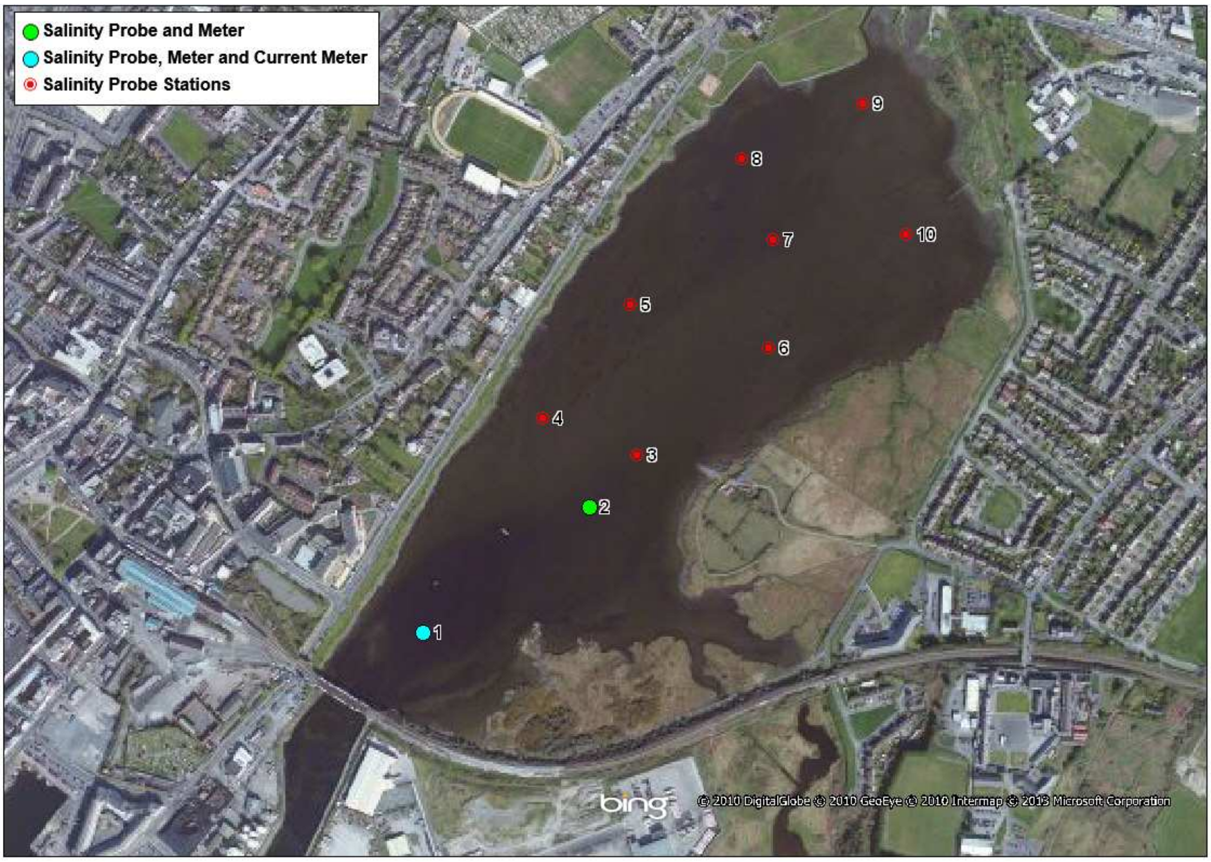


Figure 3.5. Figure showing the 10 stations where salinity profiles using a probe were collected, the two sites where continuous recording meters for both salinity and the single site where the continuous recording current meter was deployed.

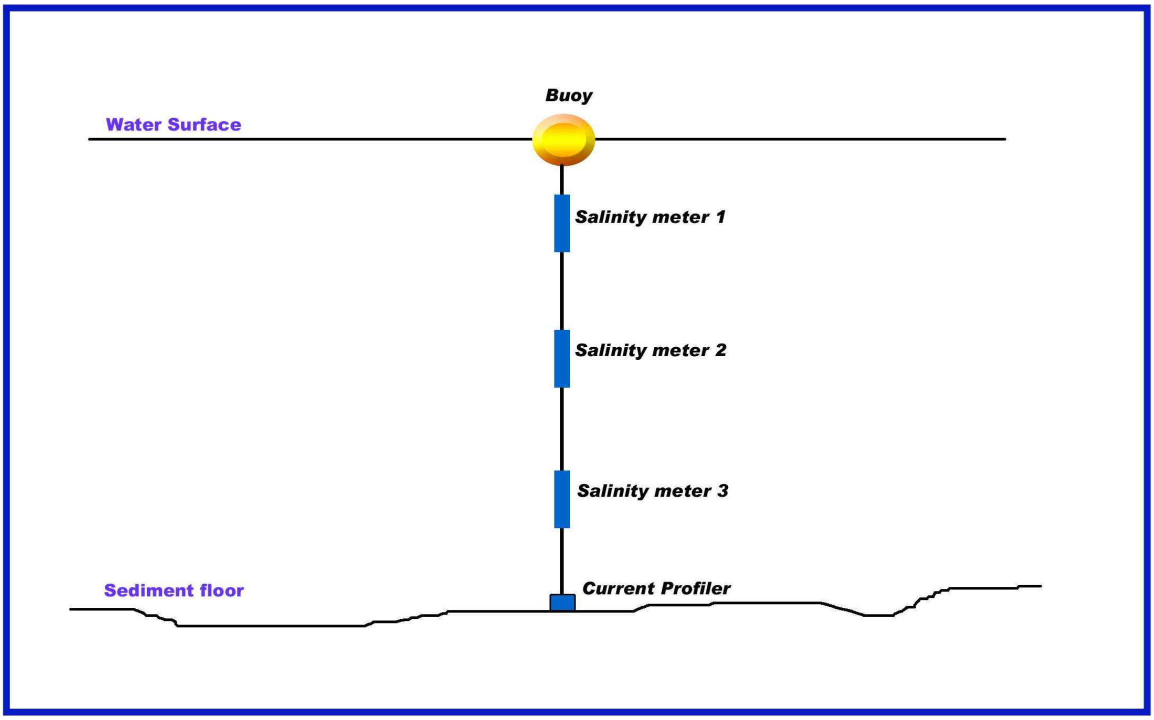


Figure 3.6 Diagram showing layout of current and salinity meter strings.

Results of some of the data collected using the probe are presented in Appendix II while data and graphs collected by the continuous recording meters over the period March 11th – 25th, 2013 are presented in Appendix III.

During the study period, salinities within Lough Atalia ranged from 0.4 to 29.4 psu (practical salinity unit) (see Appendix 1). Over the course of Spring-Neap tidal cycles, surface salinities range from 0.4 to 28.8 psu and bottom salinities range from 10 to 29.4 psu. Surface salinities are generally lower near the southern end of the lough where the mouth is located. However, low surface salinities were also recorded towards the northern end of the lough. Salinities increase with depth, leading to the highest salinities being recorded at the deepest areas of the lough. The low values at the northern end reflect the effects of surface run off. Low surface salinities recorded at the mouth are due to Corrib River water being brought in to the lough by flooding tides. There is some evidence to suggest the formation of a temporary halocline (halocline = a strong discontinuity in salinity with depth) in Lough Atalia under conditions of low mixing which disappears in high mixing conditions such as during a flooding tide.

Salinity in Renmore Lough ranged from 2.2 to 23.9 psu and extreme values were recorded at its northern end. As noted above in the section on bathymetry and shown in Figure 3.3, it is only under highest astronomical tides that water can access Renmore Lough from Lough Atalia and it is the salinity characteristics of this inflowing water that regulates salinity within the lough: if the River Corrib is in spate at the time of these high tides, salinities will be lowered (as in the recording of 2.2 psu above) whereas if River Corrib flow is low, the salinity of inflowing water from Lough Atalia into Renmore Lough will be high (23.9 psu recorded above).The salinities within Renmore Lough remain more or less constant between the southerly end and the northerly end (averaging 10.3-10.4 psu), which is further from the sea, suggesting that there are no pathways directly between the sea and Renmore Lough through the narrow land bank.

The extensive range of salinities recorded both in Lough Atalia and Renmore Lough classifies them as poikilohaline systems (poikilohaline = high variability in salinities). Millar *et al.* (1990) note that mean salinity values range from 0 – 35 psu and comment that lagoonal species are usually quite tolerant of a wide salinity range.

3.4. Turbidity

Turbidity measurements returned a value of 0 NTU (Nephelometric Turbidity Units).This value of 0 NTU was also measured in Galway Bay and on Wolfe Tone Bridge at the mouth of the River Corrib. Secchi disc measurements taken in Lough Atalia resulted in a visible reading off bottom for most stations due to the shallow depths. At the deeper stations, Secchi values of 2.5 to 2.75m were recorded. As Renmore Lough is less than 1 m depth and the sea bed could be seen on each site visit, Secchi disc measurements were not made.

3.5. Flora and fauna

49 taxa of flora and fauna recorded in Lough Atalia and Renmore Lough is shown in Table 3.1. Taxa only recorded within Renmore Lough are coded with R.L. (= Renmore Lagoon). This table was compiled from surveys by Oliver (2007) undertaken between August and October 2006, Sotillo *et al.*, (2011) undertaken in July 2010 and AQUAFACT (2010 - 2013). *Chaetomorpha*

linum, *Jaera nordmanni* and *Palaemonetes varians* are considered to be lagoonal specialist species (Healy, 2003; Oliver, 2007) and are highlighted in red in the table below. The numeral in the column on the extreme right is given to direct the reader to the species' salinity tolerance given in section 4.

Phylum	**Division/Class**	**Species**	
Plantae	Chlorophycota	*Chaetomorpha linum*	1
		Enteromorpha sp.	2
		Ulva lactuca	3
	Phaeophycota	*Fucus serratus*	4
		Fucus spiralis	5
		Fucus vesiculosus	6
		Pelvetia canaliculata	7
	Rhodophycota	*Ceramium sp.*	8
		Chondrus crispus	9
	Xanthophyceae	*Vaucheria* sp.	10
	Angiosperm	*Ruppia* sp.	11
Cnidaria	Hydrozoa	*Cordylophora caspia*	12
Nematoda		Indet.	13
Annelida	Polychaeta	*Hediste* (*Nereis*) *diversicolor*	14
		Polydora ciliata	15
		Pygospio elegans	16
	Oligochaeta	*Nais sp.*	17
		Heterochaeta costata (R.L.)	18
Crustacea	Cirripedia	*Elminius modestus*	19
	Copepoda	*Nitokra spinipes* (R.L.)	20
		Cyclopoida	21
	Mysidacea	*Neomysis integer*	22
		Praunus flexuosus	23

Phylum	Division/Class	Species	
	Isopoda	*Jaera nordmanni*	24
		Jaera albifrons	25
		Asellus sp (R.L.)	26
	Amphipoda	*Allomelita pellucida*	27
		Melita palmata	28
		Gammarus duebeni	29
		Gammarus salinus	30
		Gammarus indet.	
	Decapoda	*Palaemon elegans*	31
		Palaemonetes varians	32
		Crangon crangon	33
		Carcinus maenas	34
	Ostracoda	*Cyprideis torosa* (R.L.)	35
Acarina		Indet	36
Insecta	Diptera	Chironomidae indet.	37
	Odonata	Zygoptera (R.L.)	38
	Coleoptera	Dytiscidae (R.L.)	39
Mollusca	Pulmonata	*Peringia* (*Hydrobia*) *ulvae*	40
	Gastropoda	*Ecrobia (Hydrobia) ventrosa* (R.L.)	41
Bryozoa	Gymnolaemata	*Bowerbankia gracilis*	42
		Alcyonidium gelatinosum	43
Pisces	Osteichthyes	*Chelon labrosus*	44
		Platichthys flesus	45
		Pomatoschistus microps	46
		Gasterosteus aculeatus (R.L.)	47
		Antherina presbyter	48

Phylum	Division/Class	Species	
		Anguilla anguilla (R.L.)	49

Table 3.1. Flora and fauna recorded in Lough Atalia and Renmore Lough (based on Oliver, 2007; Sotillo *et al.*, 2011 and AQUAFACT surveys).

A benthic survey using a 0.025 m^2 grab and a 1 mm mesh was undertaken to quantitatively assess the sea bed fauna and sediments in Lough Atalia. 2 grabs were taken for faunal identification at the 10 sites shown in Figure 3.6 below and a further sample was taken for grain size and organic carbon content. During the field work when samples were being collected, except for Station 1, there was a strong smell of hydrogen sulphide from all samples collected and the sediment was black. Both these features indicate anoxic, sedimentary conditions.

Figure 3.7. Benthic grab station location map for Lough Atalia.

The faunal analyses returned exceptionally low numbers of taxa and numbers of individuals with only 8 species being recorded at 5 stations. The following 7 species (and their densities) were recorded at Station 1: *Jaera nordmanni* (15), *Allomelita pellucida* (4), *Gammarus* sp (8), *Gammarus salinus* (13), Oligochaeta (3), *Pygospio elegans* (1) and *Polydora ciliata* (4). Station 3 returned only two specimens of *Melita palmata* and Station 5 and 9 returned only 1 specimen each of *Gammarus salinus.* Stations 2, 4, 6, 7, 8 and 10 had no fauna at all.

Table 3.2 shows the results of the analyses of grain size (as percentages) and organic carbon (right hand column as %) from the same 12 stations. Station 1 had by far the highest amount of coarse sediment with almost 70% being gravel. All other stations were characterised by low amounts of coarse sediment and high percentages of fine, very fine and silt clays. Organic carbon levels ranges from 10.05 at Station 1 to 18.96 at Station 2. The mean value was 14.89.

Station	Gravel	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt-Clay	LOI
1	69.2	7.1	8.2	9.4	3.3	1.5	1.3	10.05
2	0.5	1.9	7	15	20.1	20.4	35	18.96
3	1	3.9	7.2	13.2	17	11.7	45.9	16.02
4	0.2	1.5	7.6	15.9	15.8	13.4	45.5	18.14
5	0.5	1	4.7	9	16.2	21.5	47.2	13.87
6	1	3.5	5.2	8.9	14.4	10.6	56.4	11.57
7	1.2	1	3.6	8.9	13.4	9.2	62.8	13.55
8	0	0	0.4	0.7	14.3	16.6	68.1	13.33
9	0.7	1.8	6.8	14.6	16.6	8.5	50.9	17.64
10	0.6	3.6	10.2	14.5	15.1	15.1	40.9	15.81

Table 3.2. Results of granulometric (%) and organic carbon (LOI%) analyses on 10 sediment samples collected in Lough Atalia.

Aquatic fauna from Renmore Lough was surveyed on 4^{th} and 12^{th} October 2011. Twelve invertebrate and three vertebrate taxa were recorded. Many taxa such as *Hediste diversicolor*, Chironomidae, *Ecrobia* (*Hydrobia*) *ventrosa*, *Anguilla anguilla* and *Gasterosteus aculeatus* are commonly occurring lagoonal species. Healy (2003) considers *Ecrobia ventrosa* and *Ruppia* sp. as characteristic lagoonal species. The former was present at all three stations in this survey, while the latter was recorded by Oliver (2007). *Palaemon varians* while also found in estuaries, is considered by Oliver (2007) be a characteristic lagoonal species. Other taxa such as *Hediste diversicolor, Palaemon varians* and Chironomidae are common marine or estuarine species which tolerate large salinity ranges. The Crustacea showed the most taxa present while there was only one species of mollusc, *i.e. E. ventrosa*, recorded.

Using the JNCC marine habitat classification, the above assemblage most closely fits the "sublittoral mud in low or reduced salinity (lagoons)" or SS.SMU.SMuLS grouping with the exception of *Arenicola marina, Heterochaeta costata* and *Corophium costata* which were not recorded in either water body.

In the Conservation Objectives for Galway Bay cSAC, the conservation status of Lough Atalia was assessed as 'Unfavourable- Bad' with problems of eutrophication and pollution, the threat of urbanisation, dumping and silting up. A major problem is the water quality at the site (NPWS, 2013).

A three dimensional mathematical model study (see Appendix IV for full report) was carried out to determine possible changes in salinity due to the construction of the proposed harbour extension predicted that :

the range of salinities within Lough Atalia will not change,

the frequency of zero salinity will increase from 7 to 18 hours in an average year and

the median salinity will reduce by 1.29 psu or 10% of the present value.

The model outputs can be seen in Figures 3.8 – 3.11 below for 90 (28.5 cumec (m^3/sec), 50 (82 cumec), 10 (200cumec) and 1 (272cumec) percentile flow of the River Corrib over a Neap – Spring cycle. (*N.B.* Percentile flow is the percentage of time that the flow is greater or equal to a specific flow). The full report on modelling salinity in Lough Atalia is presented as Appendix I to this report.

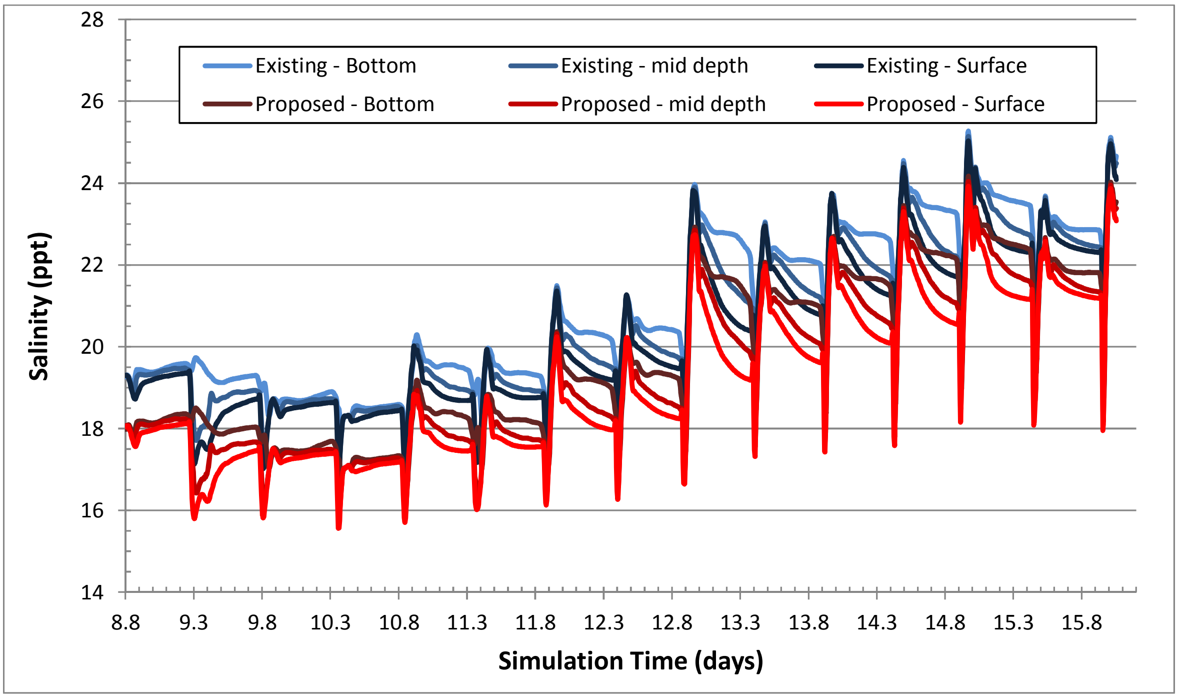


Figure 3.8. Time series output of salinities at one location (St. 9) in Lough Atalia existing and proposed cases Neap to Spring tide under 90-percentile flow (28.5 cumec).

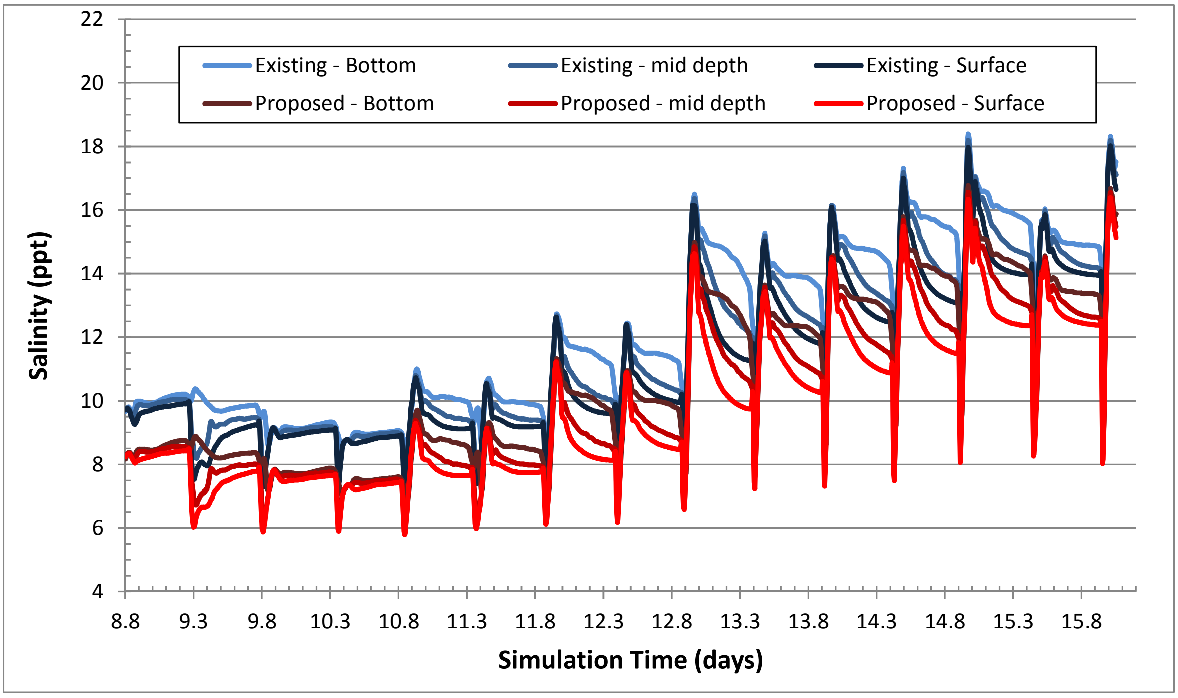


Figure 3.9. Time series output of salinities at one location (St. 9) in Lough Atalia existing and proposed cases Neap to Spring tide under 50-percentile flow (82 cumec).

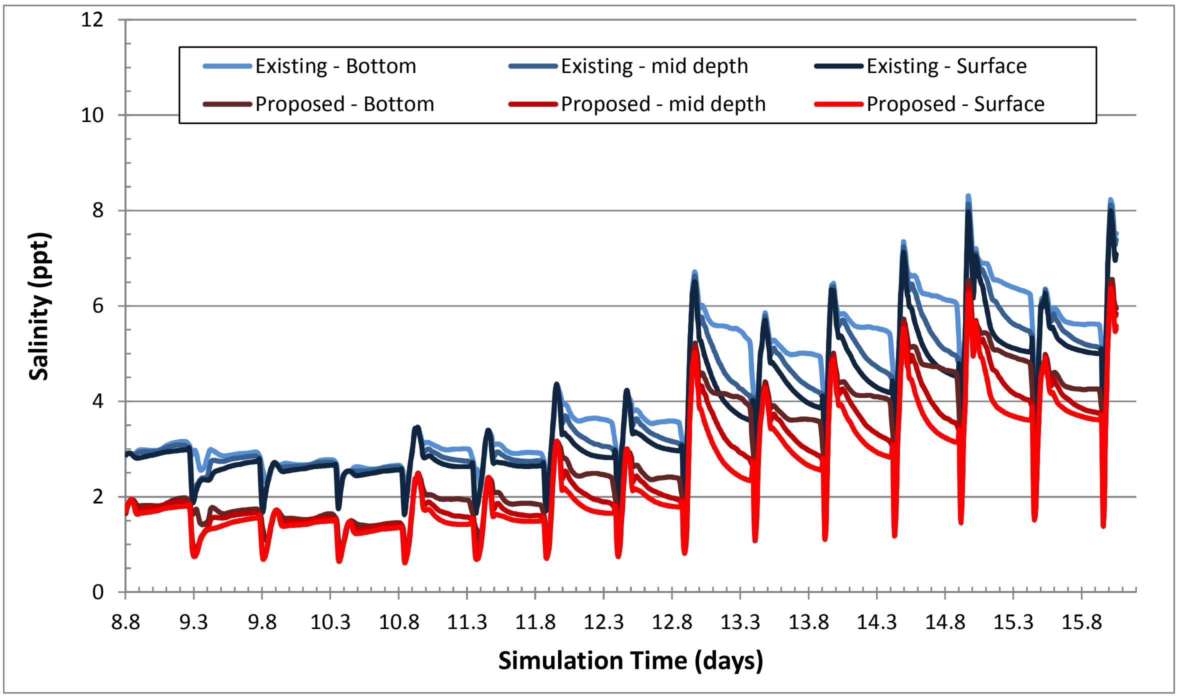


Figure 3.10. Time series output of salinities at one location (St. 9) in Lough Atalia existing and proposed cases Neap to Spring tide under 10-percentile flow (200 cumec).

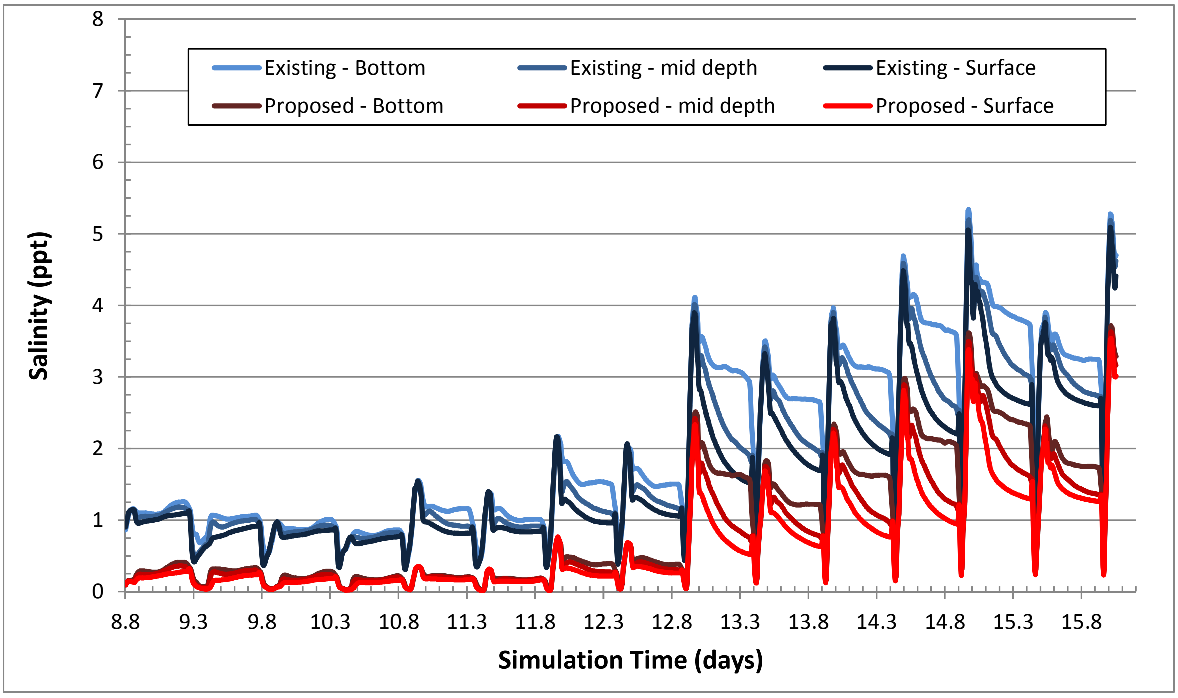


Figure 3.11. Time series output of salinities at one location (St. 9) in Lough Atalia existing and proposed cases Neap to Spring tide under 1-percentile flow (272 cumec).

4. Potential impacts from the proposed development on floral and faunal species.

In order to determine if the predicted change in salinity could affect the resident flora and fauna recorded in both Lough Atalia and Renmore Lough, the salinity ranges which each species can tolerate was examined and the individual species is discussed below. It should be noted that some of these studies were laboratory-based experiments and species were tested under constant salinity levels for extended periods of time and not under the highly variable salinity levels that occur on each tide and under different River Corrib flow conditions. For information purposes, the practical salinity scale is presented in Table 4.1 below.

Salinity Term	**PSU**	**Common Term**
Freshwater	<0.5	Freshwater
Oligohaline	0.51 - 5	Brackish
Mesohaline	5.1 -18	
Polyhaline	18.1 - 30	
Poikilohaline	0 - 35	Poikilohaline
Euryhaline	30.1 - 40	Marine

Table 4.1.Practical salinity scale for different ranges of salinity.

The evolution of lagoonal communities appears to relate to the intrinsic variation in salinity within lagoons, both in time (short term) and space (Bamber *et al.,* 2001). In addition, a large number of lagoonal species are closely related to fully marine rather than estuarine or freshwater species, are essentially sublittoral and are tolerant of a wide range of salinity (for example 10 - 45psu) (Bamber *et al.,* 2001).

de Wit (2011) uses the term poikilohaline for water that ranges from 0 – 35 psu and both Lough Atalia and Renmore Lough fit this category. These terms are used in the follow section which examines the salinity tolerances of the species recorded and some other Irish lagoon characteristic species.

Salinity values recorded in Lough Atalia extend the tolerance ranges for many taxa and these are noted in the species' commentary where these apply.

1. *Chaetomorpha linum*

There is some doubt about the taxonomic status of the unattached lagoonal form of this species and it was recorded by Hatch & Healy (1998) as *C. mediterranea* (NPWS, 2012). It is a common, characteristic alga of semi-isolated Irish lagoons, recorded at 49 of the 87 (56.3%) lagoons surveyed (Oliver, 2005). It is considered a poikilohaline species.

2. *Enteromorpha sp*.

Studies on *Enteromorpha intestinalis* (Martins *et al*., 1999) showed that its growth varies along a bell-shaped curve with salinity and that the optimum salinity range for growth is 18–22 psu. *E. intestinalis* showed the lowest growth rates at extreme low salinity values (≤ 3 psu) and for salinity ≤ 1 psu, the alga died. Growth rates at salinities lower than 5 psu and higher than 25 psu were also low, when compared with growth between salinity of 15 and 20 psu, where *E. intestinalis* showed the highest growth rates. It is considered an oligo to polyhaline species.

3. *Ulva lactuca*

Taylor *et al.* (2001) showed that *Ulva lactuca* showed a wide tolerance to salinity, exhibiting growth in 3.4 to 34 psu. It is considered an oligo to polyhaline species.

4. *Fucus serratus (*Serrated wrack)

Fucus serratus can tolerate salinities from 18 – 40 psu (Jackson, 2008). Being intertidal and subject to precipitation, *Fucus serratus* is exposed to a broad range of salinities. This species is able to compensate for these changes in salinity by adjusting internal ion concentrations. Its occurrence in Lough Atalia extends its known salinity tolerance range. It is considered a meso to euryhaline species.

5. *Fucus spiralis (*Spiral wrack*)*

Fucus spiralis can tolerate salinity from 10 – 40 psu (White, 2008a). *F. spiralis* can experimentally tolerate salinities of 3 to 34 psu, but it is only found in estuaries down to 10 psu. Its occurrence in Lough Atalia extends its known salinity tolerance range. It is considered a meso to euryhaline species.

6. *Fucus vesiculosus (*Bladder wrack)

Fucus vesiculosus can tolerate salinity from 11 – 40 psu (White, 2008b). *F. vesiculosus* tolerates a wide range of salinities as evidenced by its penetration into the Baltic. Being an intertidal species, it must withstand occasional conditions of hyposalinity during winter precipitation and hypersalinity during the summer. In the UK, the species tolerates salinity down to 11 psu, below which it is replaced by *Fucus ceranoides* (Suryono & Hardy, 1997). Its occurrence in Lough Atalia extends its known salinity tolerance range. It is considered a meso to euryhaline species.

7. *Pelvetia canaliculata (*Channel wrack*)*

Pelvetia canaliculata can tolerate salinity from 18 – 40 psu (White, 2008c). It must be able to withstand wide variations in salinity because it is usually emerged for long periods of time, during which it will be drenched in freshwater from rainfall. Its occurrence in Lough Atalia extends its known salinity tolerance range. It is considered a meso to euryhaline species.

8. *Ceramium sp.*

Ceramium sp. can tolerate salinity levels from <18 to 40 psu (Hiscock and Pizzolla, 2007). *Ceramium virgatum* occurs over a very wide range of salinities. The species penetrates almost to the innermost part of Hardanger Fjord in Norway where it experiences very low salinity values and large salinity fluctuations due to the influence of snowmelt in spring (Jorde & Klavestad, 1963). Its occurrence in Lough Atalia extends its known salinity tolerance range. It is considered a meso to euryhaline species.

9. *Chondrus crispus*

Chondrus crispus can tolerate salinities from 18 – 40 psu (Rayment & Pizzola, 2008). Mathieson & Burns (1971) recorded maximum photosynthesis of *Chondrus crispus* in culture at 24 psu, but rates were comparable at 8, 16 and 32 psu. Photosynthesis continued up to 60 psu. Bird *et al.* (1979) recorded growth of Canadian *Chondrus crispus* in culture between 10 and 50 psu, with a maximum at 30 psu. The species would therefore appear to be extremely tolerant of a wide range of salinity conditions. Its occurrence in Lough Atalia extends its known salinity tolerance range. It is considered a poikilohaline species.

10. *Vaucheria* sp.

The genus *Vaucheria* belongs to the class Xanthophyceae (yellow green algae). Christensen, (1987) cultured this genus in salinities ranging from 0 – 60 psu. It is therefore considered a poikilohaline genus.

11. *Ruppia* sp.

Certain species of *Ruppia* (*R. maritima*) grow in soft sediments in sheltered shallow coastal waters from full salinity to nearly fresh water but mainly occur in brackish waters of lagoonal habitats, lochs, estuaries, creeks and pools in salt marshes, wetlands, ditches and lakes (Tyler-Walters, 2001). de Wit (2011) notes that *Ruppia* typically occurs in meso to polyhaline conditions.

12. *Cordylophora caspia*

Cordylophora caspia can survive 0 – 35 psu as resistant stages grow between 0.2 - 30 psu, reproduce between 0.2 to 20 psu and possesses the ability to ionically regulate (Kinne, 1971). In nature, well developed colonies are usually found in water of 2 -12 psu where tidal influence is considerable or between 2 - 6 psu where conditions are constant (Arndt, 1989). It is considered a poikilohaline species.

13. Nematoda

Nematodes are very common species occurring throughout the marine environment. Foster (1998) working on 4 species of intertidal nematode species demonstrated that they all have a capacity to exist in salinities ranging through 3.33, 16.6, 33.33 and 66.66 psu. Nematodes are considered as oligo – to euryhaline species.

14. *Hediste (Nereis) diversicolor*

Hediste diversicolor is a euryhaline species able to tolerate a range of salinities from full sea water down to 5 psu or less (Barnes, 1994). Low salinities (< 8 psu) can have an adverse effect on reproduction (Ozoh & Jones, 1990; Smith 1964). It is considered an oligo to euryhaline species.

15. *Polydora ciliata*

Polydora ciliata is widely distributed around Britain and Ireland. It is a euryhaline species inhabiting both fully marine and estuarine habitats. Gulliksen (1977) found that in an area of the western Baltic Sea, where bottom salinity was between 11.1 and 15 psu, *P. ciliata* was abundant. It is otherwise predominantly found in habitats with salinity range from 18 – 35 psu. Its occurrence in Lough Atalia extends its known salinity tolerance range. It is considered a meso to euryhaline species.

16. *Pygospio elegans*

Pygospio elegans is common in both marine and brackish waters especially the latter where high abundances have been found at salinities as low as 2 psu (Hempel, 1957). However, according to The Assessment of Climate Change for the Baltic Sea Basin (2008), *P. elegans* was estimated to have a lower tolerance of 7 psu. Other studies (Van Colen *et al.* 2010) have recorded *P. elegans* in salinity ranges from 16 to 27 psu in the tidal mud flats of Paulinapolder, the Netherlands. Its occurrence in Lough Atalia extends its known salinity tolerance range. It is considered as a meso to polyhaline species.

17.*Nais sp*.

Members of the genus *Nais* are usually found in low salinity or fresh water environments (Worsfield, 2003). It is considered to be an oligo to mesohaline taxon.

18. *Heterochaeta costata*

Verdonschot (1981) and Verdonschot *et al.* (1982) showed that *Heterochaeta costata* preferred shallow water brackish waters avoiding areas of usually euryhaline salinity. However, Casellato & Poja (1984) regularly recorded *H. costata* at salinities reaching up to 30 psu. It is considered as a meso to polyhaline species.

19. *Elminius modestus*

Austrominius (Elminus) modestus displays its greatest activity, measured as cirral and valve movement, when submerged in salinity concentrations close to that of the sea 33.5 psu (Davenport 1976, Foster 1970) and stops all activity outside of the range 17 – 53 psu (Foster 1970). Barnes & Barnes (1974) reported that embryos of *A. modestus* can fully develop and hatch into functioning nauplii at salinities of 21.4 – 42.8 psu at 20 °C. This compares to the salinity level, 21 psu, at which Cawthorne & Davenport (1980) found a cessation of larval release. Once released however, the larvae can survive at salinities as low as 9 psu (Cawthorne & Davenport 1980). Dassuncao (2009) showed that the larvae can survive salinities of 20 psu up to that of sea water at ~35 psu in a wide range of temperatures (~9°C -24°C). Outside of this range, *A. modestus* will most likely be able to still breed in salinities as low as 16 psu, and possibly lower if not maintained for an extended period of time. It is considered as a meso to euryhaline species.

20. *Nitokra spinipes*

N. spinipes is typically benthic and estuarine (de Sousa *et al.,* 2012) in areas with salinity varying between 0.5 and 30 psu (Wulff, 1972; Lotufo & Abessa, 2002). It is considered as a poikilohaline species.

21. Cyclopoida

Small planktonic animals of the subclass Copepoda, Cyclopoida occur in marine, brackish and freshwater environments (Boxshall *et al.* 2012). They are considered as meso to polyhaline species.

22. *Neomysis integer*

Neomysis integer can tolerate salinities from <18 – 30 psu (Budd, 2008b). *N. integer* is a euryhaline species which typically occurs in brackish water habitats and occasionally in freshwater habitats but more rarely in fully marine conditions. *N. integer* adapted successfully to the transition from brackish lagoon to freshwater lagoon in the case of Loch Mor Barvas, Isle of Lewis, Scotland (Barnes, 1994). In laboratory experiments, Kuhlman (1984) reported the lowest salinity tolerance of the species to be lower than 5 psu, and in other studies, it is suggested that *N. integer* tolerates salinities down to 0.5 psu (Koepcke & Kausch, 1996; Barnes, 1994). It is considered as a meso to polyhaline species.

23. *Praunus flexuosus*

A salinity tolerance range of 2–33 psu has been demonstrated, over which the body tissues experience the range 11–28 psu (McCluskey & Heard, 1971).It is considered as an oligo to polyhaline species.

24.*Jaera albifrons*

This species favours sheltered areas and estuarine environments. A study conducted by Jones (1972) showed that *J. albifrons* has very good survival rate in dilute seawater. It is considered as a meso to polyhaline species.

25. *Jaera nordmanni*

Jaera nordmanni was proposed as a characteristic lagoonal species for Ireland by Oliver and Healy (1998). This isopod was recorded at 24 of the 87 lagoons surveyed (27.6%) and may occur at others where it was not recorded due to the fact that only adult males are easily identified. This species may occur in freshwater, as in L. Errol, Cape Clear, Co. Cork. It has been described in England (Barnes 1994, Hayward and Ryland 1995) as occurring in streams flowing down the shoreline on south and west coasts only. All records in Ireland are from West Cork to Donegal. It is considered as an oligo to polyhaline species.

26. *Asellus sp.*

Asellus is found in rivers, streams and standing water particularly where there are plenty of stones under which it hides although not where the water is strongly acidic. *Asellus* is relatively tolerant of a range of pollutants and has been used as an indicator of water quality (Whitton, 1982).This is a freshwater to oligohaline species.

27. *Allomelita pellucida*

Allomelita pellucida is an intertidal species which can be found in brackish waters usually living as a part of interstitial or epibenthic communities of soft sediments (Hosie, 2008). It is considered as an oligo to mesohaline species.

28. *Melita palmata*

M. palmata is a common and abundant inhabitant of brackish, lagoon and estuarine environments along the European coasts of the Atlantic (Lincoln, 1979). *M. palmata* is usually observed where the influence of fresh water is stronger, for example, lagoons and river mouths due to its tolerance to a wide range of salinities (Karaman, 1982). It is considered as an oligo to mesohaline species.

29. *Gammarus duebeni*

A brackish-water species with wide salinity tolerance: found on rocky shores in pools near to high water with freshwater influence, in estuaries amongst vegetation and in freshwater streams and lakes (Bousfield, 1973). Bettison and Davenport (1976) studied salinity preferences of gammarid amphipods. They showed that *Gammarus duebeni* showed little avoidance of any particular sea water concentration. It is considered as an oligo to polyhaline species.

30. *Gammarus salinus* is a euryhaline species and is tolerant of salinities as low as 2 psu and as high as 30 psu, but it is most abundant at 10 psu. Bulnheim (1984) recorded the respiratory

response of *Gammarus salinus* in response to an acute salinity change, from 30 to 10 psu, respiration rate moderately increased after an initial shock like response and initially specimens were quiescent as they acclimated to the decreased salinity but recovered within 24 hours. It is considered as an oligo to polyhaline species.

31. *Palaemon elegans*

Yazdani *et al.* (2010) showed that more than 50% of prawns survived at 1 to 30 psu salinity range, while above and below this range, less than 50% survived within 24 hours. Salinities between 8–18 psu were found to be the optimum range for *P. elegans*. It is considered as an oligo to mesohaline species.

32. *Palaemonetes varians*

This is a decapod crustacean and is listed as a characteristic lagoonal species in the U.K. by Barnes (1989) and Bamber (1997), but apparently is no longer regarded as such (NPWS, 2012). Although found in estuaries, this species appears to be far more characteristic of lagoons in Ireland, found in 64 of the 87 lagoons surveyed (73.6%) and may require a lagoonal environment for reproduction. It is considered as an oligo to polyhaline species.

33. *Crangon crangon*

Neal (2008) and McClusky *et al*. (1982) recorded that *Crangon crangon* can tolerate salinities of 7-40 psu and can survive extremes if previously acclimated to the high or low end of its tolerance. For example, individuals acclimated to 40 psu survived 50 psu for 38 hours in comparison 16 hours by those previously acclimated to 7 psu (McClusky *et al*., 1982). Lloyd & Yonge (1947) found that *Crangon crangon* can tolerate salinities of 7-40 psu and can survive fresh water for up to 8 hours. Its occurrence in Lough Atalia extends its known salinity tolerance range It is considered as a meso to euryhaline species.

34. *Carcinus maenas*

Carcinus maenas can tolerant salinities between 4 - 40 psu (Neal & Pizzola, 2008; Crothers, 1968; Ameyaw-Akumfi & Naylor, 1987) and has a preference for 27-40 psu. It is considered as a meso to polyhaline species.

35. *Cyprideis torosa*

The ostracod *Cyprideis torosa* is a well known and characteristic inhabitant of many brackish water areas throughout Europe. It can be described as a tolerant species to salinity change. Heip (1976) investigated the community structure of *C. torosa* in a brackish water ecosystem with a salinity of 15 psu. This increased to 22 psu over time with no apparent change to the community. Its occurrence in Lough Atalia extends its known salinity tolerance range It is a meso to polyhaline species.

36. Acarina

Acarines are extremely diverse. They live in practically every habitat and include freshwater, marine and terrestrial species. Some species can tolerate moderate salinity but do not occur in highly saline waters (Harvey, 1998).They are an oligo to mesohaline species.

37. Chironomidae

The family *Chironomidae* occur in all the types of freshwater habitat (streams, rivers, lakes and ponds), many are terrestrial or semi-terrestrial and some are marine. A study conducted by Bervoets *et al.* (1996) showed that a species belonging to *Chironomidae* (*Chironomus ripariusl*) had appeared to be very tolerant to an increase in salinity. It is considered as a meso to polyhaline family.

38. Zygoptera (larvae)

There are 20 families of Zygoptera and about 2,500 species. They are found to have an aquatic larval stage. There are a few truly marine species, several that live in brackish water, and many that survive in arid regions where the larvae can develop quickly in the warm waters of temporary ponds before they dry up (Brooks, 2000). They considered as meso to polyhaline species.

39. Dytiscidae

Dysticids or diving beetles, live in fresh to oligohaline water.

40. *Peringia (Hydrobia) ulvae*

Peringia (Hydrobia) ulvae has a salinity tolerance from <18 – 40 psu (Jackson, 2000). The species is found in a wide range of salinities. Its occurrence in Lough Atalia extends its known salinity tolerance range. It is considered as a meso to polyhaline species.

41. *Ecrobia (Hydrobia) ventrosa*

This is a gastropod mollusc commonly found in brackish lagoons and ditches and generally not on the open coast (NPWS, 2012). It was recorded at 18 of the 87 (20.7%) lagoons surveyed up to 2006. de Wit (2011) states that *E. ventrosa* occurs in lower salinity waters than its congener *E. ulvae.* It is considered as an oligo to polyhaline species.

42. *Bowerbankia gracilis*

Typical habitats for this species include seagrasses, drift algae, oyster reef, dock, pilings, breakwaters, and man-made debris. *Bowerbankia gracilis* has been collected in areas of the Indian River Lagoon where salinity was below 30 psu and is generally considered to be euryhaline (Winston 1995). Nair (1992) studied the tolerance of *B. gracilis* in varying salinities where zooids exposed to the highest salinity (37.5 psu) were initially very active but the activity declined slowly, reaching a mortality rate of 40% by the end of the experiment. In 35 psu, colonies were active during the first 13 hours and at the end of the experiment the survival rate declined to 90%. In 30 and 25 psu, colonies were very active and healthy throughout the duration of the experiment, showing 100% survival. Zooids in 20 and 15 psu were active during the first few hours followed by a decline in survival rate. The mortality rate of zooids in 10 psu increased during the first hour, reaching 40% after 4 hours, with no active zooids in the colony. In 7.5 psu, the zooids were very inactive even in the initial hours and the percentage surviving after 24 hours declined to 15%. In 3.75 psu, mortality reached 90% within 30 minutes and at the end of 5th hour the specimens were found protruded with distorted tentacles.

43. *Alcyonidium gelatinosum*

Alcyonidium gelatinosum occurs commonly on the undersides of rocks and *Fucus serratus* plants in the intertidal zone and on bedrock down into the shallow sublittoral. *A. gelatinosum* has been recorded in salinities up to 29 – 32 psu (Oliver, 2005). Its occurrence in Lough Atalia extends its known salinity tolerance range. It is a polyhaline species.

44. *Chelon labrosus* (Thicklip Grey Mullet*)*

Grey mullet are often stocked in brackish coastal lagoons to improve fish yield (Ravagnan, 1992) and are introduced into freshwater lakes and reservoirs to create new fisheries (Ben Tuvia *et al.* 1992). Cardona *et al.* (2008) reported that *C. labrosus* dominated (in Mediterranean estuaries) the assemblage where salinity levels were lower than 13 psu. Hotos & Vlahos (1998) carried out experiments on *C. labrosus* fry which revealed that the fry could tolerate salinities up to 40 psu, 20% mortality occurred at 45 psu and 100% mortality above 70 psu. Therefore the range for *C. labrosus* is taken to be <13 to 40 psu. *C. labrosus* can be seen near Wolf Tone Bridge along the River Corrib. It is an oligo to euryhaline species.

45. *Platichthys flesus*

Platichthys flesus (European flounder) is usually found on muddy seabeds from the low shore to depths exceeding 50 m. The European flounder can also be found in estuaries (Pizzolla 2005). Lundgreen *et al*. (2008) studied *P. flesus* and its physiological mechanisms involved in acclimation to variable salinity and oxygen levels and their interaction. The fish were acclimated for 2 weeks to freshwater (1 psu), brackish water (11 psu) or full strength seawater (35 psu). Results showed that gill pace and blood did not change in relation to salinity and remained stable. They can be regularly seen in the River Corrib near Wolf Tone Bridge. It is considered as a meso to polyhaline species.

46. *Pomatoschistus microps* (Common Goby)

Pomatoschistus microps has been recorded in salinities as low as 4 psu (Barnes, 1994) and has been noted to tolerate salinities from about 8 to 80 psu (Riley, 2003). Its occurrence in Lough Atalia extends its known salinity tolerance range. It is an oligo to euryhaline species.

47. *Gasterosteus aculeatus* (Three-spined Stickleback)

Common in estuaries and coastal lagoons around Britain and Ireland and in fully marine conditions from the northern Irish Sea and North Sea northwards. Described as an anadromous species, *G. aculeatus* may inhabit marine or freshwater environments (Tyler-Walters 2003). It is an oligo to euryhaline species.

48. *Atherina presbyter* (Sand Smelt)

The highest abundances of *A. presbyter* recorded by Pombo *et al.* (2005) were at salinity levels of between 28.0 and 32.0 psu. It is a polyhaline species.

49. *Anguilla anguilla* (European Eel)

The species is catadromous, living in fresh water but migrates to marine waters to breed (Freyhof & Kottelat, 2010) and it is therefore tolerant of salinity levels from freshwater to euryhaline conditions.

5. Conclusions

Biological communities of coastal lagoons are derived from

1. Marine species that can tolerate dilution of seawater,
2. Freshwater species that can tolerate a measure of salinity and
3. A group of brackish water species that are “distinctly more characteristic of lagoonal habitats than of estuaries or salt marshes” (Oliver, 2005).

The latter are referred to as lagoonal specialists and are broadly equivalent to the category of species inhabiting ‘blocked brackish water’ in the Netherlands and elsewhere (Verhoeven 1980a) and the species characterising ‘brackish lentic communities’ in Denmark (Muus 1967). Perhaps ‘specialist’ is the wrong word to use as most of these species can be found in neighbouring habitats, but far less commonly so, and ‘characteristic species’ may be a more appropriate description. Lists of lagoonal specialists have been compiled in the U.K. *e.g.* Barnes 1989a; Davidson *et al*. 1991; Bamber *et al* .1992b; Smith & Laffoley 1992; Downie 1996; JNCC, 1996; Bamber *et al*. 2001b have varied in content as species have been added or deleted, depending on the opinion of various authors. Healy (2003) lists Irish characteristic lagoonal species.

According to de Wit (2011) , species which inhabit lagoons have evolved to survive wide ranging salinity levels and this author goes on to state that because of the high fluctuations in salinity, biodiversity is lower than is found in more moderately fluctuating coastal environments. Wijeratne *et al.* (2004) working in Chilaw Lagoon, west coast of Sri Lanka, note that salinities in the lagoon are strongly influenced by seasonal variations in river discharge and vary from zero to 35 psu. Newton and Mudge who worked in Portugal on the Ria Formosa recorded somewhat similar variations in salinity with a low of 13 and a maximum of 36.5 psu. Natural England (2010) in a report on UK lagoons notes that salinities can vary from 0 to 40 psu and also comments that significant variation in salinity will be the norm in coastal saline lagoons over distances of centimetres and within time spans of minutes. It appears therefore that the natural variations recorded in Lough Atalia and Renmore Lough are typical of similar systems all around the world and that such variation relates to the flow of the River Corrib, the tidal cycle and the stage of the tide.

Natural England lists a number of lagoonal specialist taxa that are protected under the UK Wildlife and Countryside Act. These are *Lamprothamnium papulosum, Cara canescens, Clavopsella navis, Edwardsia ivelli, Nematostella vectnensis, Victorella pavida, Armandia cirrhosa, Alkmaria rominjii, Gammarus insensibilis* and *Tenellia adspersa.* None of these taxa have been recorded from either Lough Atalia or Renmore Lough.

A review of species and where they occur in Lough Atalia clearly shows that the sed bed of the lough is very species poor with six of the ten sites surveyed returning no fauna and two of the remaining four only returning 1 species each. The station nearest the open sea returned 7 species. The more biologically diverse area is the intertidal zone. However, as noted in Oliver (2007), Lough Atalia is of no conservation value.

Research from a wide range of sources within this document has outlined the tolerances capable of the species found within Lough Atalia and Renmore Lough. All fauna listed have been shown to exhibit levels of resilience towards salinity change well within the temporary changes predicted by the mathematical model output. Indeed, salinities recorded in Lough Atalia extend the tolerance ranges for many taxa by quite an amount. The impact of additional temporary, seasonal decreases in salinity to 0 psu within the ecosystems will not affect their status or their ecological functioning.

6. References

Arndt, E.A., 1984. The ecological niche of *Cordylophora caspia* (Pallas, 1771). *Limnologica*, 15, 469-477.

Ameyaw-Akumfi, C. & Naylor, E., (1987). Spontaneous and induced components of salinity preference behaviour in *Carcinus maenas*. *Marine Ecology Progress Series*, 37, 153-158.

Arnold, S.L. & Ormerod, S.J. (1997). Aquatic macroinvertebrates and environmental gradients in *Phragmites* reed swamps: implications for conservation. Aquatic Conservation: Marine and Freshwater Ecosystems, 7, 153-163.

Bamber, R.N. 1997. Assessment of saline lagoons within Special Areas of Conservation. *English Nature Research Reports* No. 235.

Bamber, R.N, Gilliland, P.M. & Shardlow, M.E.A. 2001. *Saline lagoons: a guide to their management and creation*. ISBN 1 85716573 X. Peterborough, English Nature.

Barnes, H. and Barnes, M. 1974. "The responses during development of the embryos of some common cirripedes to wide changes in salinity," *J.Mar. Biol. Ecol.* 15, 197-202

Barnes, R.S.K. 1989. Coastal lagoons of Britain: an overview and conservation appraisal. *Biological Conservation* 49: 295–313.

Barnes, R.S.K. 1994. *The brackish-water fauna of northwestern Europe: a guide to brackish-water habitats, ecology and macrofauna for field workers, naturalists and students.* Cambridge University Press. 287 pp.

Bettison J.C. and Davenport J. (1976). Salinity preference in gammarid amphipods with special reference to *Marinogammarus marinus* (Leach). Journal of the Marine Biological Association of the United Kingdom, 56, pp 135-142. doi:10.1017/S002531540002049X.

Bervoets, L.; Wils, C.; Verheyen, R. 1996. Tolerance of chironomus riparius larve to salinity. Bulletin of Environmental Contamination & Toxicology;Nov96, Vol. 57 Issue 5, p829

Bird, N.L., Chen, L.C.-M. & McLachlan, J., (1979). Effects of temperature, light and salinity of growth in culture of *Chondrus crispus, Furcellaria lumbricalis, Gracilaria tikvahiae* (Gigartinales, Rhodophyta), and *Fucus serratus* (Fucales, Phaeophyta). *Botanica Marina*, 22, 521-527.

Bos A.R., Theil R. 2005. Influence of salinity on the migration of postlarval and juvenile flounder *Pleuronectes flesus* L. in a gradient experiment. Journal of Fish Biology (2006) 68, 1411–1420

Bousfield, E.L., 1973. Shallow water gammaridean Amphipoda of New England. Cornell University Press.

Boxshall, G.; Walter, T. Chad (2012). Cyclopoida. In: Walter, T.C., Boxshall, G. (2012). World Copepoda database. Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=1101 on 2013-01-31

Brooks, S. 2000. Field Guide to the Dragonflies and Damselflies of Great Britain and Ireland.

Budd G. 2002. *Gammarus salinus*. A gammarid shrimp. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3347>

Budd, G. 2008a. *Hediste diversicolor*. Ragworm. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3470>

Budd, G. 2008b. *Neomysis integer*. An opossum shrimp. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3884>

Bulnheim, H.P., (1984). Physiological responses of various *Gammarus* species to environmental stress. *Limnologica (Berlin)*, 15, 461-467.

Cawthorne, D. F. and J. Davenport. 1980. The effects of fluctuating temperature, salinity, and aerial exposure upon larval release in *Balanus balanoides* and *Elminius modestus*," *Journal of the Marine biological Association of the UK* 60: 367-377

Casellato, S. & R. Poja. 1984. Ecology of tubificids in the lower reaches of the rivers Adige and Brenta (N.E. Italy). *Bolletino di Zoologia* 51: 339-352.

Cardona, L., Hereu, B. & X. Torras. 2008. Juvenile bottlenecks and salinity shape grey mullet assemblages in Mediterranean estuaries. *Estuarine, Coastal and Shelf Science* 77: 623-632

Cheng, L. (Ed.) (1976). Marine insects. North-Holland Publishing Company: Amsterdam, The Netherlands. ISBN 0-444-11213-8. XII, 581 pp.

Christensen, T. (1987). Salinity preference of twenty species of *Vaucheria* (Tribophyceae). Journal of the Marine Biological Association of the United Kingdom, 68, pp 531-545,

Cook, P.L. & Hayward, P.J. (1966). The development of *Conopeum seurati*(Canu), and some other species of membraniporine Polyzoa. *Cah. Biol. Mar.*, **7**, 437-443.

Crothers, J.H., (1968). The biology of the shore crab *Carcinus maenas* (L.) 2. The life of the adult crab. *Field Studies*, 2, 579-614.

Dassuncao C. 2009. Temperature and Salinity Tolerances Predict Range Expansion for Two Invasive Marine Invertebrates.

Davenport, J. 1976. A comparative study of the behaviour of some balanomorph barnacles exposed to fluctuating sea water concentrations," J. Mar. Biol. Ass. UK 56: 889-907.

de Wit, R. 2011. Biodiversity of coastal lagoon ecosystems and their vulnerability to global change. In Ecosystem Ed. O.Grillo, pps – 29 – 40. Intech, Croatia.

Dow, R.A. 2010. *Ischnura elegans*. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>.

European Commission. 2007. Interpretation Manual of European Union Habitats - EUR27.

Froese, R. and D. Pauly. Editors. 2003. FishBase. World Wide Web electronic publication. www.fishbase.org

Fossit, J. A. 2000. A guide to habitats in Ireland. The Heritage Council. pp.114.

Forster, S.J. 1998, Osmotic stress tolerance and osmoregulation of intertidal and subtidal nematodes. Journal of Experimental Marine Biology and Ecology,224 :109–125.

Foster, B. A. 1970. Responses and acclimation to salinity in the adults of some balanomorph barnacles," *Phil. Trans. Of the Royal society of London* 256 (1970): 377-400.

Freyhof, J. & Kottelat, M. 2010. *Anguilla anguilla*. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 07 December 2012.

Gulliksen, B., 1977. Studies from the U.W.L. "Helgoland" on the macrobenthic fauna of rocks and boulders in Lübeck Bay (western Baltic Sea). *Helgoländer wissenschaftliche Meeresunters*, 30, 519-526.

Haghebaert, G. (1989). Coleoptera from marine habitats, *in*: Wouters, K.; Baert, L. (Ed.) (1989). *Proceedings of the Symposium "Invertebrates of Belgium".* pp. 301-308

Harvey M. S., 1998. Australian water mites. A guide to families and genera. Monographs on invertebrate taxonomy 4, 1-150. CSIRO Australia and Western Australia Museum.

Hatch, P. & Healy, B. 1998. Aquatic vegetation of Irish coastal lagoons. *Bulletin of the Irish Biogeographical Society*. 21: 2-21.

Hayward, P.J.; Ryland, J.S. (Ed.) (1990). The marine fauna of the British Isles and North-West Europe: 1. Introduction and protozoans to arthropods. Clarendon Press: Oxford, UK. ISBN 0-19-857356-1. 627 pp.

Hayward, P. J. & Ryland, J.S. (eds.) 1995. *Handbook of the Marine Fauna of North-West Europe.* Oxford University Press. PB. 899 pp.

Healy, B. 2003. Coastal Lagoons. In: *Wetlands of Ireland.* R. Otte (ed). Chapter 4. University College Dublin Press. Dublin. 44-78.

Hempel C., 1957. Uber den Rohrenbau und die Nahrungsaufnahme einiger spioniden der deutschen Ktisten. Helgoland. wiss. Meeresunters., Bd. 6, Heft. I, pp. 100-134.

Heip C. 1976. The spatial pattern of *Cyprideis torosa* (JONES, 1850) (CRUSTACEA: OSTRACODA) *J. mar. bid.* Ass. U.K. (1976) 56, 179-189

Hiscock, K. & P. Pizzolla 2007. *Ceramium virgatum*. A red seaweed. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=2922>

Hosie A. 2008. *Allomelita pellucida.* An amphipod. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological

Association of the United Kingdom. Available from <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3347>

Hotos, G. N. & Vlahos, N., (1998).Salinity tolerance of *Mugil cephalus* and *Chelon labrosus* (Pisces: Mugilidae) fry in experimental conditions. *Aquaculture*, 167:329-338.

Ingolfsson A., 1977. Distrivbution and Habitat prefences of some intertidal amphipods in Iceland. Acta Natura Islandica. 25.

Jackson, A. 2000. *Hydrobia ulvae*. Laver spire shell. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3540>

Jackson, A. 2008. *Fucus serratus*. Toothed wrack. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: http://www.marlin.ac.uk/specieshabitats.php?speciesID=3346

Johnson, G.D. & Gill, A.C. (1998). Paxton, J.R. & Eschmeyer, W.N.. ed. *Encyclopedia of Fishes*. San Diego: Academic Press. p. 192.

Jones M.B. 1972. Effects of salinity on the survival of the *Jaera albifrons* Leach group of species (crustacea: isopoda) Journal of Experimental Marine Biology and Ecology Volume 9, Issue 3, September 1972, Pages 231–237

Jorde, I. & Klavestad, N., (1963). The natural history of the Hardangerfjord. 4. The benthonic algal vegetation. *Sarsia*, 9, 1-99.

Koepcke, B. & Kausch, H., (1996). Distribution and variability in abundance of *Neomysis integer* and *Mesopodopsis slabberi* (Mysidacea; Crustacea) in relation to environmental factors in the Elbe Estuary. *Archiv fur Hydrobiologie. Supplementband. Untersuchungen des Elbe-Aestuars. Stuggart*, 110, 263-282.

Kinne, O. (ed.), 1971a. *Marine Ecology: A Comprehensive, Integrated Treatise on Life in Oceans and Coastal Waters. Vol. 1 Environmental Factors, Part 2.* Chichester: John Wiley & Sons.

Karaman G.S. 1982. Family Gammeridae. In Ruffo S (ed). The Ampipoda of the Mediterranean, Part 1. Memoires de l'Institut Oceanographique. Fondation Albert, Prince de Monaco, Monaco. 245-360.

Kuhlmann, D., (1984). Effects of temperature, salinity, oxygen and ammonia on the mortality and growth of *Neomysis integer* Leach. *Limnologica*, 15, 479-485.

Lippert H., Iken K., Rachor E., Wiencke C.,. 2001. Macrofauna associated with macroalgae in the Kongsfjord (Spitsbergen). Polar Biology July 2001, Volume 24, Issue 7, pp 512-522

Lincoln R.J. 1979. British Marine Amphipoda: Gammeridea. British Museum (National History). London, UK

Lloyd, A.J. & Yonge, C.M., (1947). The biology of *Crangon vulgaris* L. in the Bristol Channel and Severn Estuary. *Journal of the Marine Biological Association of the United Kingdom*, 26, 626-661.

Lotufo, G.R. & D.M.S. Abessa. 2002. 2002, Testes de toxicidade com sedimento total e água intersticial estuarinos utilizando copépodos bentônicos. *In*: I. A. Nascimento, E. C. P. M. Sousa & M. G. Nipper, (eds.). *Métodos em ecotoxicologia marinha: aplicações no Brasil*. São Paulo: Artes Gráficas. p.151-162.

Lundgreen K. Kiilerich P. Tipsmark C.K. Madsen S.S. Jensen F.B. 2008. Physiological response in the European flounder (*Platichthys flesus*) to variable salinity and oxygen conditions. J Comp Physiol B. 2008 178(7):909-15.

Macan T.T., 1954a. A contribution to the study of the ecology of Corixidae (Hemipt). *J. Anim. Ecol.* 23. 155-141.

Martins, I., Oliveira, J. M., Flindt, M. R. & Marques, J. C. 1999 The effect of salinity on the growth rate of the macroalgae *Enteromorpha intestinalis* (Chlorophyta) in the Mondego estuary (west Portugal). *Acta Oecologica* 20, 259–265.

Mathieson, A.C. & Burns, R.L., 1975. Ecological studies of economic red algae. 5. Growth and reproduction of natural and harvested populations of *Chondrus crispus* Stackhouse in New Hampshire. *Journal of Experimental Marine Biology and Ecology*, 17, 137-156.

Mc Cluskey, D.S. & V. E. J. Heard. 1971. Some effects of salinity on the mysid *Praunus flexuosus*. *Journal of the Marine Biological Association of the United Kingdom* 51(3): 709-715.

Millar, J., Pietrafesa, L. and Smith, N. 1990. Principals of hydraulic management of coastal lagoons for aquaculture and fisheries. FAO technical paper no. 314. Rome.

Natural England. 2010. Coastal saline lagoons and the Water Framework Directive. Report NECR039.

Naylor, E., 1972. British Marine Isopods. Synopses of the British Fauna (NS), 3.

Neal ,K. and Avant, P., 2006. *Corophium volutator*. A mud shrimp. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 20/02/2013]. Available from: <http://www.marlin.ac.uk/speciesinformation.php?speciesID=3052>

Neal, K. & P. Pizzolla. 2008. *Carcinus maenas*. Common shore crab. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=2885>

Neal, K. 2008. *Crangon crangon*. Brown shrimp. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3078>

Newton, A. and Mudge, S. 2002. Temperature and salinity regimes in a shallow mesotidal lagoon, the Ria Formosa, Portugal. Estuarine Coastal and Shelf Science. 56 : 1 – 13.

NPWS (2011) Conservation objectives for Galway Bay Complex SAC [000268]. Generic Version 3.0. Department of Arts, Heritage & the Gaeltacht.

NPWS. 2012. Lower River Shannon SAC (site code 2165) Conservation objectives supporting document- Lagoons Version 1.

Nair R., Krishnamurthy K., Mawatari S.F. 1992. Salinity tolerance in four estuarine species of Bryozoa. Marine fouling; ISSN:0388-3531; VOL.9; PAGE.15-20.

Oliver, G.A. and Healy, B. 1998 Records of aquatic fauna from coastal lagoons in Ireland. *Bulletin of the Irish Biogeographical Society*. 21: 66-115Roden, C. 1999. *Irish coastal lagoon survey, 1998. Vol. III, Flora.* Dúchas, Dublin.

Oliver, G. 2005. *Seasonal changes and Biological Classification of Irish Coastal Lagoons.* PhD Thesis. U.C.D., Dublin. Available on www.irishlagoons.com

Oliver, G. 2007. Inventory of Irish coastal lagoons (version 2). Unpublished report to the National Parks and Wildlife Service.

Ozoh, P. T. E. and N. V. Jones. 1990. Capacity adaptation of *Hediste (Nereis) diversicolor* embryogenesis to salinity, temperature and copper. Marine Environmental Research 29: 227-243.

Pizzolla P. 2005. *Platichthys flesus*. Flounder. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 01/02/2013]. Available from <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3347>

Pombo, L., Elliott, M. & J.E. Rebelo. 2005. Ecology, age and growth of *Atherina boyeri* and *Atherina presbyter* in the Ria de Aveiro, Portugal. *Cybium* 29(1): 47-55.

Rayment, W. & P. Pizzola. 2008. *Chondrus crispus*. Carrageen. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=2971>

Richard S., Barnes K.1994. The Brackish-Water Fauna of Northwestern Europe. Cambridge University Press. Cambridge, UK

Riley K. 2003. *Pomatoschistus microps*. Common goby. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 05/02/2013]. Available from: <http://www.marlin.ac.uk/speciessensitivity.php?speciesID=4181>

Smith, J.E., (1964). On the early development of *Nereis diversicolor* in different salinities. *Journal of Morphology*, 114, 437-464.

Sotillo, A., Mensens, C., Kapasakali, D., Maugeri, G., Araújo, G., Gordon, J.C., Hubner, K., Berreto, M. and Mercado-Ortiz, M. 2011. An approach to habitat mapping of Lough Atalia. GMIT Summer School project.

Sousa de, E.C.P.M., Zaroni, L.P., Bergmann Filho, T.U., Marconato, L.A., Kirschbaum, A.A. & M.R. Gasparro. 2012. Acute sensitivity to *Nitokra* sp benthic copepod to potassium dichromate and ammonia chloride. *J. Braz. Soc. Ecotoxicol* 7(1): 75-81.

Suryono, C.A. & Hardy, F.G., 1997. Studies on the distribution of *Fucus ceranoides* L. (Phaeophyta, Fucales) in estuaries on the north-east coast of England. *Transactions of the Natural History Society of Northumbria*, 57, 153-168.

Taylor, R., Fletcher, R.L. & J. A. Ravena. 2001. Preliminary Studies on the Growth of Selected 'Green Tide' Algae in Laboratory Culture: Effects of Irradiance, Temperature, Salinity and Nutrients on Growth Rate. *Botanica Marina* 44: 327-336.

Tasende, M.G. & Fraga, M.I., (1999). The growth of *Chondrus crispus* Stackhouse (Rhodophyta, Gigartinaceae) in laboratory culture. *Ophelia*, 51, 203-213.

Tyler-Walters H. 2001. *Ruppia maritima*. Beaked tasselweed. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/02/2013]. Available from: <http://www.marlin.ac.uk/speciesinformation.php?speciesID=4272>

Tyler-Walters H. 2003. *Gasterosteus aculeatus*. Three-spined stickleback. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 01/02/2013]. Available From <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3347>

Tyler-Walters H. 2008. *Arenicola marina*. Blow lug. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 20/02/2013]. Available from <http://www.marlin.ac.uk/speciesbenchmarks.php?speciesID=2592>

Van Colen C., F. Montserrat,B.C. M. Vincx, P.M.J. Herman b, T. Ysebaert b,d, S. Degraer a,e. 2010. Long-term divergent tidal flat benthic community recovery following hypoxia-induced mortality. Marine Pollution Bulletin 60 (2010) 178–186.

Verdonschot, P.F.M. 1981. Some notes on the ecology of aquatic oligochaetes in the Delta Region of the Netherlands. *Archiv fur Hydrobiologie* 92 (1): 53-70.

Verdonschot, P.F.M., Smies, M. & A.B.J. Sepers. 1982. The distribution of aquatic oligochaetes in brackish inland waters in the SW Netherlands. *Hydrobiologia* 89(1): 29-38.

Wallace, C. 1985. On the distribution of the sexes of *Potamopyrgus jenkinsi* (Smith). *Journal of Molluscan Studies*, *51*: 290-296.

White, N. 2008a. *Fucus spiralis*. Spiral wrack. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3347>

White, N. 2008b. *Fucus vesiculosus*. Bladder wrack. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3348>

White, N. 2008c. *Pelvetia canaliculata*. Channelled wrack. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=4064>

Whitton B.A. 1982. *Rivers, Lakes and Marshes*. London: Hodder & Stoughton. pp. 131.

Wijatne, E., Rydberg, L. and Pathirana, K. 200. Modelling of sea levels, water exchange and dispersion in an intermittently closed tidal estuary: Chilaw Lagoon, west coast of SriLanka. Proc. 10th. Aisan Congress of Fluid Mechanics.

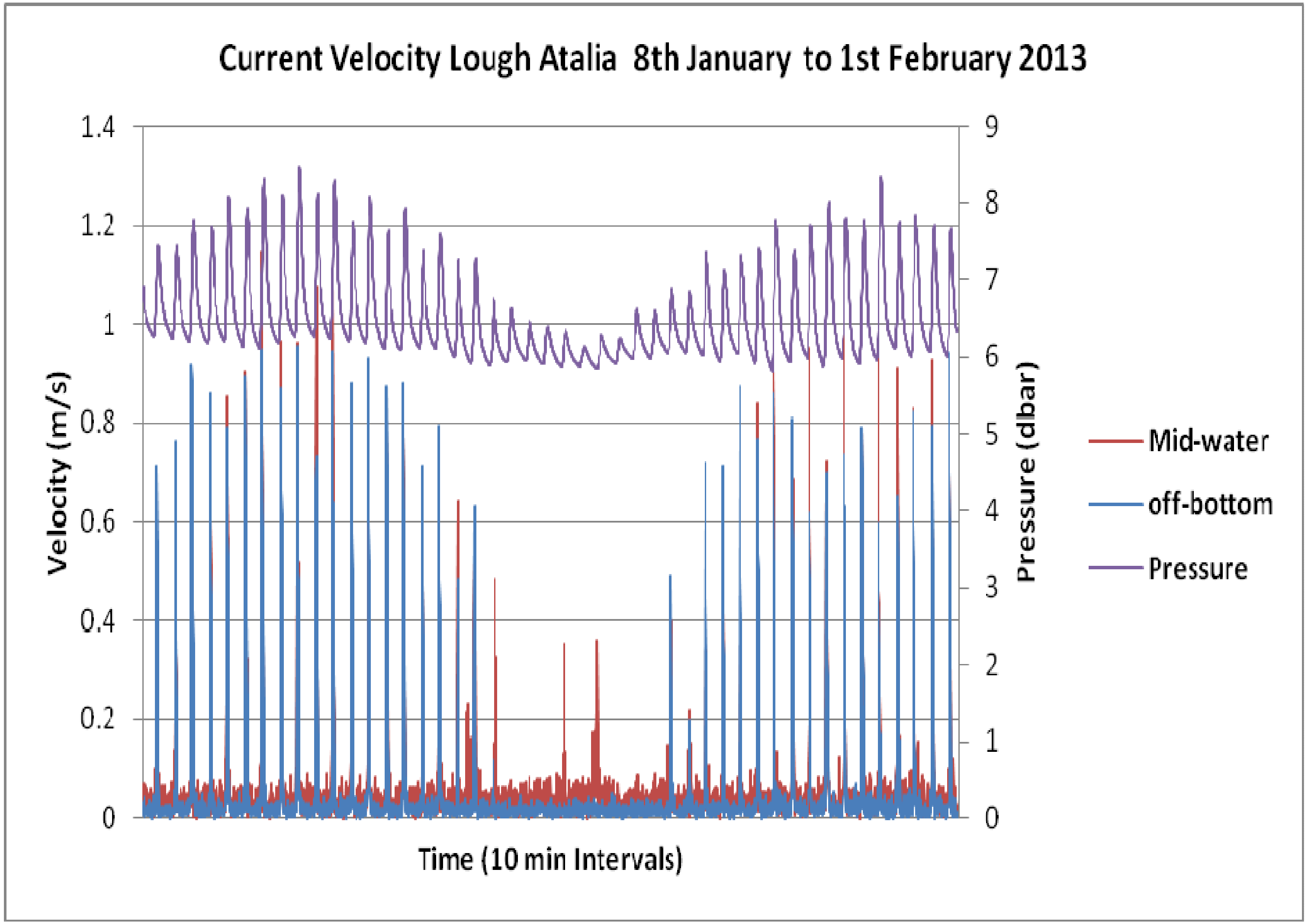
Worsfield T. 2003. Introduction to oligochaetes. NMBAQC Workshop.

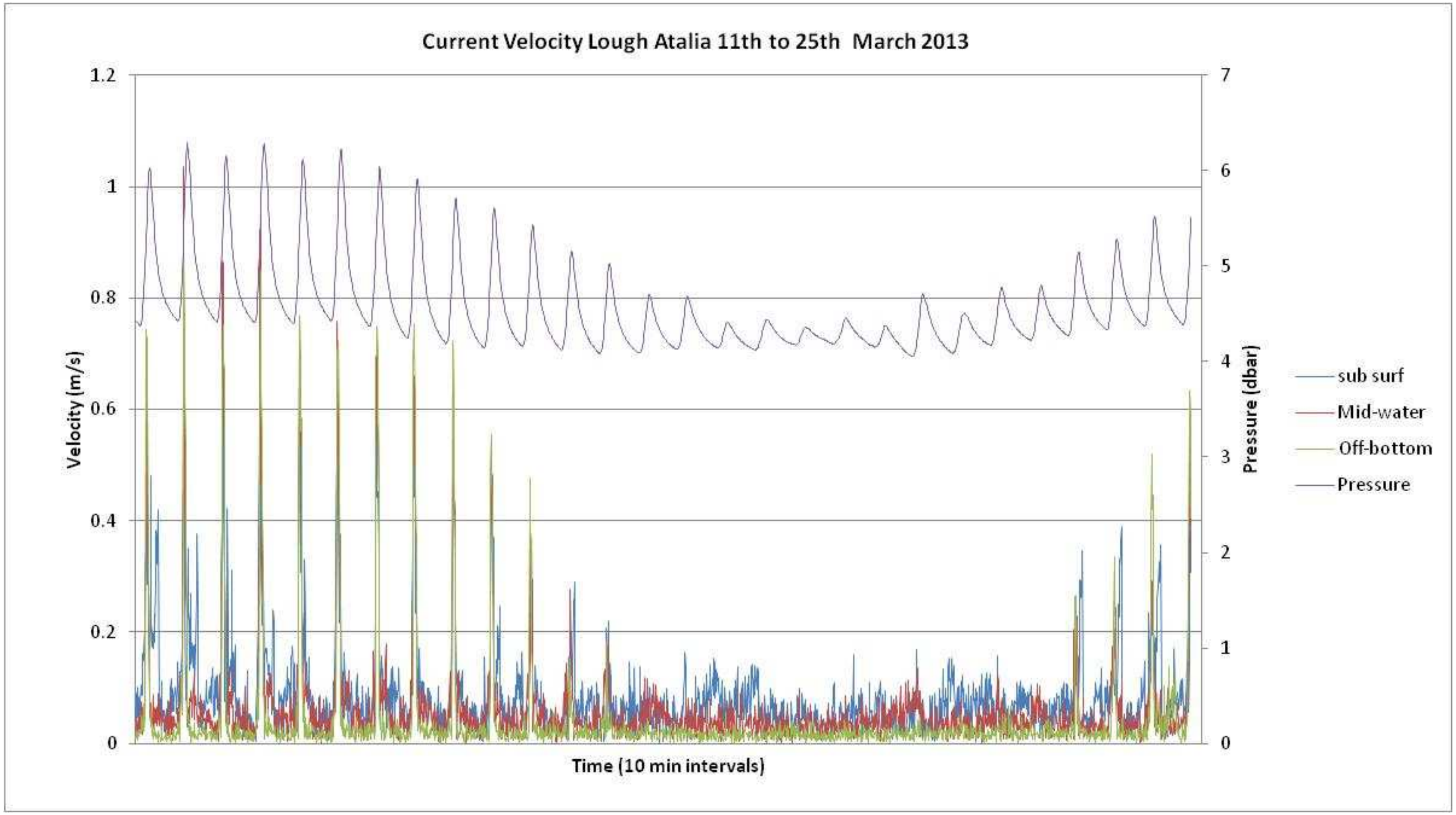
Wulff, F. 1972. Experimental studies on physiological and behavioural response mechanisms of *Nitokra spinipes* from brackish water rock pools. Marine Biology, 13: 325 – 329.

Yazdani' M., Taheri' M. & J. Seyfabadi. 2010. Effect of different salinities on survival and growth of prawn, *Palaemon elegans* (Palaemonidae). *Journal of the Marine Biological Association of the United Kingdom* 90 (2): 255-259.

Appendix I

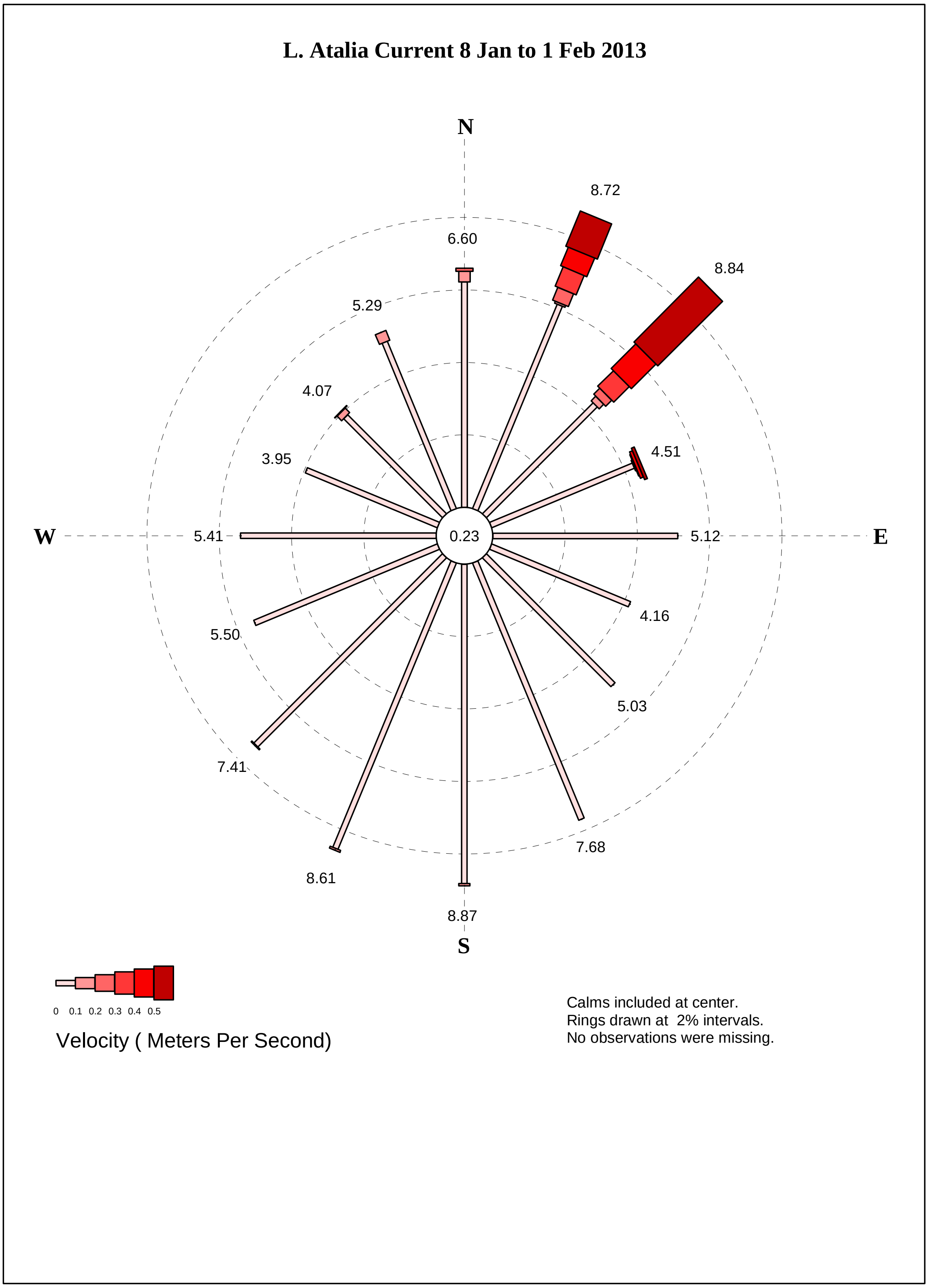
Current speed and direction data collected in Lough Atalia.


Current Velocity Lough Atalia 8th January to 1st February 2013
Velocity (m/s)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Pressure (dbar)
9
8
7
6
5
4
3
2
1
0
Time (10 min Intervals)
Mid-water
off-bottom
Pressure



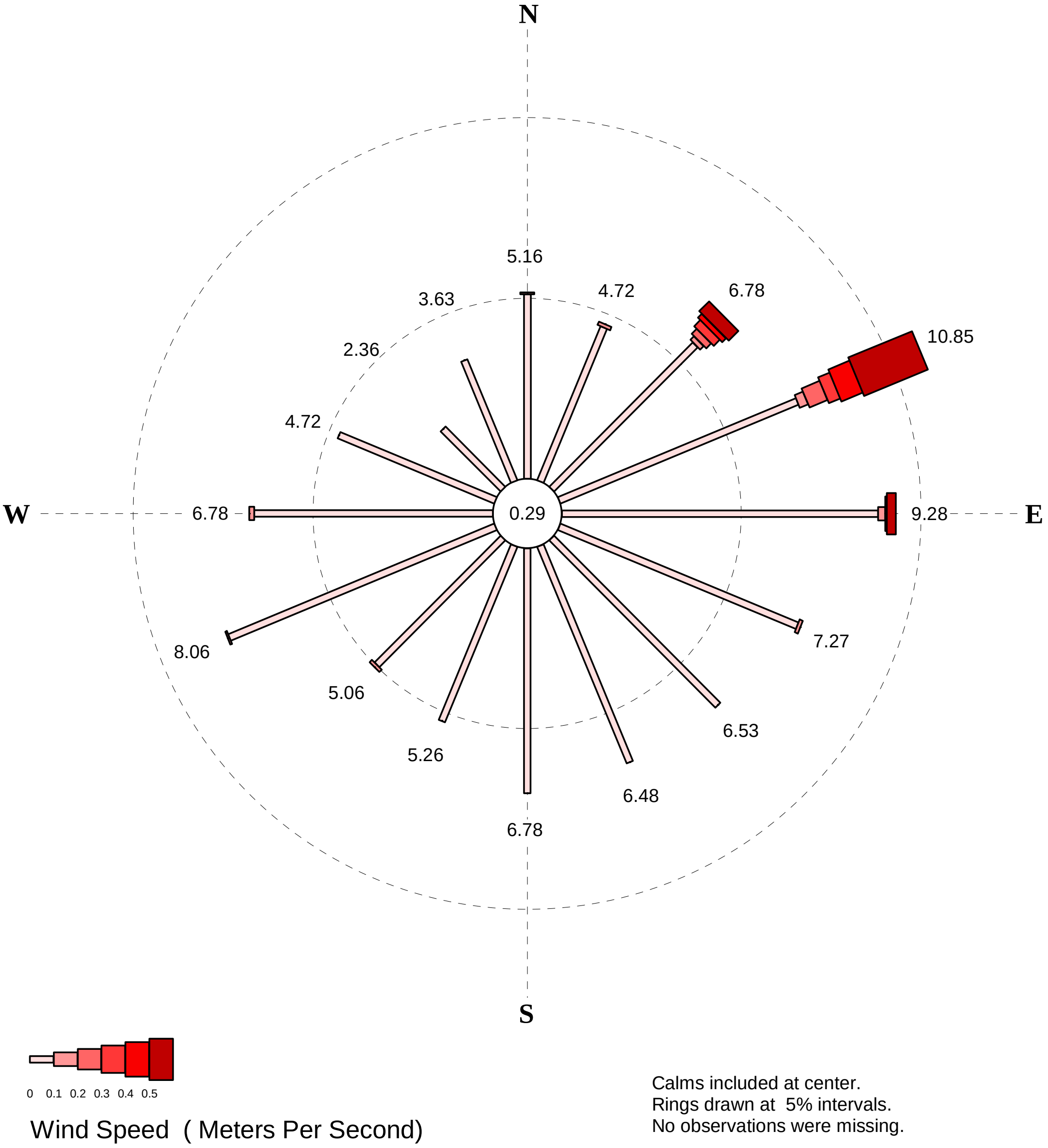
Current Velocity Lough Atalia 11th to 25th March 2013
Velocity (m/s)
Pressure (dbar)
Time (10 min intervals)
1.2
1
0.8
0.6
0.4
0.2
0
7
6
5
4
3
2
1
0
sub surf
Mid-water
Off-bottom
Pressure

.



L. Atalia Current 8 Jan to 1 Feb 2013
N
E
S
W
8.72
8.84
6.60
5.29
4.07
3.95
4.51
5.41
0.23
5.12
5.50
4.16
5.03
7.41
7.68
8.61
8.87
0
0.1
0.2
0.3
0.4
0.5
Velocity (Meters Per Second)
Calms included at center.
Rings drawn at 2% intervals.
No observations were missing.

JL. Atalia Current 11 to 25 March 2013



Calms included at center.
Rings drawn at 5% intervals.
No observations were missing.

Appendix II

Salinity results from 21 locations in Lough Atalia on a selection of dates

The first survey was carried out in the two hours preceding high tide, three days prior to a Spring tide. As can be seen in Figure 1, the lowest salinity of 8.1 psu occurs at the surface of Station 21 at the north-eastern head of the lough. This is in contrast to the surface salinities generally at this end of the lough which are around 10 psu higher. Station 21 excluded, the lower surface salinities tend to occur near the mouth of the lough. The highest salinity of 21.4 psu occurred at the deepest point of Station 8, towards the deeper south-western part at the mouth. The highest surface salinity of 19.7 psu occurred at Station 11. The greatest difference of salinity with depth occurs in Stations 2, 4, 5 and 21, all of which occur in the high flow mouth area with the exception of Station 21. Conversely, the most continuity of salinity with depth occurs at Station 16 to 20 towards the low flow northern end with the exception of Station 1 at the southern end. In the majority of the stations there is a gradual increase in salinity with depth.

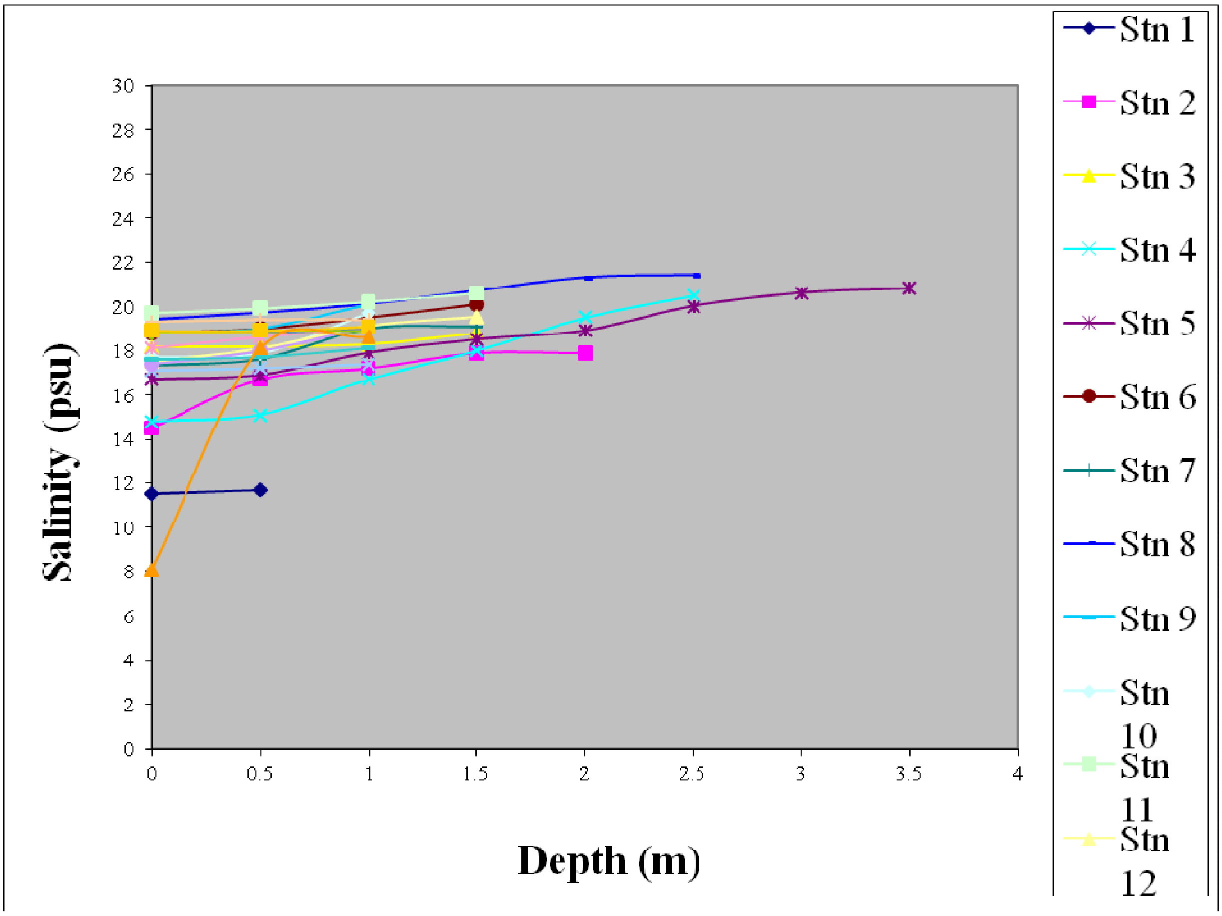


Figure 1: Salinity profiles of Lough Atalia 04/04/2012

The second survey was carried out on an ebbing tide, from approximately two to three hours after high water, on a falling spring tide (four days after a full moon). As can be seen in Figure 2, the lowest salinity was 20.5 psu in the surface waters of Station 12 while the greatest was 27.1 psu at 5.5m at Station 5. The highest salinities were recorded at the depth. This survey showed greater minimum and maximum salinities compared to the first survey. While there is also greater depth of water in survey two compared to survey one, this occurring at the deeper southerly end, the northerly end is also shallower, Stations 19 and 21 only having a depth of 0.5m. The greatest surface salinity of 24.3 occurred at Station 15. Salinity can be seen to increase with depth, however this is not as gradual as in the first survey. There is a rapid increase in salinity between 0.5 and 1m.

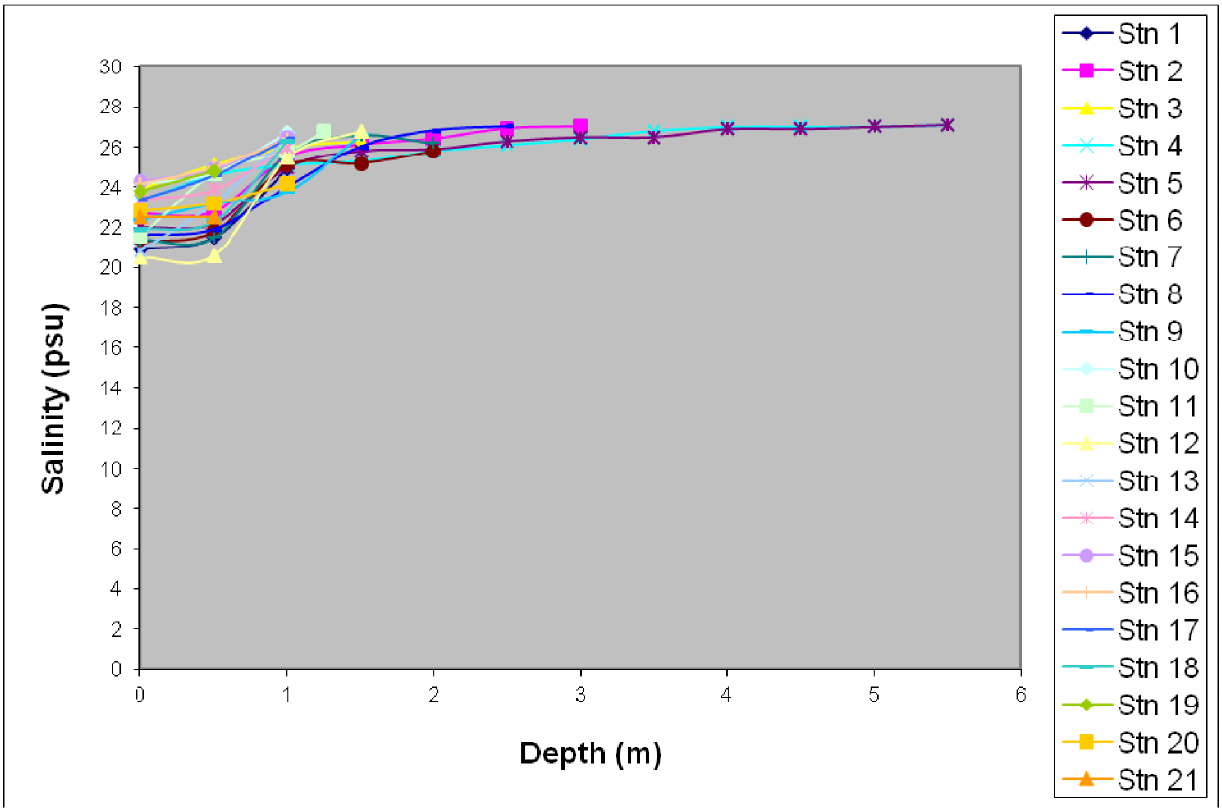


Figure 2: Salinity profiles of Lough Atalia 10/04/2012

The third survey was carried out approximately three-quarters of an hour either side of high tide, occurring two days after the peak of a neap tide. The wind was a 8-10 knots from a south-south-east direction. As can be seen in Figure 3, the salinity range was 7.5 to 23.2 psu. The former occurred at the surface of stations 2 and 10 the latter again at the deepest point of station 5. 7 psu is the lowest salinity of the first three surveys. The deepest stations with the highest salinity are Stations 2, 5, 6 and 8, all at the southern end. The highest salinity in surface waters of 12.2 psu occurred at Station 18. There is less discontinuity in the gradual increase of salinity with depth, in survey 3 than survey 2. This occurs from 1 to 2m as seen at Stations 2, 8 and 9.

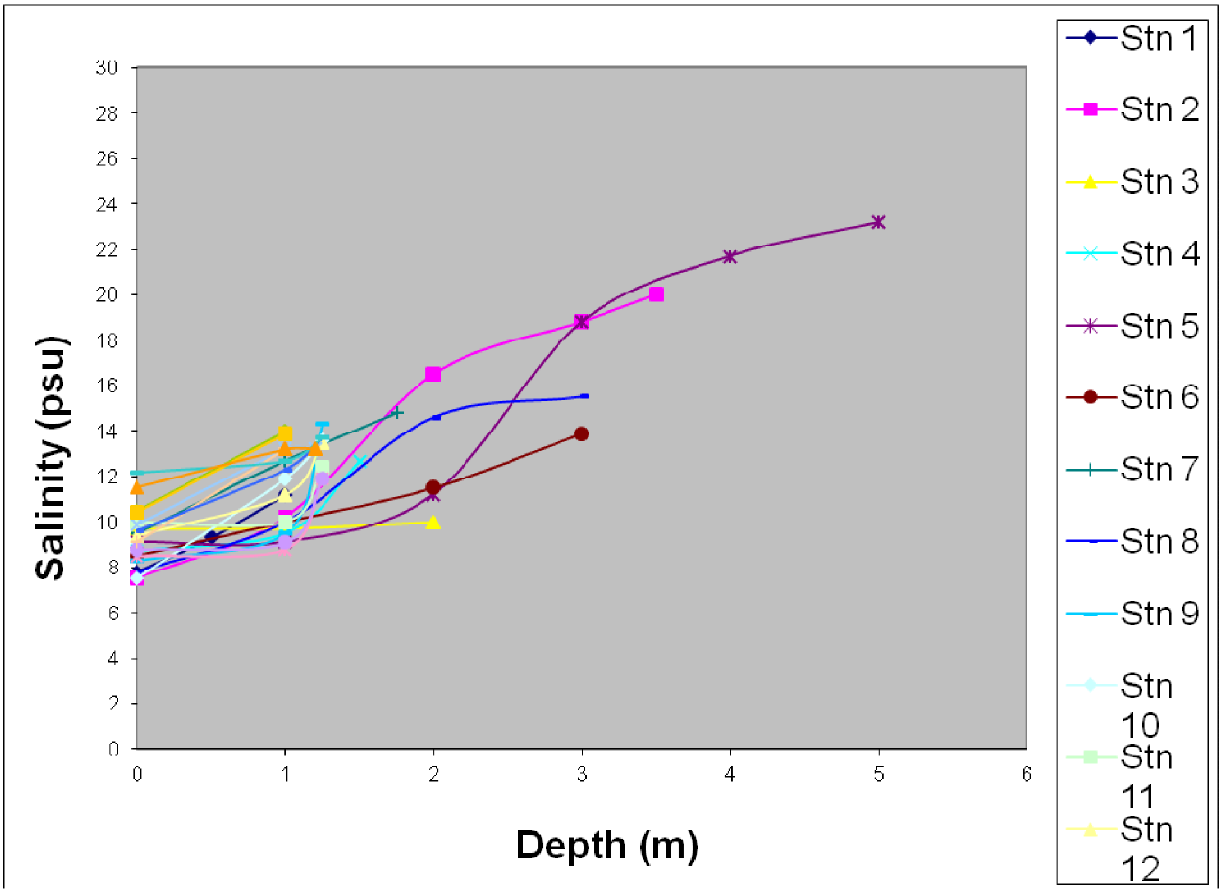


Figure 3: Salinity profiles of Lough Atalia 16/04/2012

The fourth survey was carried out approximately 15 minutes before low tide to 40 minutes after tide, two days before the peak of a spring tide. As can be seen in Figure 4, the lowest salinity of 15.6 psu occurred at the surface of Station 7, while the highest salinity of 23.9 psu occurred again at the deepest point at Station 5. The highest salinity of surface waters of 22.3psu occurred at Station 16 towards the northern end of the lough where the surface salinities generally seem to be higher than those in the southern region. There is more uniformity of salinity with depth to be seen in survey 4 compared to surveys 2 and 3. However, while similar to survey 1, in survey 4 there is also slightly more discontinuity occurring in Stations 6, 7 and 12.

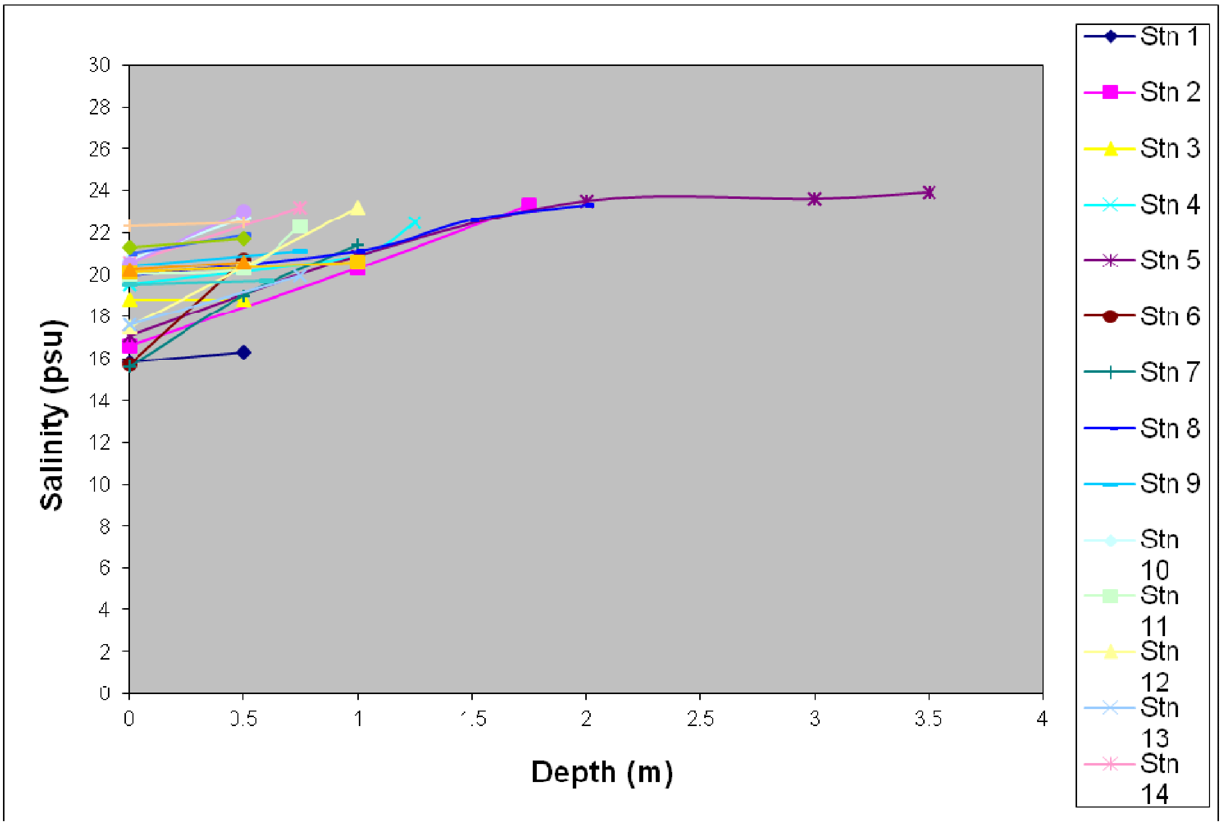


Figure 4: Salinity profiles of Lough Atalia 19/04/2012.

The fifth survey took place during 1.5 hours directly after low water, two days before the peak of a spring tide. This survey showed the lowest salinity range of 25.7 to 29.4 psu, located at the surface waters of Station 1 and the deepest point of Station 5 respectively. The highest surface salinity of 28.8 psu also occurred at Station 16, as seen in survey 4, which was the only other survey taken around low water. There is some evidence of continuous and discontinuous salinity with depth occurring in survey 5. Of the stations greater than 1m, namely Stations 2, 4, 5, 6 and 8 the most rapid increase in salinity occurs from 1 to 2m.

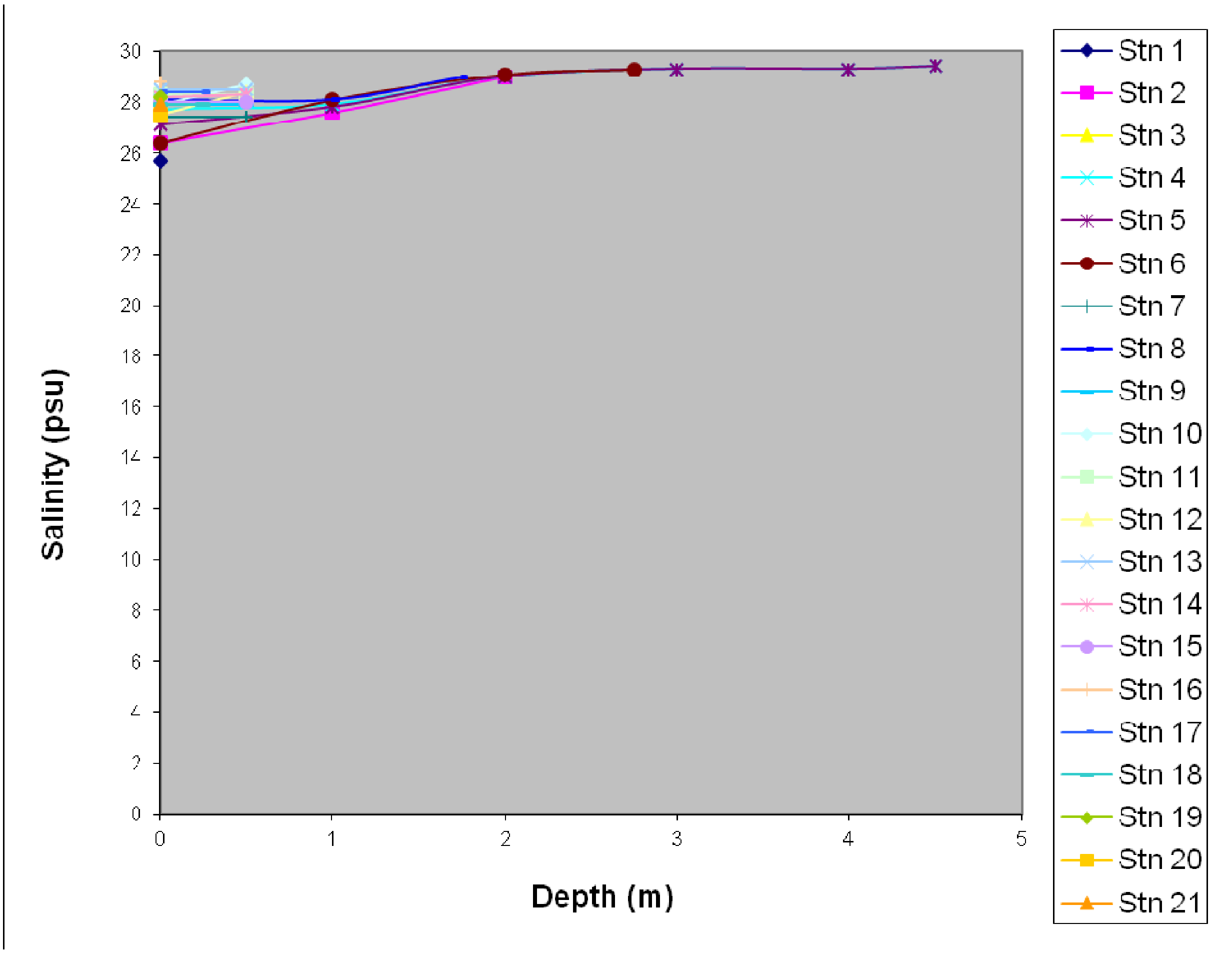


Figure 5: Salinity profiles of Lough Atalia 04/05/2012

Discussion

Salinity

The lowest salinity of 8.1 psu at Station 21 measured during survey 1 contrasts to the otherwise relatively high salinities found at the northern end of the lough during this survey. This is possibly due to a storm drain which enters at this end of the lough. With the exception of this station, the lowest surface salinities in survey 1 tended to occur at stations close to the lough mouth. Taking into account that the tide was still rising, this would suggest that water from the river Corrib is being pushed into Lough Atalia by the rising tide. Entrance of the denser, more saline water into the lough however, may be obstructed somewhat by the sill at the mouth.

Comparing survey 1 and 2, which were flooding and ebbing tides respectively, the latter had both the greater depth near the mouth and the shallowest areas at the opposite end. This shows that areas further away from the mouth, towards the northern end feel the effects of tidal change before areas around the mouth. There is a greater discontinuity of salinity with depth in survey 2 compared to survey 1, increasing the stratification within the lagoon. This is possibly due to a mixing affect that the incoming tide had on the lough and as in survey 2, which had been ebbing for 2-3 hours. This mixing affect was diminished, allowing strata to develop. However, a stronger 14-16 knots wind from the North during survey 1, may have contributed more to mixing than the weaker winds of 6-8 knots from a west-south-west direction during survey 2. Survey 2 had a relatively small salinity range of 20.5 to 27.1 psu.

The greater salinity range in survey 3 compared to survey 2 can be accounted by the tidal state. High water occurred during approximately half way through the survey and hence the freshwater did not have as much time to exit the lough over the sill before the salinities were measured. The lowest salinity of the five surveys was recorded at Station 2 during the third survey. This again can be accounted for by the tidal state as high water occurred during the survey and so water, a lot of which is freshwater from the River Corrib being pushed in by the rising tide, has being entering the lough for the maximum period of time, without having a lot of time to exit with the falling tide. There is more stratification in survey 3 than in survey 1 but less than in survey 2. This could be due to the mixing effect of the incoming tide ceasing when the tide started to ebb and that the strata seen to be more pronounced during survey 2 are starting to form. The wind during survey 3 was slightly stronger than during survey 2, but not as strong as survey 1. Partial mixing by this method cannot be ruled out.

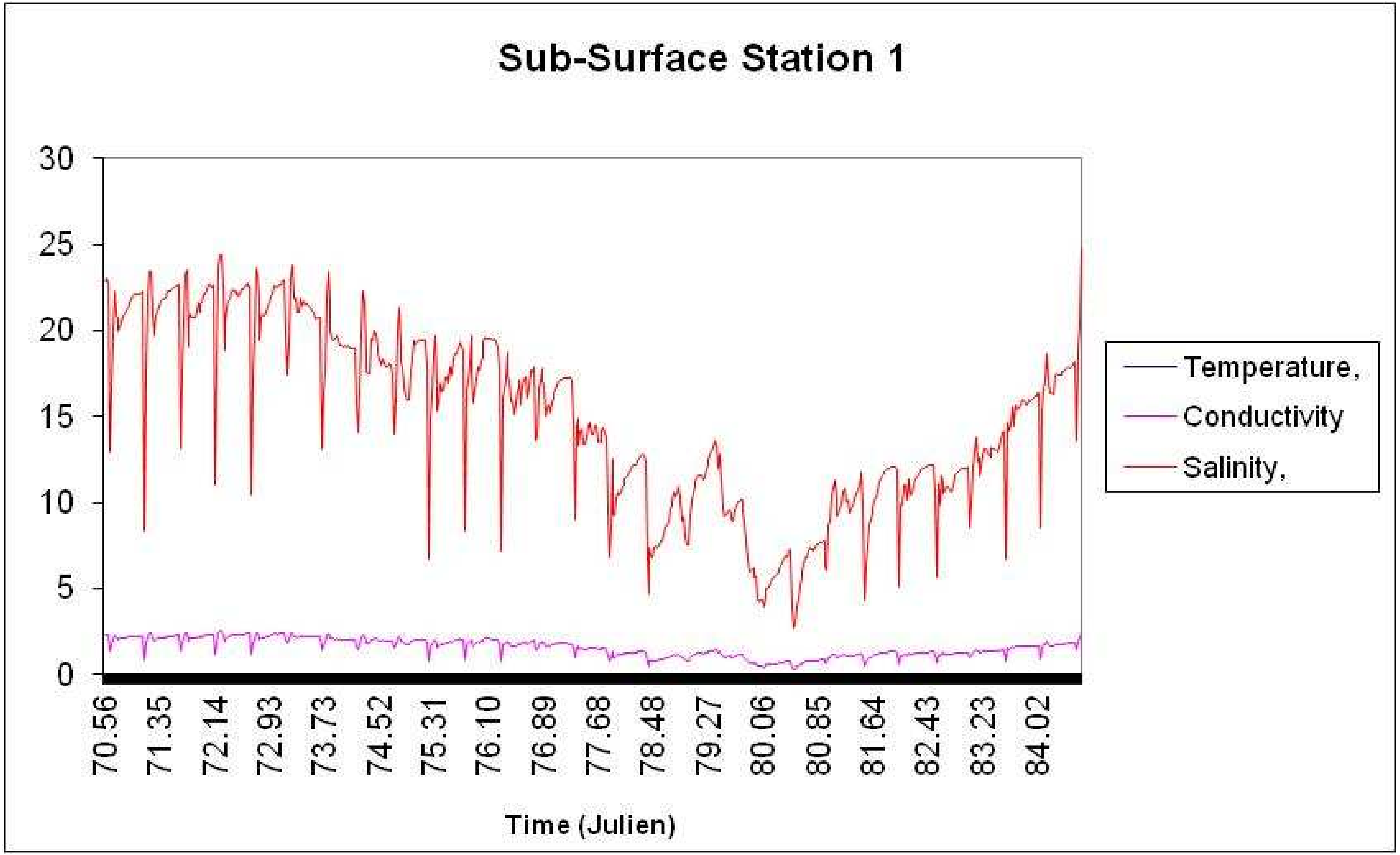
In survey 4, salinities are generally higher towards the head of the lough. This maybe explained by the tidal state. Less dense freshwater was returning back into the lough on the rising tide for approximately an hour, hence lowering the salinity at the mouth. However, not enough time after low tide had passed, when the survey occurred, to effect waters at the head of the lough. There is a mixture of continuity and discontinuity of salinity with depth in survey 4. This may be due to the fact that the spring tide had been flooding for an hour and so the strata were beginning to break down.

As in survey 4 there is a mixture of continuous and discontinuous salinities with depth seen in survey 5. The tidal state during survey 5 was similar to that during survey 4 in that they were carried out mainly after a spring low tide, with survey 4 ending 50 minutes after low water and survey 5 ending 1.5 hours after a low tide. So as with survey 4, it may be the a case that strata developed in the lough while the tide was ebbing and then with the returning tide these strata were becoming broken down due to mixing affects caused by the influx of water into the loug. At the stations were there is a more discontinuous increase in salinity with depth, the rate of change of salinity with depth is less however in survey 5 compared to survey 4. This may be because survey 5 ended longer after low water than survey 4 and hence more mixing occurred and strata were further broken down. Survey 5 showed the least salinity range, even when compared to survey 4. This may reinforce the fact that more mixing had occurred due to the extra time after low water.

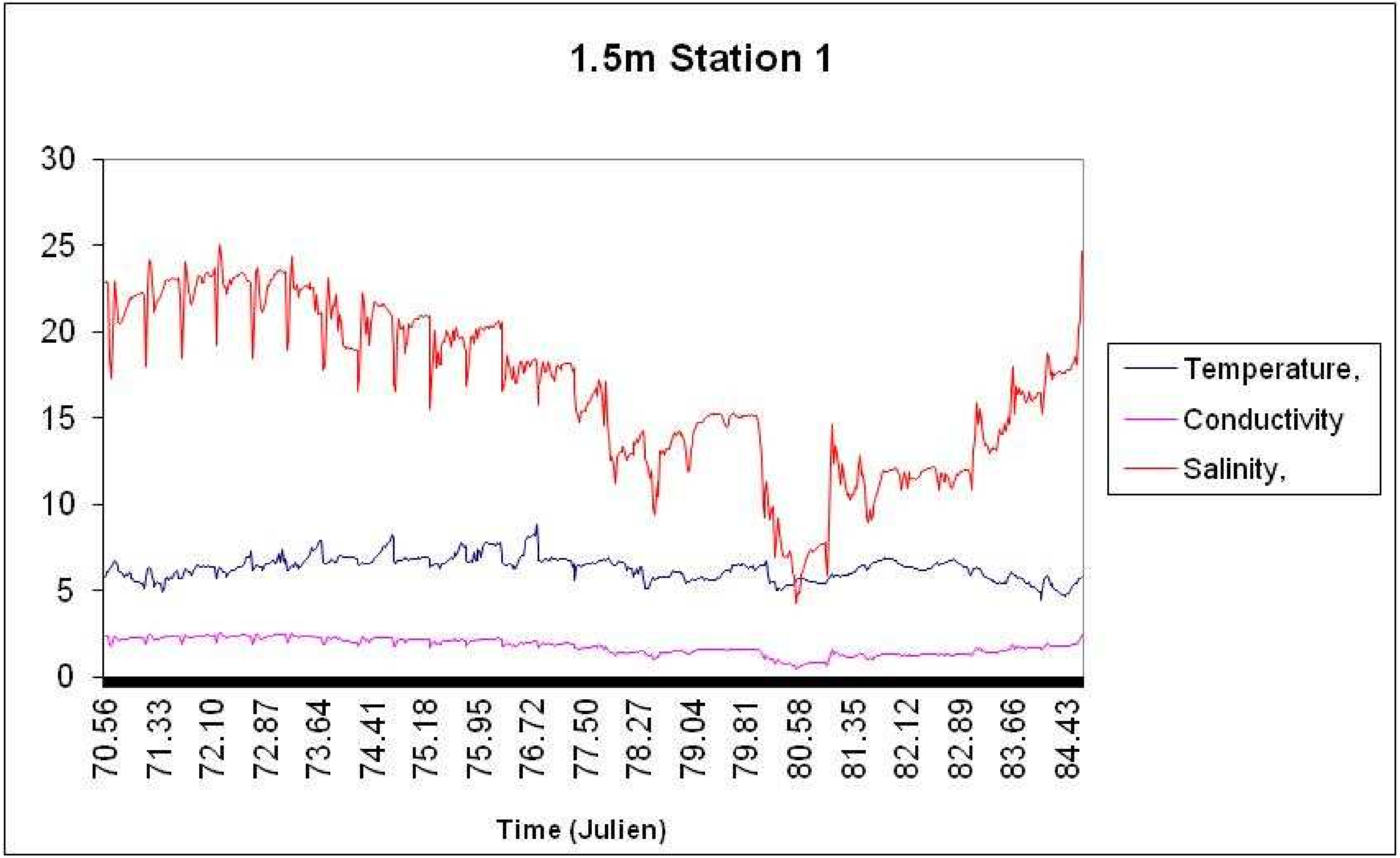
Appendix III

Salinity graphs collected by meters, March 2013.

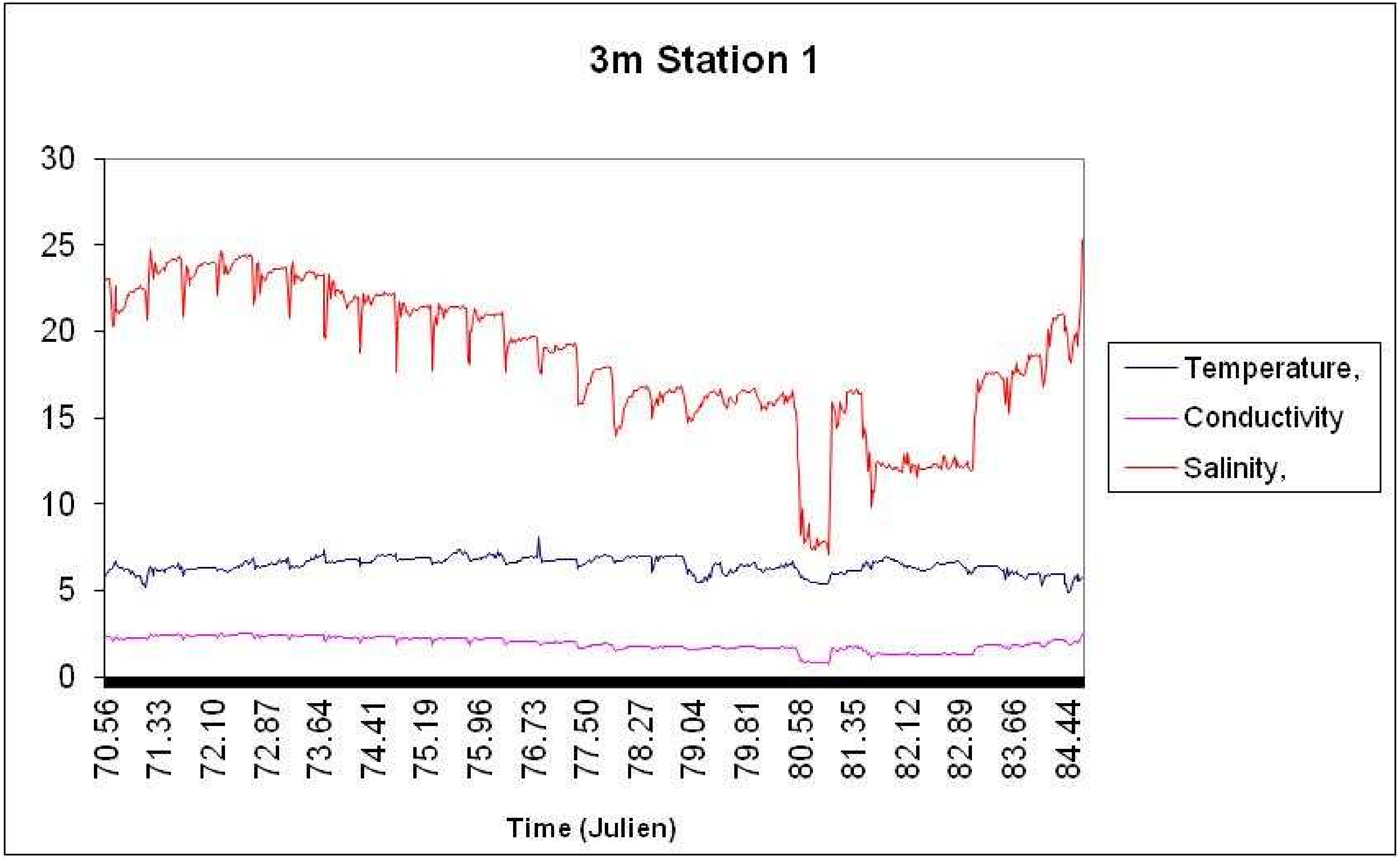
N.B. Julian Day 1 = January 1st.

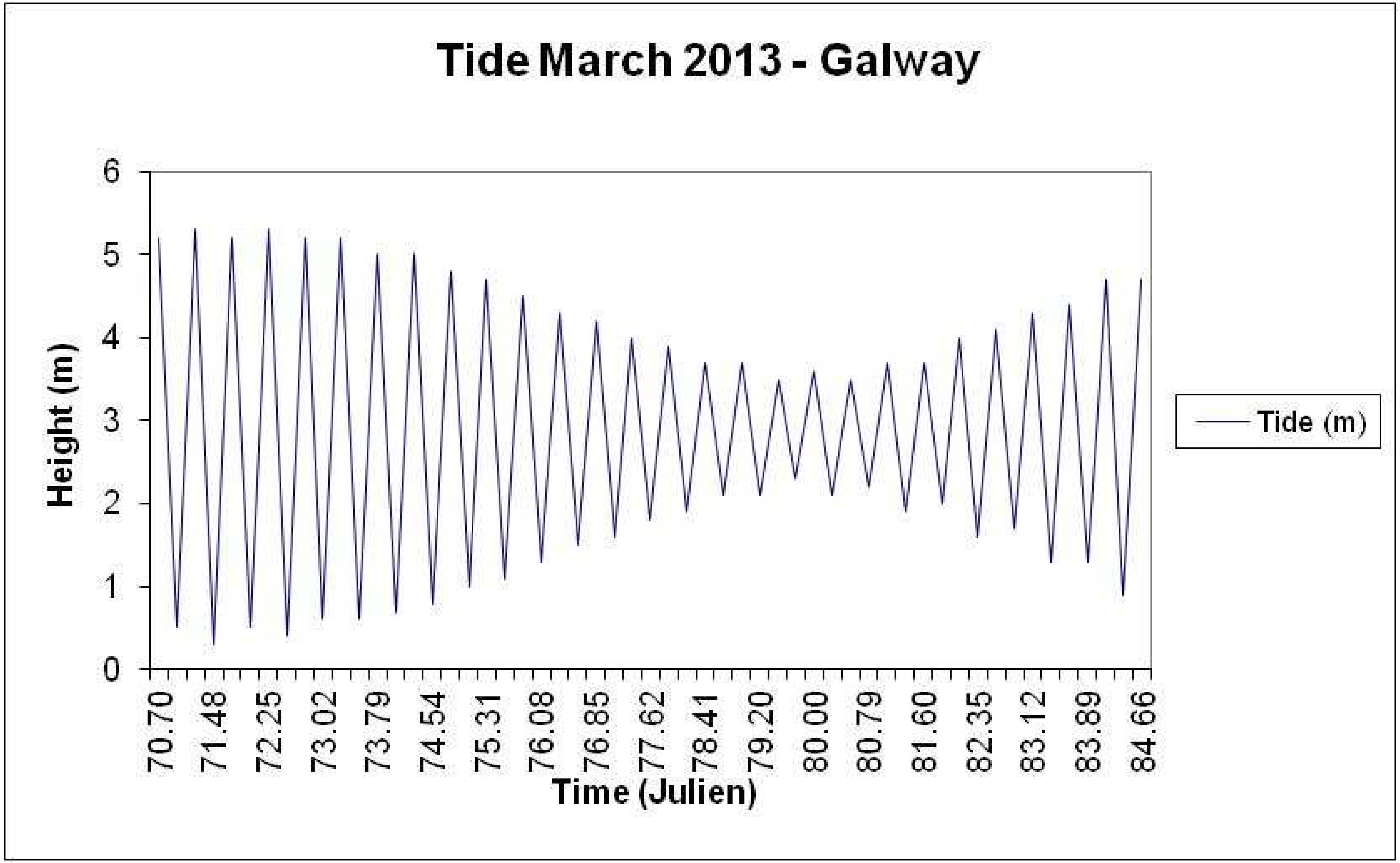


Sub-Surface Station 1
30
25
20
15
10
5
0
70.56
71.35
72.14
72.93
73.73
74.52
75.31
76.10
76.89
77.68
78.48
79.27
80.06
80.85
81.64
82.43
83.23
84.02
Time (Julien)
Temperature,
Conductivity
Salinity,



1.5m Station 1
30
25
20
15
10
5
0
70.56
71.33
72.10
72.87
73.64
74.41
75.18
75.95
76.72
77.50
78.27
79.04
79.81
80.58
81.35
82.12
82.89
83.66
84.43
Time (Julien)
Temperature,
Conductivity
Salinity,


3m Station 1
30
25
20
15
10
5
0
70.56
71.33
72.10
72.87
73.64
74.41
75.19
75.96
76.73
77.50
78.27
79.04
79.81
80.58
81.35
82.12
82.89
83.66
84.44
Time (Julien)
Temperature,
Conductivity
Salinity,


Tide March 2013 - Galway
Height (m)
0
1
2
3
4
5
6
70.70
71.48
72.25
73.02
73.79
74.54
75.31
76.08
76.85
77.62
78.41
79.20
80.00
80.79
81.60
82.35
83.12
83.89
84.66
Time (Julien)
Tide (m)

Appendix IV Mathematical model study

Research from a wide range of sources within this document has outlined the tolerances capable of the species found within Lough Atalia and Renmore Lough. All fauna listed have been shown to exhibit levels of resilience towards salinity change well within the temporary changes predicted by the mathematical model output. Indeed, salinities recorded in Lough Atalia extend the tolerance ranges for many taxa by quite an amount. The impact of additional temporary, seasonal decreases in salinity to 0 psu within the ecosystems will not affect their status or their ecological functioning.

1. References

Arndt, E.A., 1984. The ecological niche of *Cordylophora caspia* (Pallas, 1771). *Limnologica*, 15, 469-477.

Ameyaw-Akumfi, C. & Naylor, E., (1987). Spontaneous and induced components of salinity preference behaviour in *Carcinus maenas*. *Marine Ecology Progress Series*, 37, 153-158.

Arnold, S.L. & Ormerod, S.J. (1997). Aquatic macroinvertebrates and environmental gradients in *Phragmites* reed swamps: implications for conservation. Aquatic Conservation: Marine and Freshwater Ecosystems, 7, 153-163.

Bamber, R.N. 1997. Assessment of saline lagoons within Special Areas of Conservation. *English Nature Research Reports* No. 235.

Bamber, R.N, Gilliland, P.M. & Shardlow, M.E.A. 2001. *Saline lagoons: a guide to their management and creation*. ISBN 1 85716573 X. Peterborough, English Nature.

Barnes, H. and Barnes, M. 1974. “The responses during development of the embryos of some common cirripedes to wide changes in salinity,” *J.Mar. Biol. Ecol.* 15, 197-202

Barnes, R.S.K. 1989. Coastal lagoons of Britain: an overview and conservation appraisal. *Biological Conservation* 49: 295–313.

Barnes, R.S.K. 1994. *The brackish-water fauna of northwestern Europe: a guide to brackish-water habitats, ecology and macrofauna for field workers, naturalists and students.* Cambridge University Press. 287 pp.

Bettison J.C. and Davenport J. (1976). Salinity preference in gammarid amphipods with special reference to *Marinogammarus marinus* (Leach). Journal of the Marine Biological Association of the United Kingdom, 56, pp 135-142. doi:10.1017/S002531540002049X.

Bervoets, L.; Wils, C.; Verheyen, R. 1996. Tolerance of chironomus riparius larve to salinity. Bulletin of Environmental Contamination & Toxicology;Nov96, Vol. 57 Issue 5, p829

Bird, N.L., Chen, L.C.-M. & McLachlan, J., (1979). Effects of temperature, light and salinity of growth in culture of *Chondrus crispus, Furcellaria lumbricalis, Gracilaria tikvahiae* (Gigartinales, Rhodophyta), and *Fucus serratus* (Fucales, Phaeophyta). *Botanica Marina*, 22, 521-527.

Bos A.R., Theil R. 2005. Influence of salinity on the migration of postlarval and juvenile flounder *Pleuronectes flesus* L. in a gradient experiment. Journal of Fish Biology (2006) 68, 1411–1420

Bousfield, E.L., 1973. Shallow water gammaridean Amphipoda of New England. Cornell University Press.

Boxshall, G.; Walter, T. Chad (2012). Cyclopoida. In: Walter, T.C., Boxshall, G. (2012). World Copepoda database. Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=1101 on 2013-01-31

Brooks, S. 2000. Field Guide to the Dragonflies and Damselflies of Great Britain and Ireland.

Budd G. 2002. *Gammarus salinus*. A gammarid shrimp. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3347>

Budd, G. 2008a. *Hediste diversicolor*. Ragworm. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3470>

Budd, G. 2008b. *Neomysis integer*. An opossum shrimp. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3884>

Bulnheim, H.P., (1984). Physiological responses of various *Gammarus* species to environmental stress. *Limnologica (Berlin)*, 15, 461-467.

Cawthorne, D. F. and J. Davenport. 1980. The effects of fluctuating temperature, salinity, and aerial exposure upon larval release in *Balanus balanoides* and *Elminius modestus*," *Journal of the Marine biological Association of the UK* 60: 367-377

Casellato, S. & R. Poja. 1984. Ecology of tubificids in the lower reaches of the rivers Adige and Brenta (N.E. Italy). *Bolletino di Zoologia* 51: 339-352.

Cardona, L., Hereu, B. & X. Torras. 2008. Juvenile bottlenecks and salinity shape grey mullet assemblages in Mediterranean estuaries. *Estuarine, Coastal and Shelf Science* 77: 623-632

Cheng, L. (Ed.) (1976). Marine insects. North-Holland Publishing Company: Amsterdam, The Netherlands. ISBN 0-444-11213-8. XII, 581 pp.

Christensen, T. (1987). Salinity preference of twenty species of *Vaucheria* (Tribophyceae). Journal of the Marine Biological Association of the United Kingdom, 68, pp 531-545,

Cook, P.L. & Hayward, P.J. (1966). The development of *Conopeum seurati*(Canu), and some other species of membraniporine Polyzoa. *Cah. Biol. Mar.*, **7**, 437-443.

Crothers, J.H., (1968). The biology of the shore crab *Carcinus maenas* (L.) 2. The life of the adult crab. *Field Studies*, 2, 579-614.

Dassuncao C. 2009. Temperature and Salinity Tolerances Predict Range Expansion for Two Invasive Marine Invertebrates.

Davenport, J. 1976. A comparative study of the behaviour of some balanomorph barnacles exposed to fluctuating sea water concentrations," J. Mar. Biol. Ass. UK 56: 889-907.

de Wit, R. 2011. Biodiversity of coastal lagoon ecosystems and their vulnerability to global change. In Ecosystem Ed. O.Grillo, pps – 29 – 40. Intech, Croatia.

Dow, R.A. 2010. *Ischnura elegans*. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>.

European Commission. 2007. Interpretation Manual of European Union Habitats - EUR27.

Froese, R. and D. Pauly. Editors. 2003. FishBase. World Wide Web electronic publication. www.fishbase.org

Fossit, J. A. 2000. A guide to habitats in Ireland. The Heritage Council. pp.114.

Forster, S.J. 1998, Osmotic stress tolerance and osmoregulation of intertidal and subtidal nematodes. Journal of Experimental Marine Biology and Ecology,224 :109–125.

Foster, B. A. 1970. Responses and acclimation to salinity in the adults of some balanomorph barnacles," *Phil. Trans. Of the Royal society of London* 256 (1970): 377-400.

Freyhof, J. & Kottelat, M. 2010. *Anguilla anguilla*. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 07 December 2012.

Gulliksen, B., 1977. Studies from the U.W.L. "Helgoland" on the macrobenthic fauna of rocks and boulders in Lübeck Bay (western Baltic Sea). *Helgoländer wissenschaftliche Meeresunters*, 30, 519-526.

Haghebaert, G. (1989). Coleoptera from marine habitats, *in*: Wouters, K.; Baert, L. (Ed.) (1989). *Proceedings of the Symposium "Invertebrates of Belgium".* pp. 301-308

Harvey M. S., 1998. Australian water mites. A guide to families and genera. Monographs on invertebrate taxonomy 4, 1-150. CSIRO Australia and Western Australia Museum.

Hatch, P. & Healy, B. 1998. Aquatic vegetation of Irish coastal lagoons. *Bulletin of the Irish Biogeographical Society*. 21: 2-21.

Hayward, P.J.; Ryland, J.S. (Ed.) (1990). The marine fauna of the British Isles and North-West Europe: 1. Introduction and protozoans to arthropods. Clarendon Press: Oxford, UK. ISBN 0-19-857356-1. 627 pp.

Hayward, P. J. & Ryland, J.S. (eds.) 1995. *Handbook of the Marine Fauna of North-West Europe.* Oxford University Press. PB*.* 899 pp*.*

Healy, B. 2003. Coastal Lagoons. In: *Wetlands of Ireland.* R. Otte (ed). Chapter 4. University College Dublin Press. Dublin. 44-78.

Hempel C., 1957. Uber den Rohrenbau und die Nahrungsaufnahme einiger spioniden der deutschen Ktisten. Helgoland. wiss. Meeresunters., Bd. 6, Heft. I, pp. 100-134.

Heip C. 1976. The spatial pattern of *Cyprideis torosa* (JONES, 1850) (CRUSTACEA: OSTRACODA) *J. mar. bid.* Ass. U.K. (1976) 56, 179-189

Hiscock, K. & P. Pizzolla 2007. *Ceramium virgatum*. A red seaweed. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=2922>

Hosie A. 2008. *Allomelita pellucida.* An amphipod. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological

Association of the United Kingdom. Available from
<http://www.marlin.ac.uk/specieshabitats.php?speciesID=3347>

Hotos, G. N. & Vlahos, N., (1998).Salinity tolerance of *Mugil cephalus* and *Chelon labrosus* (Pisces: Mugilidae) fry in experimental conditions. *Aquaculture*, 167:329-338.

Ingolfsson A., 1977. Distrivbution and Habitat prefences of some intertidal amphipods in Iceland. Acta Natura Islandica. 25.

Jackson, A. 2000. *Hydrobia ulvae*. Laver spire shell. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3540>

Jackson, A. 2008. *Fucus serratus*. Toothed wrack. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: http://www.marlin.ac.uk/specieshabitats.php?speciesID=3346

Johnson, G.D. & Gill, A.C. (1998). Paxton, J.R. & Eschmeyer, W.N.. ed. *Encyclopedia of Fishes*. San Diego: Academic Press. p. 192.

Jones M.B. 1972. Effects of salinity on the survival of the *Jaera albifrons* Leach group of species (crustacea: isopoda) Journal of Experimental Marine Biology and Ecology Volume 9, Issue 3, September 1972, Pages 231–237

Jorde, I. & Klavestad, N., (1963). The natural history of the Hardangerfjord. 4. The benthonic algal vegetation. *Sarsia*, 9, 1-99.

Koepcke, B. & Kausch, H., (1996). Distribution and variability in abundance of *Neomysis integer* and *Mesopodopsis slabberi* (Mysidacea; Crustacea) in relation to environmental factors in the Elbe Estuary. *Archiv fur Hydrobiologie. Supplementband. Untersuchungen des Elbe-Aestuars. Stuggart*, 110, 263-282.

Kinne, O. (ed.), 1971a. *Marine Ecology: A Comprehensive, Integrated Treatise on Life in Oceans and Coastal Waters. Vol. 1 Environmental Factors, Part 2.* Chichester: John Wiley & Sons.

Karaman G.S. 1982. Family Gammeridae. In Ruffo S (ed). The Ampipoda of the Mediterranean, Part 1. Memoires de l'Institut Oceanographique. Fondation Albert, Prince de Monaco, Monaco. 245-360.

Kuhlmann, D., (1984). Effects of temperature, salinity, oxygen and ammonia on the mortality and growth of *Neomysis integer* Leach. *Limnologica*, 15, 479-485.

Lippert H., Iken K., Rachor E., Wiencke C.,. 2001. Macrofauna associated with macroalgae in the Kongsfjord (Spitsbergen). Polar Biology July 2001, Volume 24, Issue 7, pp 512-522

Lincoln R.J. 1979. British Marine Amphipoda: Gammeridea. British Museum (National History). London, UK

Lloyd, A.J. & Yonge, C.M., (1947). The biology of *Crangon vulgaris* L. in the Bristol Channel and Severn Estuary. *Journal of the Marine Biological Association of the United Kingdom*, 26, 626-661.

Lotufo, G.R. & D.M.S. Abessa. 2002. 2002, Testes de toxicidade com sedimento total e água intersticial estuarinos utilizando copépodos bentônicos. *In*: I. A. Nascimento, E. C. P. M. Sousa & M. G. Nipper, (eds.). *Métodos em ecotoxicologia marinha: aplicações no Brasil*. São Paulo: Artes Gráficas. p.151-162.

Lundgreen K. Kiilerich P. Tipsmark C.K. Madsen S.S. Jensen F.B. 2008. Physiological response in the European flounder (*Platichthys flesus*) to variable salinity and oxygen conditions. J Comp Physiol B. 2008 178(7):909-15.

Macan T.T., 1954a. A contribution to the study of the ecology of Corixidae (Hemipt). *J. Anim. Ecol.* 23. 155-141.

Martins, I., Oliveira, J. M., Flindt, M. R. & Marques, J. C. 1999 The effect of salinity on the growth rate of the macroalgae *Enteromorpha intestinalis* (Chlorophyta) in the Mondego estuary (west Portugal). *Acta Oecologica* 20, 259–265.

Mathieson, A.C. & Burns, R.L., 1975. Ecological studies of economic red algae. 5. Growth and reproduction of natural and harvested populations of *Chondrus crispus* Stackhouse in New Hampshire. *Journal of Experimental Marine Biology and Ecology*, 17, 137-156.

Mc Cluskey' D.S. & V. E. J. Heard· 1971. Some effects of salinity on the mysid *Praunus flexuosus*. *Journal of the Marine Biological Association of the United Kingdom* 51(3): 709-715.

Millar, J., Pietrafesa, L. and Smith, N. 1990. Principals of hydraulic management of coastal lagoons for aquaculture and fisheries. FAO technical paper no. 314. Rome.

Natural England. 2010. Coastal saline lagoons and the Water Framework Directive. Report NECR039.

Naylor, E., 1972. British Marine Isopods. Synopses of the British Fauna (NS), 3.

Neal ,K. and Avant, P., 2006. *Corophium volutator*. A mud shrimp. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 20/02/2013]. Available from: <http://www.marlin.ac.uk/speciesinformation.php?speciesID=3052>

Neal, K. & P. Pizzolla. 2008. *Carcinus maenas*. Common shore crab. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=2885>

Neal, K. 2008. *Crangon crangon*. Brown shrimp. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3078>

Newton, A. and Mudge, S. 2002. Temperature and salinity regimes in a shallow mesotidal lagoon, the Ria Formosa, Portugal. Estuarine Coastal and Shelf Science. 56 : 1 – 13.

NPWS (2011) Conservation objectives for Galway Bay Complex SAC [000268]. Generic Version 3.0. Department of Arts, Heritage & the Gaeltacht.

NPWS. 2012. Lower River Shannon SAC (site code 2165) Conservation objectives supporting document- Lagoons Version 1.

Nair R., Krishnamurthy K., Mawatari S.F. 1992. Salinity tolerance in four estuarine species of Bryozoa. Marine fouling; ISSN:0388-3531; VOL.9; PAGE.15-20.

Oliver, G.A. and Healy, B. 1998 Records of aquatic fauna from coastal lagoons in Ireland. *Bulletin of the Irish Biogeographical Society*. 21: 66-115Roden, C. 1999. *Irish coastal lagoon survey, 1998. Vol. III, Flora.* Dúchas, Dublin.

Oliver, G. 2005. *Seasonal changes and Biological Classification of Irish Coastal Lagoons.* PhD Thesis. U.C.D., Dublin. Available on www.irishlagoons.com

Oliver, G. 2007. Inventory of Irish coastal lagoons (version 2). Unpublished report to the National Parks and Wildlife Service.

Ozoh, P. T. E. and N. V. Jones. 1990. Capacity adaptation of *Hediste (Nereis) diversicolor* embryogenesis to salinity, temperature and copper. Marine Environmental Research 29: 227-243.

Pizzolla P. 2005. *Platichthys flesus*. Flounder. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 01/02/2013]. Available from <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3347>

Pombo, L., Elliott, M. & J.E. Rebelo. 2005. Ecology, age and growth of *Atherina boyeri* and *Atherina presbyter* in the Ria de Aveiro, Portugal. *Cybium* 29(1): 47-55.

Rayment, W. & P. Pizzola. 2008. *Chondrus crispus*. Carrageen. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=2971>

Richard S., Barnes K.1994. The Brackish-Water Fauna of Northwestern Europe. Cambridge University Press. Cambridge, UK

Riley K. 2003. *Pomatoschistus microps*. Common goby. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 05/02/2013]. Available from: <http://www.marlin.ac.uk/speciessensitivity.php?speciesID=4181>

Smith, J.E., (1964). On the early development of *Nereis diversicolor* in different salinities. *Journal of Morphology*, 114, 437-464.

Sotillo, A., Mensens, C., Kapasakali, D., Maugeri, G., Araújo, G., Gordon, J.C., Hubner, K., Berreto, M. and Mercado-Ortiz, M. 2011. An approach to habitat mapping of Lough Atalia. GMIT Summer School project.

Sousa de, E.C.P.M., Zaroni, L.P., Bergmann Filho, T.U., Marconato, L.A., Kirschbaum, A.A. & M.R. Gasparro. 2012. Acute sensitivity to *Nitokra* sp benthic copepod to potassium dichromate and ammonia chloride. *J. Braz. Soc. Ecotoxicol* 7(1): 75-81.

Suryono, C.A. & Hardy, F.G., 1997. Studies on the distribution of *Fucus ceranoides* L. (Phaeophyta, Fucales) in estuaries on the north-east coast of England. *Transactions of the Natural History Society of Northumbria*, 57, 153-168.

Taylor, R., Fletcher, R.L. & J. A. Ravena. 2001. Preliminary Studies on the Growth of Selected 'Green Tide' Algae in Laboratory Culture: Effects of Irradiance, Temperature, Salinity and Nutrients on Growth Rate. *Botanica Marina* 44: 327-336.

Tasende, M.G. & Fraga, M.I., (1999). The growth of *Chondrus crispus* Stackhouse (Rhodophyta, Gigartinaceae) in laboratory culture. *Ophelia*, 51, 203-213.

Tyler-Walters H. 2001. *Ruppia maritima*. Beaked tasselweed. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/02/2013]. Available from: <http://www.marlin.ac.uk/speciesinformation.php?speciesID=4272>

Tyler-Walters H. 2003. *Gasterosteus aculeatus*. Three-spined stickleback. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 01/02/2013]. Available From <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3347>

Tyler-Walters H. 2008. *Arenicola marina*. Blow lug. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 20/02/2013]. Available from <http://www.marlin.ac.uk/speciesbenchmarks.php?speciesID=2592>

Van Colen C., F. Montserrat,B.C. M. Vincx, P.M.J. Herman b, T. Ysebaert b,d, S. Degraer a,e. 2010. Long-term divergent tidal flat benthic community recovery following hypoxia-induced mortality. Marine Pollution Bulletin 60 (2010) 178–186.

Verdonschot, P.F.M. 1981. Some notes on the ecology of aquatic oligochaetes in the Delta Region of the Netherlands. *Archiv fur Hydrobiologie* 92 (1): 53-70.

Verdonschot, P.F.M., Smies, M. & A.B.J. Sepers. 1982. The distribution of aquatic oligochaetes in brackish inland waters in the SW Netherlands. *Hydrobiologia* 89(1): 29-38.

Wallace, C. 1985. On the distribution of the sexes of *Potamopyrgus jenkinsi* (Smith). *Journal of Molluscan Studies*, *51*: 290-296.

White, N. 2008a. *Fucus spiralis*. Spiral wrack. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3347>

White, N. 2008b. *Fucus vesiculosus*. Bladder wrack. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=3348>

White, N. 2008c. *Pelvetia canaliculata*. Channelled wrack. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 06/12/2012]. Available from: <http://www.marlin.ac.uk/specieshabitats.php?speciesID=4064>

Whitton B.A. 1982. *Rivers, Lakes and Marshes*. London: Hodder & Stoughton. pp. 131.

Wijatne, E., Rydberg, L. and Pathirana, K. 200. Modelling of sea levels, water exchange and dispersion in an intermittently closed tidal estuary: Chilaw Lagoon, west coast of SriLanka. Proc. 10th. Aisan Congress of Fluid Mechanics.

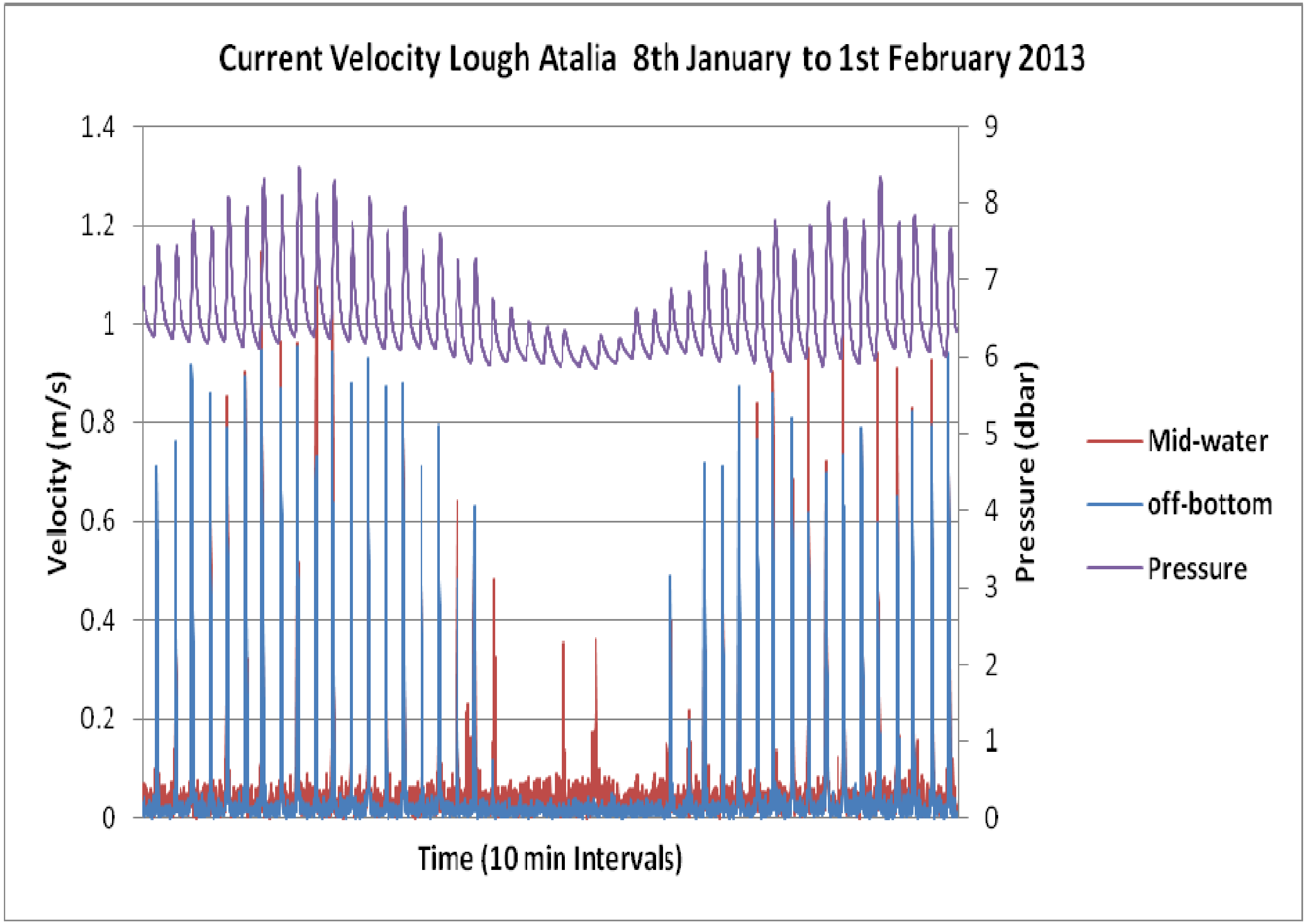
Worsfield T. 2003. Introduction to oligochaetes. NMBAQC Workshop.

Wulff, F. 1972. Experimental studies on physiological and behavioural response mechanisms of *Nitokra spinipes* from brackish water rock pools. Marine Biology, 13: 325 – 329.

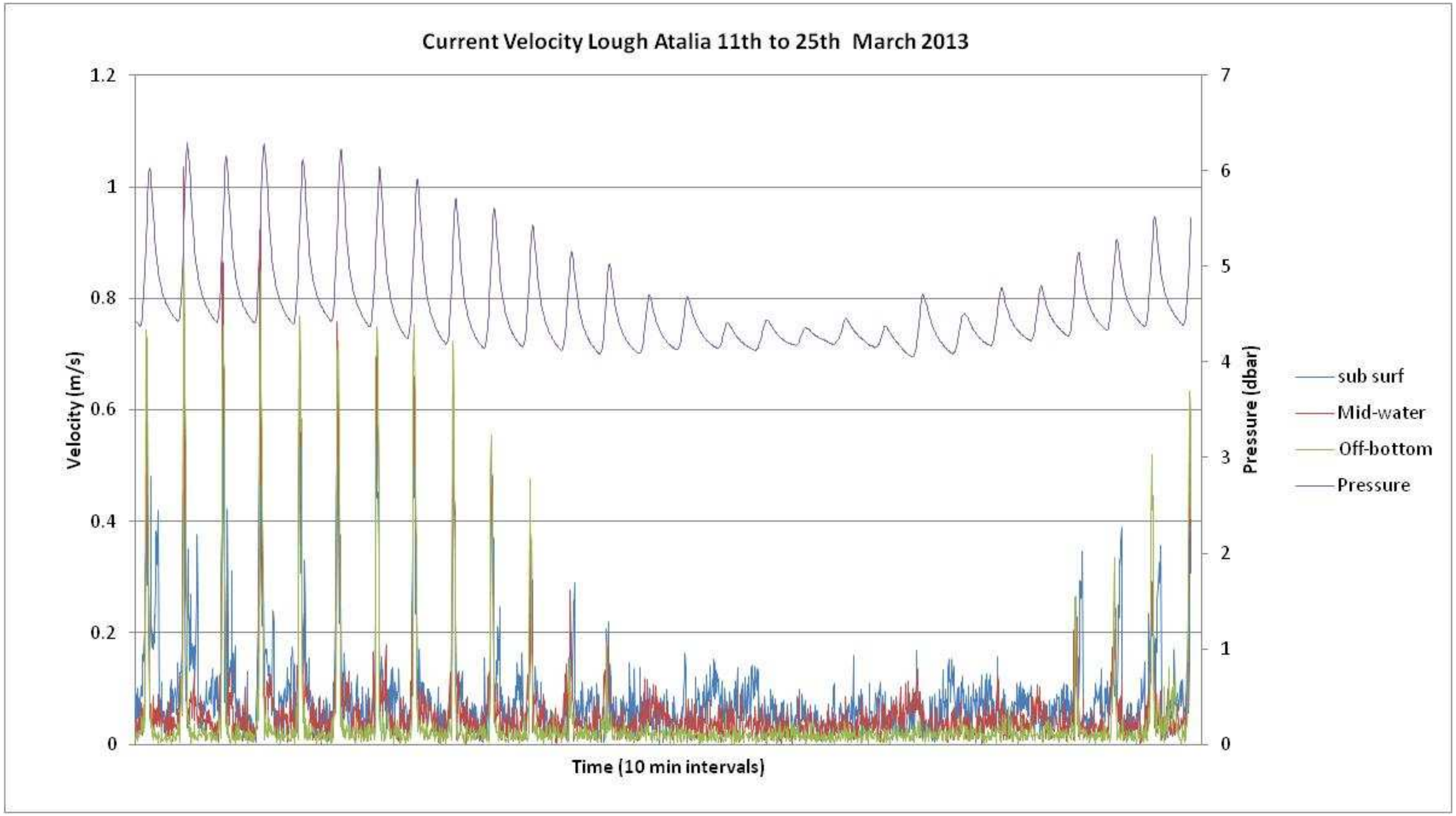
Yazdani' M., Taheri' M. & J. Seyfabadi. 2010. Effect of different salinities on survival and growth of prawn, *Palaemon elegans* (Palaemonidae). *Journal of the Marine Biological Association of the United Kingdom* 90 (2): 255-259.

Appendix I

Current speed and direction data collected in Lough Atalia.



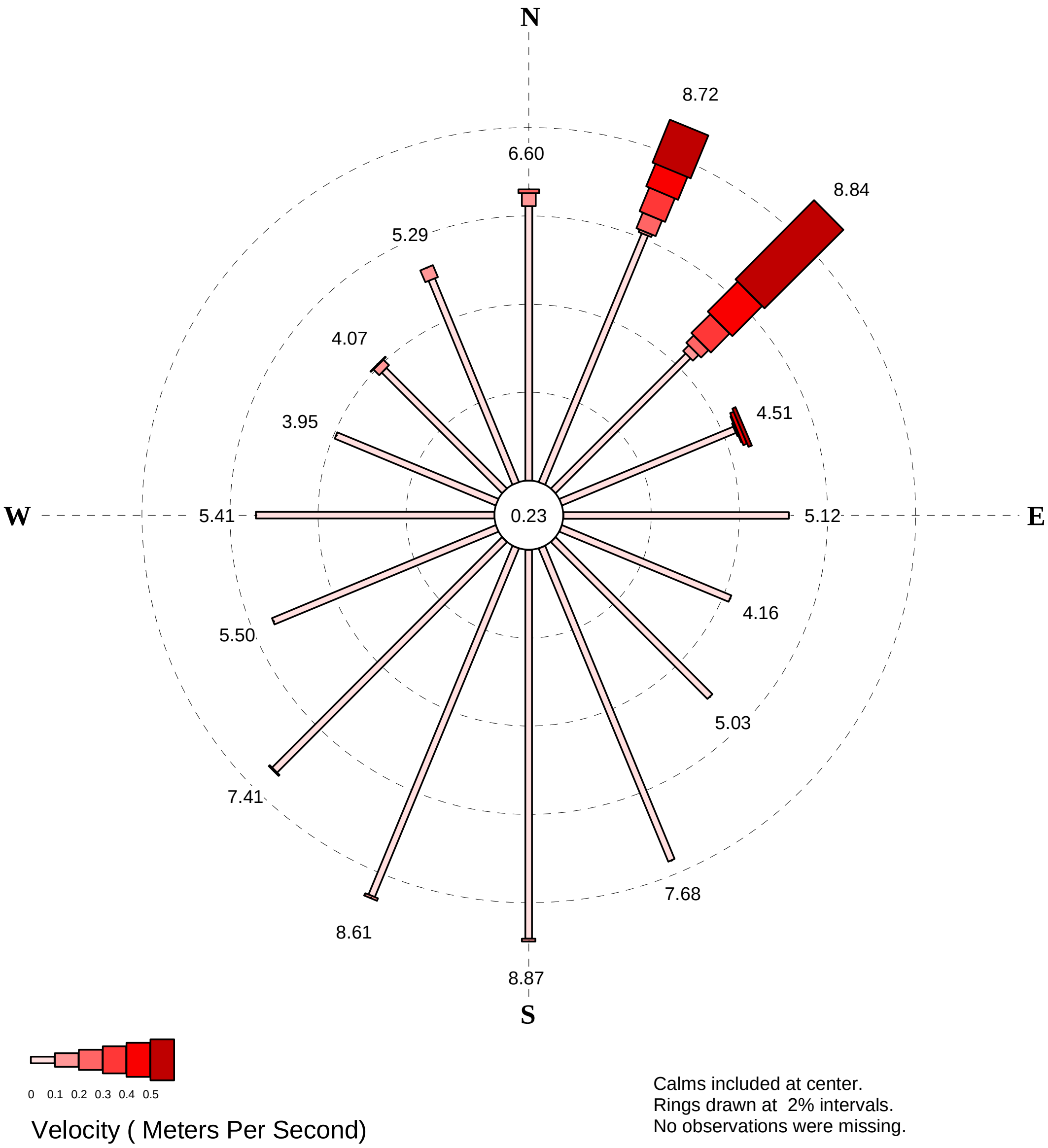
Current Velocity Lough Atalia 8th January to 1st February 2013
Velocity (m/s)
Pressure (dbar)
Time (10 min Intervals)
Mid-water
off-bottom
Pressure
1.4
1.2
1
0.8
0.6
0.4
0.2
0
9
8
7
6
5
4
3
2
1
0



Current Velocity Lough Atalia 11th to 25th March 2013
Velocity (m/s)
Pressure (dbar)
Time (10 min intervals)
sub surf
Mid-water
Off-bottom
Pressure

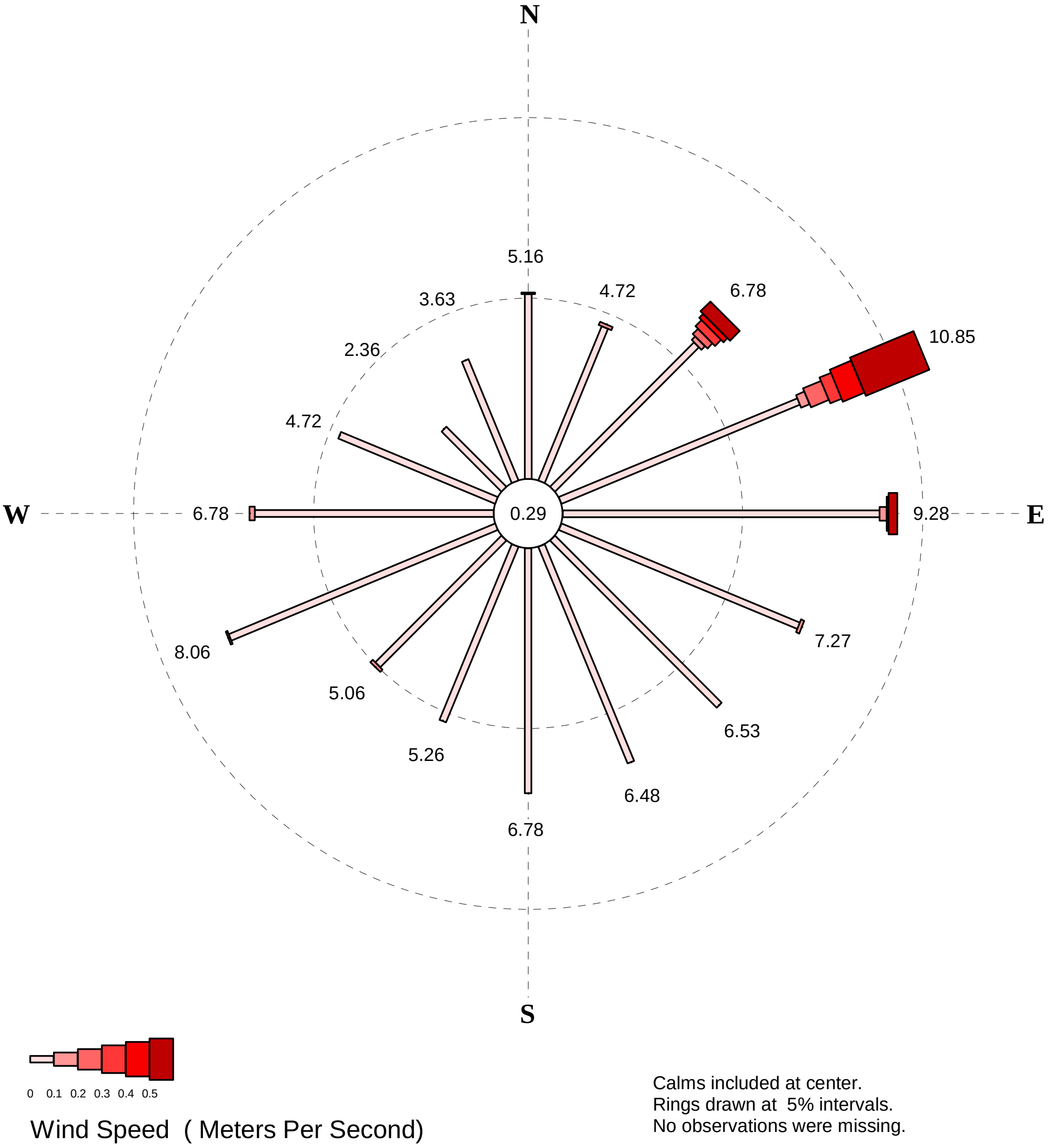
.

L. Atalia Current 8 Jan to 1 Feb 2013



Calms included at center.
Rings drawn at 2% intervals.
No observations were missing.

JL. Atalia Current 11 to 25 March 2013



Calms included at center.
Rings drawn at 5% intervals.
No observations were missing.

Appendix II

Salinity results from 21 locations in Lough Atalia on a selection of dates

The first survey was carried out in the two hours preceding high tide, three days prior to a Spring tide. As can be seen in Figure 1, the lowest salinity of 8.1 psu occurs at the surface of Station 21 at the north-eastern head of the lough. This is in contrast to the surface salinities generally at this end of the lough which are around 10 psu higher. Station 21 excluded, the lower surface salinities tend to occur near the mouth of the lough. The highest salinity of 21.4 psu occurred at the deepest point of Station 8, towards the deeper south-western part at the mouth. The highest surface salinity of 19.7 psu occurred at Station 11. The greatest difference of salinity with depth occurs in Stations 2, 4, 5 and 21, all of which occur in the high flow mouth area with the exception of Station 21. Conversely, the most continuity of salinity with depth occurs at Station 16 to 20 towards the low flow northern end with the exception of Station 1 at the southern end. In the majority of the stations there is a gradual increase in salinity with depth.

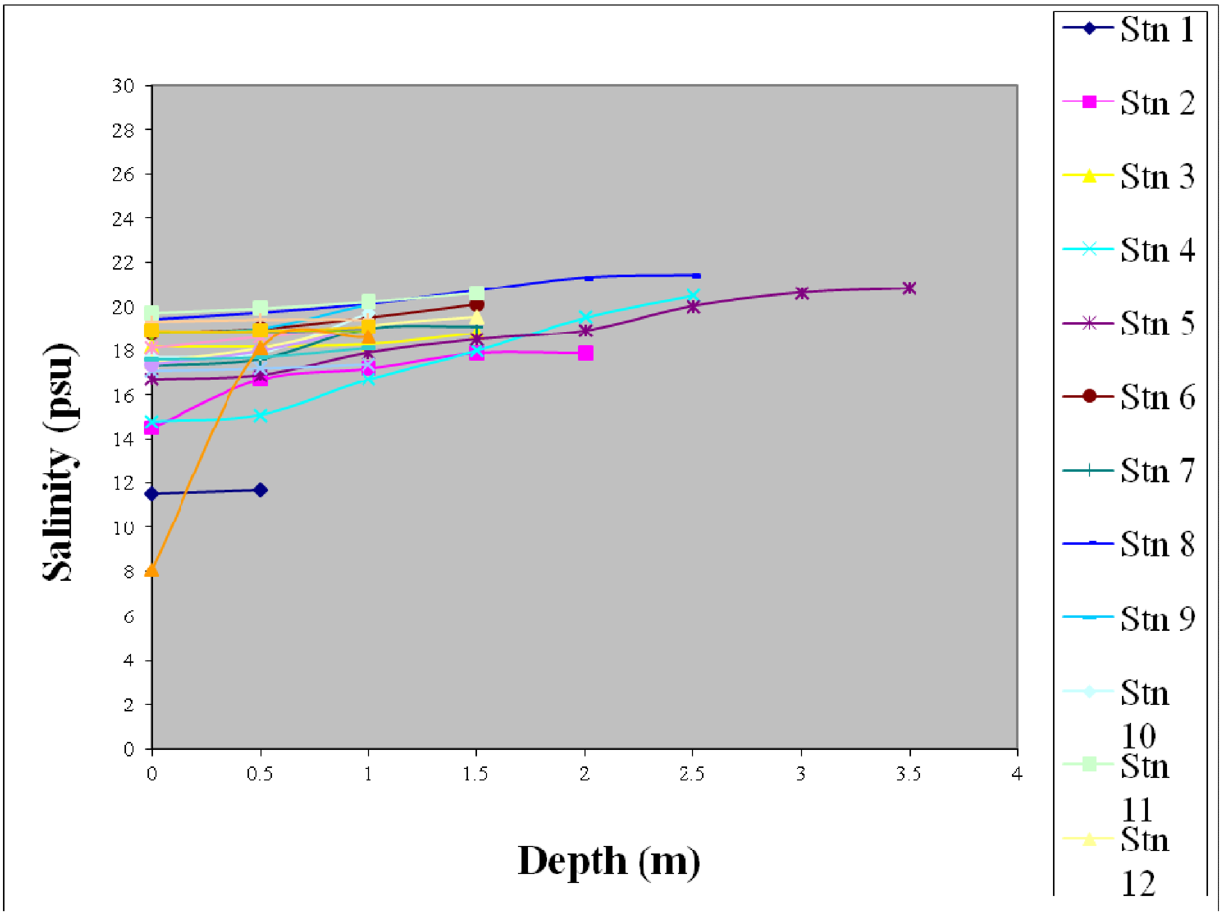


Figure 1: Salinity profiles of Lough Atalia 04/04/2012

The second survey was carried out on an ebbing tide, from approximately two to three hours after high water, on a falling spring tide (four days after a full moon). As can be seen in Figure 2, the lowest salinity was 20.5 psu in the surface waters of Station 12 while the greatest was 27.1 psu at 5.5m at Station 5. The highest salinities were recorded at the depth. This survey showed greater minimum and maximum salinities compared to the first survey. While there is also greater depth of water in survey two compared to survey one, this occurring at the deeper southerly end, the northerly end is also shallower, Stations 19 and 21 only having a depth of 0.5m. The greatest surface salinity of 24.3 occurred at Station 15. Salinity can be seen to increase with depth, however this is not as gradual as in the first survey. There is a rapid increase in salinity between 0.5 and 1m.

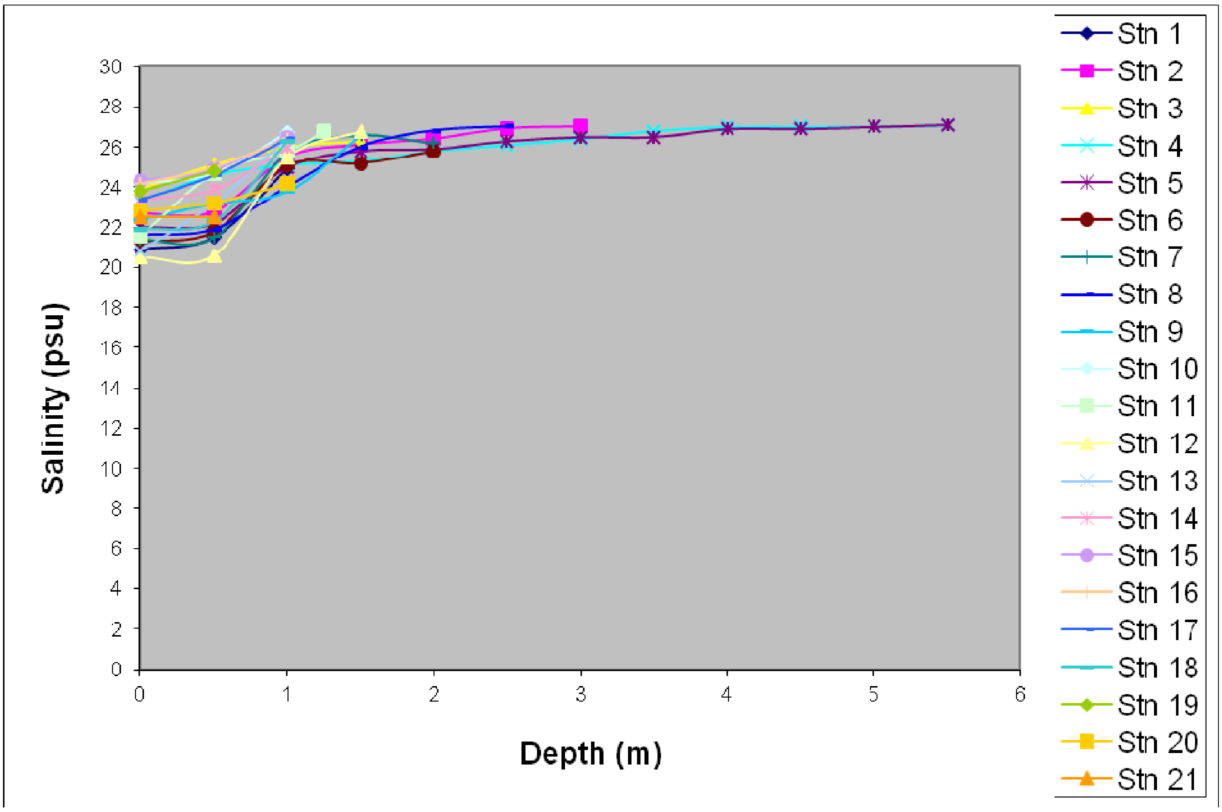


Figure 2: Salinity profiles of Lough Atalia 10/04/2012

The third survey was carried out approximately three-quarters of an hour either side of high tide, occurring two days after the peak of a neap tide. The wind was a 8-10 knots from a south-south-east direction. As can be seen in Figure 3, the salinity range was 7.5 to 23.2 psu. The former occurred at the surface of stations 2 and 10 the latter again at the deepest point of station 5. 7 psu is the lowest salinity of the first three surveys. The deepest stations with the highest salinity are Stations 2, 5, 6 and 8, all at the southern end. The highest salinity in surface waters of 12.2 psu occurred at Station 18. There is less discontinuity in the gradual increase of salinity with depth, in survey 3 than survey 2. This occurs from 1 to 2m as seen at Stations 2, 8 and 9.

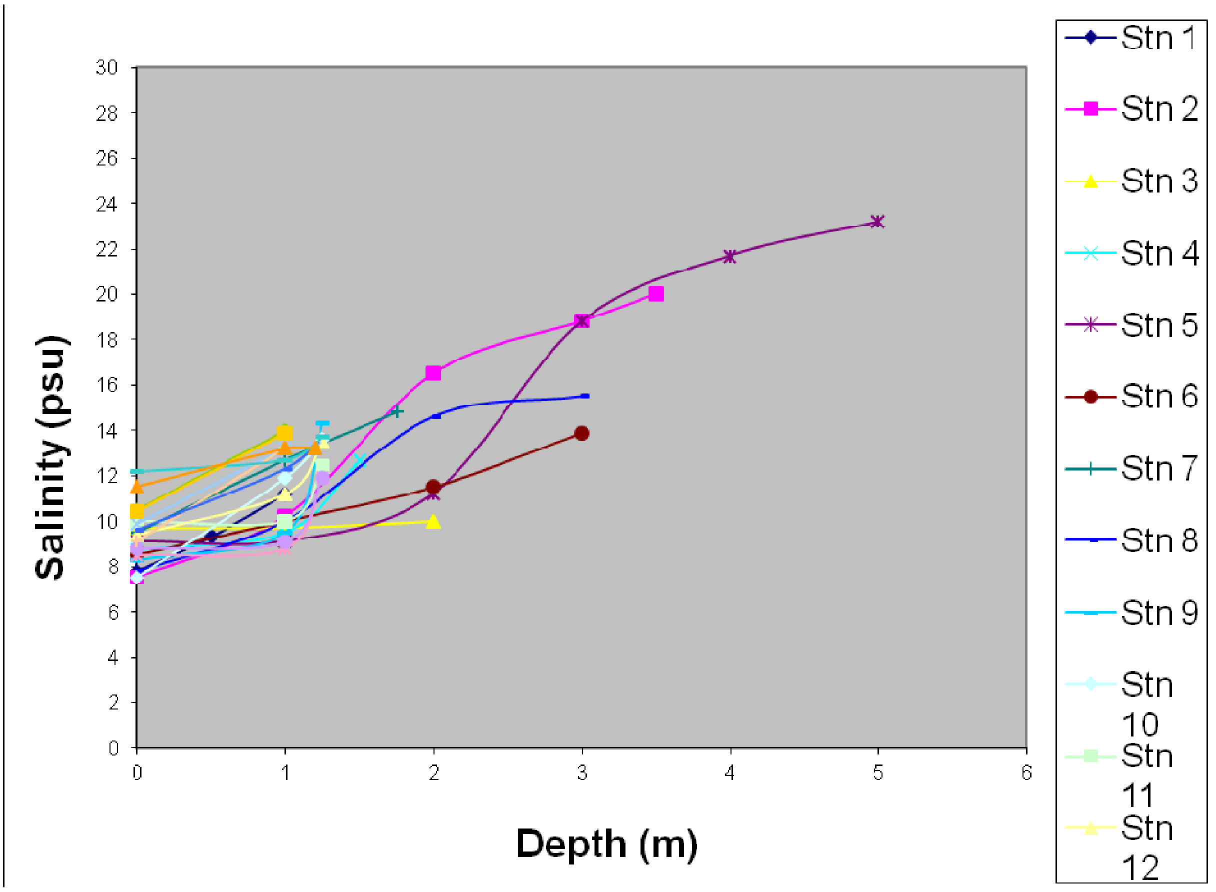


Figure 3: Salinity profiles of Lough Atalia 16/04/2012

The fourth survey was carried out approximately 15 minutes before low tide to 40 minutes after tide, two days before the peak of a spring tide. As can be seen in Figure 4, the lowest salinity of 15.6 psu occurred at the surface of Station 7, while the highest salinity of 23.9 psu occurred again at the deepest point at Station 5. The highest salinity of surface waters of 22.3psu occurred at Station 16 towards the northern end of the lough where the surface salinities generally seem to be higher than those in the southern region. There is more uniformity of salinity with depth to be seen in survey 4 compared to surveys 2 and 3. However, while similar to survey 1, in survey 4 there is also slightly more discontinuity occurring in Stations 6, 7 and 12.

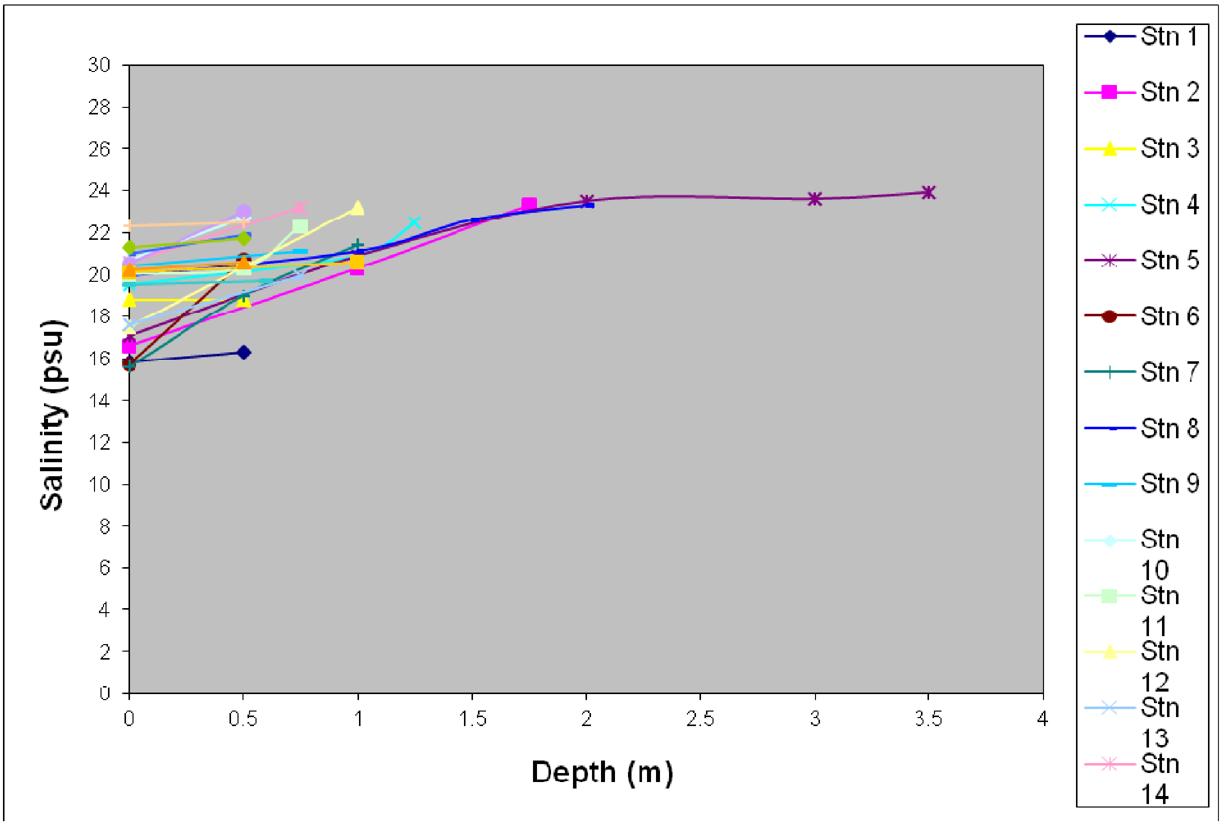


Figure 4: Salinity profiles of Lough Atalia 19/04/2012.

The fifth survey took place during 1.5 hours directly after low water, two days before the peak of a spring tide. This survey showed the lowest salinity range of 25.7 to 29.4 psu, located at the surface waters of Station 1 and the deepest point of Station 5 respectively. The highest surface salinity of 28.8 psu also occurred at Station 16, as seen in survey 4, which was the only other survey taken around low water. There is some evidence of continuous and discontinuous salinity with depth occurring in survey 5. Of the stations greater than 1m, namely Stations 2, 4, 5, 6 and 8 the most rapid increase in salinity occurs from 1 to 2m.

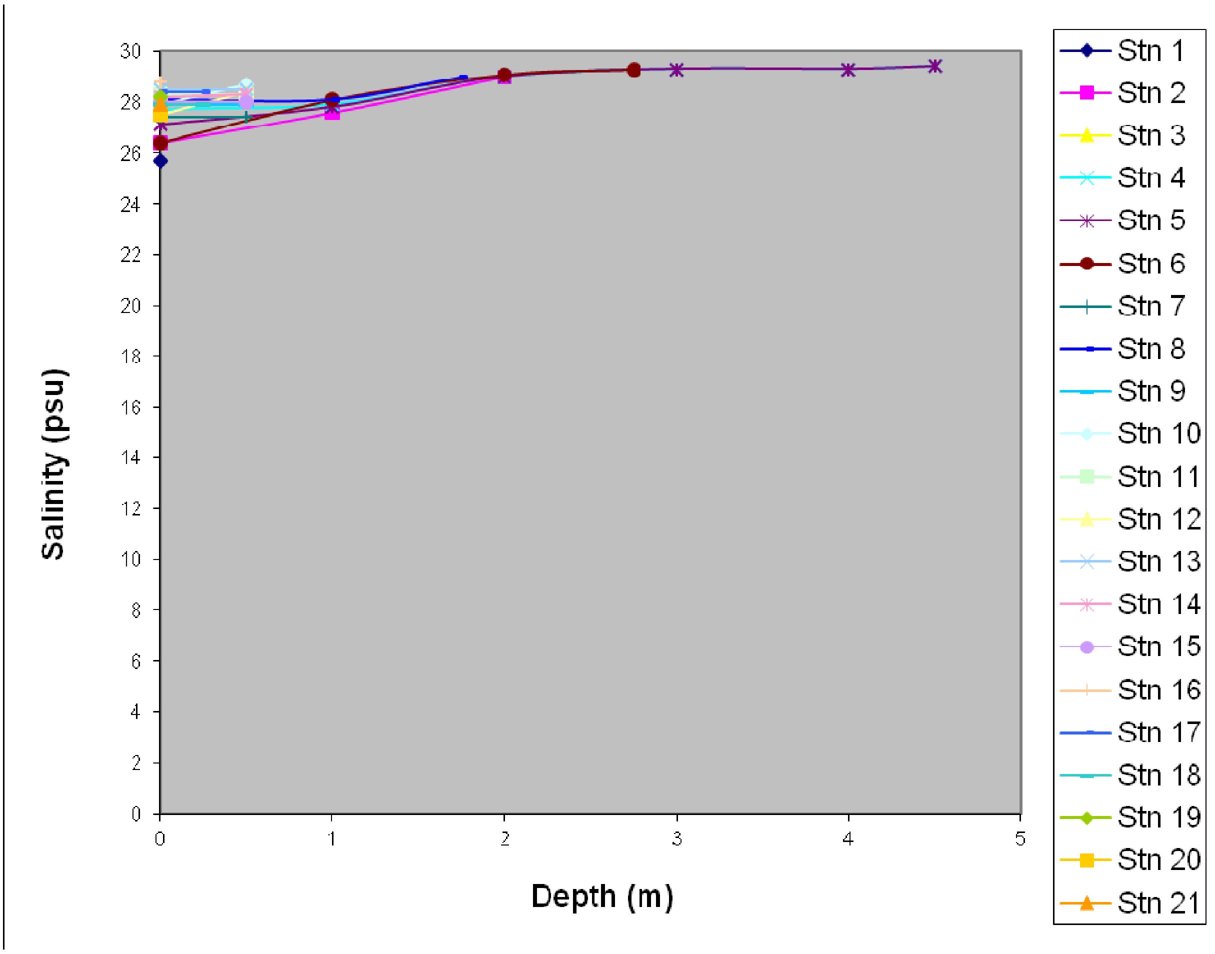


Figure 5: Salinity profiles of Lough Atalia 04/05/2012

Discussion

Salinity

The lowest salinity of 8.1 psu at Station 21 measured during survey 1 contrasts to the otherwise relatively high salinities found at the northern end of the lough during this survey. This is possibly due to a storm drain which enters at this end of the lough. With the exception of this station, the lowest surface salinities in survey 1 tended to occur at stations close to the lough mouth. Taking into account that the tide was still rising, this would suggest that water from the river Corrib is being pushed into Lough Atalia by the rising tide. Entrance of the denser, more saline water into the lough however, may be obstructed somewhat by the sill at the mouth.

Comparing survey 1 and 2, which were flooding and ebbing tides respectively, the latter had both the greater depth near the mouth and the shallowest areas at the opposite end. This shows that areas further away from the mouth, towards the northern end feel the effects of tidal change before areas around the mouth. There is a greater discontinuity of salinity with depth in survey 2 compared to survey 1, increasing the stratification within the lagoon. This is possibly due to a mixing affect that the incoming tide had on the lough and as in survey 2, which had been ebbing for 2-3 hours. This mixing affect was diminished, allowing strata to develop. However, a stronger 14-16 knots wind from the North during survey 1, may have contributed more to mixing than the weaker winds of 6-8 knots from a west-south-west direction during survey 2. Survey 2 had a relatively small salinity range of 20.5 to 27.1 psu.

The greater salinity range in survey 3 compared to survey 2 can be accounted by the tidal state. High water occurred during approximately half way through the survey and hence the freshwater did not have as much time to exit the lough over the sill before the salinities were measured. The lowest salinity of the five surveys was recorded at Station 2 during the third survey. This again can be accounted for by the tidal state as high water occurred during the survey and so water, a lot of which is freshwater from the River Corrib being pushed in by the rising tide, has being entering the lough for the maximum period of time, without having a lot of time to exit with the falling tide. There is more stratification in survey 3 than in survey 1 but less than in survey 2. This could be due to the mixing effect of the incoming tide ceasing when the tide started to ebb and that the strata seen to be more pronounced during survey 2 are starting to form. The wind during survey 3 was slightly stronger than during survey 2, but not as strong as survey 1. Partial mixing by this method cannot be ruled out.

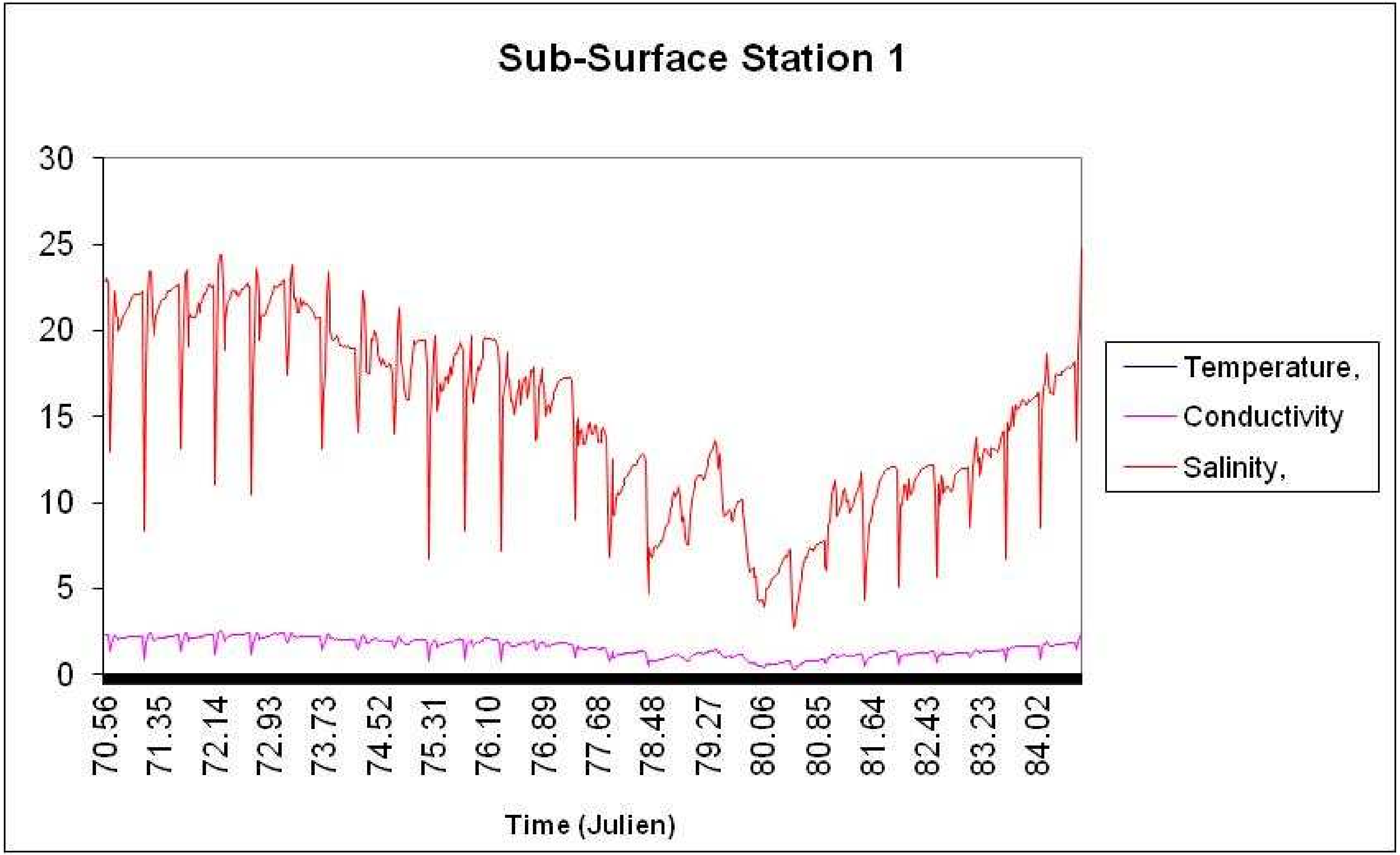
In survey 4, salinities are generally higher towards the head of the lough. This maybe explained by the tidal state. Less dense freshwater was returning back into the lough on the rising tide for approximately an hour, hence lowering the salinity at the mouth. However, not enough time after low tide had passed, when the survey occurred, to effect waters at the head of the lough. There is a mixture of continuity and discontinuity of salinity with depth in survey 4. This may be due to the fact that the spring tide had been flooding for an hour and so the strata were beginning to break down.

As in survey 4 there is a mixture of continuous and discontinuous salinities with depth seen in survey 5. The tidal state during survey 5 was similar to that during survey 4 in that they were carried out mainly after a spring low tide, with survey 4 ending 50 minutes after low water and survey 5 ending 1.5 hours after a low tide. So as with survey 4, it may be the a case that strata developed in the lough while the tide was ebbing and then with the returning tide these strata were becoming broken down due to mixing affects caused by the influx of water into the loug. At the stations were there is a more discontinuous increase in salinity with depth, the rate of change of salinity with depth is less however in survey 5 compared to survey 4. This may be because survey 5 ended longer after low water than survey 4 and hence more mixing occurred and strata were further broken down. Survey 5 showed the least salinity range, even when compared to survey 4. This may reinforce the fact that more mixing had occurred due to the extra time after low water.

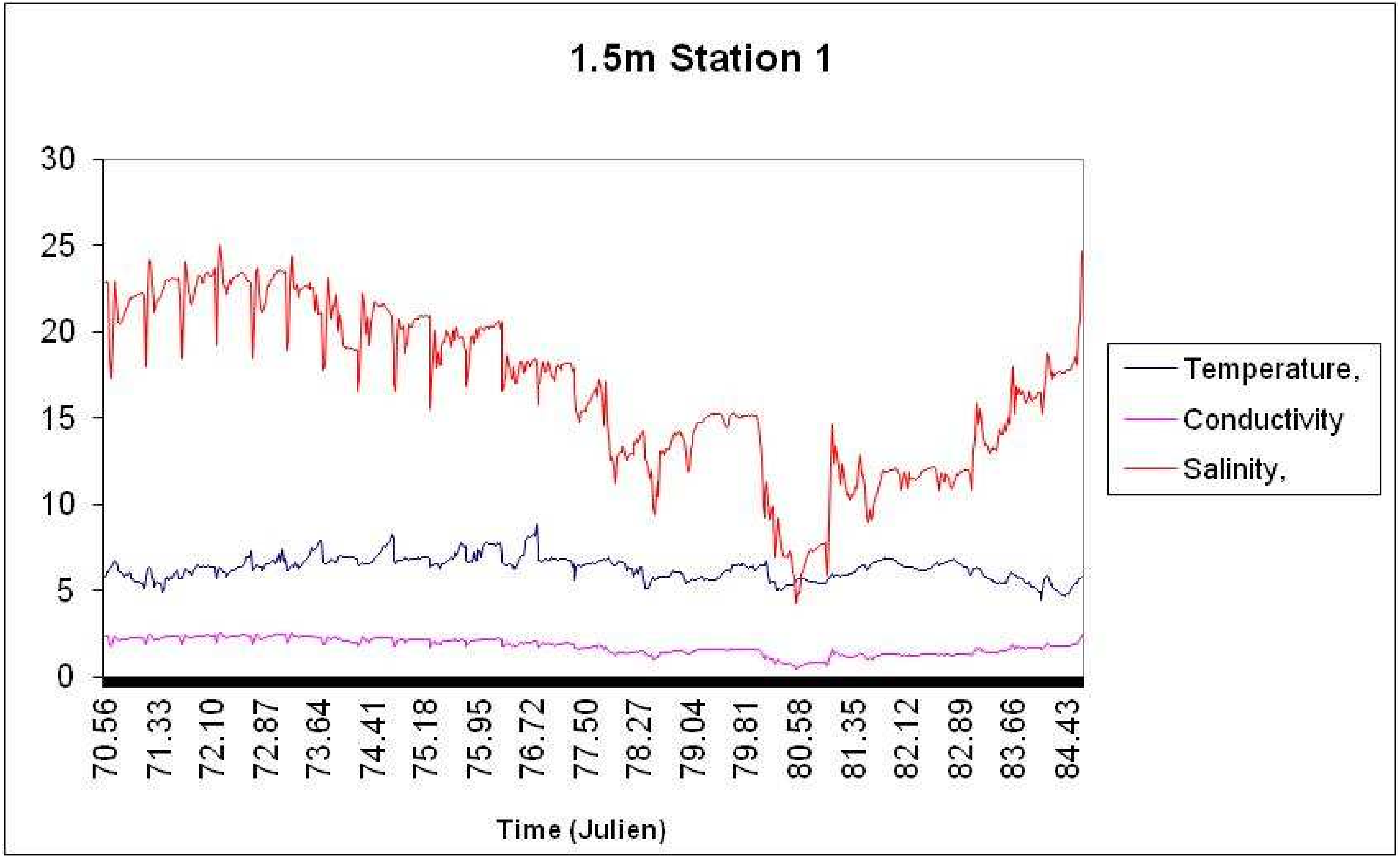
Appendix III

Salinity graphs collected by meters, March 2013.

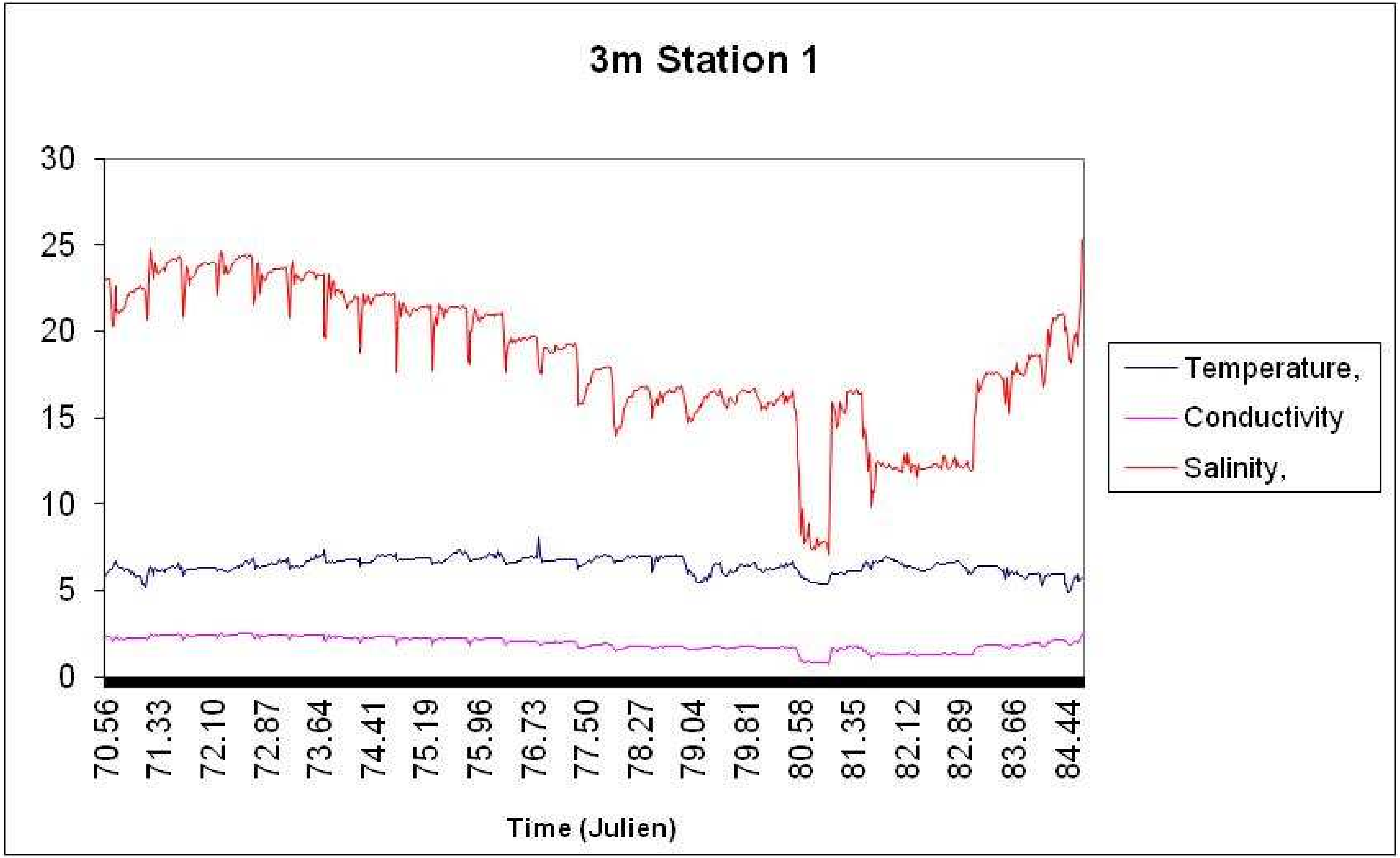
N.B. Julian Day 1 = January 1st.

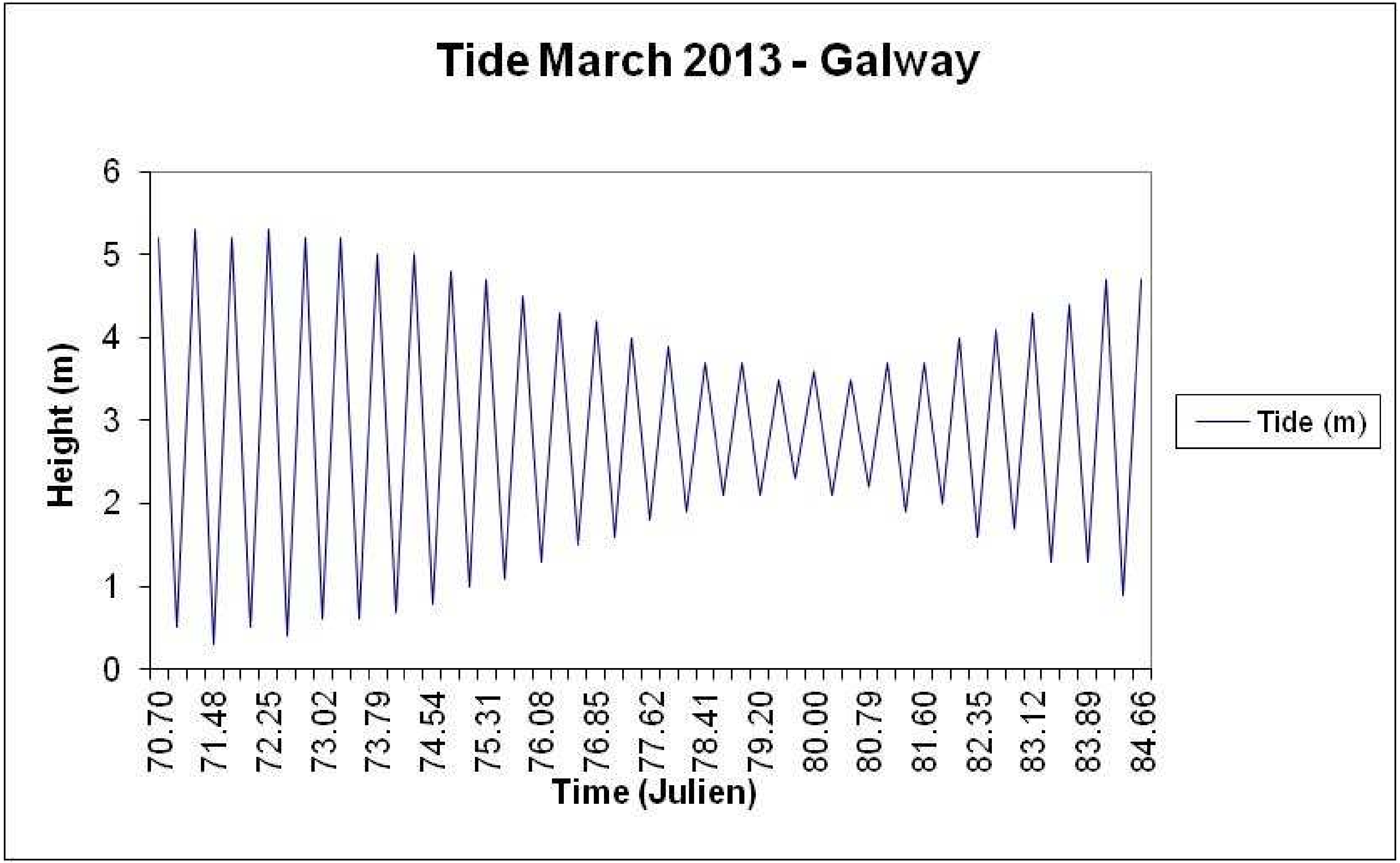


Sub-Surface Station 1
30
25
20
15
10
5
0
70.56
71.35
72.14
72.93
73.73
74.52
75.31
76.10
76.89
77.68
78.48
79.27
80.06
80.85
81.64
82.43
83.23
84.02
Time (Julien)
Temperature,
Conductivity
Salinity,



1.5m Station 1
30
25
20
15
10
5
0
70.56
71.33
72.10
72.87
73.64
74.41
75.18
75.95
76.72
77.50
78.27
79.04
79.81
80.58
81.35
82.12
82.89
83.66
84.43
Time (Julien)
Temperature,
Conductivity
Salinity,


3m Station 1
30
25
20
15
10
5
0
70.56
71.33
72.10
72.87
73.64
74.41
75.19
75.96
76.73
77.50
78.27
79.04
79.81
80.58
81.35
82.12
82.89
83.66
84.44
Time (Julien)
Temperature,
Conductivity
Salinity,



Tide March 2013 - Galway
Height (m)
0
1
2
3
4
5
6
70.70
71.48
72.25
73.02
73.79
74.54
75.31
76.08
76.85
77.62
78.41
79.20
80.00
80.79
81.60
82.35
83.12
83.89
84.66
Time (Julien)
Tide (m)

Appendix IV Mathematical model study

Report No. HEL098001 v1.2

Dispersion Modelling of Salinity in Inner Galway Bay and Lough Atalia for the Galway Harbour Extension Project

Prepared for

Galway Harbour Authority

May 2013

Hydro
Environmental Ltd
No. 4 Caiseal Riada,
Clarinbridge,
Co. Galway.
Tel / Fax: 091 796734
email: info@HydroE.ie

Dispersion Modelling of Salinity in Inner Galway Bay and Lough Atalia for the Galway Harbour Extension Project

Job No.:	098001
Report No.:	HEL098001 v1.2
Prepared by:	Anthony Cawley BE, MEngSc, CEng MIEI
Date:	12th May 2013
Issue	**Final**

DISCLAIMER

This report has been prepared for Galway Harbour Company for the Galway Harbour Extension Project SEA and EIS Assessments. Hydro Environmental Ltd. accept no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned.

Table of Contents

2. 1. Background

Hydro Environmental Ltd was commissioned by Galway Harbour Authority to perform a detailed Dispersion modelling assessment of potential changes to water salinity in Lough Atalia and Inner Galway Bay as a result of the proposed Galway Harbour Extension. In support of this assessment extensive field work involving bathymetry, and hydrometric measurements hydrodynamics and salinity measurements was carried out in January and March 2013.

A full baroclinic (density varying) three-dimensional hydrodynamic model TELEMAC-3D had to be employed to tackle this complex problem of a buoyant freshwater flow interacting with the more dense saline tidal waters at the Mouth to Galway Docks and Lough Atalia.

Salinity Units ppt and psu

Please note that the salinity measurement data referred to in this report are in the units of psu, whereas the hydrodynamic salinity model TELEMAC-3D refers to salinities in grams of salt per kilogram of solution (g/l or parts per thousand (ppt)). The modern oceanographic definition of salinity is the Practical Salinity Scale of 1978 (PSS-78). The numeric unit from PSS-78 is psu (practical salinity unit) and is distinct from the previous physical quantity ppt (kg salt per kg water in parts per thousand). Salinity values in ppt and psu are nearly equivalent by design, and for the purposes of this assessment can be treated as equivalent.

3. 2. Hydrology of Lough Atalia

3.1. 2.1 General Description

Lough Atalia is a tidal Lough of some 39ha in area, located to the northeast of Galway Docks in Galway City. The Lough is connected to the sea via a 430m long inlet channel which has a railway bridge crossing at its north end, the Galway Harbour Enterprise Park road bridge crossing towards its southern seaward end and a low stone boulder weir located across a wide section of the channel towards the north end, (refer to Figure 1 and 2). The surrounding catchment area to the Lough is of the order of 2.2km^2 and is an urbanised catchment with approximately 30 to 40% paved area.

The bedrock geology of the catchment and the majority of the Lough is a Visean pure bedded limestone, which is classified as regionally important karstic (conduit flow) bedrock aquifer. The southern end of the Lough near the Railway Bridge is classified as a Metagabbro and Orthogneiss bedrock which is a metamorphic rock derived from igneous rock. This represents a hard and impervious rock formation whereas the Visean Limestone is softer and prone to weathering and solution. The bedrock underlying the Docks and the proposed Harbour Extension area is also shown to be Metagabbro and Orthogneiss bedrock.

The Bathymetry of Lough Atalia reveals generally a shallow bay except for a deep pocket towards the southern end of the Lough inside the inlet channel (refer to Figures 5 and 6). This deep pocket is coincides with the interface between the igneous and limestone bedrock formations, with the softer limestone bedrock being eroded over time by the locally high velocities inflowing to the Lough and the igneous rock being much more resistant to erosion. There is only one identified spring feature referred to on the older OSI maps and which is marked on-site by a white Cross as St. Augustine's Well with no other springs being identified either on the OSI or GSI karst database in the vicinity of Lough Atalia.

The salinity in Lough Atalia has been shown to vary significantly with the tidal range and the River Corrib flow rate. Recorded salinities within the lough varied from 1 up to 29 psu over a range of sampling dates in 2012 and 2013. The lough is relatively shallow and is practically completely flushed in a single spring tide. The incoming spring tide initially pushes freshwater into the lough and then as the tide rises sufficiently a more saline wedge is introduced. On neap tides the tidal range (< 0.4m) is insufficient to draw the deeper saline wedge into the lough and consequently the water entering primarily comprises Corrib freshwater from the buoyant surface layer. This affect significantly lowers the salinity within the Lough during the neap tide period. As tidal cycle proceeds from neap to spring tides more saline conditions are returned to the Lough by the deeper saline flows. The magnitude of the Corrib freshwater flow has a significant effect on salinity levels within Lough Atalia being the principal source of freshwater inflow to this tidal Lough.

Because of the large attenuating effect of Lough Corrib and the control of flows and water levels in the Corrib by the OPW at the Salmon Weir sluice facilities, the magnitude of the flow rate discharging to the estuary is a gradually varying discharge with the majority of storm fluctuations dampened out by the lake control (being retained as lake storage for slower release).

Figure 1 Aerial View of Galway Docks, Claddagh Basin and Lough Atalia

Figure 2 Lough Atalia Inlet/outlet Channel, showing bridges and Stone culvert

3.2. 2.2 Hydrodynamics of Lough Atalia

Hydrometric measurements carried out in Lough Atalia in January and March 2013 indicate low water levels in the Lough of 0.5 to 0.6m O.D. and highwater levels of 2.3 to 2.4m OD Malin on spring tides. This tidal range is significantly lower than the tidal range measured inside the Lough at the Galway Docks tidal gauge which registers a spring tide low water level of -2.5m O.D. and highwater level of 2.5m O.D. .

On neap tides the tidal range in Lough Atalia was found to be very weak and practically non-existent at 0.2 to 0.3m range (low water between 0.3 and 0.4m and high water 0.5 to 0.6m OD). The neap tidal range registered for this period at Galway Docks had a low water level of -0.6m and high water level of 1.2m O.D.

The tidal inflow period on spring and neap tides was found to be approximately 2 to 2.5hours and the outflow period from the Lough being a slow release for nearly 10hours. At monitoring location S1 within the Lough the ADCP current profiles showed a strong pulse of inflow to Lough Atalia on spring tides and reducing to little or no appreciable pulse on the neap tides (refer to Figures 3 and 4).

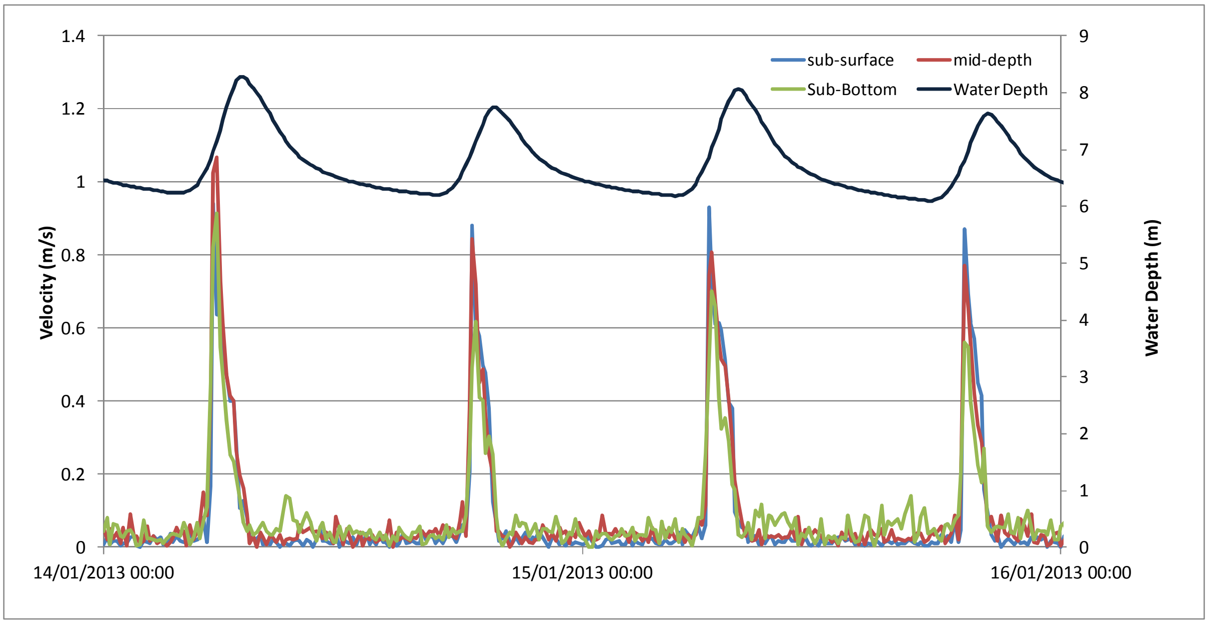


Figure 3 Spring tide observations of current speed and depth at S1 (refer to figure 5 for location) in Lough Atalia

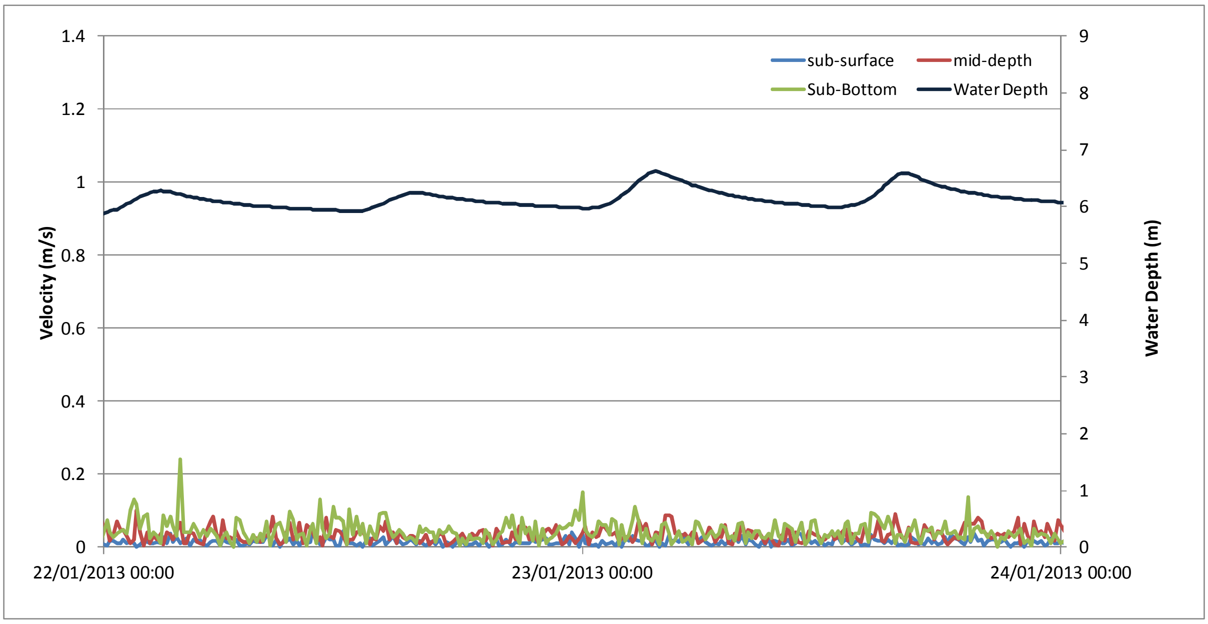


Figure 4 Neap tide observations of current speed and depth at S1 in Lough Atalia

3.3. 2.3 Tidal Exchange

Lough Atalia from inside the Railway Bridge is approximately 39ha in Area. The entrance channel to Lough Atalia dictates the tidal range and tidal flows entering the Lough. This channel acts as a low profile weir maintaining a typically a low water level within the Lough of 0.3 to 0.6m O.D. Malin for neap and spring tides respectively. The channel width varies typically from 45 to 70m with the narrowest point at the Road culvert having an opening width of c. 35m. A stone boulder weir located approximately 100m downstream of the Railway Bridge crosses approximately 75% of the channel width with a top elevation of 0.8 to 1m O.D.

On a spring tide the surface area of Lough Atalia is typically 39ha at high water and 25ha at Low water. The volume of the Lough at highwater is estimated to be 771,200 m^3 (water level of 2.4m O.D.) and 197,500 m^3 at Low water (water level of 0.6m OD). This represents an exchange volume of 573,700m^3 over a tidal cycle (approx 75% of the Lough volume at high water). This exchange volume practically flushes out the entire Lough on a single tide. This tidal exchange represents and average inflow rate over the 2.5hr inflow period of 64m^3/sec (13m^3/sec averaged over the full 12.4hr tidal cycle). The hydraulic residence time within the Lough for a spring tide is 4.2hours which is very short representing excellent flushing characteristics.

On neap tides the surface area of Lough Atalia is typically 25ha at high water and 21ha at Low water. The volume of the Lough at highwater is estimated to be 197,500 m^3 at high water (water level of 0.6m O.D.) and 139,900 m^3 at Low water (water level of 0.35m OD) This represents an exchange volume of 57,600m^3 (approx 30% of the Lough Volume at high water). This tidal exchange represents and average inflow rate over the 2.5hr inflow period of 6.4m^3/sec (a factor of 10 lower than the spring tide rate) or 1.3m^3/sec averaged over the full 12.4hr tidal cycle. The hydraulic residence time within the Lough for a neap tide is about 30hours.

3.4. 2.4 Sources of freshwater inflow

The principal source of freshwater flow to Lough Atalia is from the Corrib which enters Lough Atalia during the relatively short inflow period of 2 to 2.5hours around high water at Galway Docks. Other potential sources of freshwater inflow are from groundwater and direct storm runoff to the Lough from the surrounding Urban Catchment via a number of storm outfalls.
Groundwater inflow contribution to Lough Atalia is estimated to be less than 0.1cumec based on an empirical baseflow equation from the FSR method (NERC 1975) for a catchment area of 2.2km^2 and annual rainfall amount of 1200mm. This rate is not significant in comparison to the tidal exchange volumes entering lough Atalia. However given the karstic nature of the limestone bedrock larger groundwater inflows cannot be ruled out, but the measured salinity data does not suggest any major groundwater inflow source. A further source of freshwater inflow is from direct storm water runoff from surrounding roads and paved areas. On balance such a contribution will generally be minor given the relatively small contributing catchment area.

Table 1 River Corrib Flow and Water Level Magnitudes – Duration Curve

DURATION PERCENTILES
Flows equalled or exceeded for the given percentage of time (m^3/s)

(Data derived for the period 1950 to 2005)							
1%	5%	10%	50%	80%	90%	95%	99%
272	230	200	82.1	35.0	28.5	24.6	9.12
Levels equalled or exceeded for the given percentage of time (mAOD Poolbeg) (Data derived for the period 1950 to 2005)							
1%	5%	10%	50%	80%	90%	95%	99%
4.37	4.04	3.84	3.32	3.02	2.96	2.93	2.85

3.5. 2.5 Salinity measurements

Salinity measurements from discrete sampling surveys within Lough Atalia were carried out on 5 dates in 2012 at 21 sampling sites and for a range of depths through the water column. The dates were 4th, 10th, 16th, 24th April and 4th May 2012. Contour plots of measured salinities at 0.5 to 1m depth below surface are presented in Figure 7 for these dates.

A second series of discrete sampling surveys at 10 sites within Lough Atalia and for a range of depths through the water column was conducted in January 2013. The dates were 11th, 14th, 15th, 18th, 21st, 23rd and 24th of January 2013. Discrete sampling of salinities on the inlet channel to Lough Atalia at the Docks Enterprise Park Road Bridge was carried out for a spring and neap cycle on the 11 and 18th February 2013.

In-situ salinity probes were installed for continuous monitoring of salinity at reference sites S1 and S2 (refer to Figure 6 for locations) for the sampling period 8th Jan to 1st Feb 2013 and 12th March to the 26th March 2013. At S1 three probes were installed to measure near surface, 1.5m depth and 3m depth and at S2, 2 probes were installed near bottom (malfunctioned) and near surface at S2.

The discrete salinity surveys confirmed that spatially there is not generally significant variation in salinity concentrations with the southern end of the Lough being slightly less saline due to its proximity to the inlet channel. The different sampling dates did reveal significant variation between dates in the salinity concentration with neaps being considerably less saline than spring tide periods. The measurements showed increasing salinity with depth particularly for the deeper southern section of the Lough towards the inlet/outlet channel. In the shallower areas of the Lough the variation in salinity with depth was only slight.

The discrete sampling in the lough generally reflected the salinity observations from the continuous probes at S1 and S2. The continuous monitoring at S1 and S2 clearly capture the pulse of the incoming spring tide with a more freshwater inflow preceding a stronger more saline pulse as the incoming tidal height increases, refer to Figure 9 for spring tide monitoring at S1 (12th - 16th January 2013). The neap tide monitoring (See Figure 10) shows considerably lower salinities entering with no definite pulse being observed by the probes due to the weakness of the inflow rate. Inflow water levels are considerable lower and thus only a more freshwater surface layer enters without the deeper more saline water entering the Lough.

The measured salinities on neap tides shown in Figure 10 have salinities consistently below 2.5 psu for repeated neap tides over a 3 to 4 day period. The Corrib Freshwater Flow during this period varied from approximately 150 to 160cumec (25 to 21-percentile Corrib flow rate, (exceeded on average 77 to 91 days per annum) and the neap tidal elevation range in Lough Atalia was only 0.2 to 0.4m. The Spring tide salinities for similar Corrib flows presented in Figure 9 are significantly higher at 12 to 13psu as the tidal range allows the deeper saline wedge to enter Lough Atalia, whereas the neap tide range practically only allows the surface freshwater plume to enter.

The continuous and discrete monitoring shows that depending on the strength of the tide and the Corrib Freshwater flow (which is generally less variable) that salinities within the entire Lough can change rapidly over a number of tidal cycles. This rapid change in salinity is due to the relatively small volume in the Lough that can easily be flushed, the regular lunar variation in the tidal cycle with spring tides declining to neaps and returning to springs over a 14 day interval and other meteorological factors such as storm surges and local wind effects on the flow and tide regime.

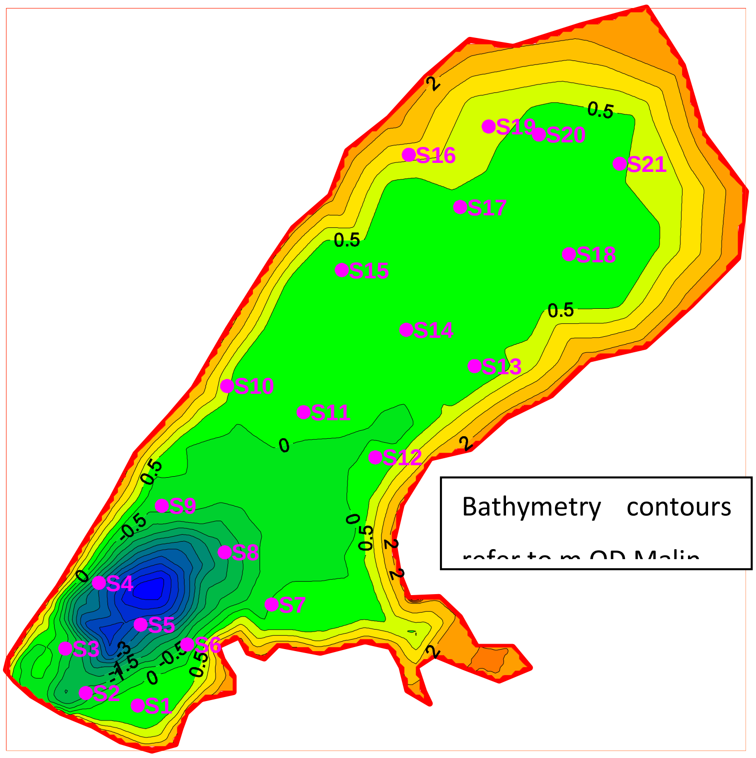


Figure 5 Sampling Locations S1 to S21 in Lough Atalia for 2012 Salinity surveys

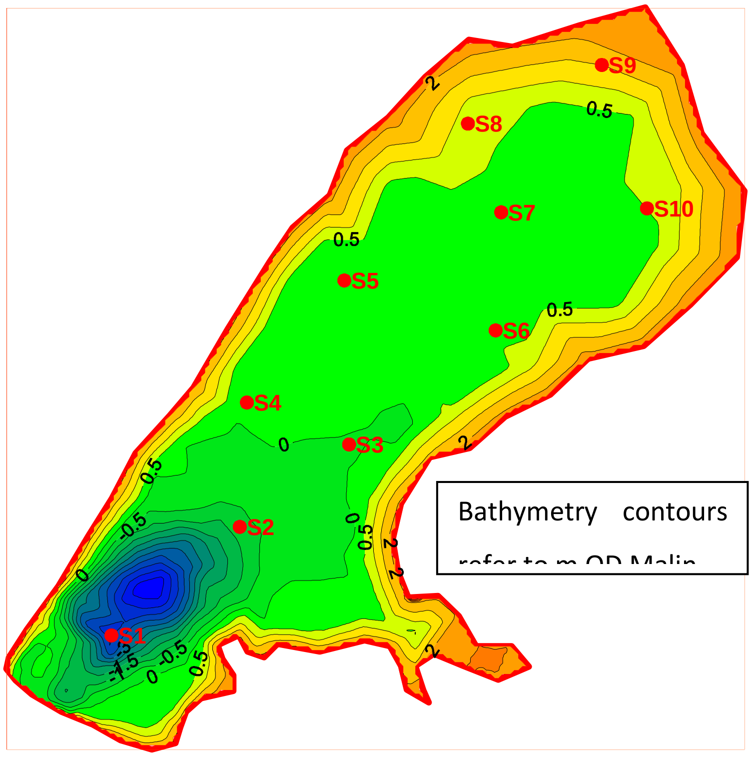


Figure 6 Sampling Locations S1 to S10 in Lough Atalia for 2013 Salinity surveys

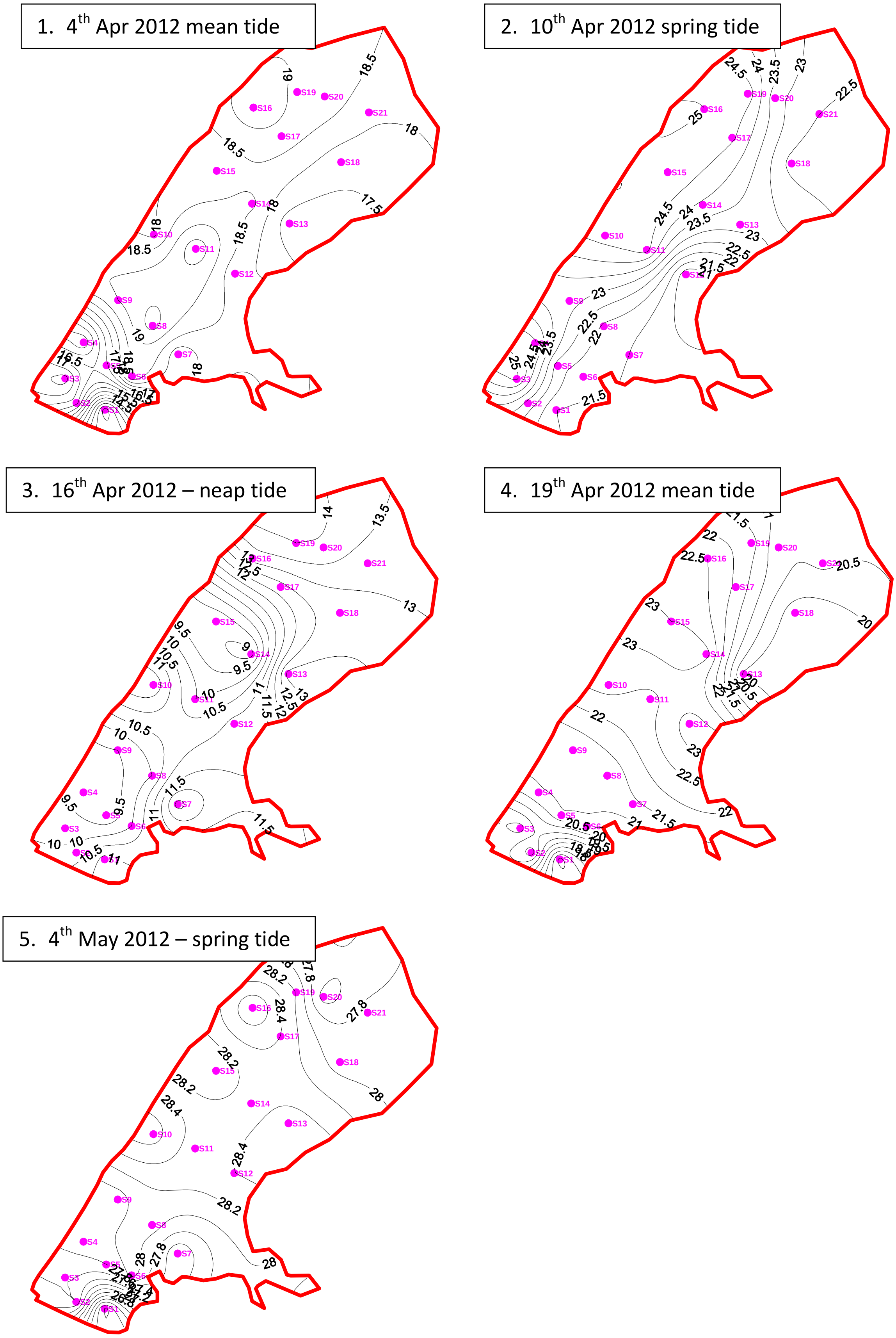
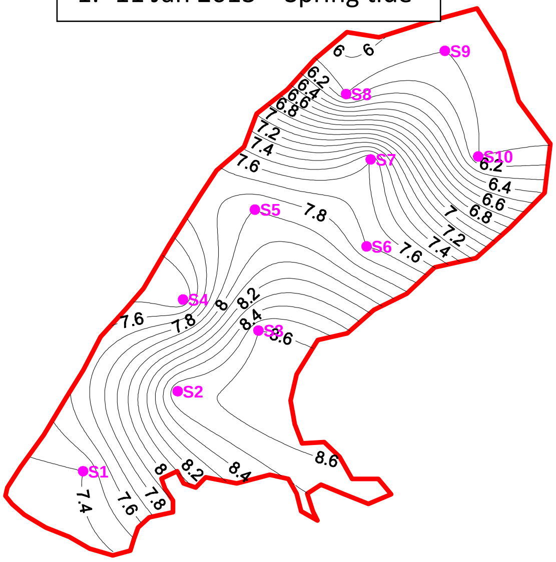
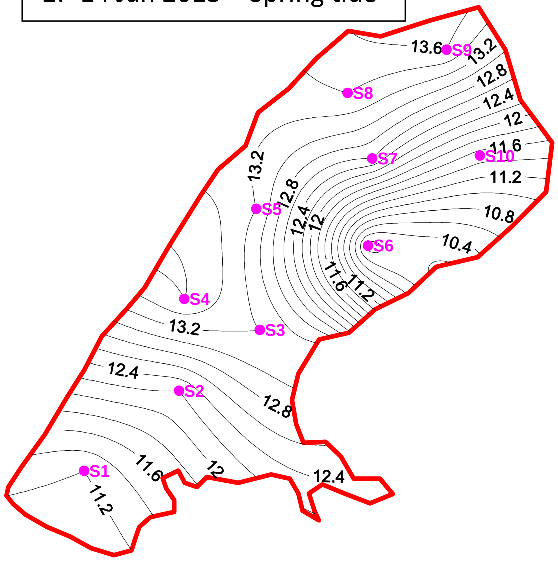


Figure 7 Salinity measurements (psu) at sub-surface 0.5 – 1m depth April – May 2012

1. 11 Jan 2013 – Spring tide

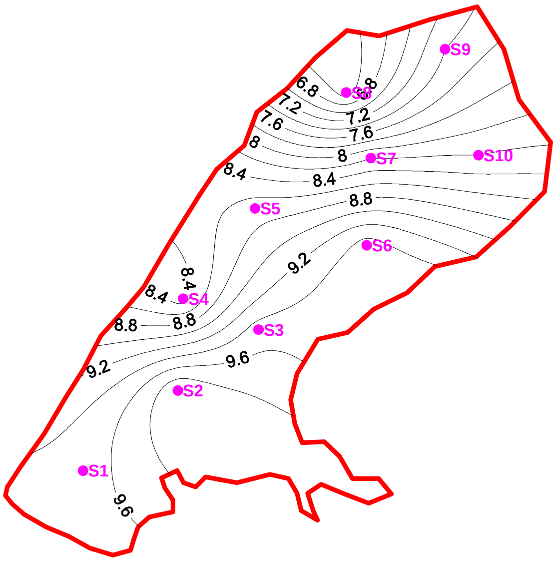


2. 14 Jan 2013 – Spring tide



3. 15 Jan 2013 – Spring tide

4. 18 Jan 2013 – Mean tide



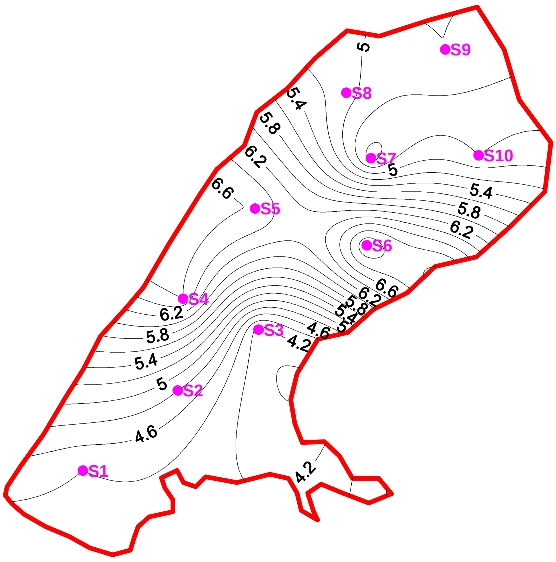
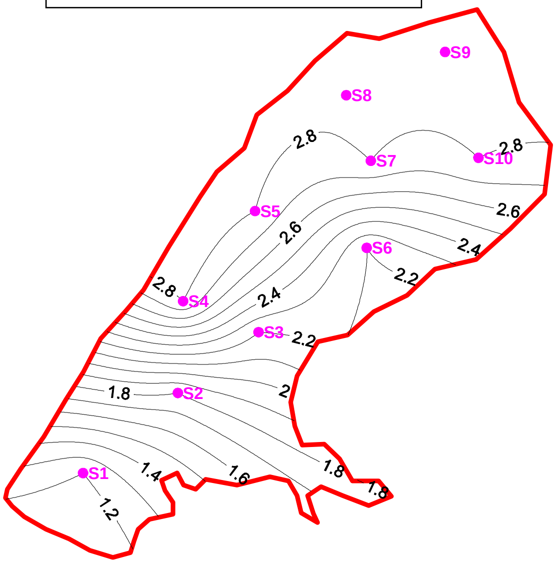
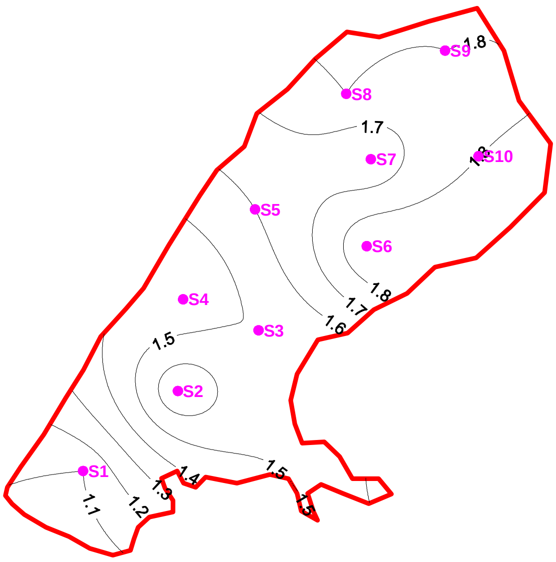


Figure 8 Salinity measurements (psu) at sub-surface (0.5m) depth (14:30 to 15:30hrs) January 2013

5. 21 Jan 2013 – Neap tide

6. 23 Jan 2013 – Neap tide





7. 24 Jan 2013 – Neap tide

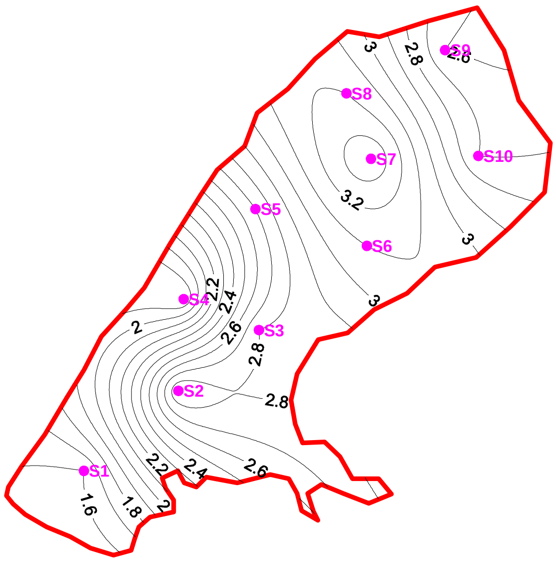


Figure 8 Cont'd. Salinity measurements (psu) at sub-surface (0.5m) depth (14:30 to 15:30hrs) January 2013

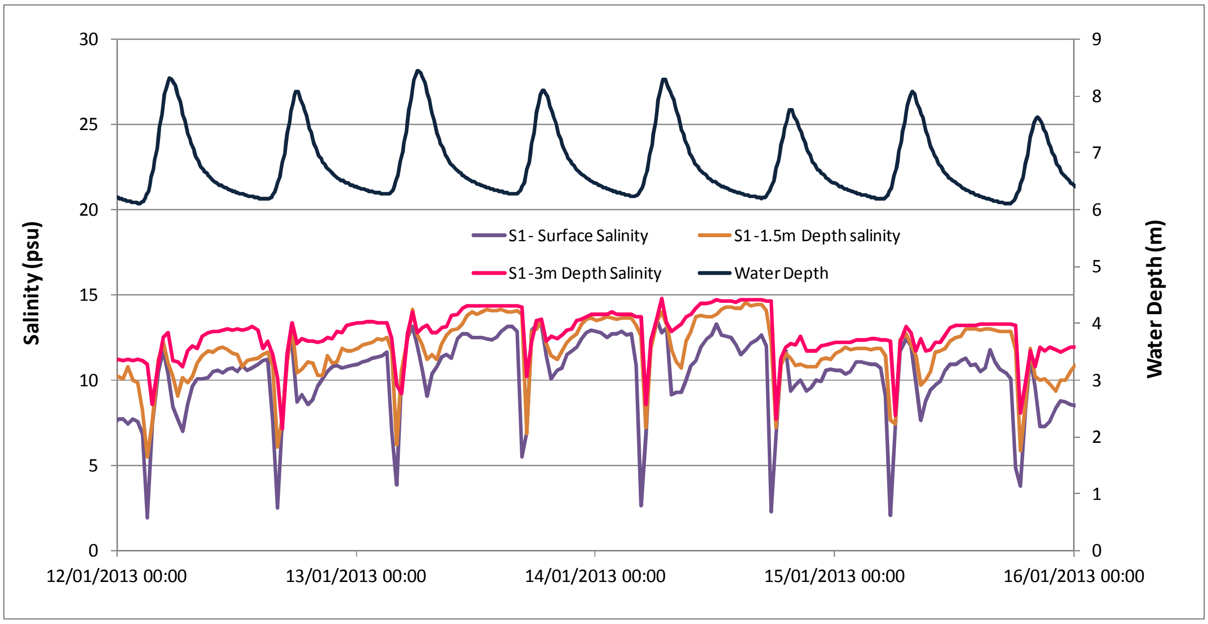


Figure 9 Salinity and Water Depth Measurements for Spring Tidal period at Site S1 - (12 to 16th Jan 2013)

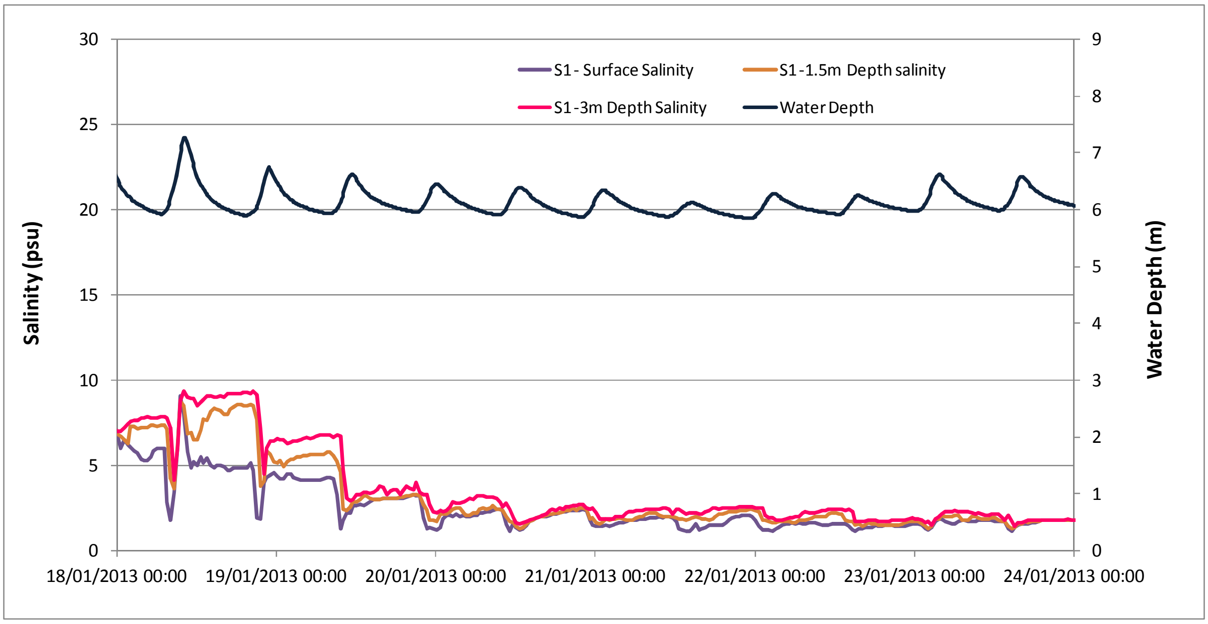
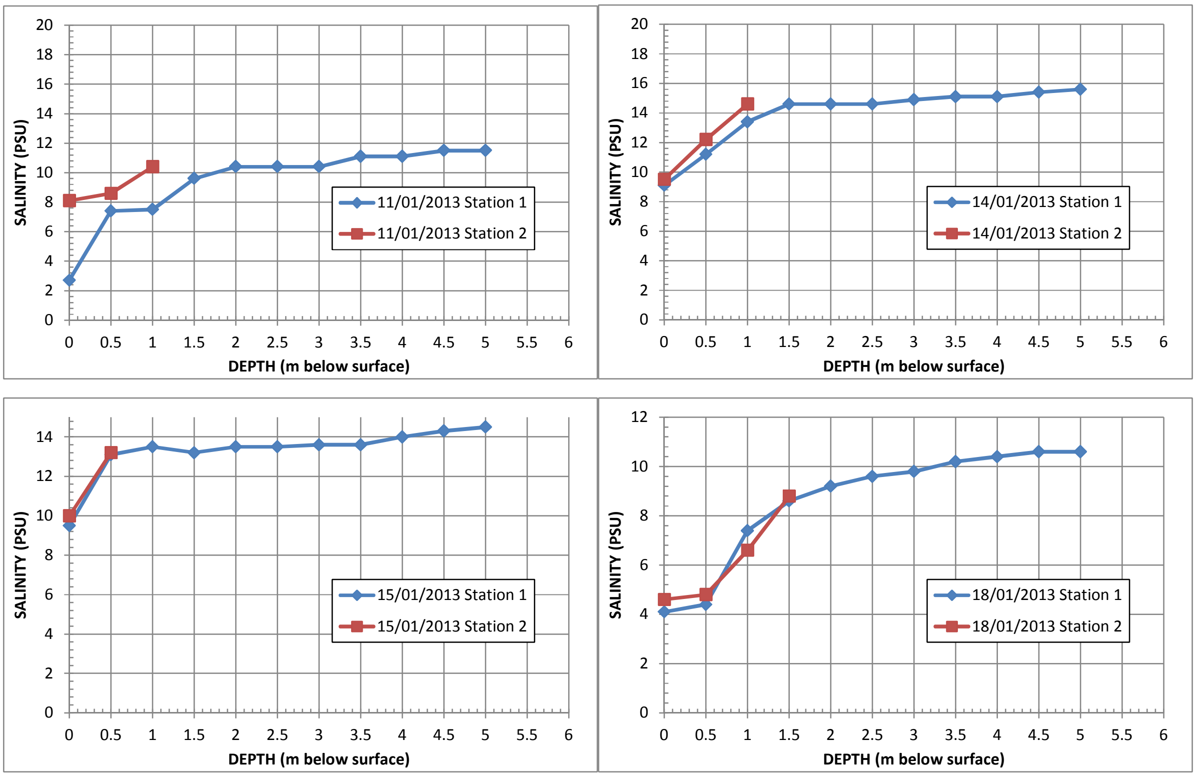


Figure 10 Salinity and Water Depth Measurements for Neap Tidal period at Site S1 - (20 to 24th Jan 2013)



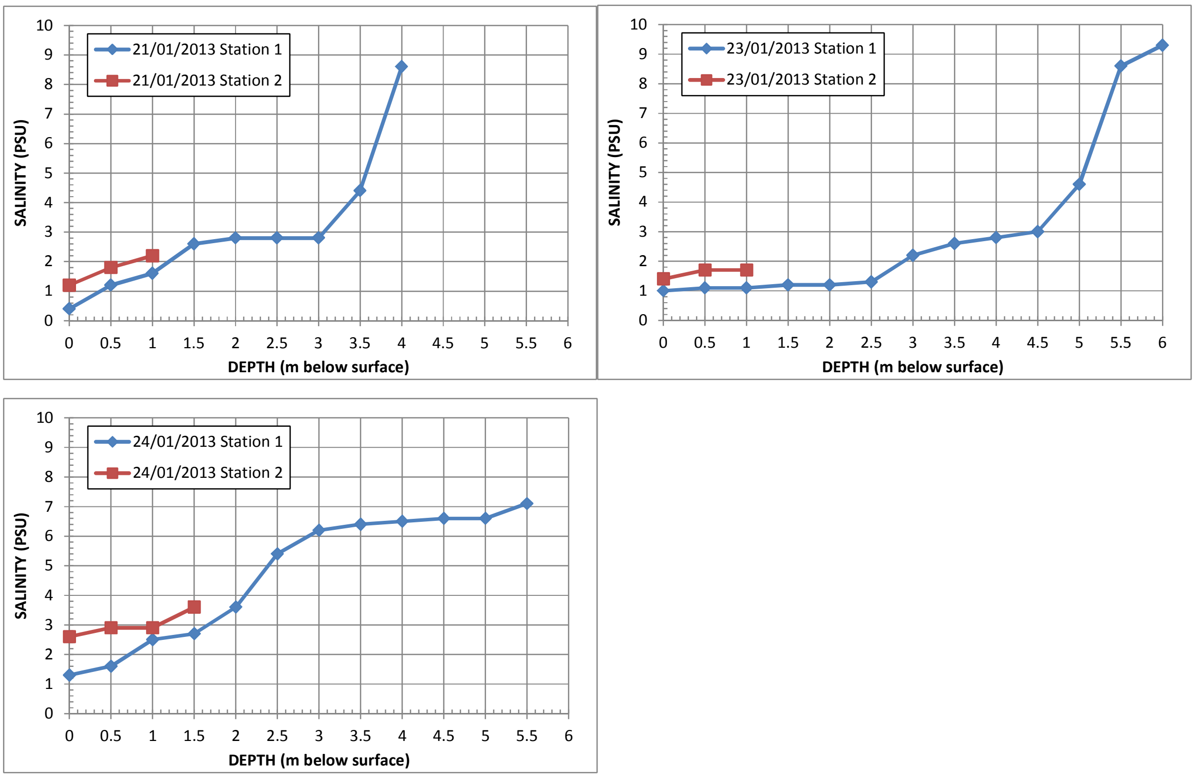


Figure 11 Measured vertical profiles of Salinity at S1 and S2 for January 2013 discrete sampling

4. 3. TELEMAC Hydraulic Software System

4.1. 3.1 Description

The TELEMAC system is the software of choice for modelling the complicated hydrodynamics of the Inner Galway Bay. Particularly given the very high computation refinement required to model the proposed Harbour extension area, the Cladding, Docks and Lough Atalia with its narrow inlet/outlet channel. TELEMAC is a software system designed to study environmental processes in free surface transient flows. It is therefore applicable to seas and coastal domains, estuaries, rivers and lakes. Its main fields of application are in hydrodynamics, water quality, sedimentology and water waves.

TELEMAC is an integrated, user friendly software system for free surface waters. TELEMAC was originally developed by Laboratoire National d'Hydraulique of the French Electricity Board (EDF-LNHE), Paris. It is now under the directorship of a consortium of organisations including EDF-LNHE, HR Wallingford, SOGREAH, BAW and CETMEF. It is regarded as one of the leading software packages for free surface water hydraulic applications and with more than 5,000 Telemac Installations Worldwide.

The TELEMAC system is a powerful integrated modelling tool for use in the field of free-surface flows. Having been used in the context of very many studies throughout the world (many thousands to date), it has become one of the major standards in its field. The various simulation modules use high-capacity algorithms based on the finite-element method. Space is discretised in the form of an unstructured grid of triangular elements, which means that it can be refined particularly in areas of special interest. This avoids the need for systematic use of embedded models, as is the case with the finite-difference method. Telemac-3D is a full three-dimensional computational code describing the horizontal and vertical velocities, water depth and free surface over space and time under barotrophic and density gradients. In addition it solves the transport of several tracers which can be grouped into two categories, active and passive, with salinity and temperature being the active tracers which alter density and thus the hydrodynamics.

4.2. 3.2 Background Theory

TELEMAC-3D is a three-dimensional computational code describing the 3D velocity field (*u*, *v*, *w*) and the water depth *h* (and, from the bottom depth, the free surface *S*) at each time step. It also solves the transport of several tracers which can be grouped into two categories, namely the "active" tracers (temperature and salinity), which change the water density and act on flow through gravity), and "passive" tracers which do not affect the flow and are merely transported.

NON-HYDROSTATIC (Baroclinic) NAVIER-STOKES EQUATIONS

The following system (with an equation for W which is similar to those for U and V) is then to be solved:

$$\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}+\frac{\partial W}{\partial z}=0$$
$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}+W\frac{\partial U}{\partial z}=-g\frac{\partial Z_S}{\partial x}+\upsilon\,\Delta(U)+F_x$$
$$\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}+W\frac{\partial V}{\partial z}=-g\frac{\partial Z_S}{\partial y}+\upsilon\,\Delta(V)+F_y$$
$$\frac{\partial W}{\partial t}+U\frac{\partial W}{\partial x}+V\frac{\partial W}{\partial y}+W\frac{\partial W}{\partial z}=-g\frac{\partial Z_S}{\partial z}+g+\upsilon\,\Delta(W)+F_z$$

Where,

h	(m)	water depth
S	m O.D.	water surface elevation
U, V, W	(m/s)	x, y and z three-dimensional components of velocity
T	^{o}C or g/l	active (acting on density) or passive tracer
ν ν_T	m2/s	viscosity and tracer diffusion coefficients
g	(m/s2)	gravitational acceleration
p	(Pa)	pressure
p_{atm}	(Pa)	atmospheric pressure
ρ_o	kg/m3 (g/l)	reference water density
$\Delta\rho$	kg/m3 (g/l)	variation in density
t	(s)	time
x, y	(m)	horizontal space component
z	(m)	vertical space component
Fx, Fy	(m/s2)	Source terms (wind, the Coriolis and the bottom friction forces)
Q	(tracer unit)	Tracer source or sink
Z_f	(m)	Bottom Depth

h, *U*, *V*, *W* and *T* are the unknown quantities, also known as computational variables.

In order to share a common core as much as possible with the solution of the equations with the hydrostatic pressure hypothesis, the pressure is split up into a hydrostatic pressure and a "dynamic" pressure term.

The TELEMAC-3D algorithm solves a hydrostatic step which is the same as in the previous paragraph, the only differences lying in the continuity step ("projection" step in which the dynamic pressure gradient changes the velocity field in order to provide the required zero divergence of velocity) and the computation of the free surface.

$$p=p_{atm}+\rho_0 g(Z_S-z)+\rho_0 g\int_z^{Z_S}\frac{\Delta\rho}{\rho_0}dz+p_d$$

In most of the simulations, salinity and temperature make it possible to compute the variations of density. The following law expresses the variation of density from these two parameters.

$$\rho = \rho_{ref}\left[1 - \left(T\left(T - T_{ref}\right)^2 - 750S\right)10^{-6}\right]$$

With T_{ref} as a reference temperature of 4℃ and ρ_{ref} as a reference density at that temperature when the salinity is zero, then ρ_{ref} = 999.972 kg/m3. That law remains valid for 0℃ < T < 40℃ and 0 g/L < S < 42 g/L.

EQUATIONS OF TRACERS

The tracer can be either active (it affects hydrodynamics) or passive in TELEMAC-3D. Temperature, salinity and in some cases a sediment are active tracers. The tracer evolution equation is formulated as:

$$\frac{\partial T}{\partial t} + U\frac{\partial T}{\partial x} + V\frac{\partial T}{\partial y} + W\frac{\partial T}{\partial z} = \frac{\partial}{\partial x}\left(\nu_T\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\nu_T\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\nu_T\frac{\partial T}{\partial z}\right) + Q$$

TURBULENCE MODEL

The Reynolds numbers ($R = UL/\nu$) reached by the currents at sea or in an estuary are excessively high and illustrate basically turbulent flows (L, the scale of eddies, for example, assumes the value of water depth h for a vertically homogeneous flow). For such a kind of flow, the turbulence-induced momentum is by far prevailing (in relation to the molecular diffusion). That diffusion is strictly defined by a tensor which represents different characteristics according to the directions.

The concept of eddy scale, however, is spatially constrained by the horizontal and vertical scales of the modelled domain. At sea, for example, a one kilometre long cape can generates eddies the dimensions of which are horizontally related to that scale. Vertically, however, the eddy size is constrained by the water depth also and even more by possible effects of stratifications.

MIXING LENGTH MODEL

In the Mixing Length Turbulence model the vertical diffusivity of velocities is computed by means of the selected mixing length model taking or not taking the effects of density into account. The mixing length model expresses the turbulent viscosity (or diffusion coefficient) as a function of the mean velocity gradient and the mixing length (i.e. Prandtl's mixing theory):

$$\nu = L_m^2\sqrt{2D_{ij}D_{ij}} \text{ , where } D_{ij} = \frac{1}{2}\left(\frac{\partial \overline{U}_i}{\partial x_j} + \frac{\partial \overline{U}_j}{\partial x_i}\right)$$

The following options for the mixing length model are available

- Prandtl (default). Standard Prandtl's model. That formulation suits such flows with a strong barotropic component as the tidal flows,
- Nezu and Nakagawa. Nezu and Nakagawa model,
- Quetin. Better representation of wind drift. In windy weather, a surface boundary layer is formed and viscosity decreases,
- Tsanis. Better representation of wind drift.

The graph below shows the variations of the mixing length for the various models.

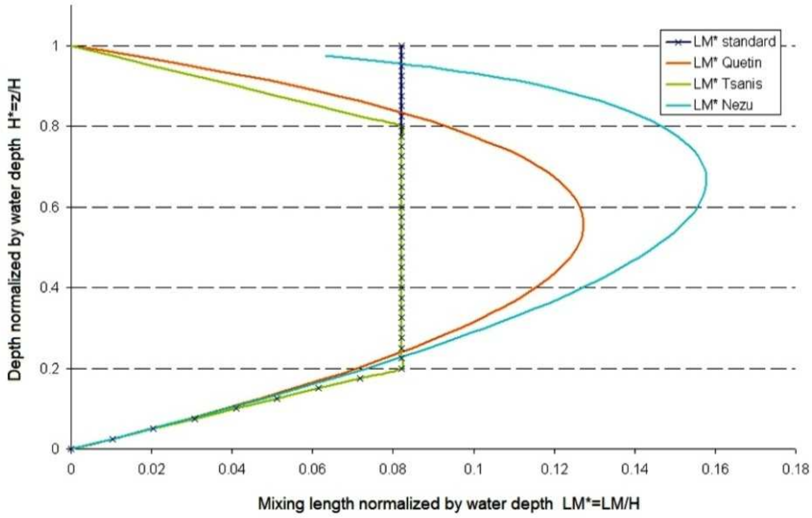


Figure 12 Mixing Length Models

In the presence of a vertical density gradient, the environment stability (respectively the instability) hinders (enhances) the vertical exchanges of mass and momentum. In order to quantify the effects of the gravity terms in the turbulent power balance, the dimensionless Richardson number is commonly used. It is a local number the value of which can obviously be different at each flow point. In order to take the mixture reduction into a stable stratified flow into account, a damping law is introduced into the turbulence model according to the Richardson number. The available damping function options are:

- Viollet,
- Munk and Anderson.

The graph below illustrates the variation of the Munk and Anderson damping function according to the Richardson number for velocity and salinity. In the case of a stable stratification, the pressure fluctuations more readily transmit a momentum flux than a mass flux and the diffusion coefficient becomes higher for the velocities than for the mass.

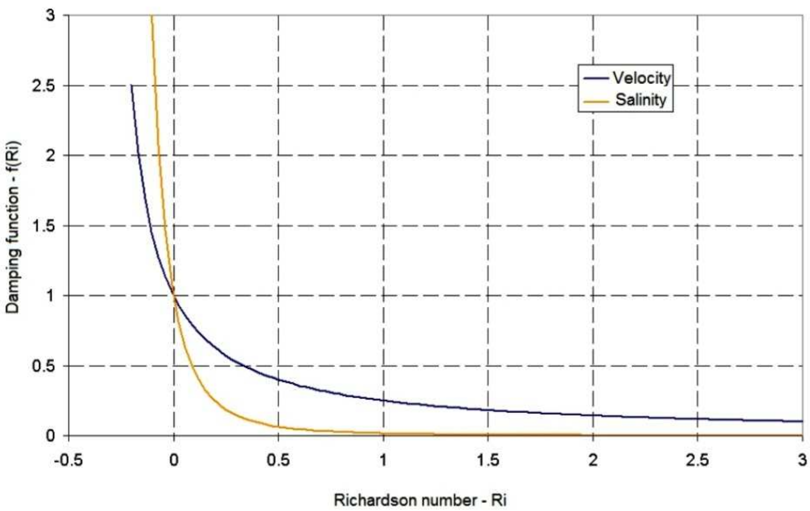


Figure 13 Munk-Anderson Dampening Function

THE DISCRETIZATION

The TELEMAC-3D mesh structure is made of prisms (eventually split in tetrahedrons). In order to prepare that mesh of the 3D flow domain, a two-dimensional mesh comprising triangles which covers the computational domain (the bottom) in a plane is first constructed, as for TELEMAC-2D. The second step consists in duplicating that mesh along the vertical direction in a number of curved surfaces known as "planes". Between two such planes, the links between the split triangles make up prisms. The computational variables are defined at each point of the three-dimensional mesh, inclusive of bottom and surface.

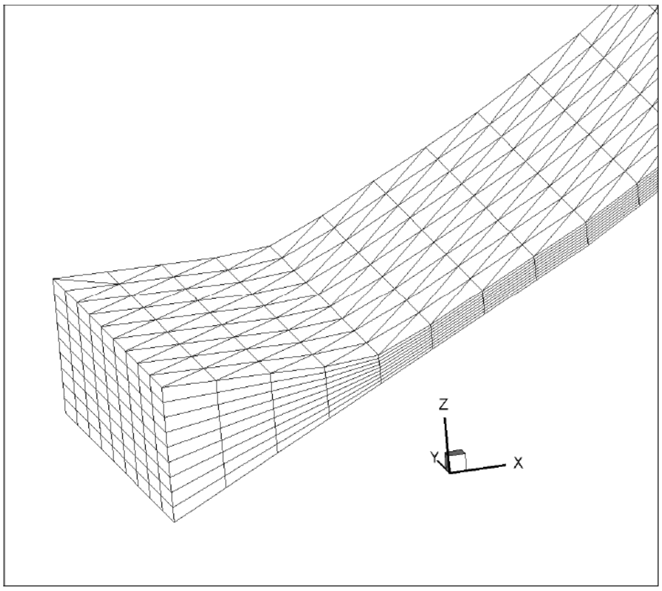


Figure 14 Three-dimensional meshing using sigma coordinates in the vertical direction

4.3. 3.3 Data Sources

BATHYMETRY
The sources of data used to define the existing Bathymetry are as follows:

- Aquafact Surveys of the Approach Channel, Cladding area, Lough Atalia, the Proposed Harbour Extension area east of the approach channel.
- Survey of the Lough Atalia channel January 2013
- The Infomar (GSI) Lidar Data Set of Galway Bay – survey 22may to 14 June 2008.

MARINE & HYDROLOGICAL DATA

- Waterlevels.ie for Gauge 30061 – Corrib Estuary at Wolfe Tone Bridge
- Tide Levels for Galway Docks – Irish National Tide gauge Network
- ADCP currents and depth measurements in Lough Atalia January and March - 2013 Aquafact International
- Continuous Salinity monitoring by in-situ salinity probes in Lough Atalia January and March 2013
- Discrete Sampling surveys of Salinity in Lough Atalia – April-May 2012 and January 2013

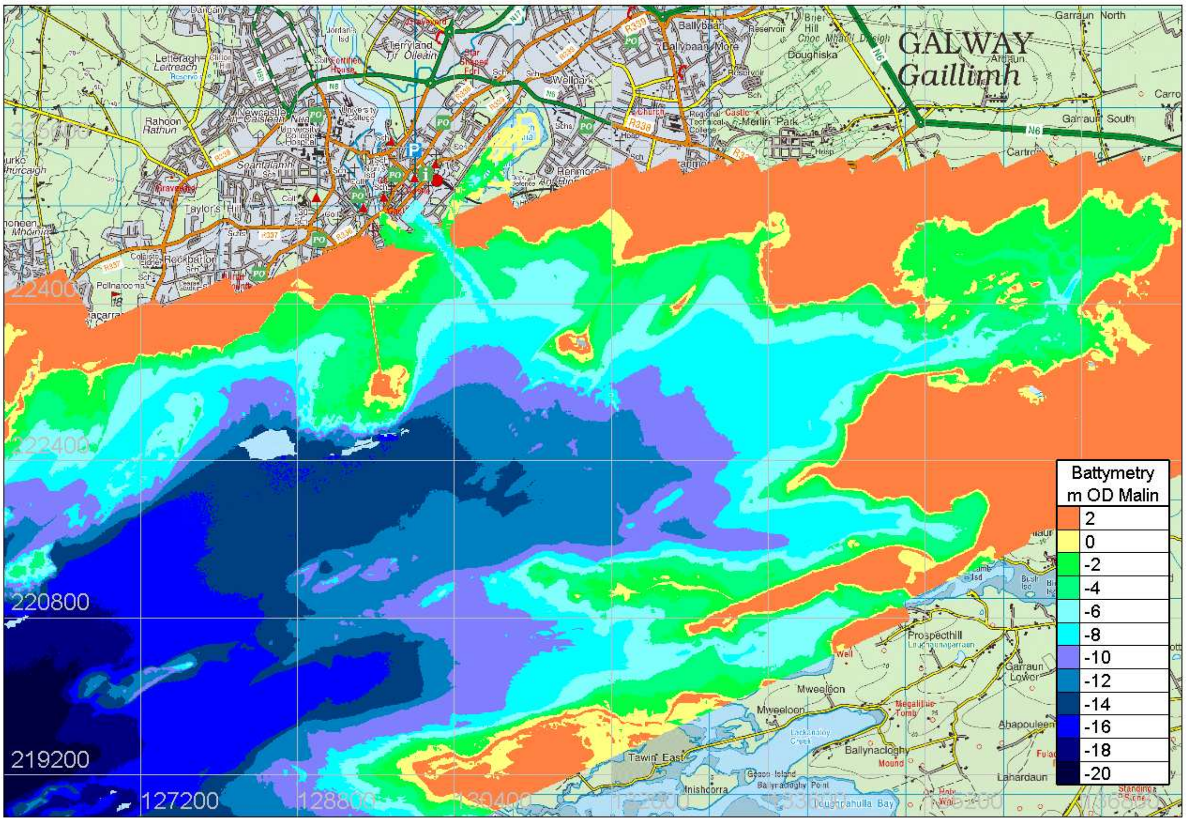


Figure 15 Bathymetry Data from GSI Lidar Aquafact Local bathymetry surveys

4.4. 3.4 Model Development

Due to the high computational requirement of a full three-dimensional baroclinic model the modelled domain for assessing the impact of the Harbour Extension on salinities was confined to the inner northerly section of Galway Bay. The model domain area is presented in Figure 16 which extends from Blakes Hill at and Kilcolgan Pt. on Twain Island easterly into Oranmore Bay. Very high refinement is provided in the Docks area, Lough Atalia Channel and the proposed harbour extension area (refer to Figure 17). This model domain represents a tidal water body of some 41 km^2 in Area.

Two models of the Study area were required to represent the existing case (without the Harbour Extension) and the proposed case (with the Harbour Extension). In order to achieve accurate comparisons between existing Case and proposed case models the same mesh structure was used, with the only difference being that the elements located within the harbour extension infill footprint are retained for the existing case and removed for the proposed case and the resultant land boundary nodes defined. This meshing approach ensures that nodal points within the live domain at which velocity, depth, surface elevation and tracer concentration are computed exactly match up and that the same resolution/refinement is achieved for both models. This approach minimises any numerical differences in the predicted results associated with the meshing effects.

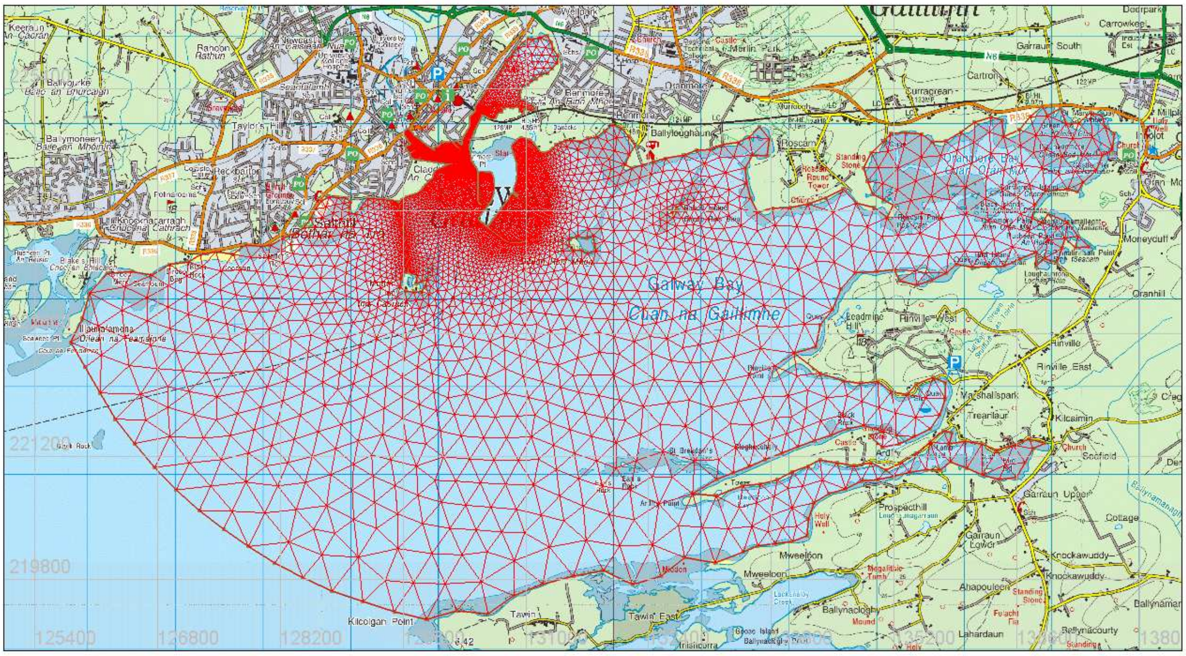


Figure 16 Extent of Three-dimensional Model Domain for Salinity Predictions

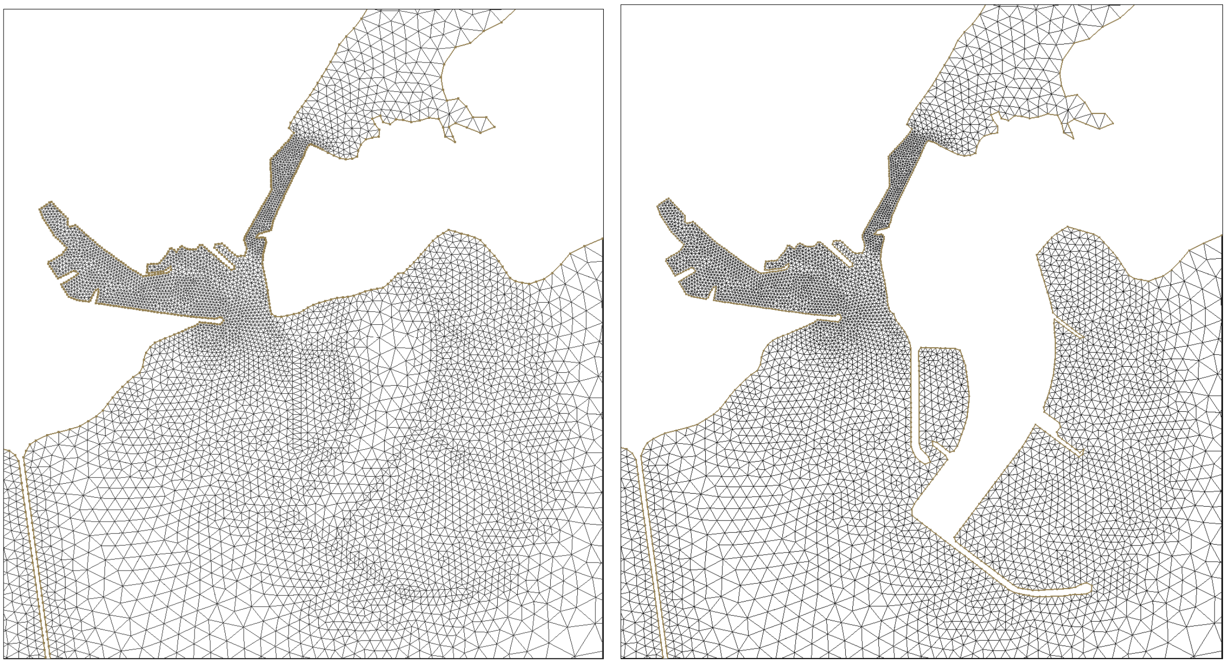


Figure 17 Model Grid structure and refinement for Existing and Proposed Development Cases

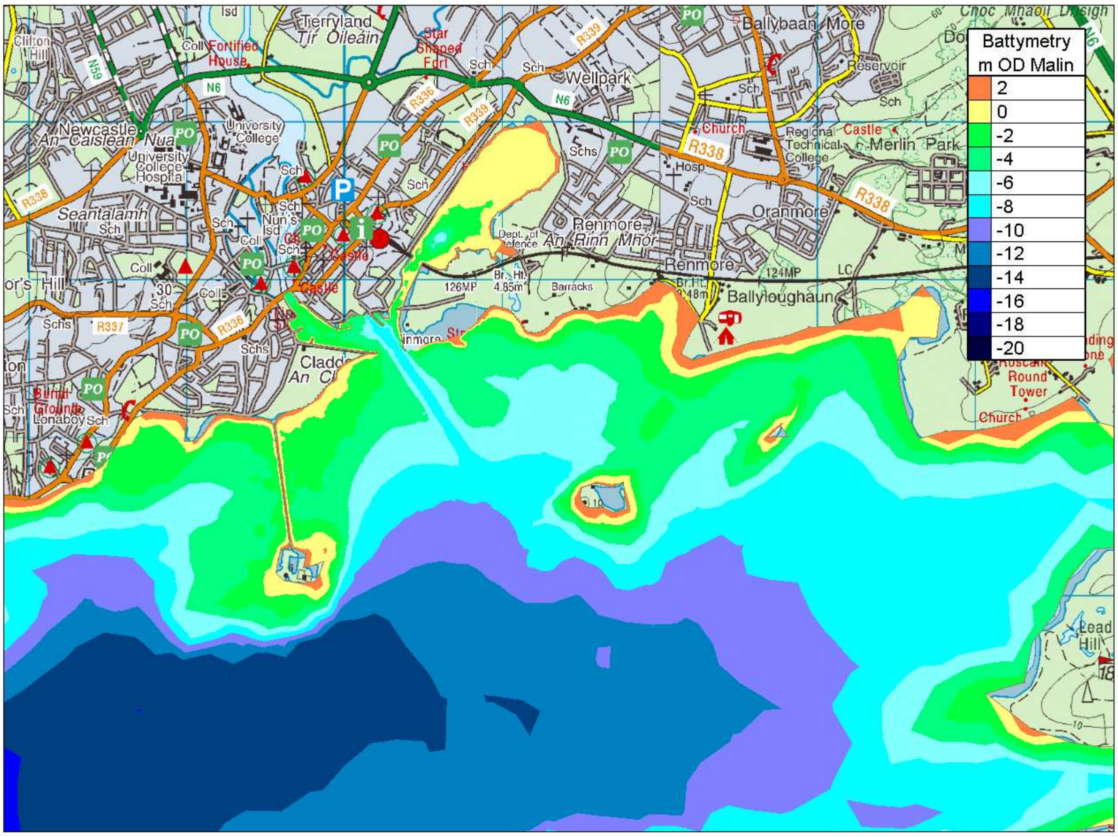


Figure 18 Modelled Bathymetry in the vicinity of the subject site – Existing Case

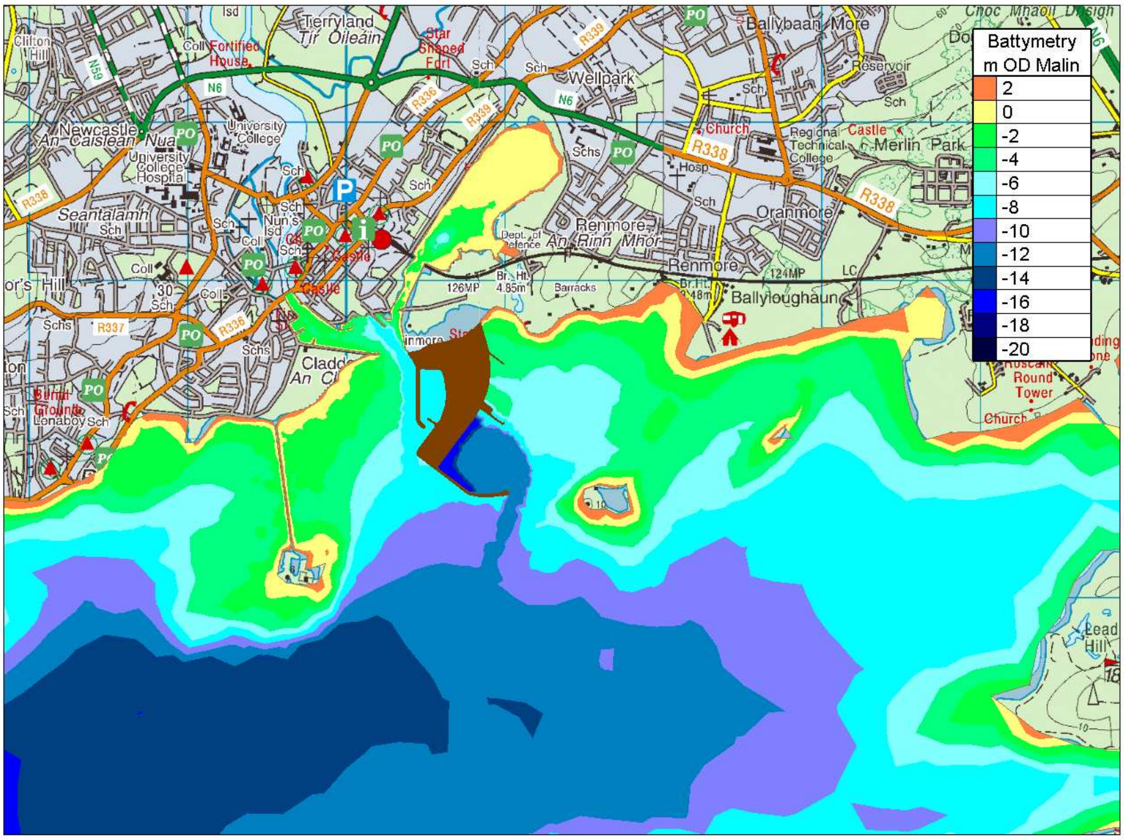


Figure 19 Modelled Bathymetry in the vicinity of the subject site – Proposed Case

The finite element mesh for the existing case model has 33,665 nodal points and 150,888 elements and the finite element mesh for the proposed case model has 32,205 nodal points and 141,120 elements. The number of vertical layers specified in the model is 5. A sigma transformation is used which sets a homogeneous distribution of levels in the vertical direction (known as a classical sigma transformation). The height of the layers vary depending on the water depth, all planes can move (refer to Figure 20).

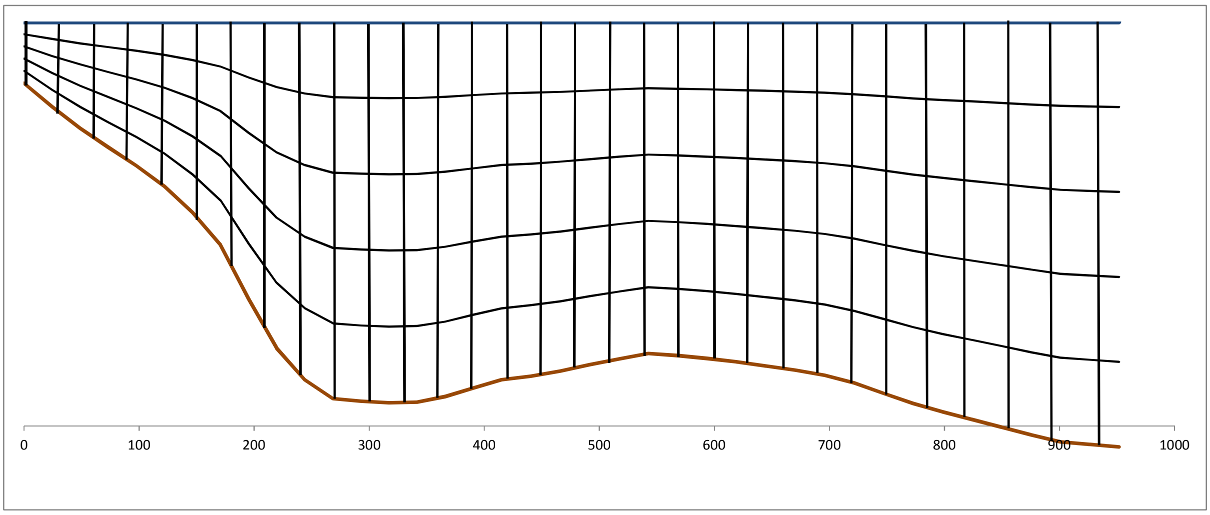


Figure 20   Representation of 5 vertical Layers in sigma coordinates

4.5. 2.5 Boundary Conditions

The boundary conditions specified in the model was tidal elevation along the western open sea boundary and the River Corrib discharge on the north boundary downstream of Wolfe Tone Bridge.
The OPW flow duration curve for their Wolf Tone Gauging site (refer to Table 1 presented earlier) is used to specify the design flow events and the gauged daily flows for the Wolf Tone Gauging site specified for the relevant calibration periods.

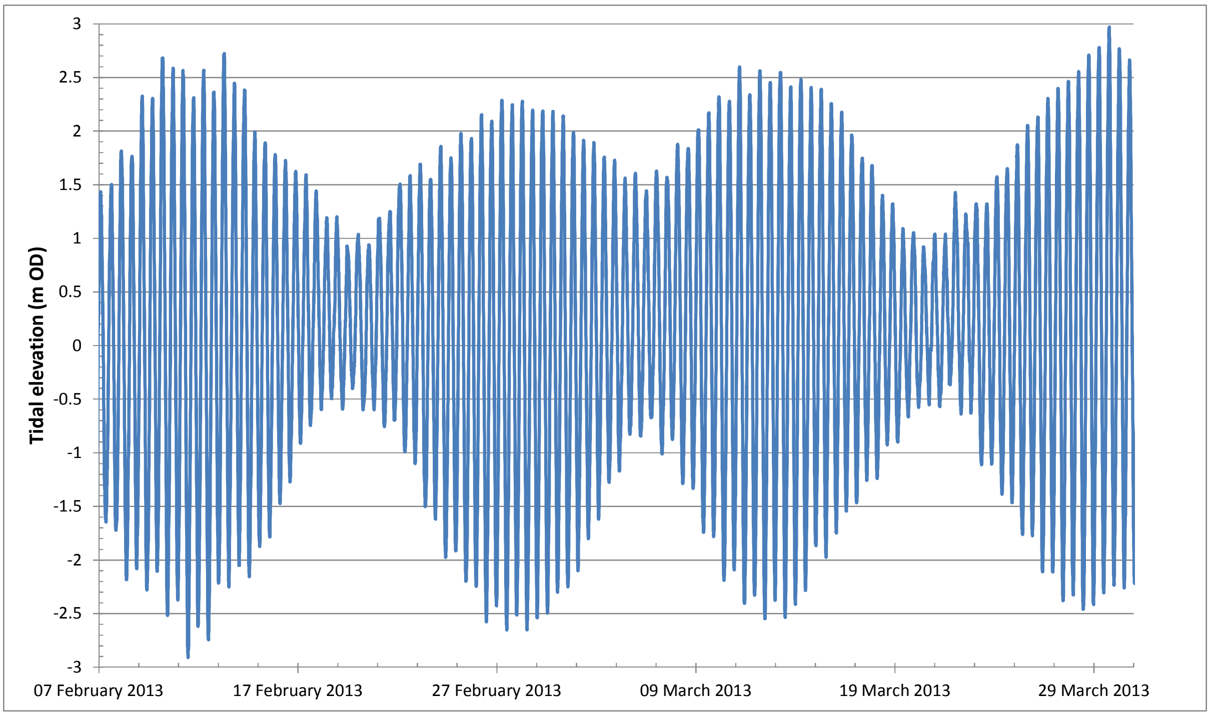


Figure 21 Tidal Data for Galway Docks

Table 2 **Tidal Heights in the Galway Bay**

Water level m O.D. Site	MHW Springs	MHW Neaps	MLW Neaps	MLW Springs	Highest Astronomical Tide
Galway Bay - Inner	2.19	0.99	-0.91	-2.31	2.75

4.6. 3.6 Dispersion Model Calibration

The three-dimensional hydrodynamic and dispersion model was calibrated against continuous measurements of current speeds, depth and salinity concentrations in Lough Atalia for January and March 2013 monitoring periods. The recorded tidal elevations and Corrib flows for these calibration events are presented in Figures 22 and 23. Both calibration events cover the spring neap tidal range and River Corrib flows of 145 to 175cumec for the January 2013 event and 55 to 70cumec for March 2013 event.
The model calibration parameters for tuning the model equations to achieve best agreement was bed roughness, horizontal and vertical viscosity and diffusion coefficients. The Lough Atalia inlet channel was artificially roughened to achieve good agreement with the measured velocities and water depths

in Lough Atalia, refer to Figures 24 to 29 for January calibration event and Figures 32 to 36 for the March event. The model captures the pulse of inflow through raised velocities over a 2 to 2.5hr period and the slow reduced velocities during the outflow period. Importantly it also captures the reduced range in tide levels within Lough Atalia relative to the Galway docks and the significantly reduced tide levels and velocities associated with neap tides.

The Salinity calibration involved selecting a density driven baroclinic model to achieve suitable agreement with measured time series of salinity at sites S1 and S2 (refer to Figure 6 for location). Originally a hydrostatic model was run in which density obeyed the hydrostatic law and salinity treated as a passive tracer. The results from this model produced poor agreement with measurement and tended to mix over the depth the Corrib freshwater flow with almost freshwater conditions produced in Lough Atalia with little variation between Spring and neap tides. A Baroclinic model which is considerably more computationally demanding was used and through the introduction of the Prandtl mixing length vertical turbulence model with Munk Anderson damping for stratification much more realistic results were produced for Lough Atalia, refer to Figure 30 and 31 for January 2013 events and Figure 39 for March 2013 events.

As can be seen from these figures reasonable agreement is achieved with the measured salinities and replicating the trend of spring tides introducing higher saline concentrations and the neap tides producing considerably lower salinities, which are almost steady, non-varying over the neap tidal cycle due to the low tidal range within Lough Atalia. The actual measured data in comparison to the model predictions show greater variation in salinity concentrations over the tidal cycle with neap tides consistently less saline within Lough Atalia than the modelled salinities. The model is unable to achieve this range in salinity due to unavoidable numerical mixing in the horizontal and vertical layers associated with the numerical scheme. However the salinity calibration results show that the model is sufficiently capable of predicting salinities and salinity variation within Lough Atalia and is considered fit for the purpose of predicting relative difference in salinity between the existing and proposed cases.

The measured data for neap tides at only moderate winter Corrib flows of 150 to 160 cumec (on average exceeded at least 77 to 91days per annum) show almost freshwater like conditions within Lough Atalia (i.e. measured salinities consistently below 2.5 psu). For larger flows of 1 to 5percentile occurrence (230 to 272cumec), on average 4 to 18days per annum it is expected that the salinities in Lough Atalia will tend towards nil salinity throughout the neaps tides.

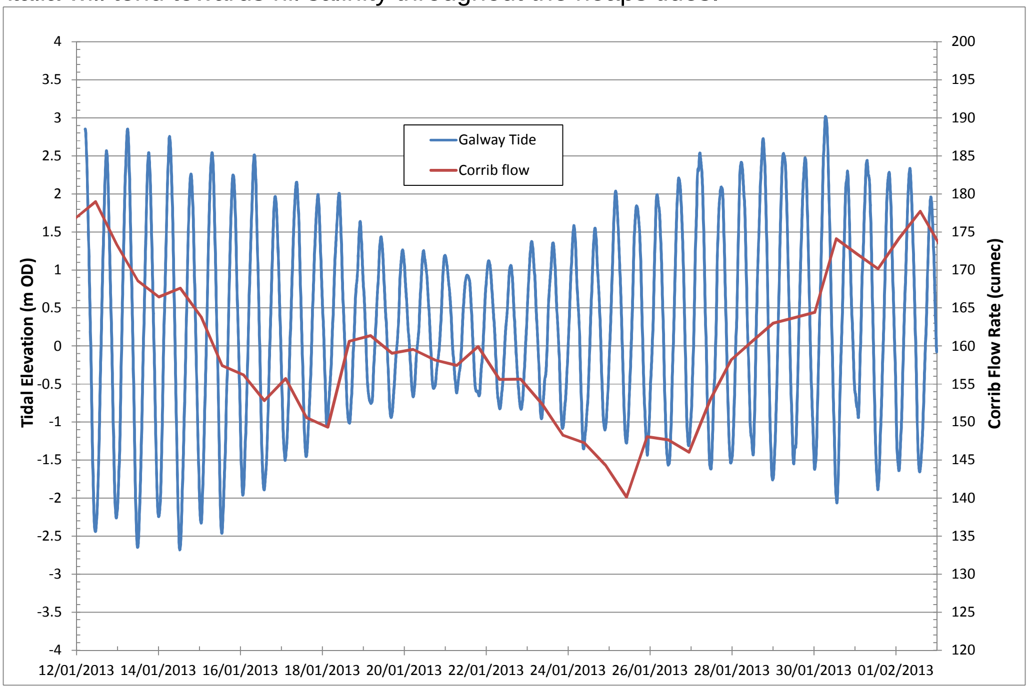


Figure 22 Boundary conditions specified for the January 2013 Salinity Calibration Simulation

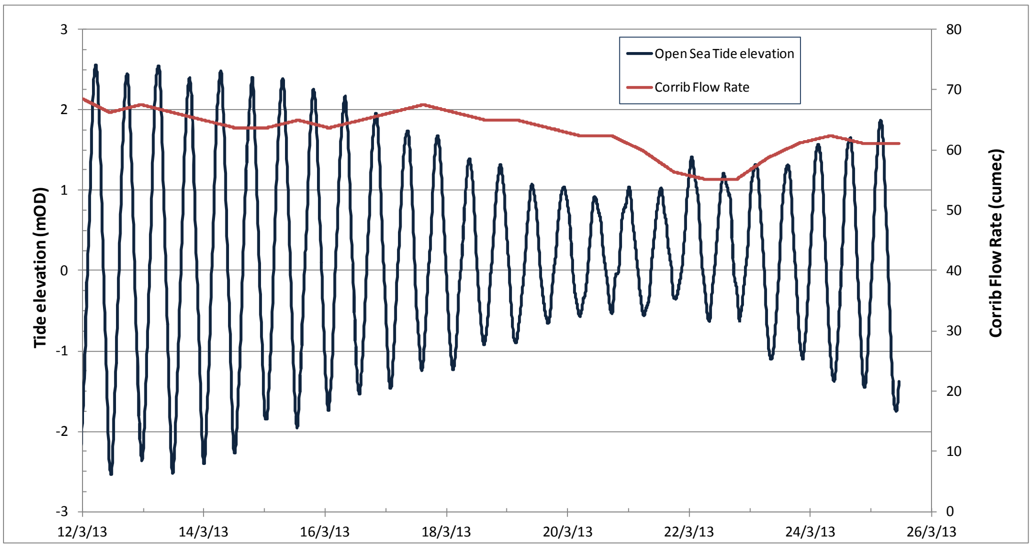


Figure 23 Boundary Conditions Specified for March 2013 Salinity Calibration Simulation

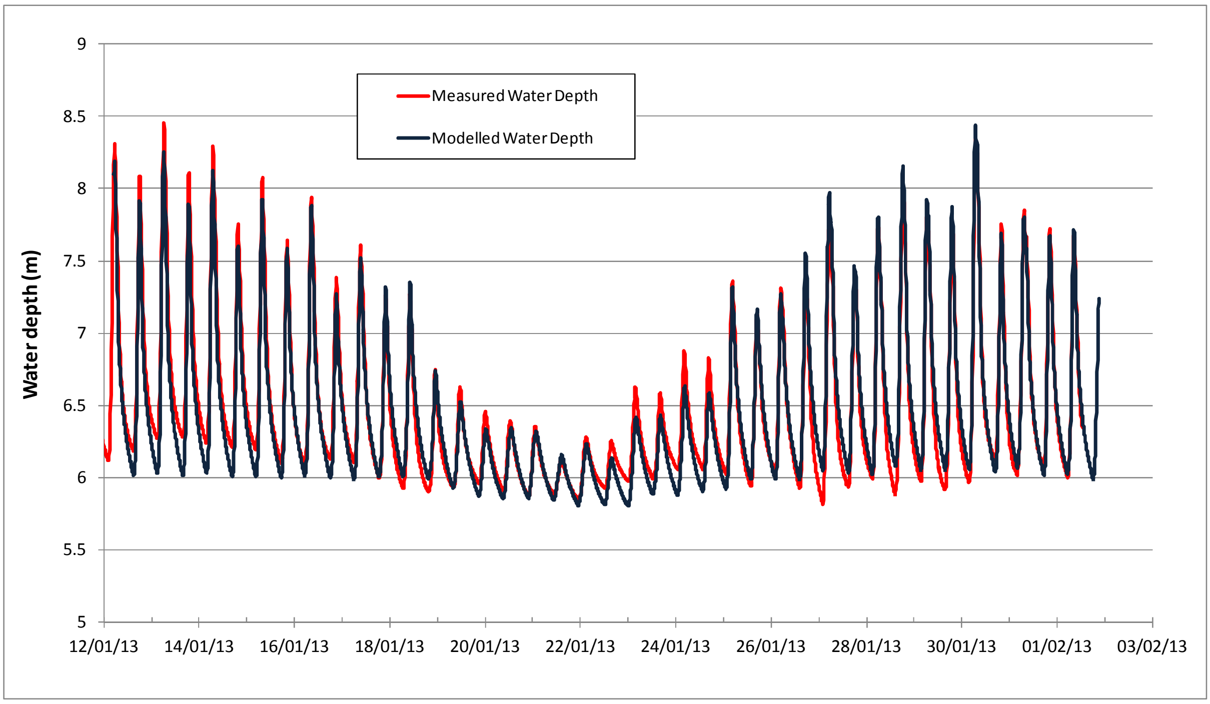


Figure 24 Comparison between measured and computed (modelled) water depth at reference Site S1 in Lough Atalia 12th January to 1st Feb 113

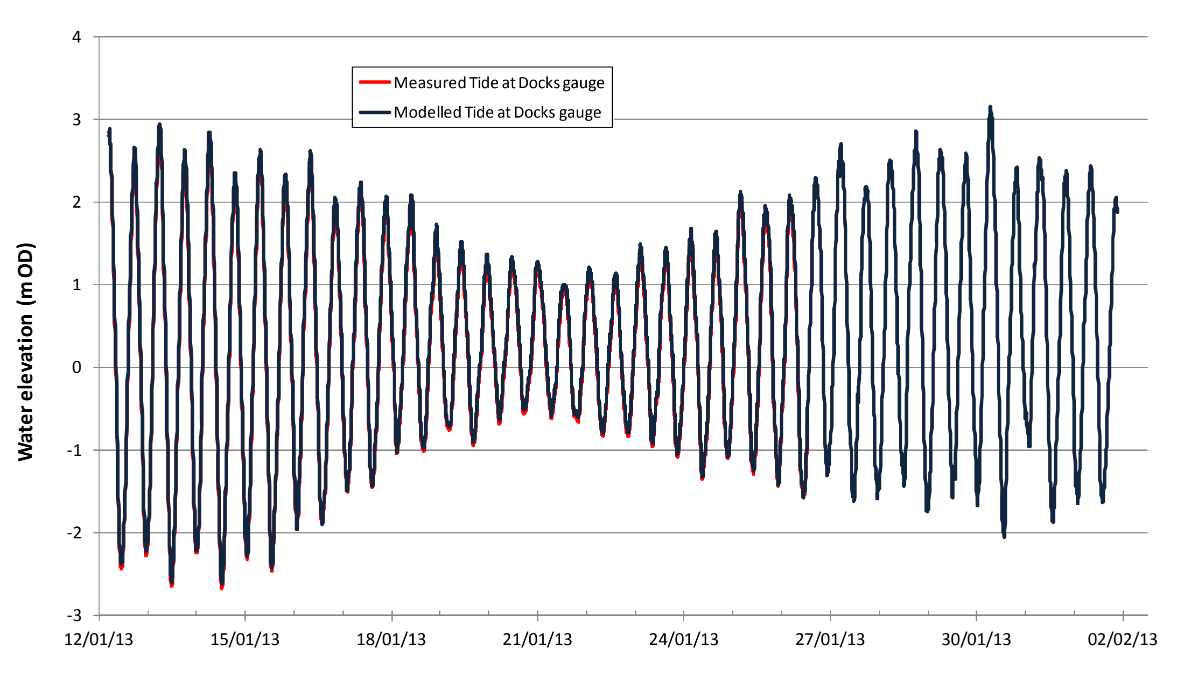


Figure 25 Comparison between measured and computed (modelled) tide elevation at Galway Docks gauge 12th January to 1st Feb 2013

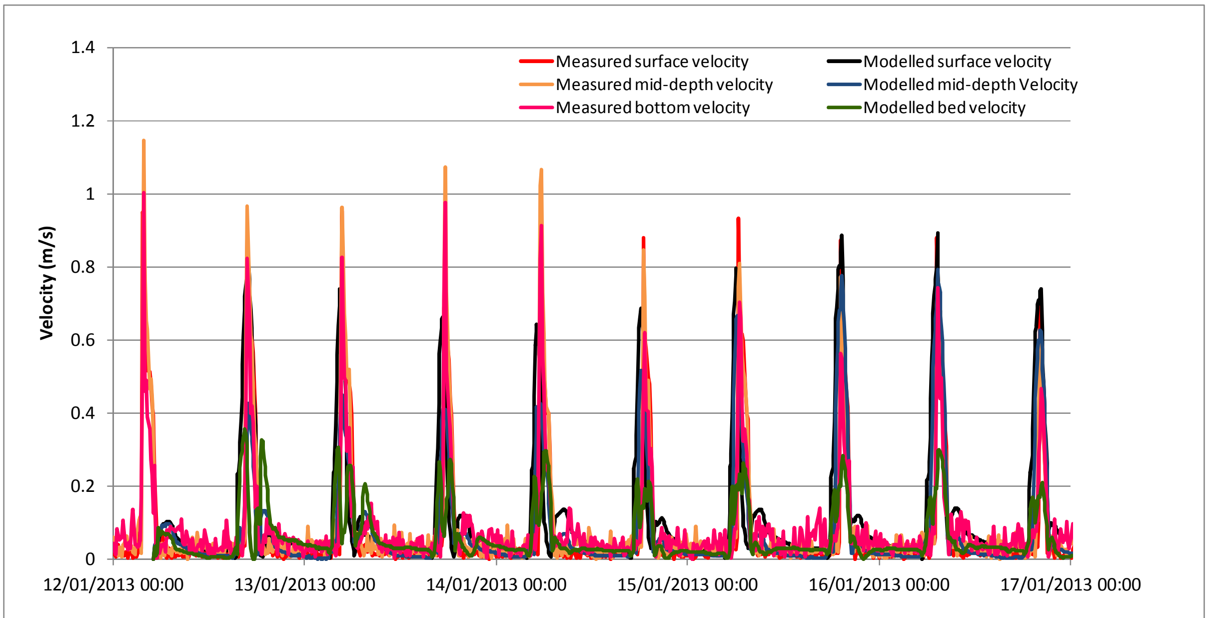


Figure 26 Comparison between measured and computed tide velocities at S1 for the monitoring period 12th January to 17th Jan 2013

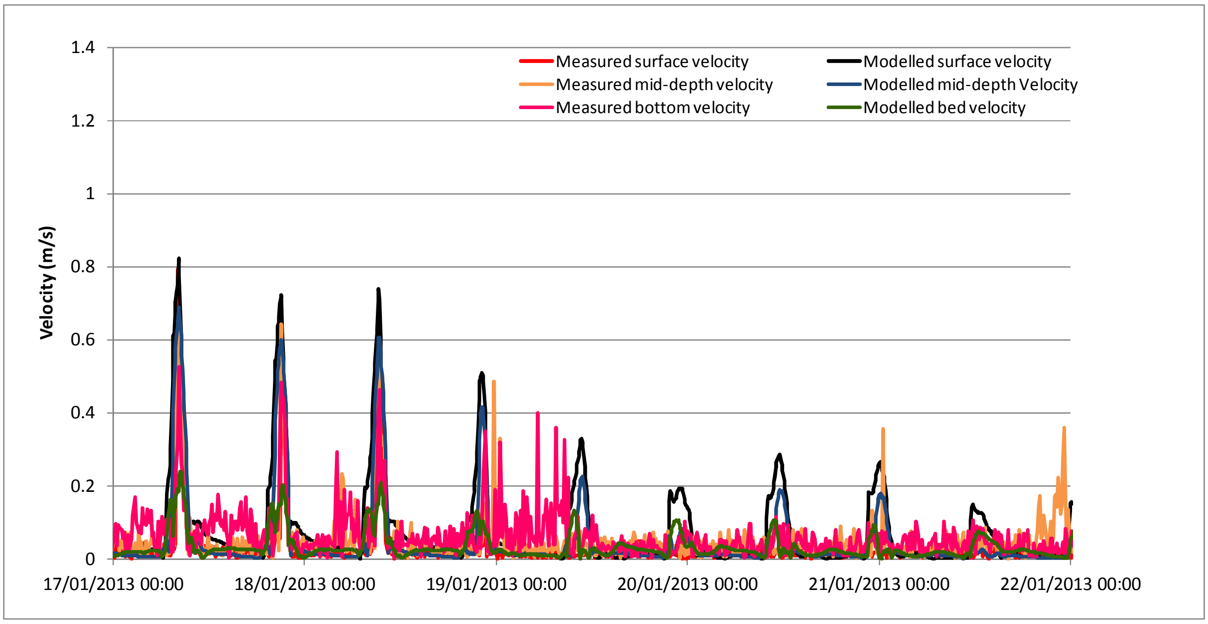


Figure 27 Comparison between measured and computed tide velocities at S1 for the monitoring period 17th Jan to 22nd Jan 2013

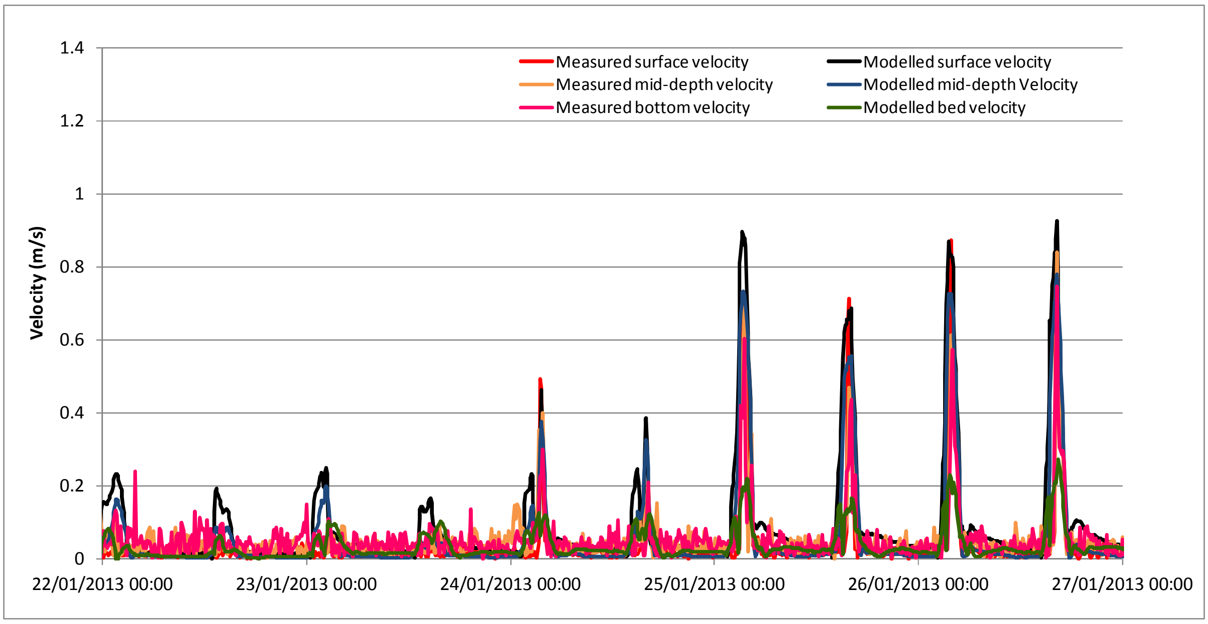


Figure 28 Comparison between measured and computed tide velocities at S1 for the monitoring period 22nd Jan to 27th Jan 2013

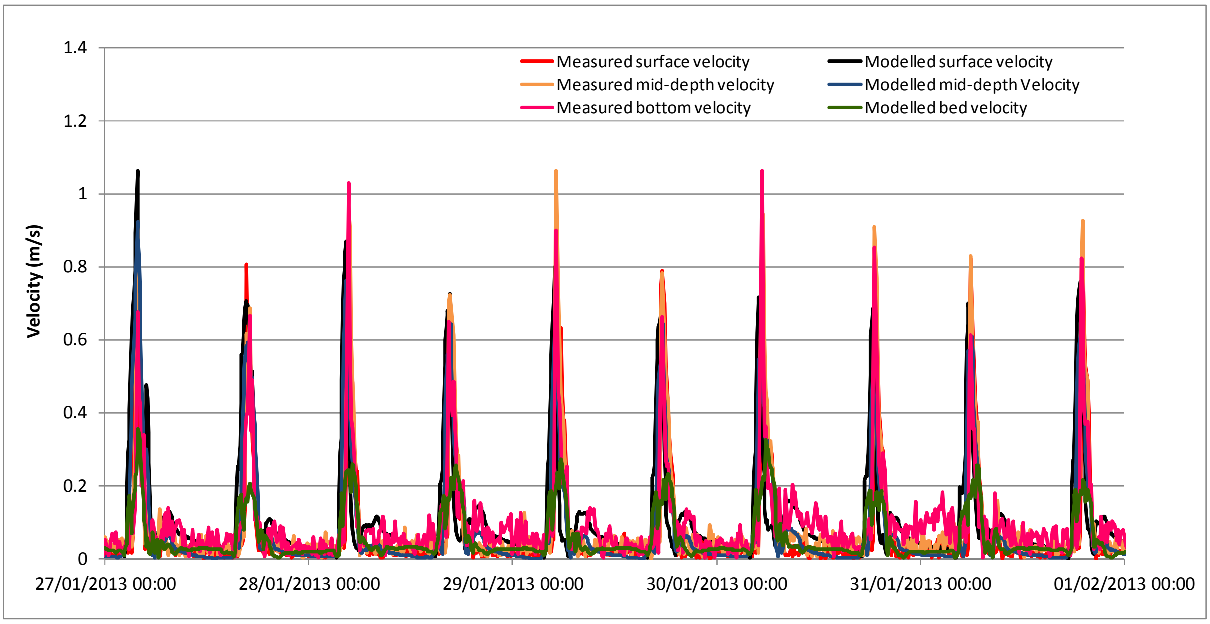


Figure 29 Comparison between measured and computed tide velocities at S1 for the monitoring period 27th Jan to 1st Feb 2013

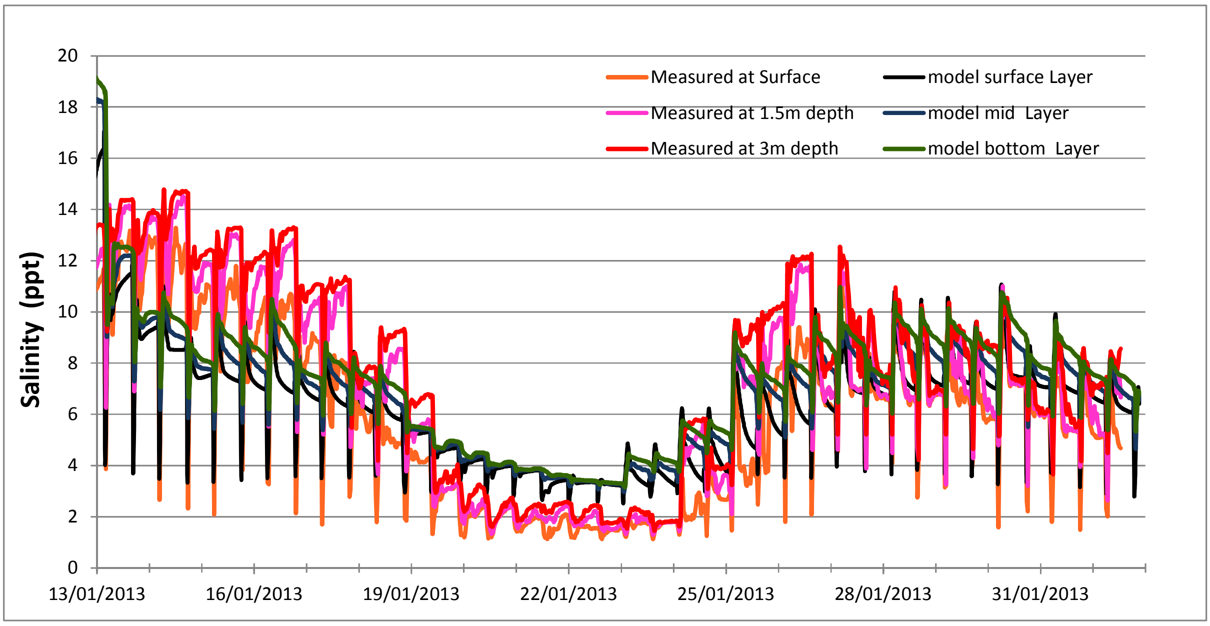


Figure 30 Measured V's Computed Salinities in Lough Atalia at Site S1 for January monitoring period

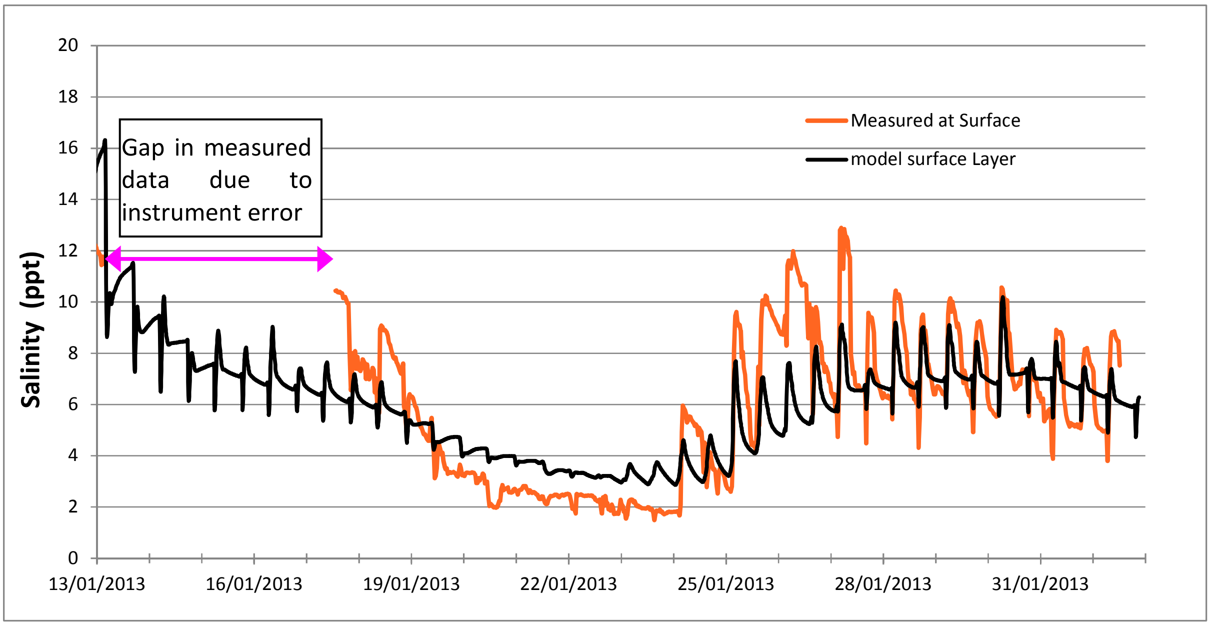


Figure 31 Measured V's Computed Salinities in Lough Atalia at Site S2 for January monitoring period

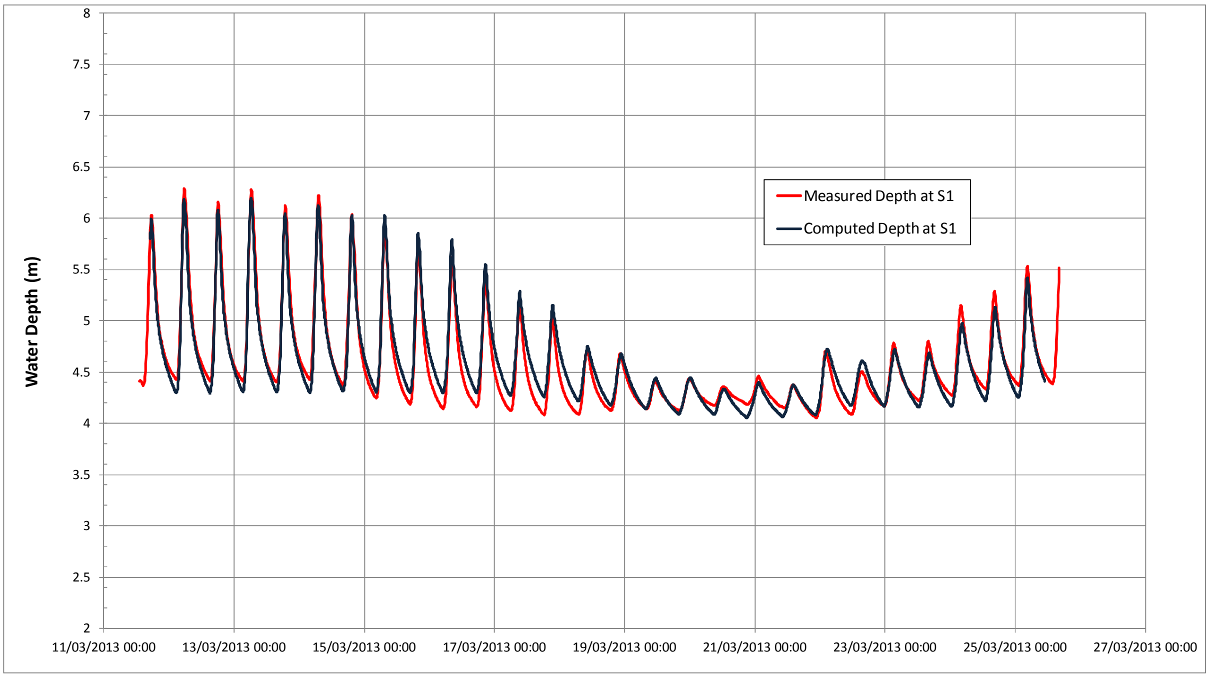


Figure 32 Computed and measured water depth at S1 for March 2013 Monitoring period

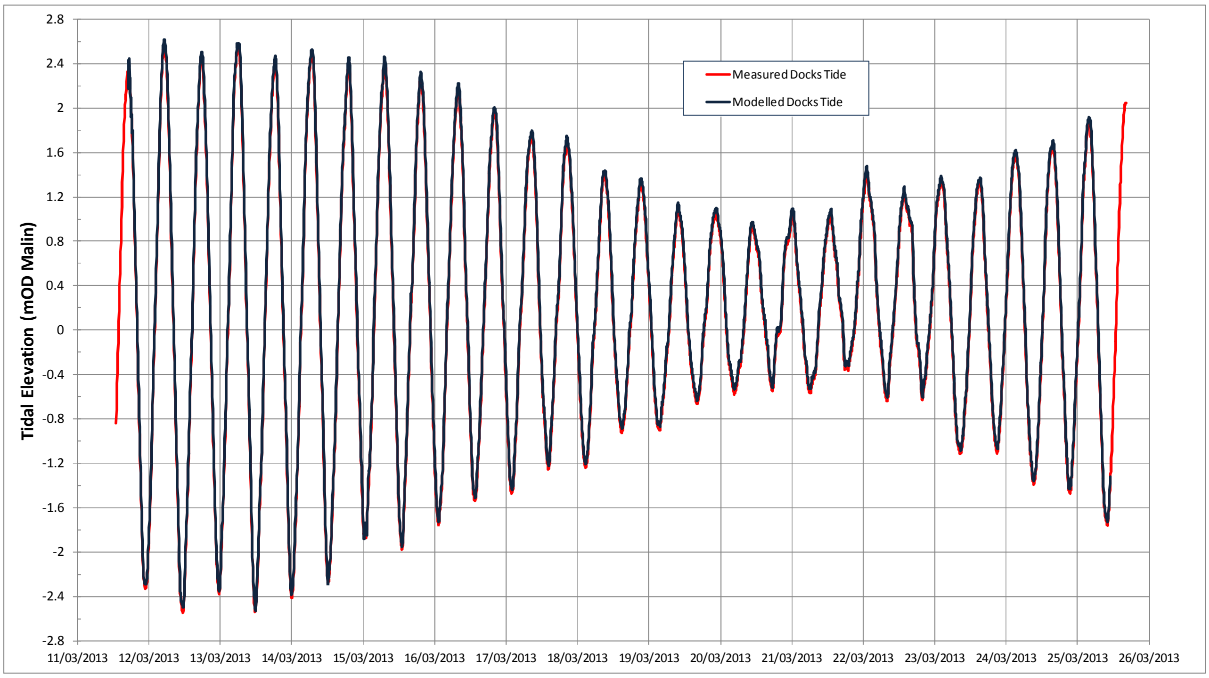


Figure 33 Comparison between measured and computed(model) tide elevation at Galway Docks gauge for 11 to 26th March 2013 monitoring period

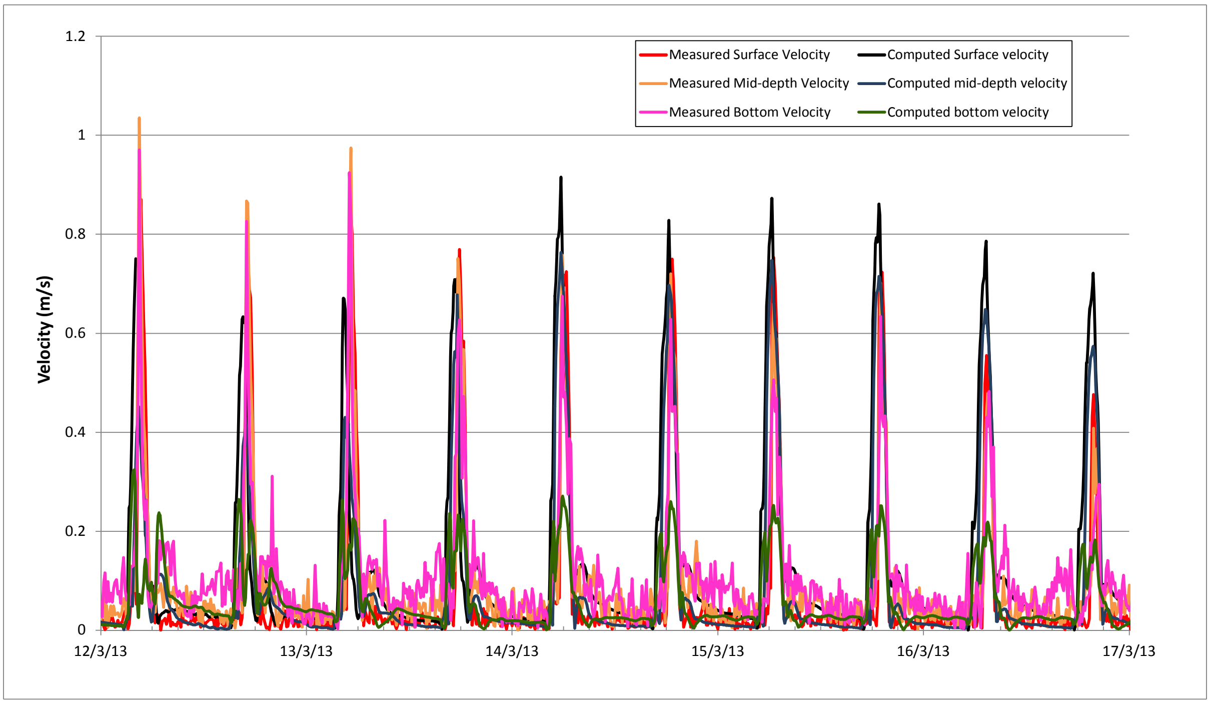


Figure 34 Comparison between measured and computed tide velocities at S1 for the March monitoring period 12th March to 17th March 2013

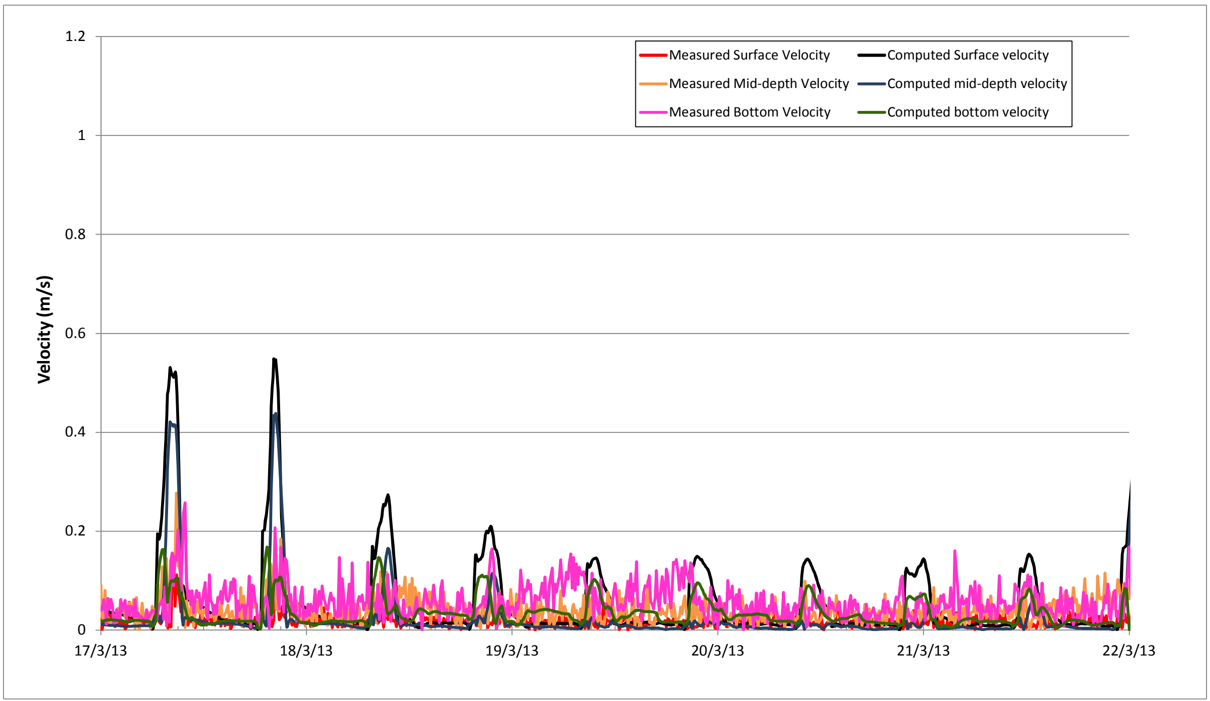


Figure 35 Comparison between measured and computed tide velocities at S1 for the March monitoring period 17th March to 22nd March 2013

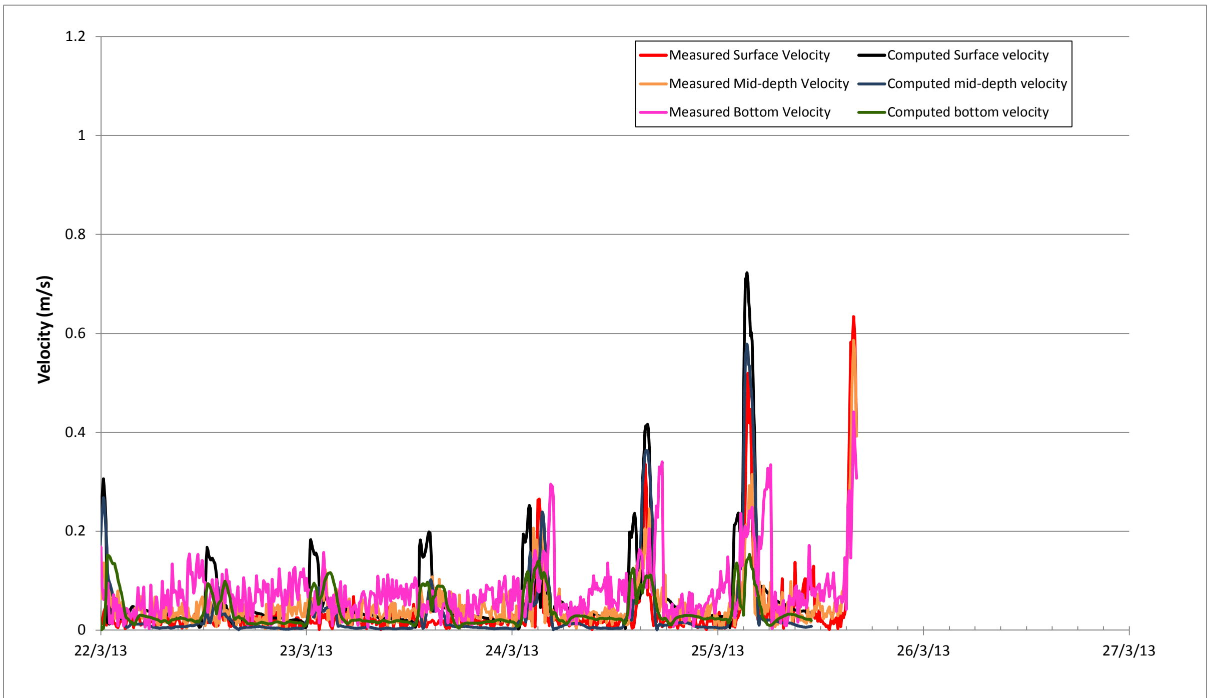


Figure 36 Comparison between measured and computed tide velocities at S1 for the March monitoring period 2nd March to 26th March 2013

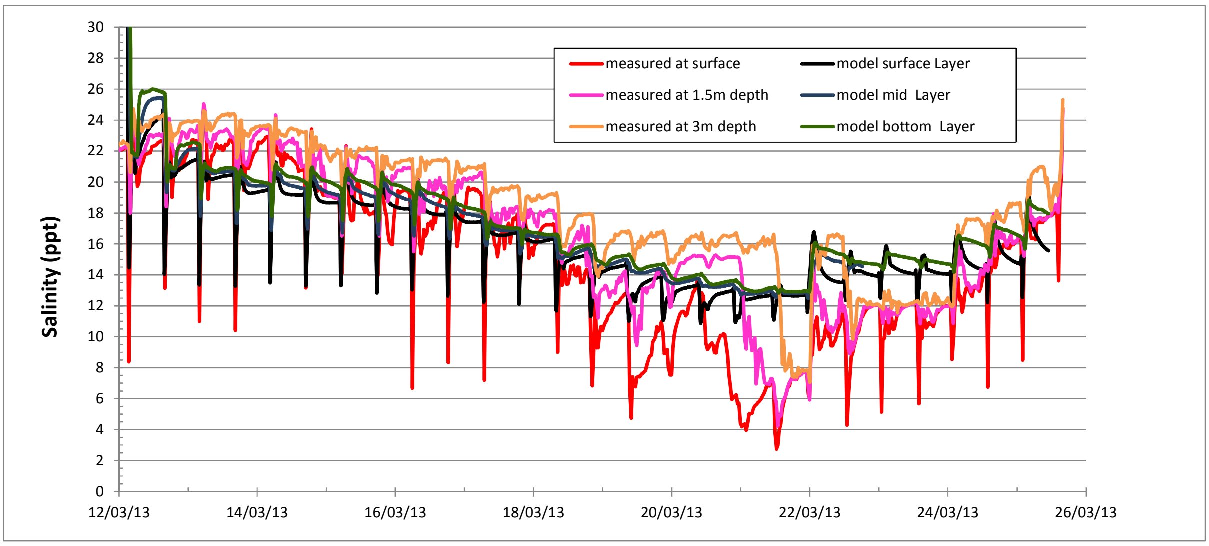


Figure 37 Measured V's Computed Salinities in Lough Atalia at Site S1 for March monitoring period

Refer also to Figures 32 and 33

5. 4. Salinity Simulations

5.1. 4.1 Introduction

A range of model simulation runs were performed with and without the proposed Galway Harbour Extension to assess and quantify the overall impact of the development on salinity levels in Lough Atalia, the Galway docks and approaches area and in vicinity of the proposed Harbour Extension. Model simulations were performed for a range of open sea tide and freshwater inflows from the Corrib. All other sources of freshwater inflow (i.e. small streams, storm outfalls, groundwater baseflow and springs) were ignored as their flow contribution was considered minor in comparison to the River Corrib source.

The model simulations were performed for a 16.5 day period (32 tidal cycles) and a time step of 2 seconds. This was sufficient to attain equilibrium salinity concentrations within Lough Atalia and in the vicinity of the Harbour Extension area, as it provided a 2.5day warm-up period and 14day spring-neap-spring cycle. The time varying tidal curve specified at the open sea western boundary to drive the model simulations is presented below in Figure 38.

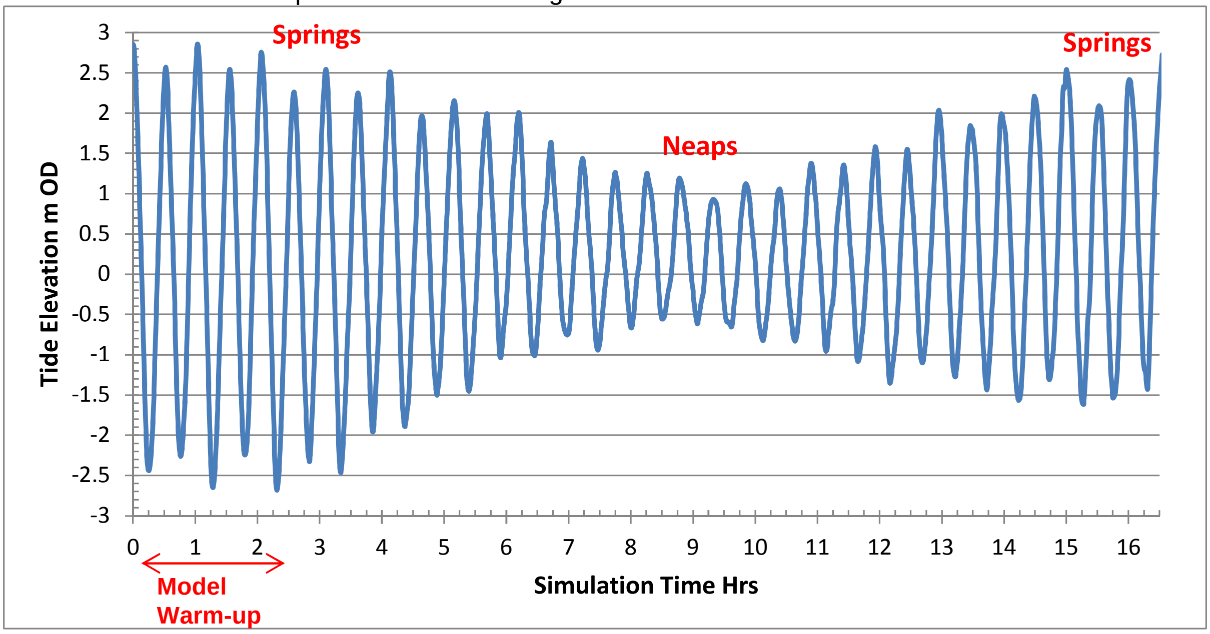


Figure 38 Open Sea Tidal conditions used in salinity simulations

Using the River Corrib flow duration curve information at Wolfe Tone Bridge gauge (30061) (refer to Table 1 in Section 3) the following range of flow conditions were examined in order to quantify the overall impact on salinity by the proposed development:

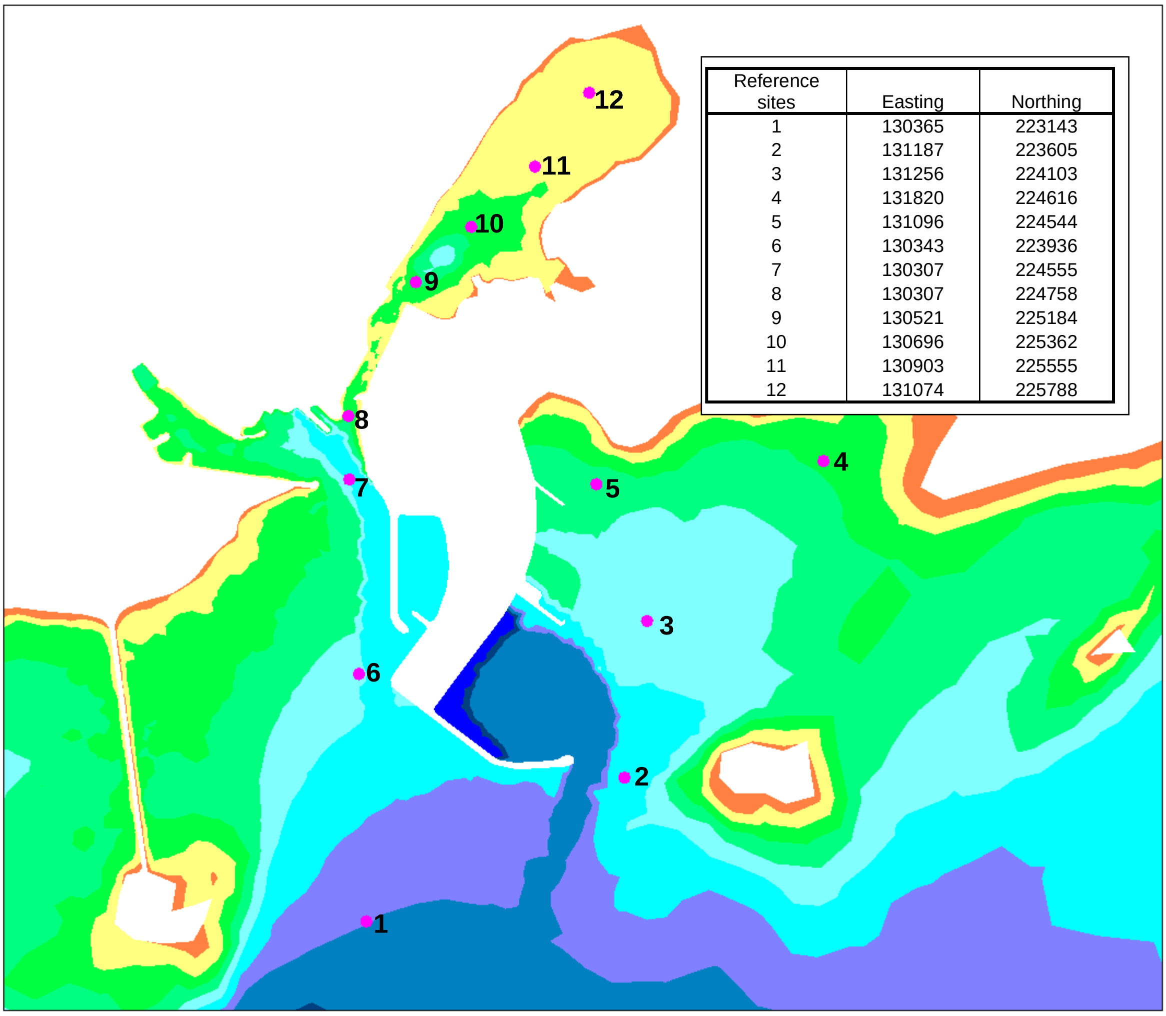
1. 99-percentile River Corrib low flow of 9.1 cumec
2. 90-percentile River Corrib flow of 28.5cumec
3. 50-percentile River Corrib flow of 82 cumec
4. 10-percentile River Corrib flow of 200 cumec
5. 1-percentile River Corrib flood flow of 272cumec

These flows were specified as constant inflows as opposed to a time varying flow hydrograph. This approach is considered reasonable and appropriate for the River Corrib given the highly damped nature due to the large Lough Corrib and its flow regulation by OPW at the Salmon Weir Sluice Barrage in Galway City.

5.2. 4.2 Simulation results

In order to compare the predicted salinities with and without the proposed Harbour Extension, a number of reference sites within Lough Atalia the Approach Channel and the proposed harbour extension area were selected. At these reference sites time series of salinity concentrations were generated and analysed for each simulation run so as to directly compare the change in salinity value. These reference sites are presented below in Figure 39.

A salinity of 33 ppt was specified at the western open sea boundary and 0 ppt in the Corrib and an initial starting condition of 32 ppt throughout the bay. Simulations were then run for a 16.5day (32 tidal cycle period (spring-neap-spring) so as to obtain equilibrium conditions within the area of interest and particularly for the final 14 tidal cycles representing neap to spring tides.



Reference sites	Easting	Northing
1	130365	223143
2	131187	223605
3	131256	224103
4	131820	224616
5	131096	224544
6	130343	223936
7	130307	224555
8	130307	224758
9	130521	225184
10	130696	225362
11	130903	225555
12	131074	225788

Figure 39 Reference site for time series output of computed salinities

For each simulation run the temporal mean for the final 14 tidal cycles (neaps to springs) was performed and salinity contour plots of these mean salinities with and without the proposed development in the bottom, mid-depth and surface layers are presented in Figures 46 to 60. These demonstrate the stratification between the freshwater surface layer and the underlying saline layers, with the bottom layer being the most saline. The plots also demonstrate the sheltering effect that the harbour extension will have on the buoyant freshwater outflow resulting in more saline conditions to the East of the harbour extension (Renmore Bay area) and less saline conditions to the west and south of the development.

For each of the five hydrodynamic simulations summary tables of the salinity predictions at the 12 reference sites for proposed and existing cases, along with a summary of salinity differences are presented in Tables 3 to 17. Times series plots of surface mid column and bottom salinities for existing and proposed cases at sites 5 (Renmore area), 7 (off Nimmo's Pier) and 9 (Lough Atalia) for each of the five hydrodynamic runs are presented in Figures 61 to 75. These time series plots illustrate the effect of the development on salinities for spring-neap-spring tidal cycles.

5.3. 4.3 Discussion of Results

<u>Renmore area</u>

The tide simulations for various freshwater inflows from the Corrib show the deflection of the Corrib freshwater plume westward due to the harbour extension site with freshwater only arriving into Renmore Bay area on the subsequent flooding tide. In the existing case there is a wider area for the plume to disperse with no physical structure to prevent the plume migrating east and southeast on the ebbing tide and thus availing of a greater area for dispersion. With the proposed development, the Corrib plume is directed more southwards with reduced opportunity for the freshwater plume to directly disperse into the Renmore Bay area on the returning tide. The modelling demonstrates significant increases in salinity to the east of development with greatest changes occurring to the northeast of proposed harbour extension, with the model reference sites 3, 4, and 5 showing an average rise in salinity of 2.4, 4.2 and 5.4ppt respectively.

<u>Lough Atalia</u>

The impact of the proposed harbour extension on salinity in Lough Atalia (using reference Sites 9, 10, 11 and 12 of Figure 39) and integrating the results over the five hydrodynamic simulation runs considered gives an overall predicted reduction in the mean salinity within Lough Atalia of 1.29ppt, refer to Table 3 below for summary of salinity Predictions for Lough Atalia. Figure 40 to 44 present the tidal average and tidal maximum and minimum salinities for neap to spring tides and demonstrate the impact of the harbour extension on salinities in Lough Atalia.

Both the simulation results and the measured salinity data (presented in Section 2) for Lough Atalia show considerable temporal variation in salinity concentrations under tidal and river flow conditions. The measured and predicted salinities in Lough Atalia range from 30 ppt (psu) to low salinities of less than 1ppt and a mean salinity of 12.1 ppt. This Lough has a short residence time being easily flushed by the tide and thus represents a very dynamic system with significant changes in salinity occurring over a relatively short periods of time, significant changes occur; (i) within a spring tidal cycle, (ii) over a number of tidal cycles between spring and neaps and (iii) seasonally with changes in the River Corrib freshwater flow conditions. The predicted reduction in salinity, refer again to Table 3 and Figure 45, for the various tide and flow conditions of 0.59 to 1.51ppt (mean reduction of 1.29ppt) is minor relative to the range of salinities encountered within the Lough. The smallest predicted impact by the proposed harbour extension occurs when the Corrib is in low flow.

Table 3 Summary of Lough Atalia Salinity Results

		Existing mean Salinity (ppt)	Proposed mean Salinity (ppt)	Change in mean Salinity (ppt)
Hydro 1 Neap-Spring with 99% low flow ($9.1m^3/s$)	5.5%	27.29	26.70	-0.59
Hydro 2 Neap-Spring with 90% flow ($28.5m^3/s$)	24.5%	20.419	19.22	-1.19
Hydro 3 Neap-Spring with 50% flow ($82m^3/s$)	40%	11.36	9.85	-1.51
Hydro 4 Neap-Spring with 10% flow ($200m^3/s$)	24.5%	3.76	2.49	-1.27
Hydro 5 Neap-Spring with 1% flood flow ($272m^3/s$)	5.5%	1.68	0.69	-0.99
Overall Mean	100%	**12.06**	**10.77**	**-1.29**

The salinity within Lough Atalia for a given Corrib Flow condition is lowest on neap tides and highest on spring tides. On spring tides sufficient tidal depth is available towards the latter stages of the flood tide (as it approaches high-water) to push the more dense saline bottom layer into Lough Atalia. The variation between minimum and maximum salinities is also higher on spring tides as the initial stages of the incoming flood tide introduce the fresher surface layer (i.e. when the tidal depth is small) followed as the depth increases by the deeper saline layer (See Figures 40 to 44). As the tidal cycles weaken towards neap tides the tidal depth and range reduces significantly such that the fresher surface layer becomes the predominant inflow into Lough Atalia resulting in significantly lower salinities. On neap tides during large floods flows practically the complete inflow is freshwater from the upper surface layer. There is limited tidal storage in Lough Atalia due to its relatively small surface area and the shallow water depth, resulting in high exchange / flushing rates (i.e. 75% of the high water lough volume is replaced on a single spring tide and 30% on a single neap tide). Therefore the transition from spring to neap tides at times of large flood flows results in a lowering of the lough salinities to practically those of freshwater over the 2 to 3 days of neap tides. Even on Spring tides at the more extreme flood flow conditions in the Corrib the salinity in the Lough will practically become nil, in the pre development circumstances.

Figure 45 demonstrates the impact of the harbour extension on typical Neap and Spring tides for the complete range of Corrib Freshwater Flows. The accedence probability of these flows derived from the flow duration curve for the Corrib at Wolfe Tone Bridge gauge is also shown. This graph suggests that nil salinity within Lough Atalia occurs at approximately 301cumec for the existing case and reducing to a rate of 285cumec for the proposed harbour extension case on neap tides. A Corrib flow of 301cumec occurs 0.135% of the time, or 0.5days in an average year (for the existing case), whereas, a flow of 285cumec occurs 0.345% of the time, or 1.25days in an average year (for the proposed case).

Therefore the probability of a nil salinity occurring during neap tides (given that these tides occur approximately one third of the time) is 0.045% for existing case and increasing to 0.115% for the proposed case.

The same analysis for spring tides gives nil salinity occurring at 368cumec for the existing case and 329cumec for the proposed case. The probability of these flows being equalled or exceeded is

0.022% (2hours in an average year) for the existing case and 0.070% (6hours in an average year) for the proposed Harbour development case.

Therefore the probability of a nil salinity occurring during spring tides (given that these tides will occur approximately one third of the time) is 0.007% for existing case and increasing to 0.023% for the proposed case.

Integrating over both spring and neap tides the overall probability of nil salinity occurring in a given year in Lough Atalia is 0.08% (or 7 hours in an average year) for the existing case and increasing to 0.21% (or 18hours in an average year) for the proposed harbour extension case.

5.4. 4.4 Conclusions

The tide simulations for various freshwater inflows from the Corrib show the deflection of the Corrib freshwater plume westward due to the harbour extension site resulting in reduced dispersion and lower salinities (i.e. more fresh) in the upper water column layers off Nimmo's pier (mouth to Lough Atalia and Galway Docks) and west of the Harbour extension site. The impact of this reduced dispersion of the Corrib freshwater plume is to introduce a slightly fresher water into Lough Atalia resulting in a slight lowering of the salinity concentration there. Conversely considerably more saline conditions are predicted east of the Harbour Extension in the Renmore Bay area and north of Hare Island.

Within Lough Atalia the measurement and model study combined show for both existing and proposed cases that the lowest salinities and tidal variation of salinities is when the River Corrib is in flood (maximum flows) and the tide range is at its minimum (i.e. neap tides). The measured and modelled data indicates that the salinity within Lough Atalia will tend towards complete freshwater (nil salinity) during the Larger flood flows. On neaps tides the tidal range is extremely weak and the water introduced on the inflowing period is from the surface layer and is basically freshwater. The Lough is relatively small and shallow with a high exchange/flushing rate which eliminates any significant build-up / storage of salinity in the Lough that could be used to maintain salinities during neap and Corrib flood flow periods. The high flushing rate of the Lough ensures a dynamic Lough having large temporal variation in salinities over a single tidal cycle, over lunar cycles and seasonally.

The Impact of the Harbour Extension Development on salinity concentrations within Lough Atalia is to reduce salinities by on average by 1.29ppt over the complete range of flow and tide conditions. Given the relative range of salinities within the Lough from c. 30ppt to nil ppt, this reduction of 1.29ppt in salinity, which is only 10% of the mean salinity, is not considered significant. The model analysis also demonstrates that the range of salinities (maximum to minimum) within Lough Atalia will not alter as a result of the harbour extension, only the frequency of occurrence will change, as demonstrated by Figure 45.

Periodic large and extreme flood flows in the Corrib will reduce salinities to practically nil in Lough Atalia for both the existing and proposed cases, principally during neap tides but also on spring tides for a less frequent more extreme flood flow. Over the full tidal range the probability of nil Salinity in a given year occurring within Lough Atalia will increase from 0.08% to 0.21% (7 to 18hours in an average year).

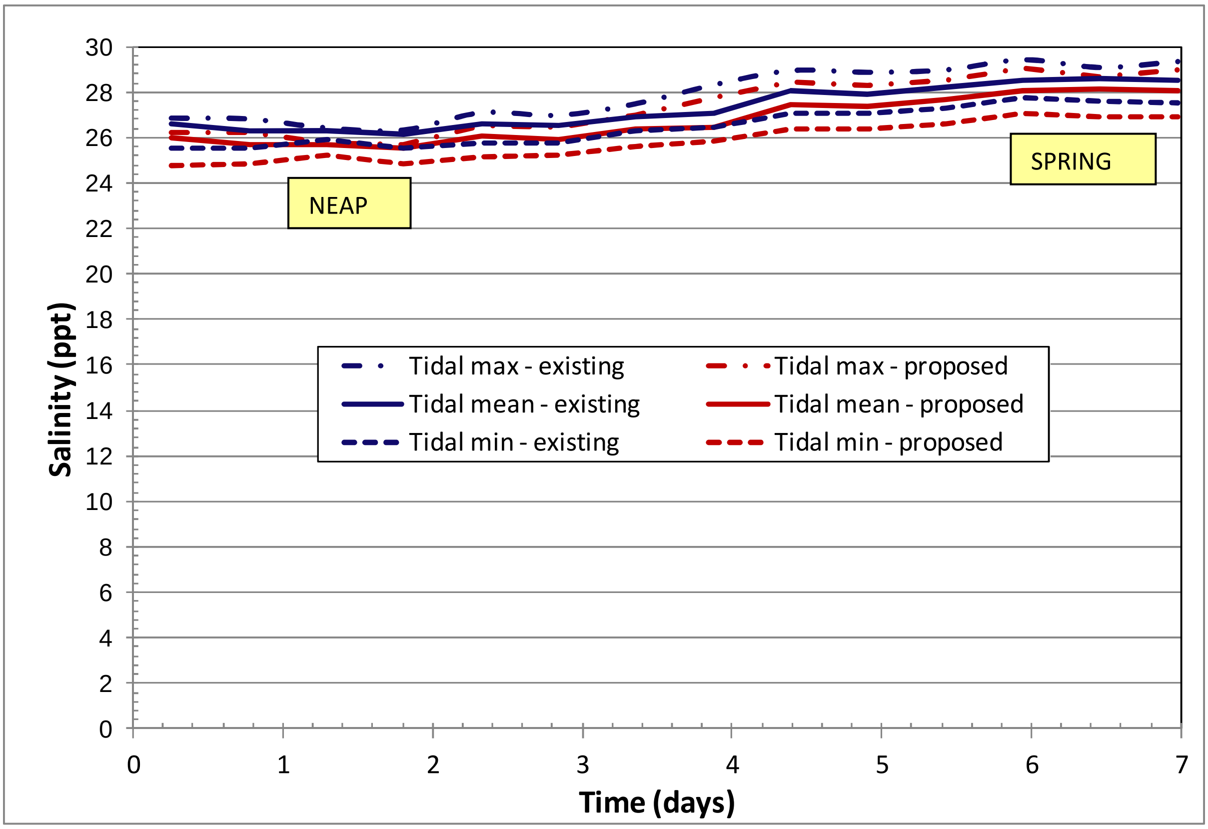


Figure 40 Predicted Tide averaged, maximum and minimum Salinities in Lough Atalia for 99-percentile Corrib Low Flow with and without Harbour Extension

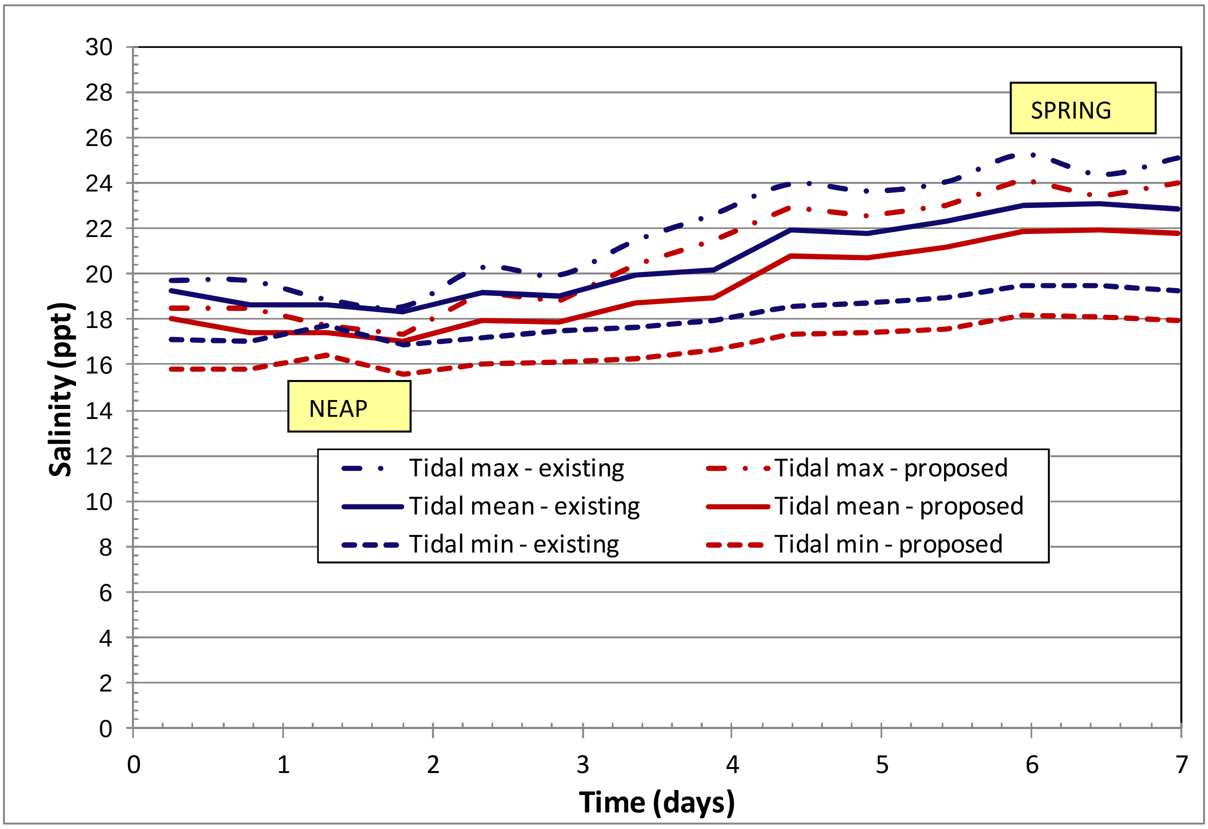


Figure 41 Predicted Tide averaged, maximum and minimum Salinities in Lough Atalia for 90-percentile Corrib Flow with and without Harbour Extension

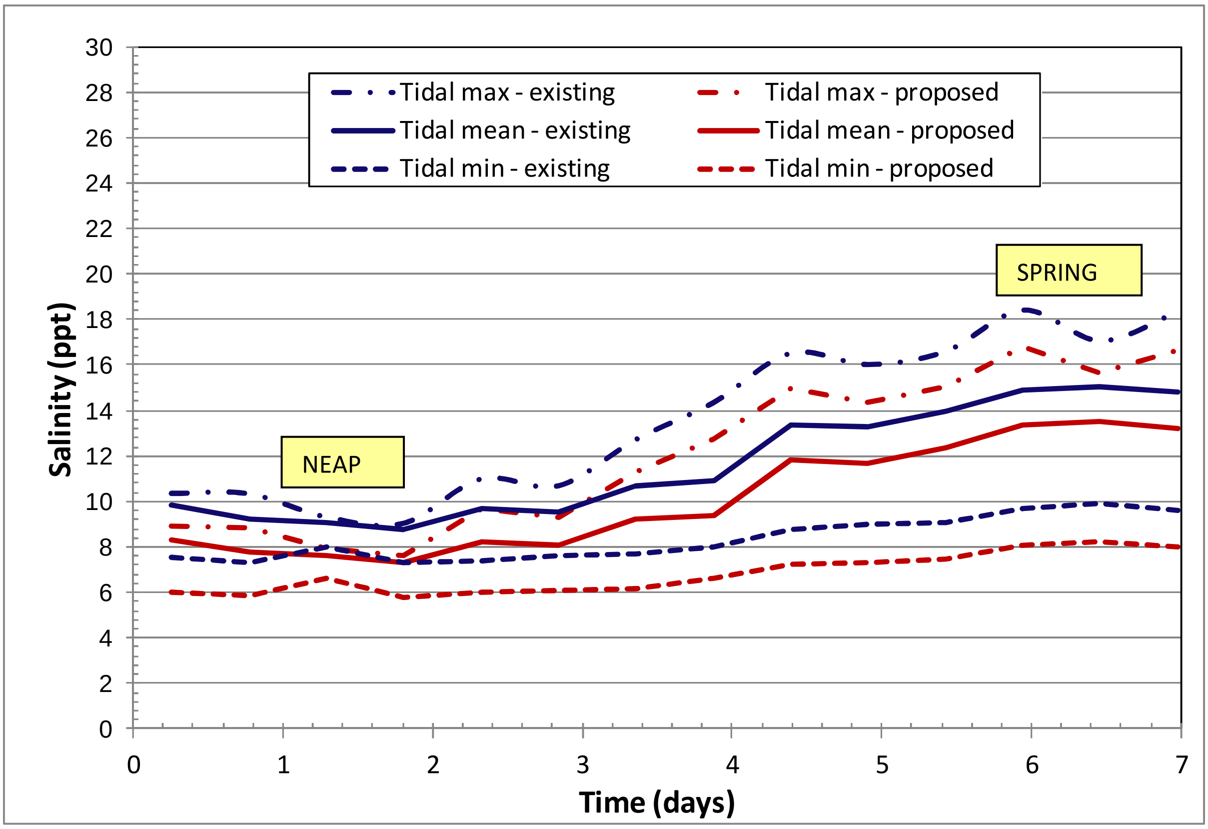


Figure 42 Predicted Tide averaged, maximum and minimum Salinities in Lough Atalia for 50-percentile (median) Corrib Flow with and without Harbour Extension

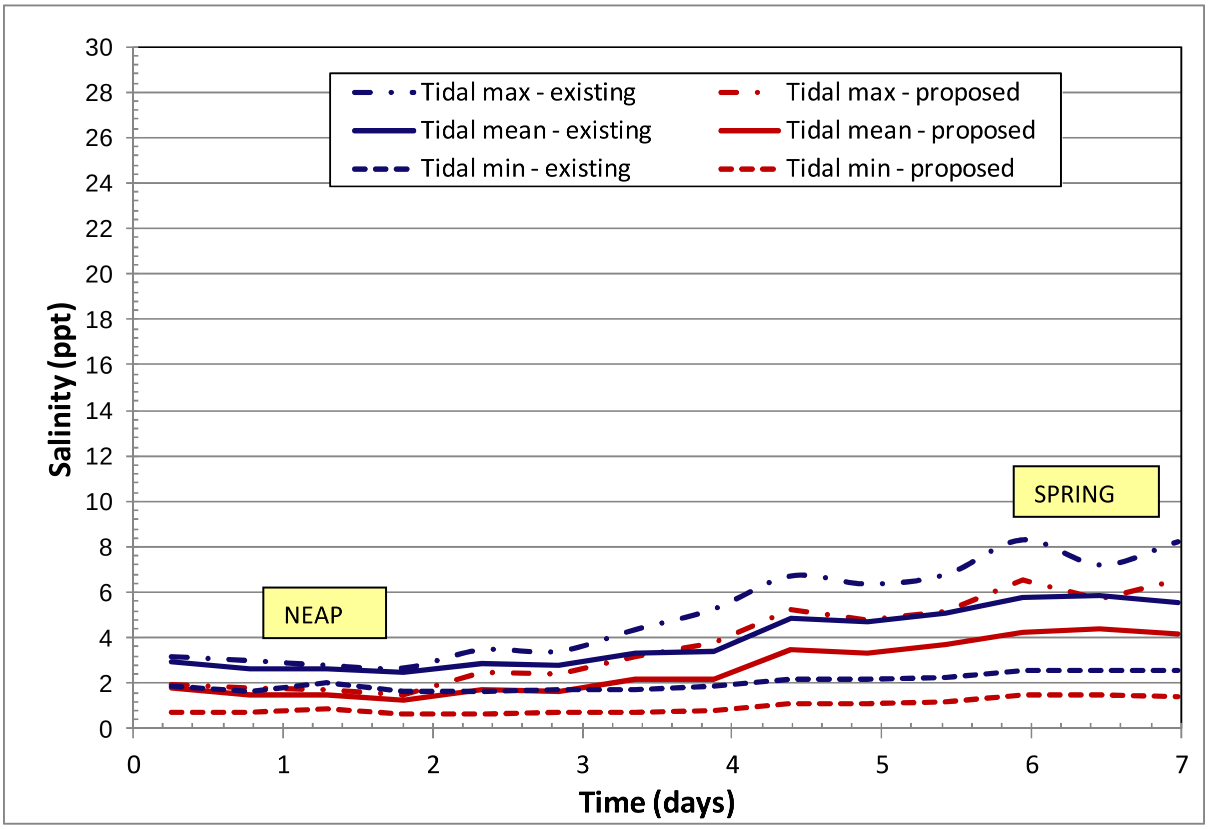


Figure 43 Predicted Tide averaged, maximum and minimum Salinities in Lough Atalia for 10-percentile Corrib Flow with and without the Harbour Extension

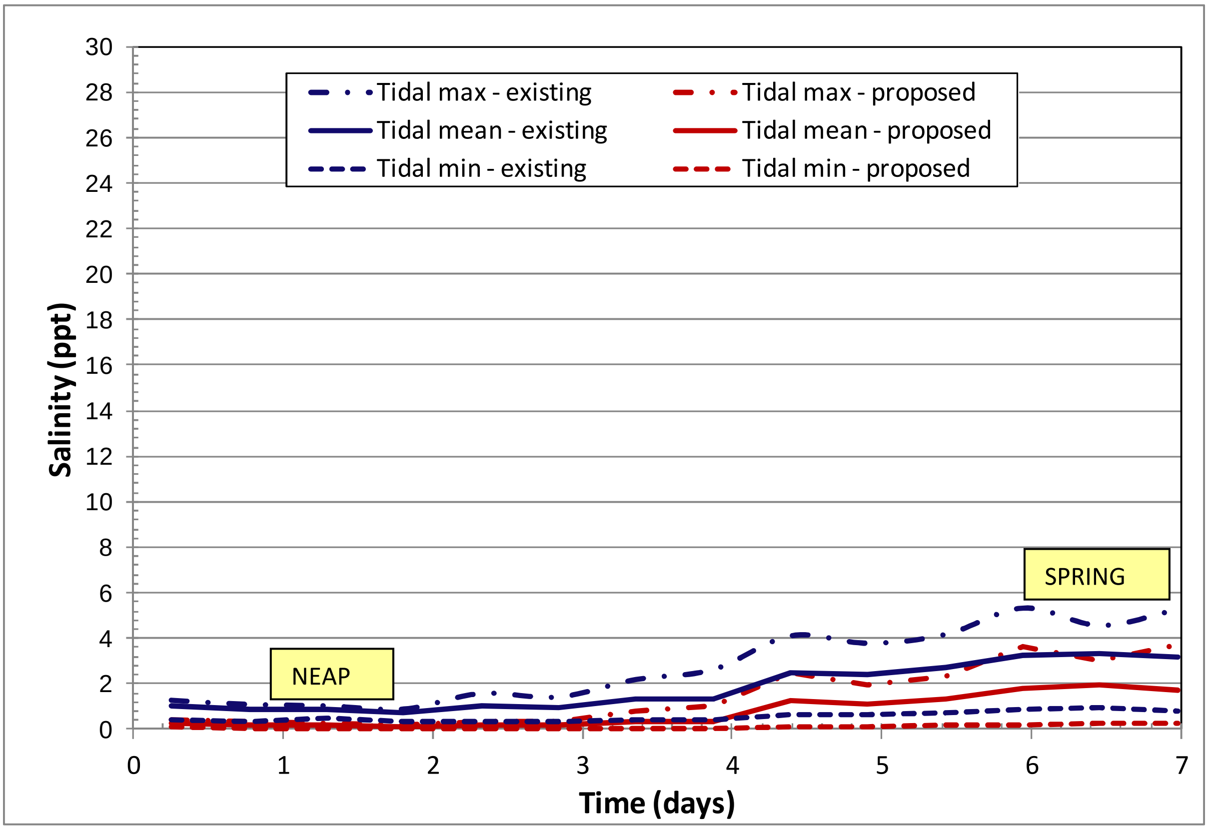


Figure 44 Predicted Tide averaged, maximum and minimum Salinities in Lough Atalia for 1-percentile Corrib Flood Flow with and without the Harbour Extension

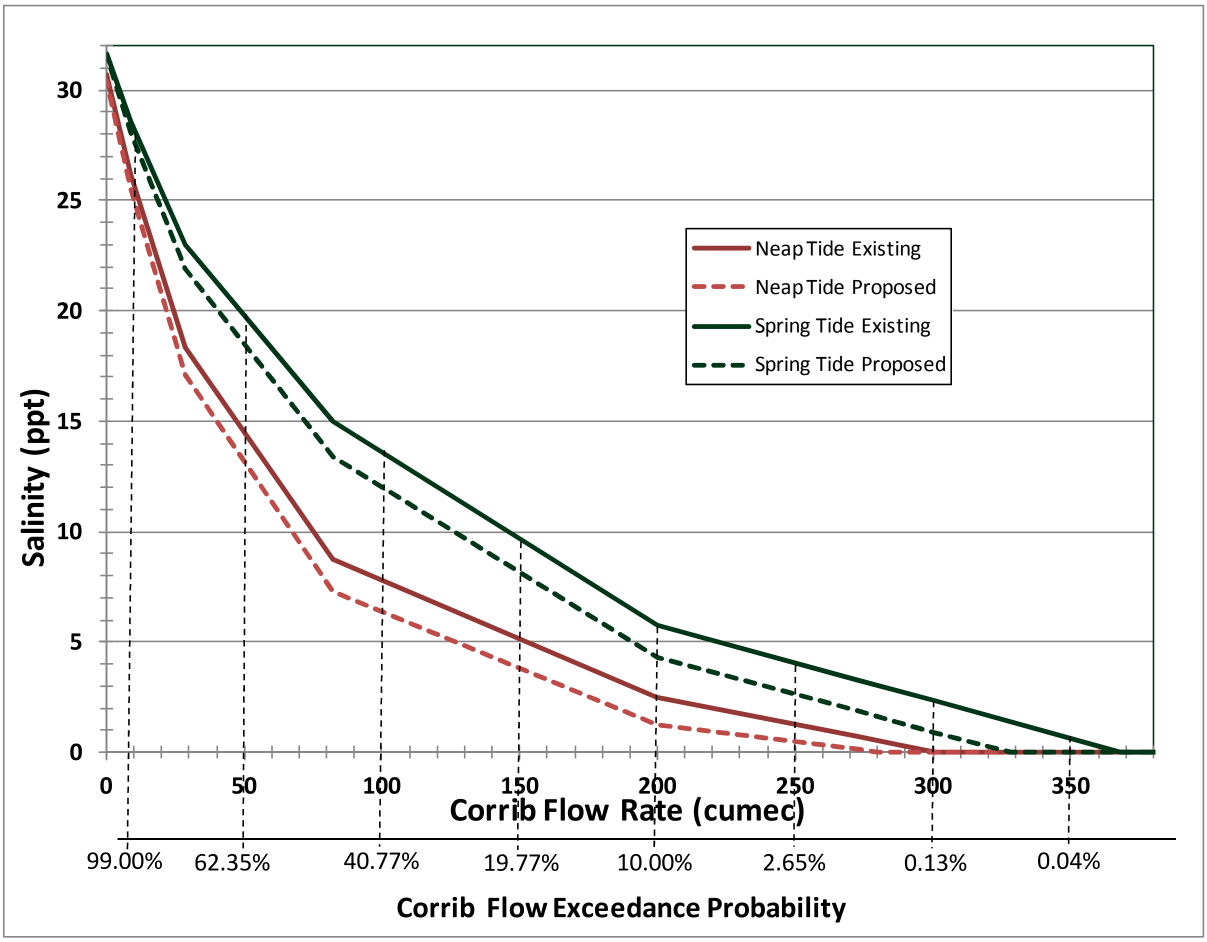


Figure 45 Predicted Mean Tidal Salinity for Spring and Neap Tides in Lough Atalia V's Corrib Flow Rate for complete range of Corrib Freshwater Flow Conditions (0cumec to 400cumec)

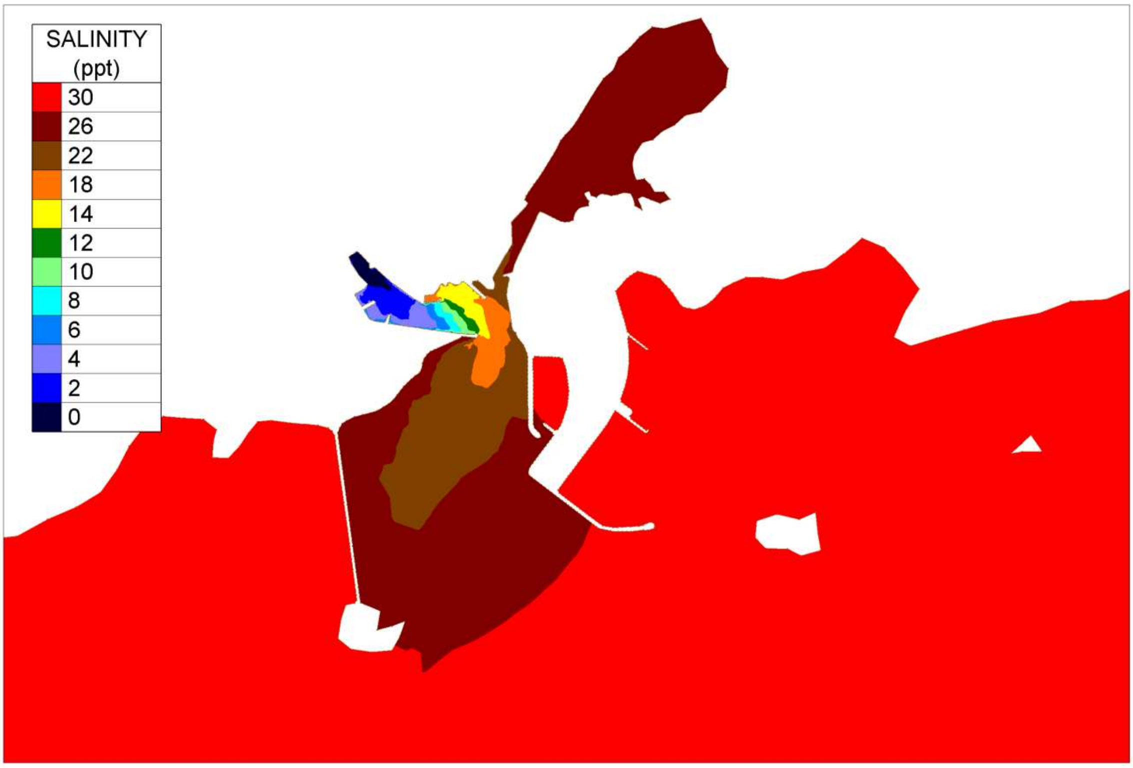


Figure 46 Mean Salinity concentration in bottom layer for existing and proposed cases under 99-percentile Corrib Low Flow (9.1 cumec)

Figure 47 Mean Salinity concentration in mid-depth layer for existing and proposed cases under 99-percentile Corrib Low Flow (9.1 cumec)

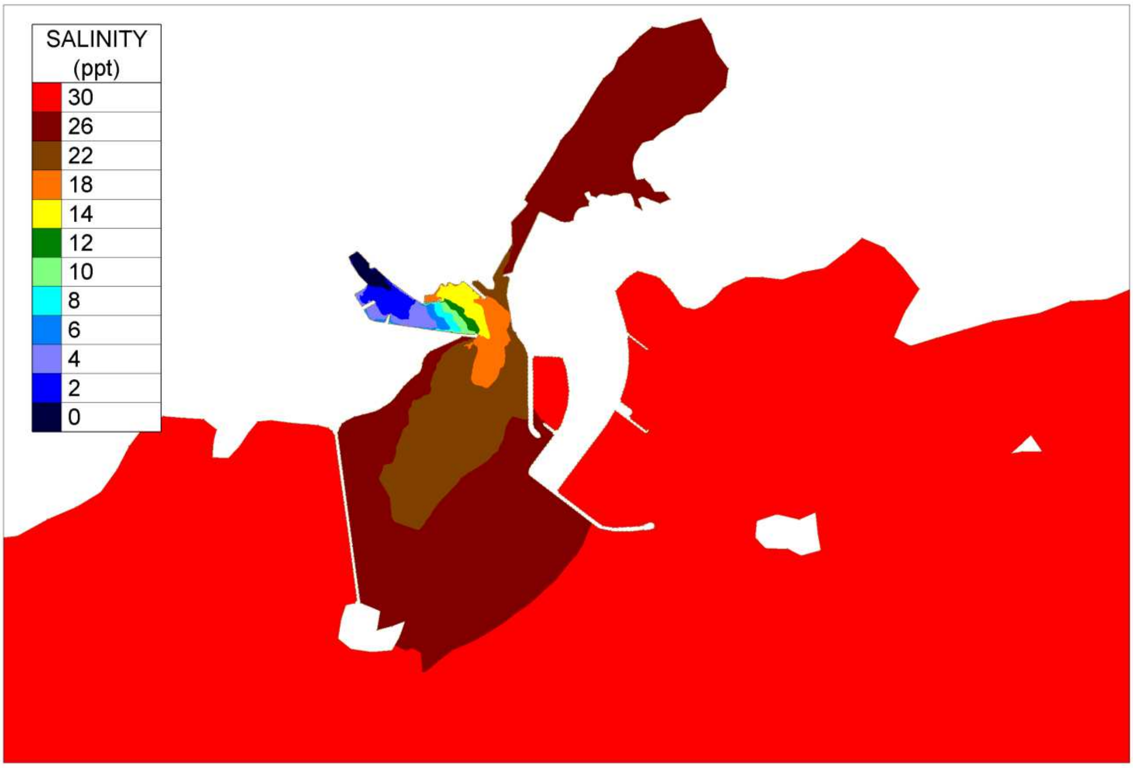


Figure 48 Mean Salinity concentration in surface layer for existing and proposed cases under 99-percentile Corrib Low Flow (9.1 cumec)

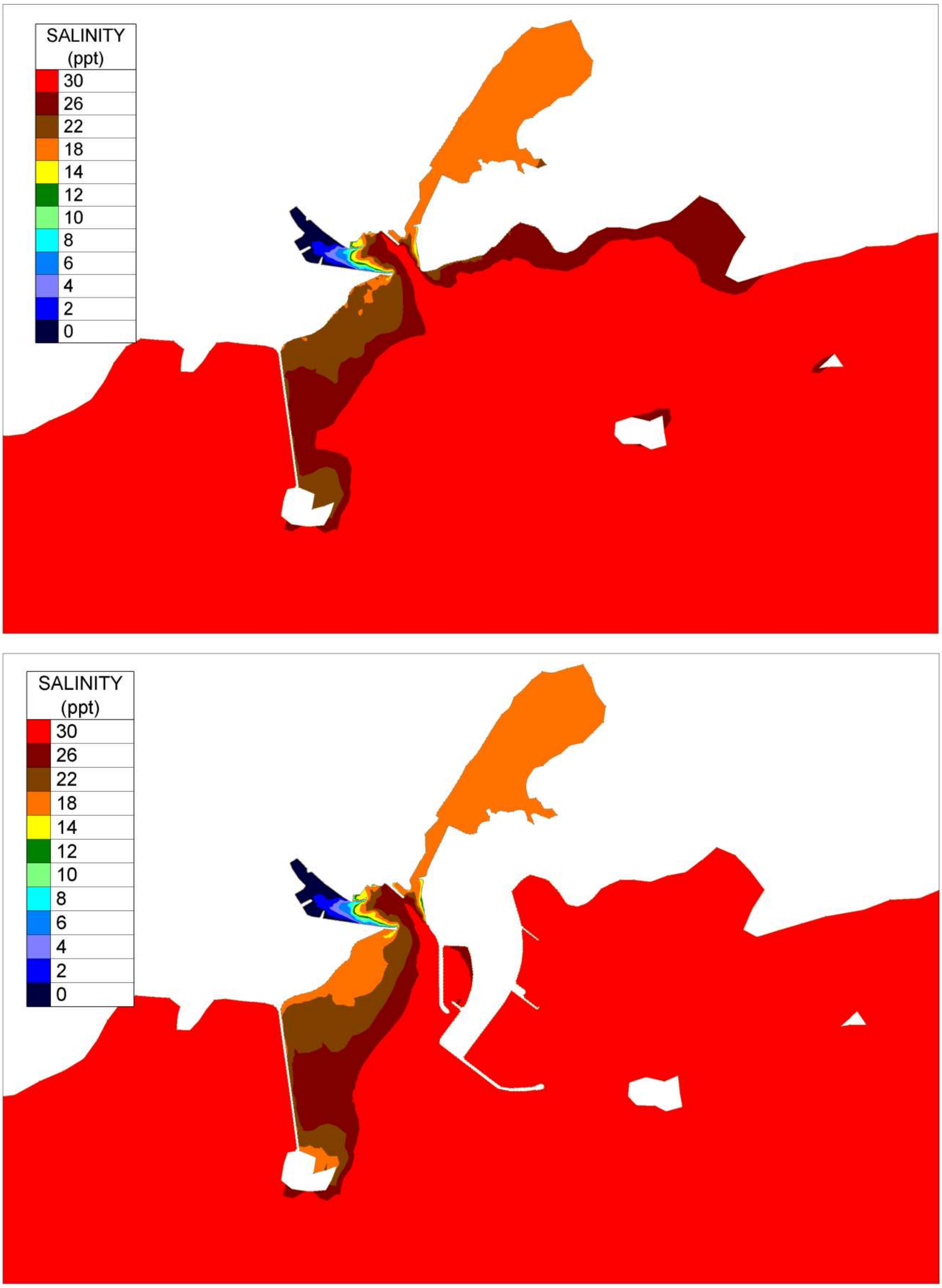


Figure 49 Mean Salinity concentration in bottom layer for existing and proposed cases under 90-percentile Corrib Flow (28.5cumec)

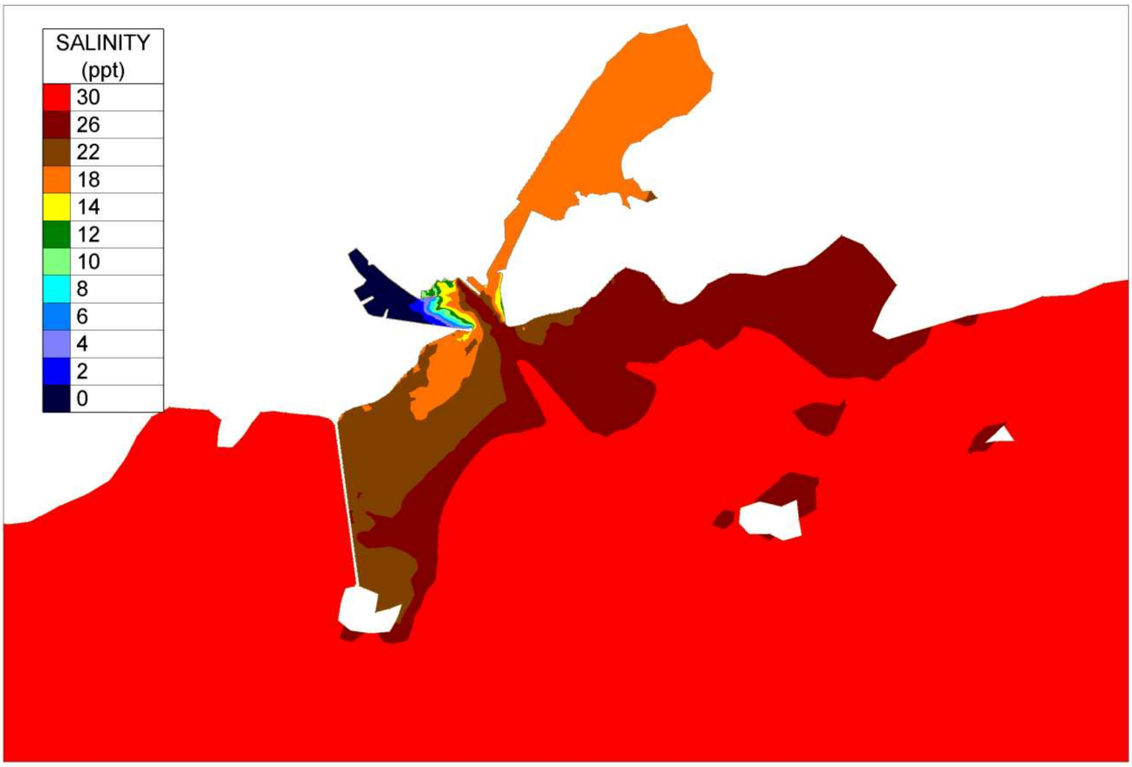


Figure 50 Mean Salinity concentration in mid-depth layer for existing and proposed cases under 90-percentile Corrib Flow (28.5cumec)

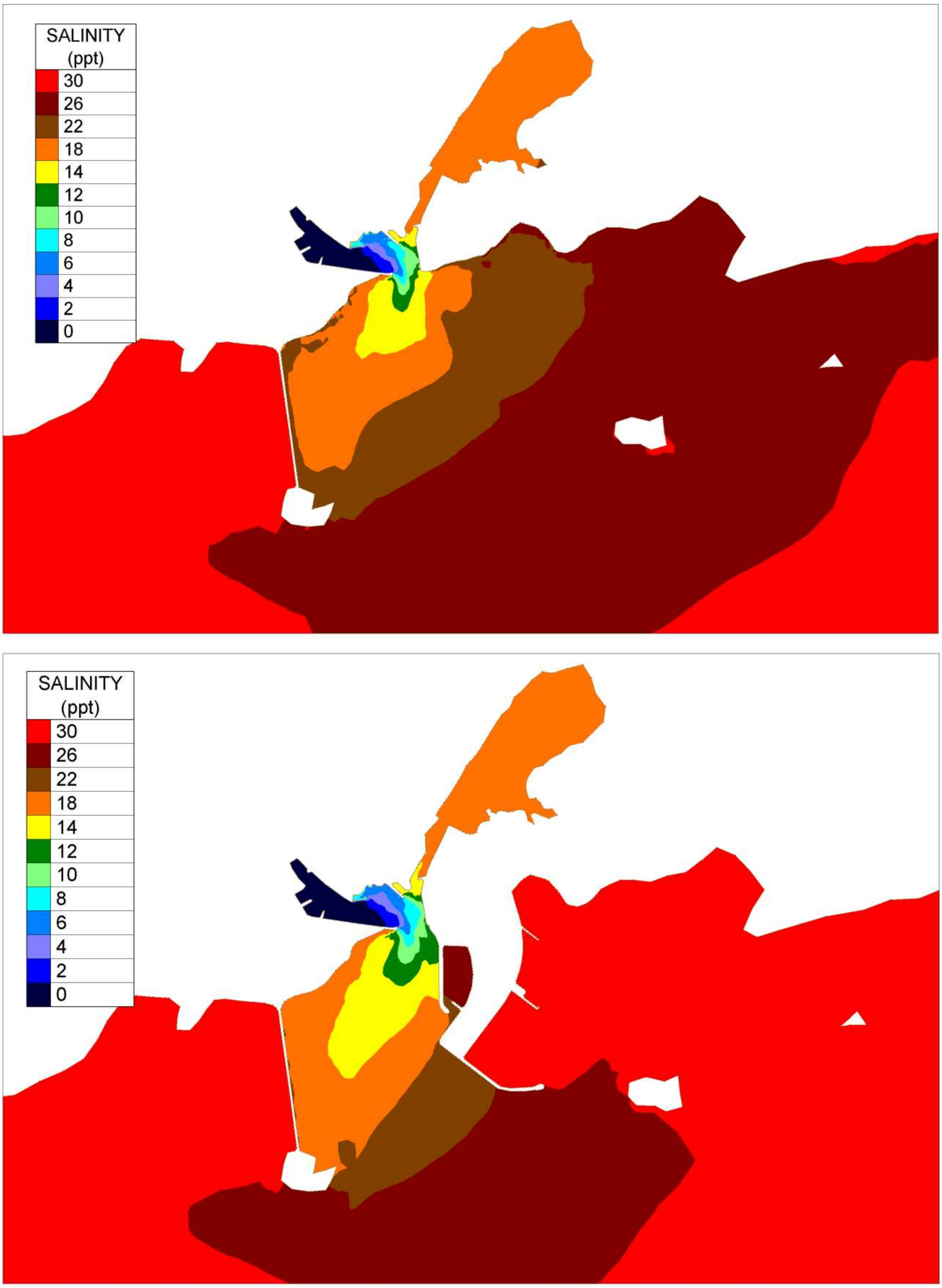


Figure 51 Mean Salinity concentration in surface layer for existing and proposed cases under 90-percentile Corrib Flow (28.5cumec)

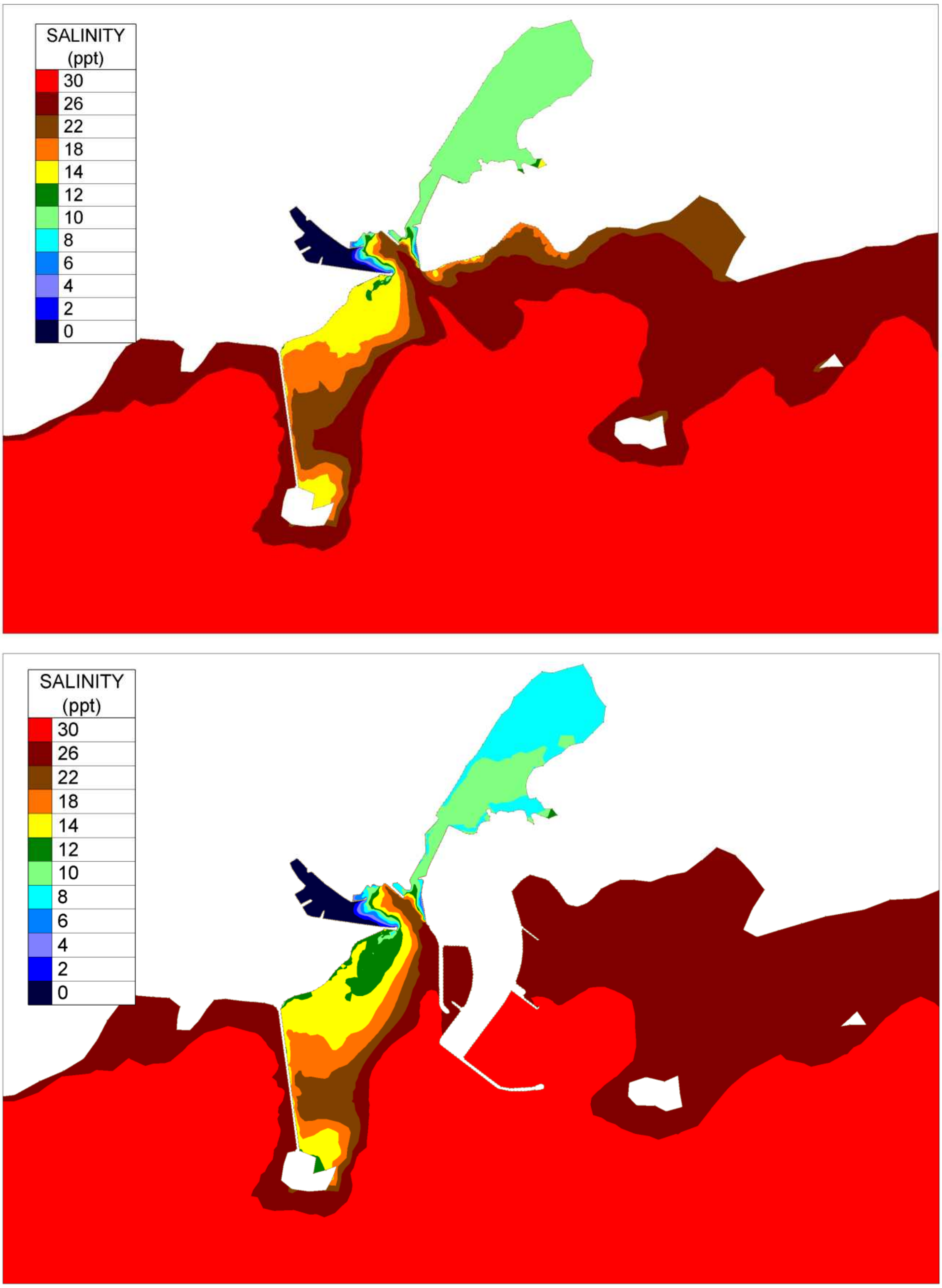


Figure 52 Mean Salinity concentration in bottom layer for existing and proposed cases under 50-percentile Corrib Flow (82cumec)

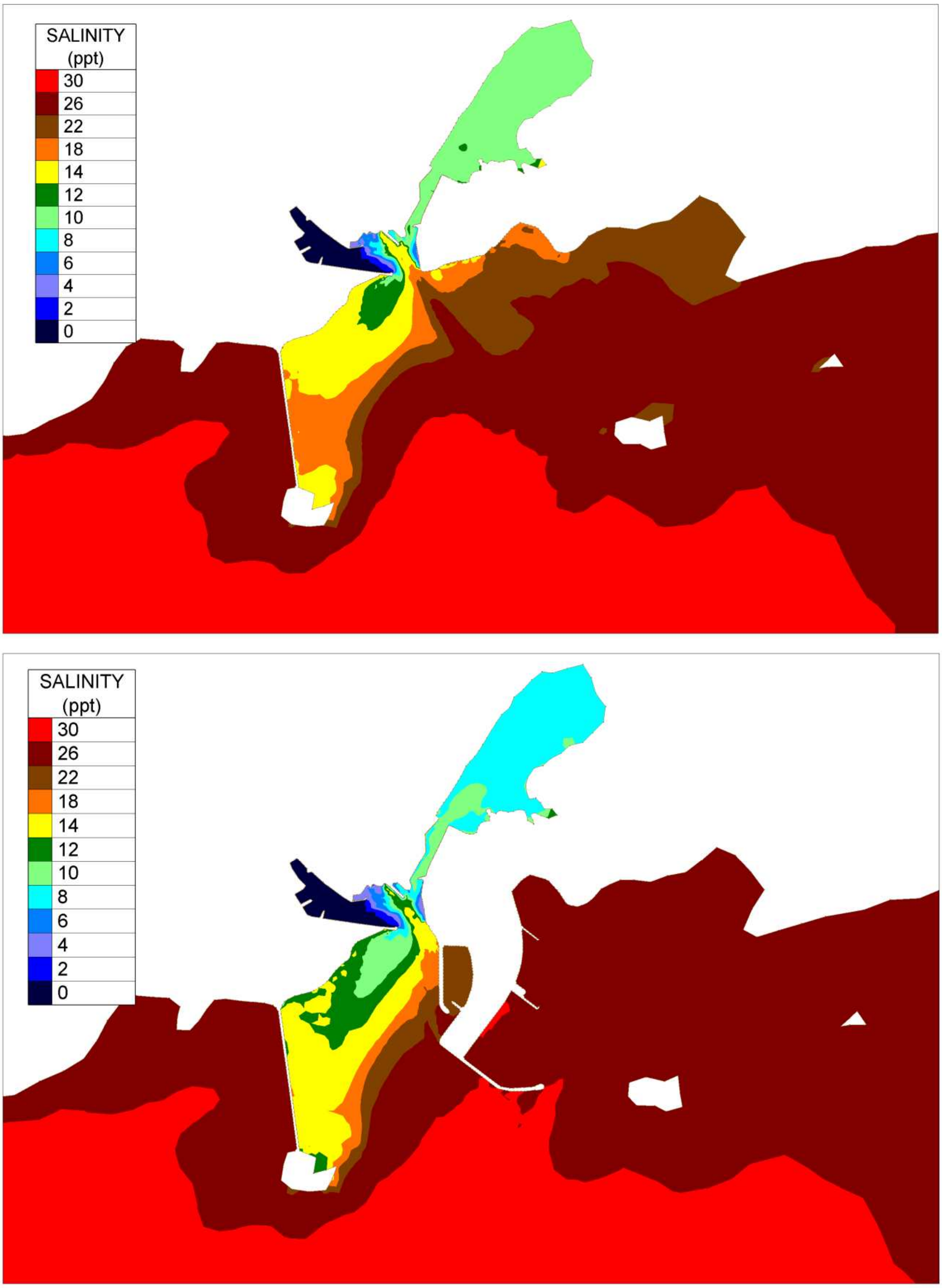


Figure 53 Mean Salinity concentration in mid-depth layer for existing and proposed cases under 50-percentile Corrib Flow (82 cumec)

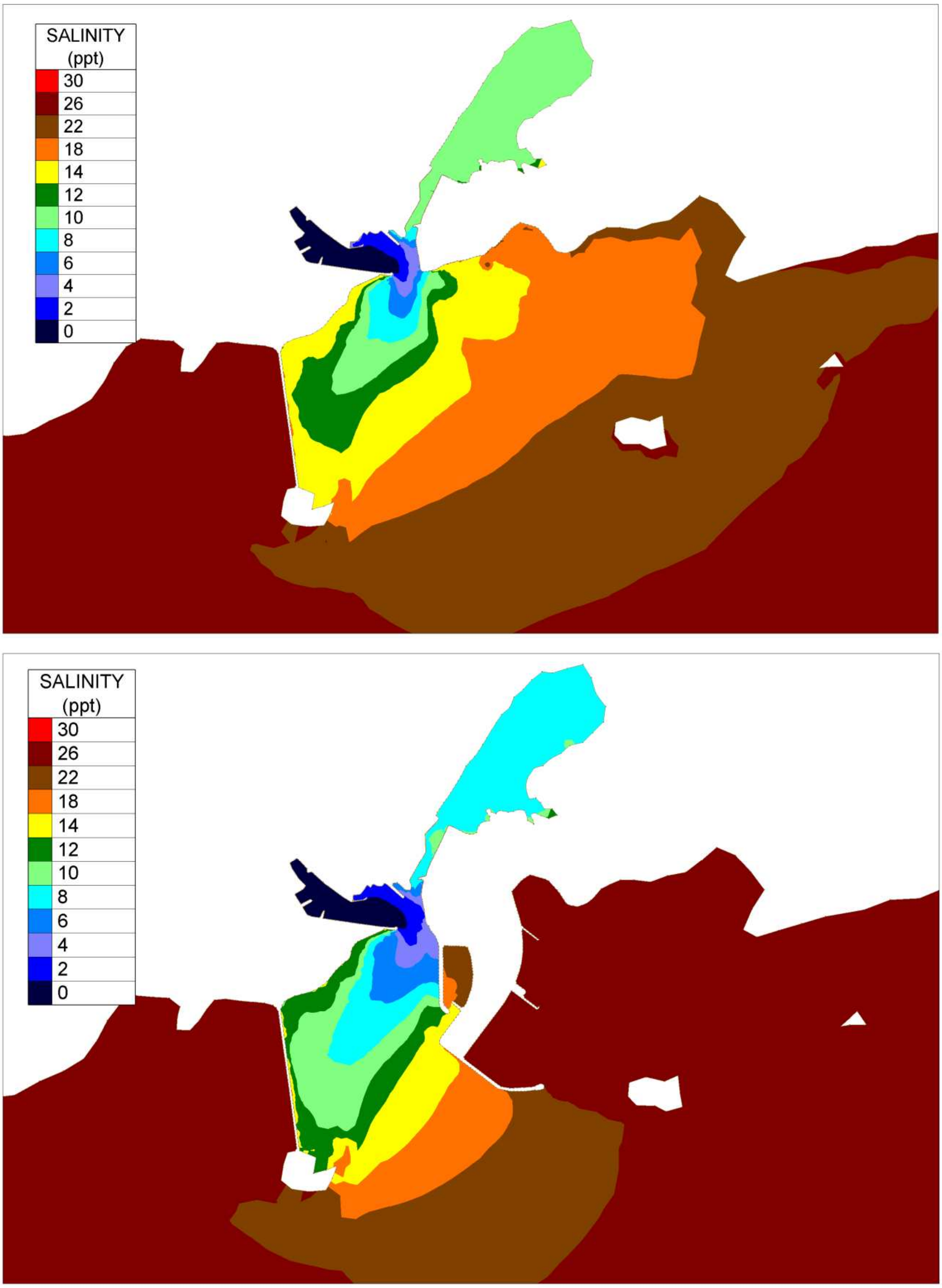
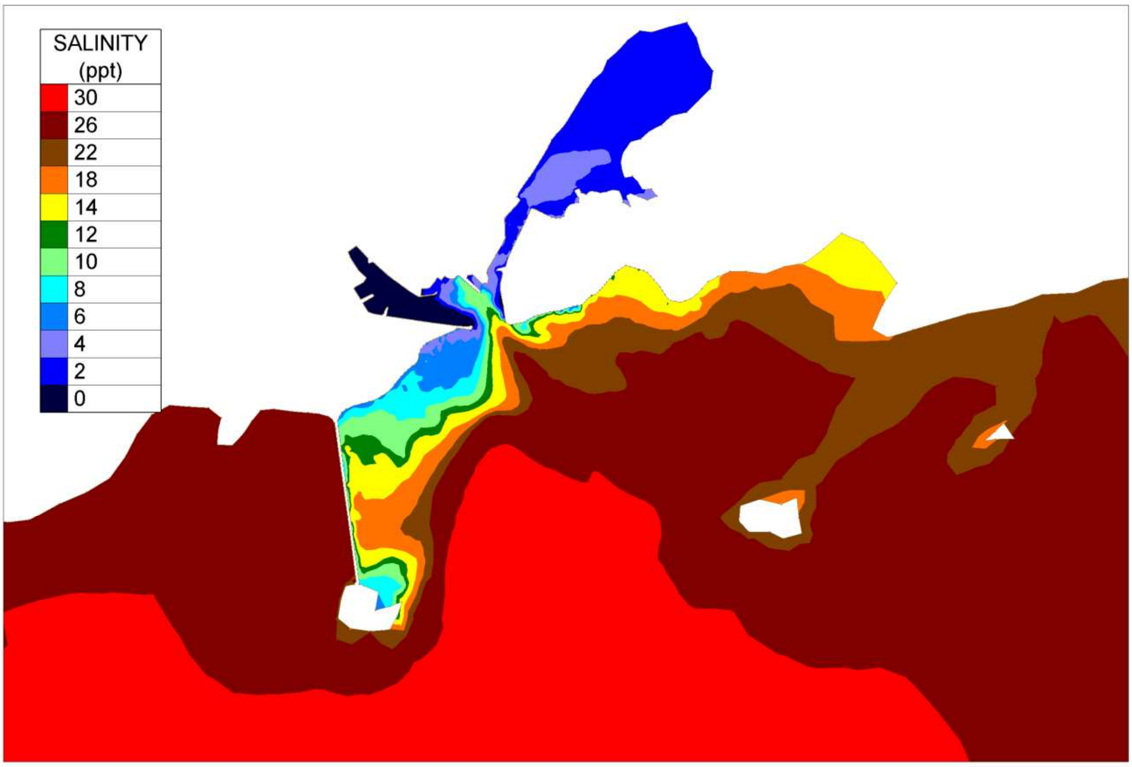


Figure 54 Mean Salinity concentration in surface layer for existing and proposed cases under 50-percentile Corrib Flow (82cumec)



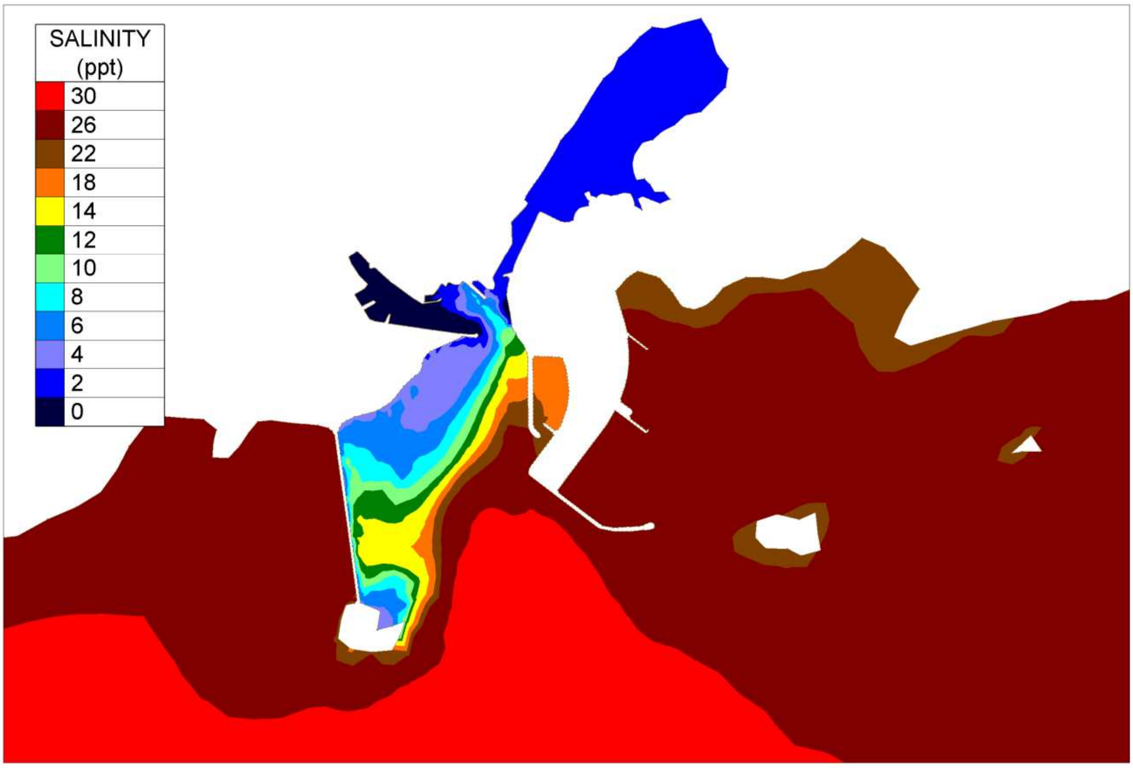


Figure 55 Mean Salinity concentration in bottom layer for existing and proposed cases under 10-percentile Corrib Flow (200cumec)

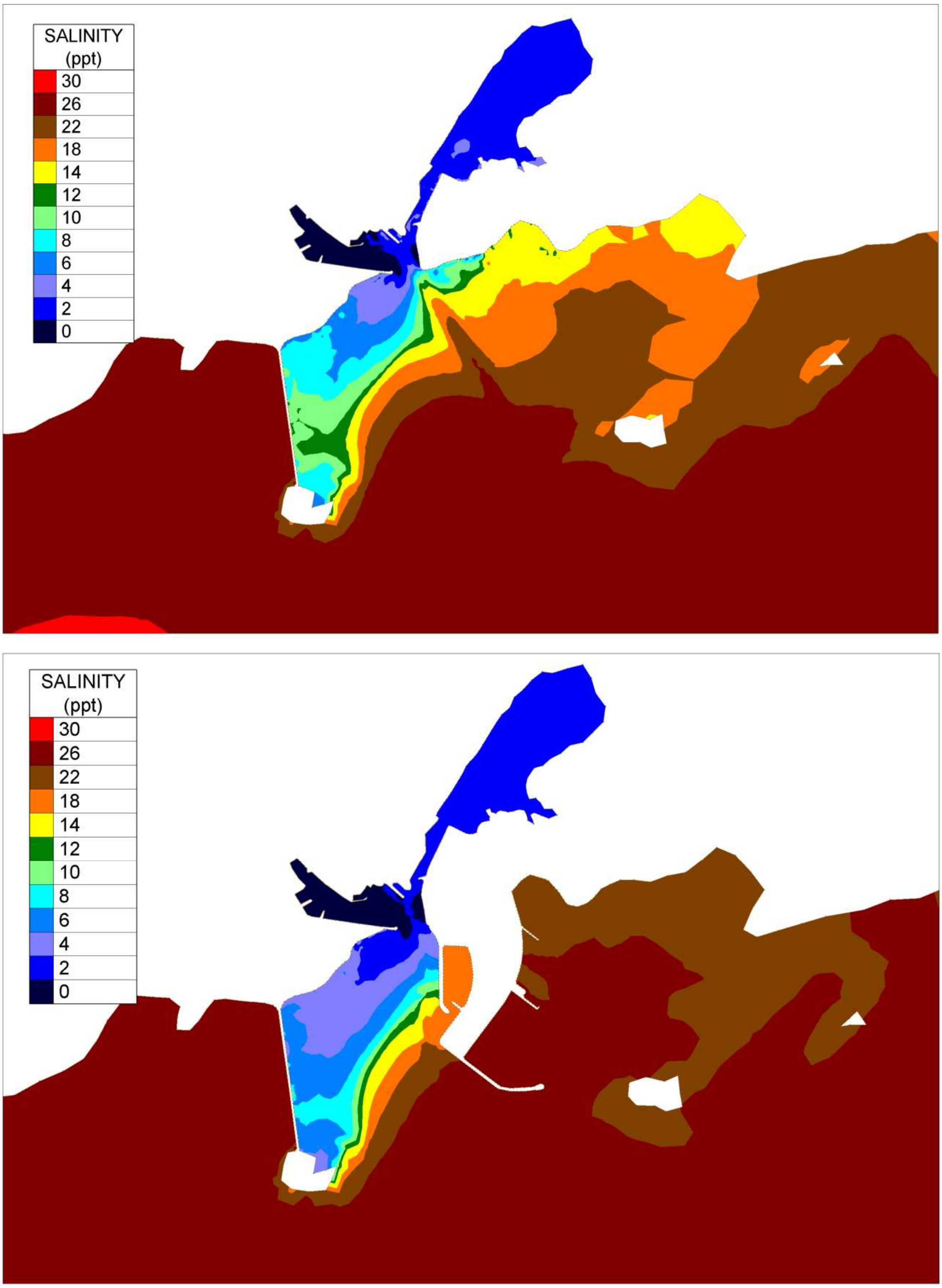
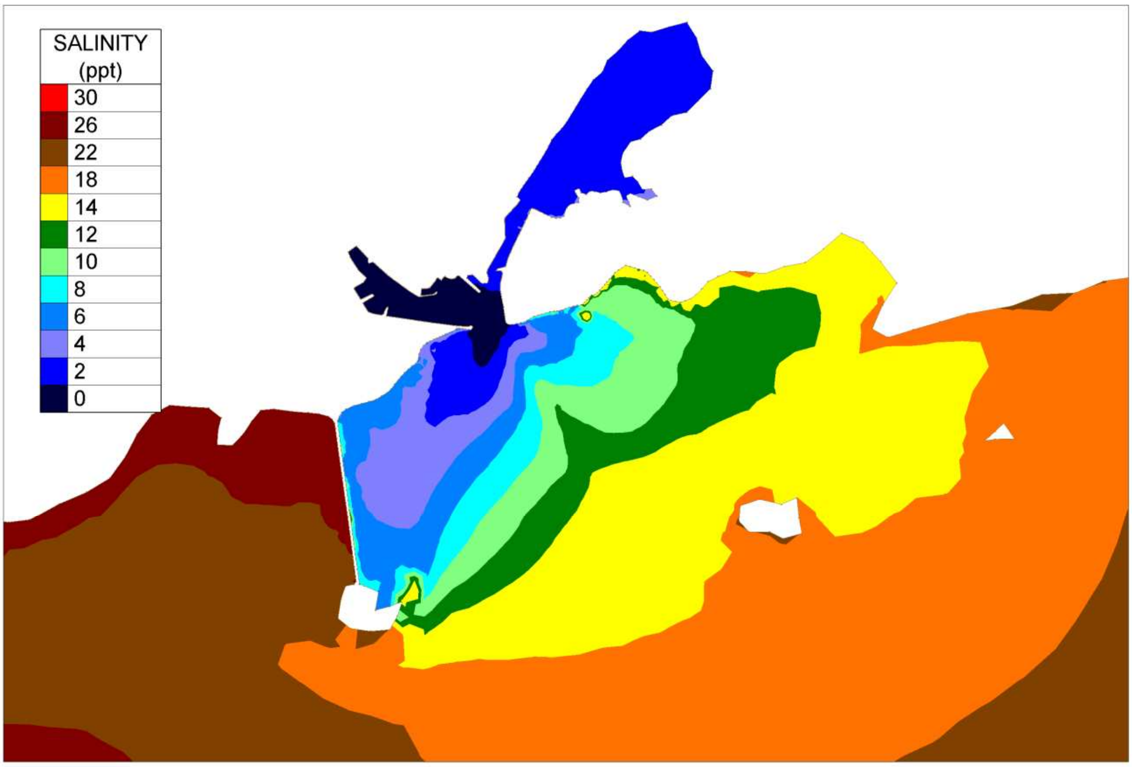


Figure 56 Mean Salinity concentration in mid-depth layer for existing and proposed cases under 10-percentile Corrib Flow (200cumec)



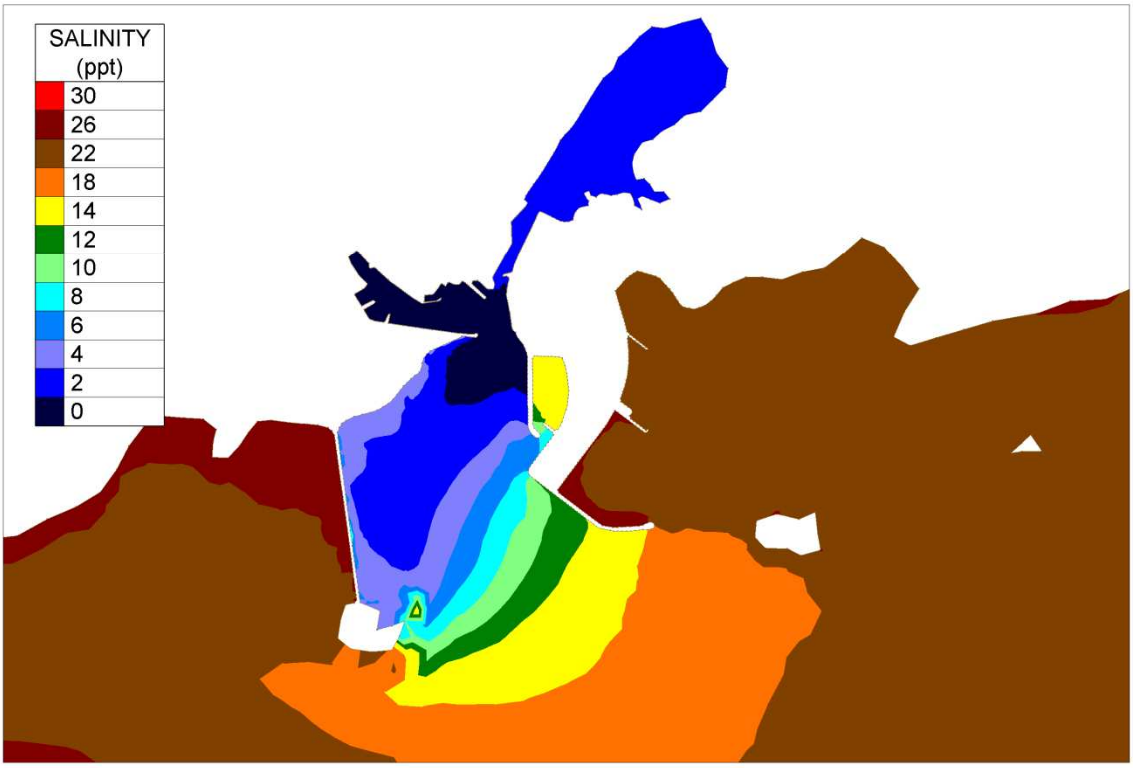


Figure 57 Mean Salinity concentration in surface layer for existing and proposed cases under 10-percentile Corrib Flow (200cumec)

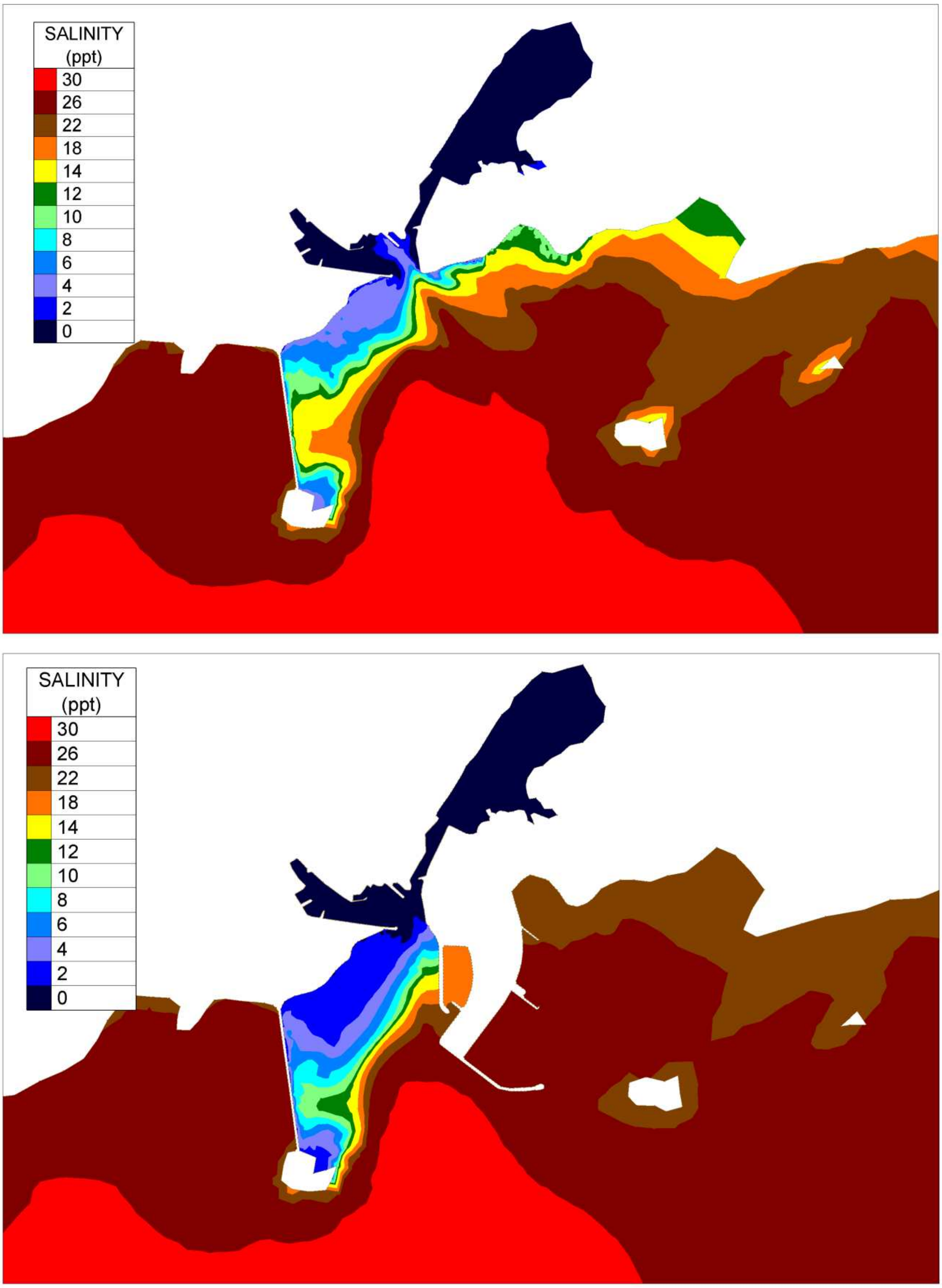


Figure 58 Mean Salinity concentration in bottom layer for existing and proposed cases under 1-percentile Corrib Flood Flow (272cumec)

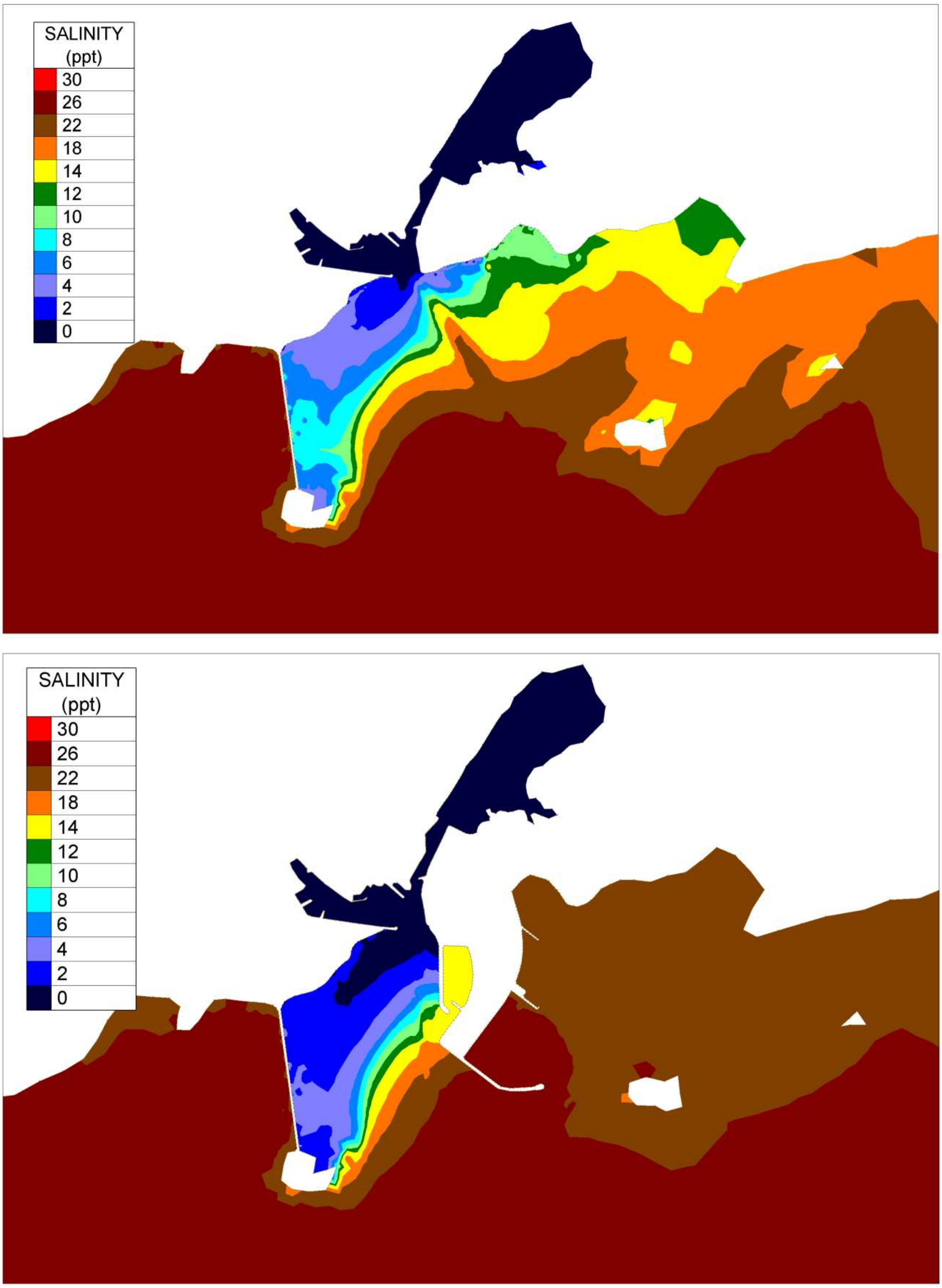


Figure 59 Mean Salinity concentration in mid-depth layer for existing and proposed cases under 1-percentile Corrib Flood Flow (272cumec)

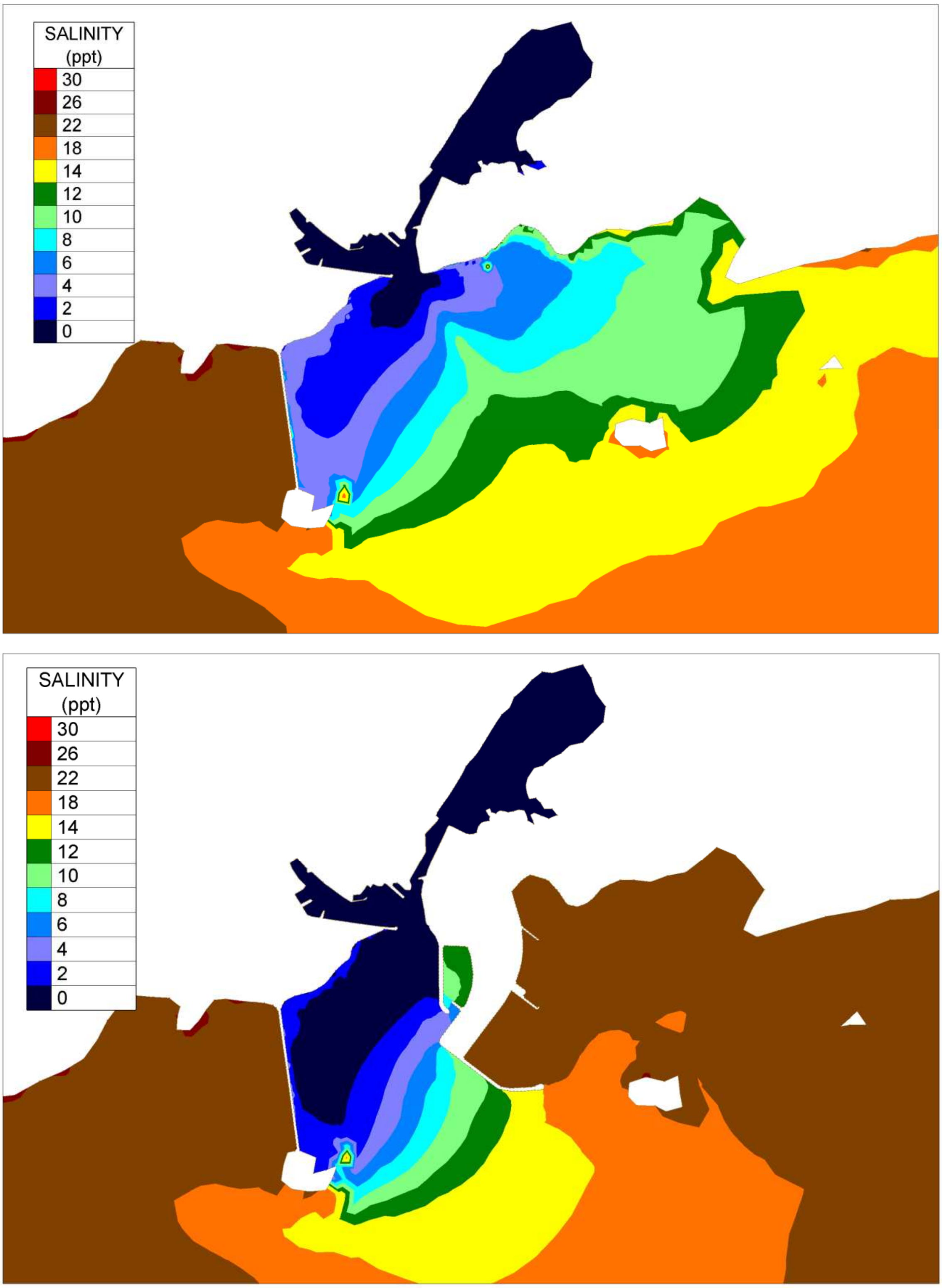


Figure 60 Mean Salinity concentration in surface layer for existing and proposed cases under 1-percentile Corrib Flood Flow (272cumec)

Table 4 Salinity Concentrations for neap to spring tides under 99-percentile low flow in Corrib – Existing Case (without development)

Reference	Surface Layer (5)			Mid-depth Layer (3)			Bottom Layer (1)		
Sites	max	min	mean	max	min	mean	max	min	mean
1	32.31	29.74	30.81	32.71	32.16	32.48	32.87	32.58	32.75
2	32.02	30.27	30.91	32.64	31.86	32.34	32.8	32.19	32.63
3	31.31	29.2	30.28	32.39	31.44	32.01	32.76	32.08	32.52
4	32.03	29.28	30.54	32.03	30.75	31.42	32.25	31.4	31.9
5	30.99	26.39	29.41	31.91	29.05	31.1	32.43	29.5	31.77
6	30.69	25.22	27.89	32.43	30.18	31.88	32.79	32.22	32.62
7	25.76	15.58	21.31	31.54	26.64	30.2	32.51	29.96	31.94
8	29.17	21.98	26.03	30.62	25.56	27.76	31.83	25.57	28.44
9	29.39	25.5	27.2	29.41	25.62	27.31	29.44	25.89	27.45
10	29.1	26.13	27.12	29.11	26.2	27.25	29.15	26.36	27.48
11	29.09	26.29	27.22	29.09	26.28	27.29	29.09	26.28	27.32
12	28.26	26.64	27.25	28.27	26.65	27.29	28.29	26.66	27.31

Table 5 Salinity Concentrations (ppt) for neap to spring tides under 99-percentile low flow in Corrib – Proposed Case (with Harbour Extension)

Reference	Surface Layer (5)			Mid-depth Layer (3)			Bottom Layer (1)		
Sites	max	min	mean	max	min	mean	max	min	mean
1	32.02	29.58	30.4	32.64	32.16	32.47	32.87	32.49	32.76
2	32.38	30.51	31.65	32.58	31.87	32.35	32.75	32.15	32.53
3	32.12	31.53	31.88	32.56	32.07	32.31	32.64	32.12	32.43
4	32.19	31.7	31.94	32.21	32.03	32.11	32.27	32.06	32.17
5	32.14	31.87	32.05	32.22	32.08	32.14	32.31	32.09	32.2
6	29.92	23.45	26.91	32.25	28.82	31.45	32.8	31.82	32.64
7	25.71	14.43	20.45	31.08	25.09	29.61	32.37	28.88	31.78
8	28.76	21.19	25.43	30.27	24.97	27.2	31.65	24.9	27.96
9	28.98	24.8	26.62	29.01	24.91	26.75	29.05	25.22	26.89
10	28.66	25.47	26.52	28.7	25.55	26.67	28.75	25.72	26.91
11	28.65	25.64	26.62	28.66	25.64	26.69	28.65	25.64	26.72
12	27.73	26.01	26.64	27.74	26.02	26.68	27.77	26.04	26.7

Table 6 Difference in Salinities (ppt) between the Existing and Proposed Case for neap to spring tides under 99-percentile low flow in Corrib

Reference Sites	Surface Layer (5)	Mid depth Layer (3)	Bottom Layer (1)	Depth averaged
1	-0.41	-0.01	0.01	-0.14
2	0.74	0.01	-0.1	0.22
3	1.6	0.3	-0.09	0.60
4	1.4	0.69	0.27	0.79
5	2.64	1.04	0.43	1.37
6	-0.98	-0.43	0.02	-0.46
7	-0.86	-0.59	-0.16	-0.54
8	-0.6	-0.56	-0.48	-0.55
9	-0.58	-0.56	-0.56	-0.57
10	-0.6	-0.58	-0.57	-0.58
11	-0.6	-0.6	-0.6	-0.60
12	-0.61	-0.61	-0.61	-0.61

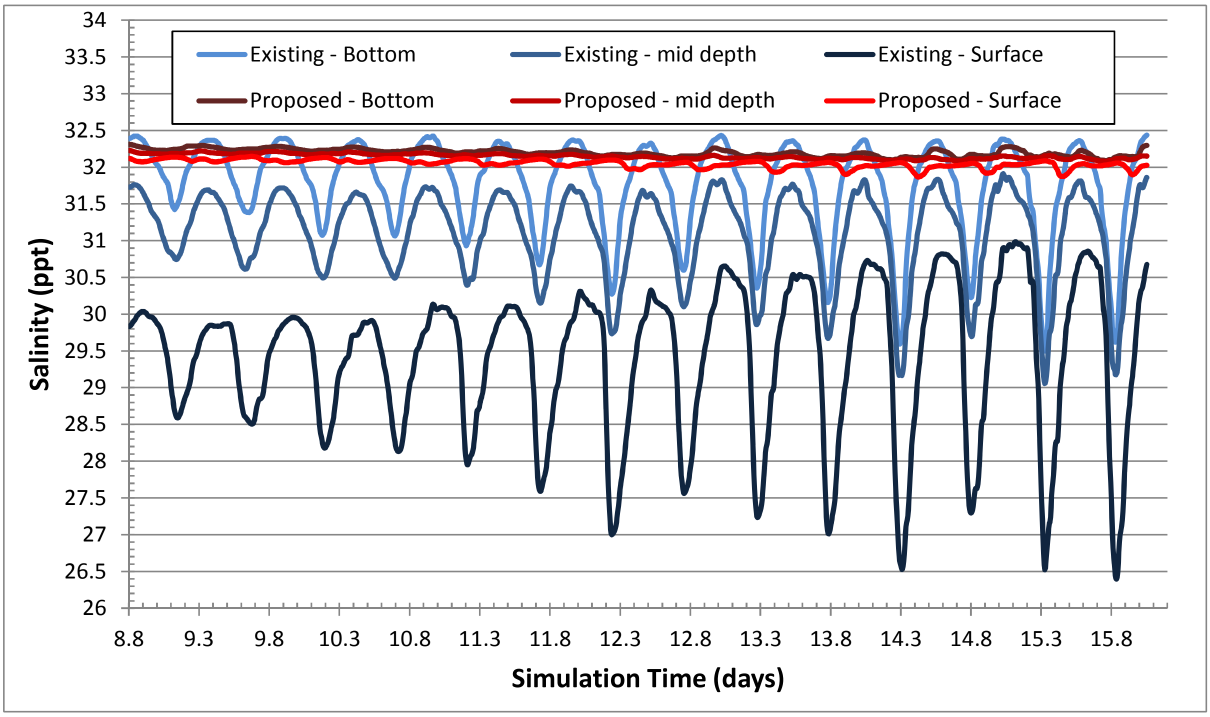


Figure 61 Time Series Output of Salinities for Site 5 existing and Proposed Cases neap to spring tide under 99-percentile Low Flow

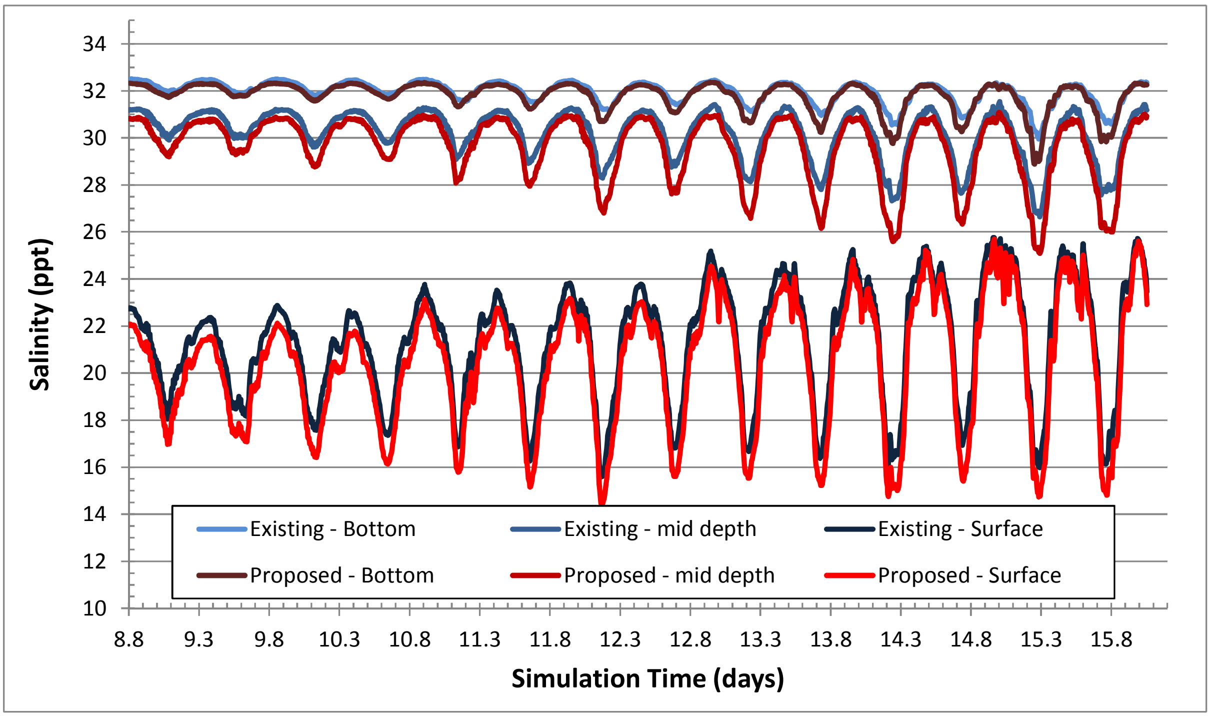


Figure 62 Time Series Output of Salinities for Site 7 Existing and Proposed cases neap to spring tide under 99-percentile Low Flow

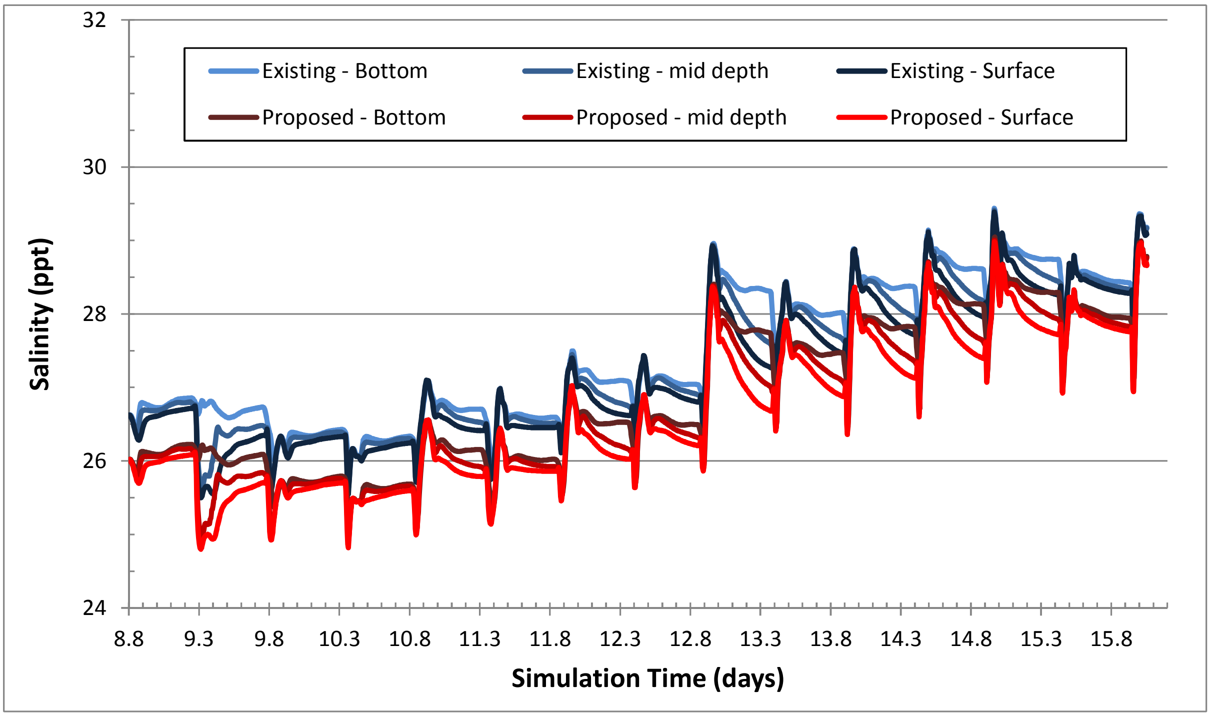


Figure 62 Time Series Output of Salinities for Site 9 in Lough Atalia Existing and Proposed cases neap to spring tide under 99-percentile Low Flow

Table 7 Salinity Concentrations for neap to spring tides under 90-percentile flow in Corrib – Existing Case (without development)

Reference	Surface Layer (5)			Mid-depth Layer (3)			Bottom Layer (1)		
Sites	max	min	mean	max	min	mean	max	min	mean
1	30.76	25.73	27.45	32.37	31.50	32.10	32.85	32.31	32.70
2	29.41	25.83	27.31	32.11	30.24	31.58	32.72	31.25	32.42
3	28.88	23.62	26.36	31.85	29.56	30.91	32.62	31.22	32.18
4	30.37	24.03	26.84	30.60	27.02	29.01	31.74	28.69	30.49
5	28.09	19.37	24.67	30.75	23.45	28.49	32.06	24.22	30.21
6	26.48	15.63	21.22	31.98	26.64	30.69	32.72	32.12	32.49
7	18.13	5.13	11.17	29.69	18.22	26.21	32.03	26.37	30.72
8	24.33	12.71	18.17	27.70	16.24	21.10	30.41	17.62	22.76
9	25.03	16.86	20.26	25.14	17.11	20.55	25.27	17.87	20.93
10	23.96	18.03	20.02	24.41	18.24	20.40	24.67	18.61	20.88
11	23.82	18.40	20.15	23.97	18.42	20.34	24.16	18.43	20.51
12	22.24	19.02	20.23	22.27	19.04	20.33	22.75	19.06	20.43

Table 8 Salinity Concentrations (ppt) for neap to spring tides under 90-percentile flow in Corrib – Proposed Case (with Harbour Extension)

Reference	Surface Layer (5)			Mid-depth Layer (3)			Bottom Layer (1)		
Sites	max	min	mean	max	min	mean	max	min	mean
1	29.19	24.68	26.54	32.39	31.30	32.02	32.86	32.14	32.68
2	31.38	27.75	29.70	32.05	30.58	31.58	32.54	31.32	32.09
3	30.91	29.79	30.47	31.90	31.05	31.44	32.27	31.26	31.85
4	31.39	29.97	30.54	31.40	30.84	30.99	31.51	31.03	31.20
5	30.99	30.49	30.79	31.19	30.97	31.07	31.51	31.10	31.27
6	25.34	14.74	20.16	31.33	23.54	29.26	32.67	31.27	32.38
7	17.46	3.71	9.84	28.66	14.32	24.58	31.67	22.53	29.90
8	23.39	11.32	16.93	26.64	14.66	19.91	29.66	16.29	21.64
9	23.92	15.56	19.07	24.04	15.82	19.37	24.17	16.61	19.79
10	22.78	16.79	18.82	23.29	16.99	19.21	23.57	17.37	19.71
11	22.64	17.15	18.93	22.79	17.17	19.13	23.03	17.18	19.31
12	21.10	17.79	19.02	21.11	17.81	19.11	21.60	17.83	19.22

Table 9 Difference in Salinities (ppt) between the Existing and Proposed Case for neap to spring tides under 90-percentile flow in Corrib

Reference Sites	Surface Layer (5)	Mid depth Layer (3)	Bottom Layer (1)	Depth averaged
1	-0.91	-0.08	-0.02	-0.34
2	2.39	0	-0.33	0.69
3	4.11	0.53	-0.33	1.44
4	3.7	1.98	0.71	2.13
5	6.12	2.58	1.06	3.25
6	-1.06	-1.43	-0.11	-0.87
7	-1.33	-1.63	-0.82	-1.26
8	-1.24	-1.19	-1.12	-1.18
9	-1.19	-1.18	-1.14	-1.17
10	-1.2	-1.19	-1.17	-1.19
11	-1.22	-1.21	-1.2	-1.21
12	-1.21	-1.22	-1.21	-1.21

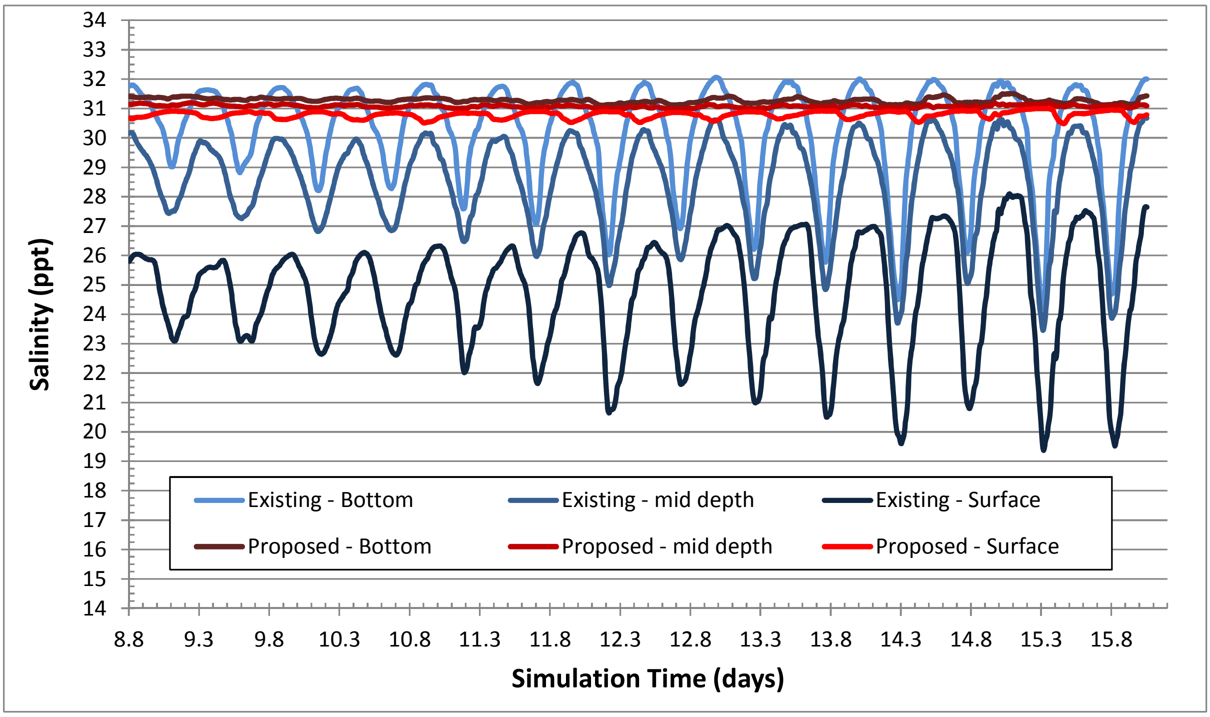


Figure 64 Time Series Output of Salinities for Site 5 existing and Proposed Cases neap to spring tide under 90-percentile Flow

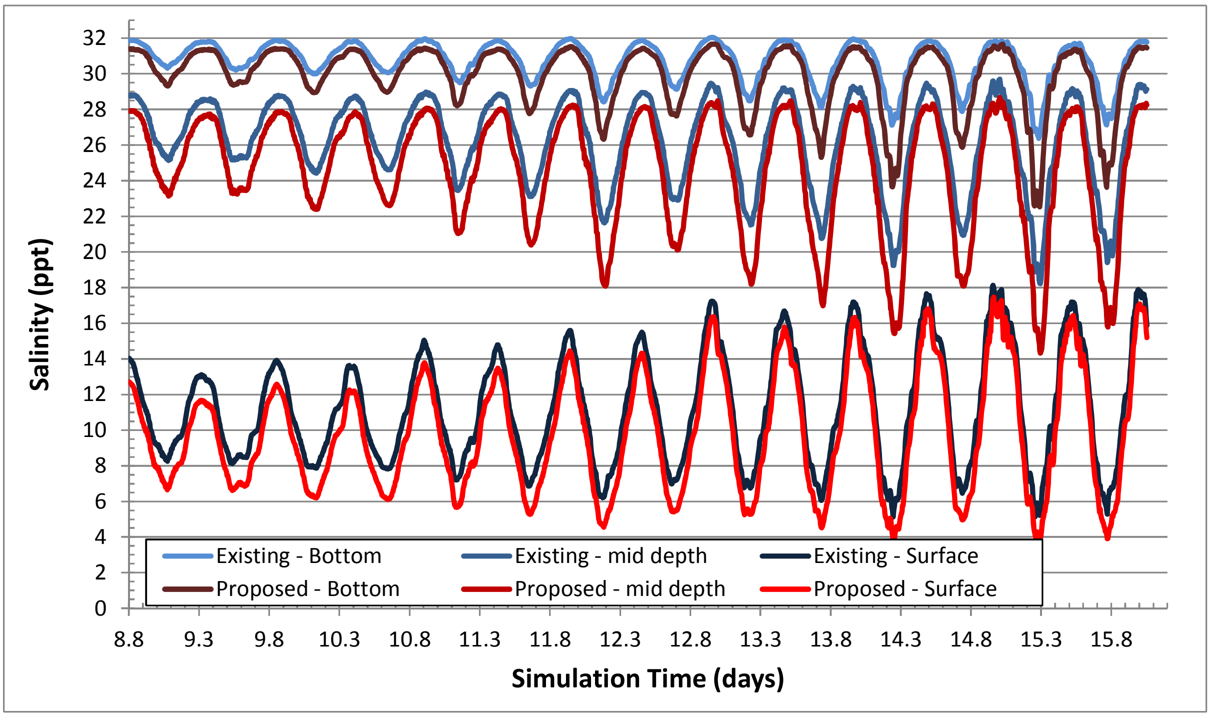


Figure 65 Time Series Output of Salinities for Site 7 Existing and Proposed cases neap to spring tide under 90-percentile Flow

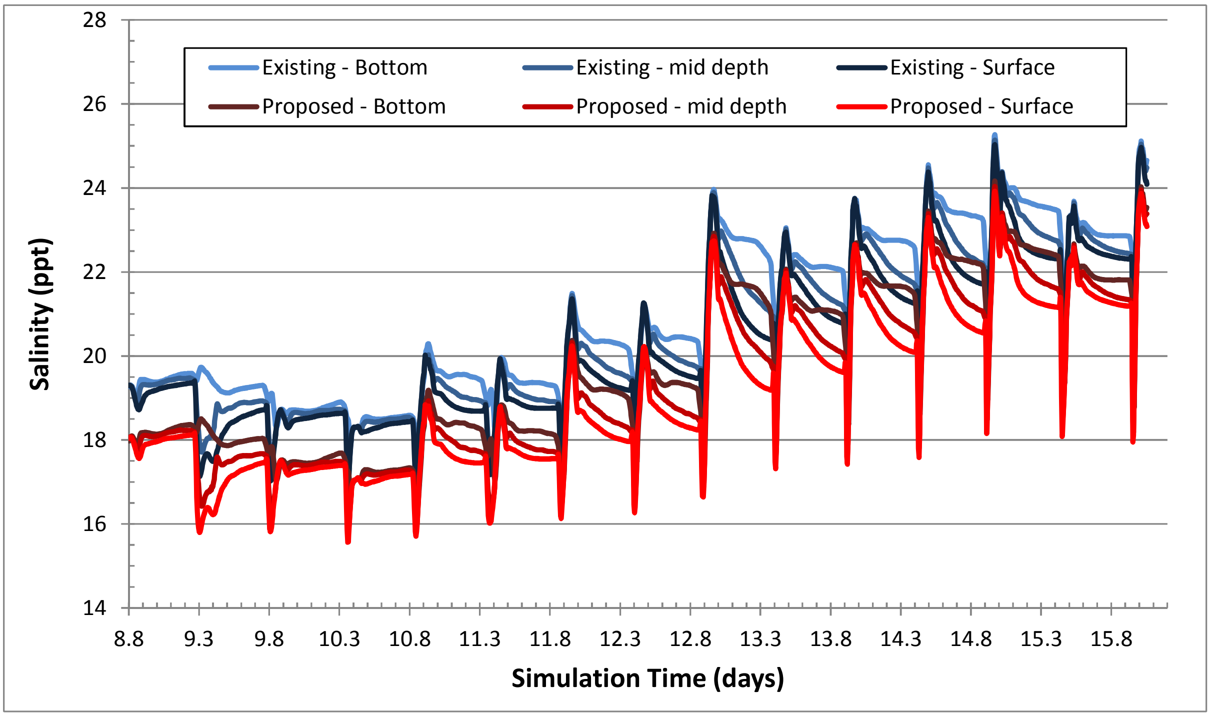


Figure 66 Time Series Output of Salinities for Site 9 in Lough Atalia Existing and Proposed cases neap to spring tide under 90-percentile Flow

Table 10 Salinity Concentrations for neap to spring tides under 50-percentile flow in Corrib – Existing Case (without development)

Reference Sites	Surface Layer (5)			Mid-depth Layer (3)			Bottom Layer (1)		
	max	min	mean	max	min	mean	max	min	mean
1	27.46	19.80	22.33	31.13	29.70	30.62	31.89	31.14	31.67
2	25.07	19.68	22.25	30.62	27.29	29.54	31.62	29.35	31.17
3	24.40	16.00	20.82	30.20	25.23	28.28	31.39	28.77	30.70
4	24.80	16.92	21.42	27.99	20.65	24.72	30.29	22.32	27.47
5	23.29	10.97	18.43	28.34	15.31	23.99	30.63	16.39	27.02
6	21.07	8.05	14.40	30.28	20.29	27.39	31.70	30.72	31.35
7	10.51	0.99	4.16	25.15	4.14	17.79	30.41	15.58	27.27
8	16.95	4.29	9.42	21.28	6.55	11.95	26.78	7.95	14.34
9	18.02	7.28	11.19	18.19	7.49	11.58	18.40	8.23	12.17
10	16.39	8.41	10.83	17.21	8.64	11.37	17.66	9.03	12.04
11	15.80	8.79	10.92	16.11	8.83	11.19	16.66	8.84	11.51
12	13.90	9.48	11.04	14.02	9.51	11.18	14.88	9.54	11.35

Table 11 Salinity Concentrations (ppt) for neap to spring tides under 50-percentile flow in Corrib – Proposed Case (with Harbour Extension)

Reference Sites	Surface Layer (5)			Mid-depth Layer (3)			Bottom Layer (1)		
	max	min	mean	max	min	mean	max	min	mean
1	25.10	18.13	21.06	31.14	29.17	30.43	31.90	30.85	31.62
2	29.05	24.00	26.22	30.57	28.06	29.54	31.35	29.34	30.55
3	28.54	26.45	27.65	30.00	28.77	29.29	30.78	29.26	30.11
4	29.36	26.83	27.84	29.38	28.29	28.58	29.81	28.70	29.06
5	28.65	27.62	28.16	29.05	28.48	28.70	29.77	28.79	29.15
6	19.32	7.53	13.32	29.27	16.45	24.65	31.63	28.75	30.95
7	9.56	0.17	3.13	23.82	0.83	14.39	29.86	1.15	24.30
8	15.68	3.16	8.07	19.60	4.95	10.42	25.81	6.37	12.74
9	16.39	5.79	9.68	16.56	6.01	10.08	16.78	6.74	10.69
10	14.75	6.92	9.32	15.59	7.15	9.85	16.04	7.55	10.53
11	14.18	7.31	9.40	14.48	7.35	9.68	15.02	7.35	9.99
12	12.31	8.02	9.52	12.41	8.05	9.66	13.25	8.08	9.82

Table 12 Difference in Salinities (ppt) between the Existing and Proposed Case for neap to spring tides under 50-percentile flow in Corrib

Reference Sites	Surface Layer (5)	Mid depth Layer (3)	Bottom Layer (1)	Depth averaged
1	-1.27	-0.19	-0.05	-0.50
2	3.97	0	-0.62	1.12
3	6.83	1.01	-0.59	2.42
4	6.42	3.86	1.59	3.96
5	9.73	4.71	2.13	5.52
6	-1.08	-2.74	-0.4	-1.41
7	-1.03	-3.4	-2.97	-2.47
8	-1.35	-1.53	-1.6	-1.49
9	-1.51	-1.5	-1.48	-1.50
10	-1.51	-1.52	-1.51	-1.51
11	-1.52	-1.51	-1.52	-1.52
12	-1.52	-1.52	-1.53	-1.52

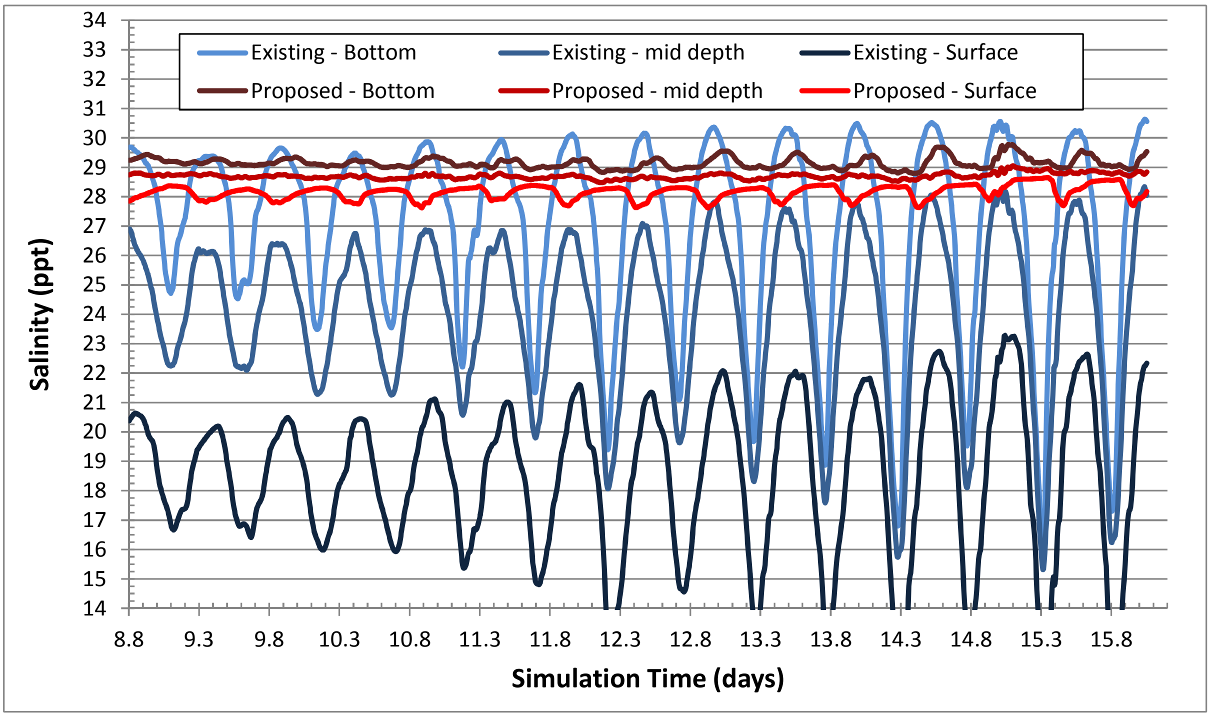


Figure 67 Time Series Output of Salinities for Site 5 existing and Proposed Cases neap to spring tide under 50-percentile Flow

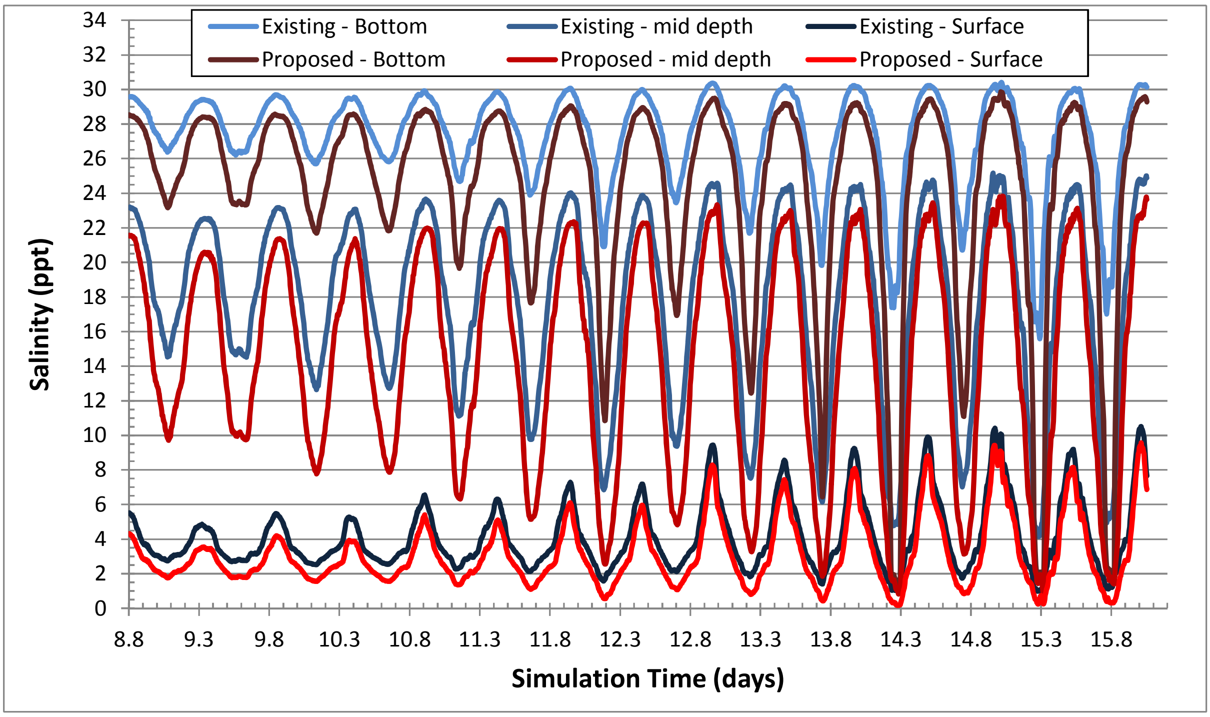


Figure 68 Time Series Output of Salinities for Site 7 Existing and Proposed cases neap to spring tide under 50-percentile Flow

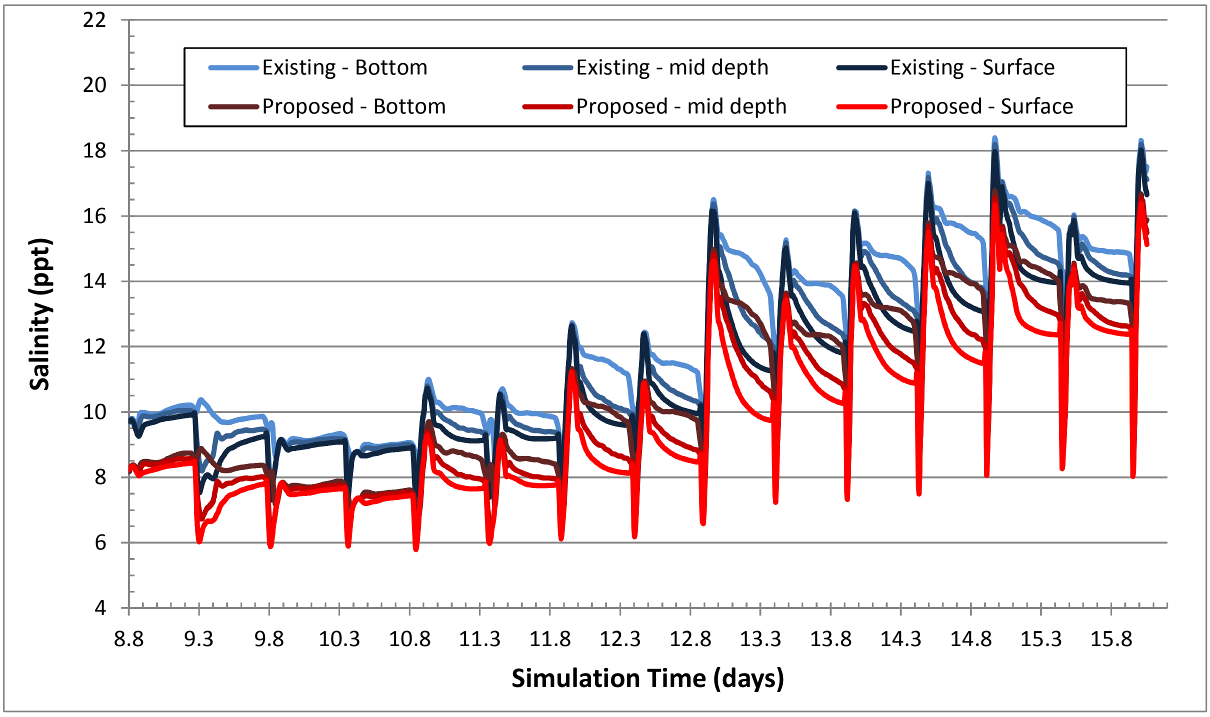


Figure 69 Time Series Output of Salinities for Site 9 in Lough Atalia Existing and Proposed cases neap to spring tide under 50-percentile Flow

Table 131 Salinity Concentrations for neap to spring tides under 10-percentile flow in Corrib – Existing Case (without development)

Reference	Surface Layer (5)			Mid-depth Layer (3)			Bottom Layer (1)		
Sites	max	min	mean	max	min	mean	max	min	mean
1	21.66	12.44	15.62	29.64	27.37	28.91	30.91	29.76	30.56
2	20.06	10.82	16.26	28.59	22.61	26.71	30.61	27.52	29.82
3	17.98	6.36	13.28	27.88	16.61	23.92	30.12	24.37	28.96
4	18.12	6.52	13.77	23.99	10.43	18.28	28.23	13.84	22.72
5	16.99	1.90	10.49	24.32	3.67	16.90	28.69	4.50	21.61
6	14.50	2.82	8.04	27.41	11.86	21.06	30.65	28.21	30.12
7	3.51	0.00	0.81	15.31	0.02	4.44	27.66	0.05	14.34
8	7.06	0.66	3.09	10.43	1.13	3.89	18.85	1.98	5.34
9	8.00	1.62	3.68	8.13	1.70	3.89	8.31	1.99	4.18
10	6.95	2.27	3.50	7.56	2.38	3.76	7.89	2.62	4.13
11	6.35	2.50	3.56	6.63	2.50	3.68	7.07	2.50	3.78
12	4.97	2.88	3.61	4.99	2.89	3.66	5.46	2.90	3.72

Table 14 Salinity Concentrations (ppt) for neap to spring tides under 10-percentile flow in Corrib – Proposed Case (with Harbour Extension)

Reference	Surface Layer (5)			Mid-depth Layer (3)			Bottom Layer (1)		
Sites	max	min	mean	max	min	mean	max	min	mean
1	19.46	10.38	14.31	29.68	26.14	28.39	30.89	29.61	30.50
2	25.62	18.40	21.57	28.61	24.78	26.83	30.09	26.72	28.71
3	25.45	22.11	23.88	27.47	25.73	26.44	29.12	26.64	27.96
4	26.51	22.89	24.30	26.63	24.92	25.37	27.52	25.54	26.24
5	25.65	23.75	24.71	26.35	25.21	25.58	27.63	25.67	26.38
6	12.08	0.97	6.68	25.54	5.14	16.59	30.55	20.17	28.73
7	2.74	0.00	0.44	12.30	0.00	2.35	25.90	0.01	9.12
8	5.82	0.09	2.09	8.34	0.25	2.63	16.41	0.74	3.71
9	6.36	0.61	2.42	6.46	0.67	2.63	6.56	0.83	2.92
10	5.42	1.08	2.24	5.97	1.17	2.48	6.30	1.41	2.84
11	4.89	1.28	2.30	5.10	1.29	2.40	5.46	1.29	2.48
12	3.55	1.69	2.35	3.55	1.71	2.39	3.90	1.71	2.44

Table 15 Difference in Salinities (ppt) between the Existing and Proposed Case for neap to spring tides under 10-percentile flow in Corrib

Reference Sites	Surface Layer (5)	Mid depth Layer (3)	Bottom Layer (1)	Depth averaged
1	-1.31	-0.52	-0.06	-0.63
2	5.31	0.12	-1.11	1.44
3	10.6	2.52	-1	4.04
4	10.53	7.09	3.52	7.05
5	14.22	8.68	4.77	9.22
6	-1.36	-4.47	-1.39	-2.41
7	-0.37	-2.09	-5.22	-2.56
8	-1	-1.26	-1.63	-1.30
9	-1.26	-1.26	-1.26	-1.26
10	-1.26	-1.28	-1.29	-1.28
11	-1.26	-1.28	-1.3	-1.28
12	-1.26	-1.27	-1.28	-1.27

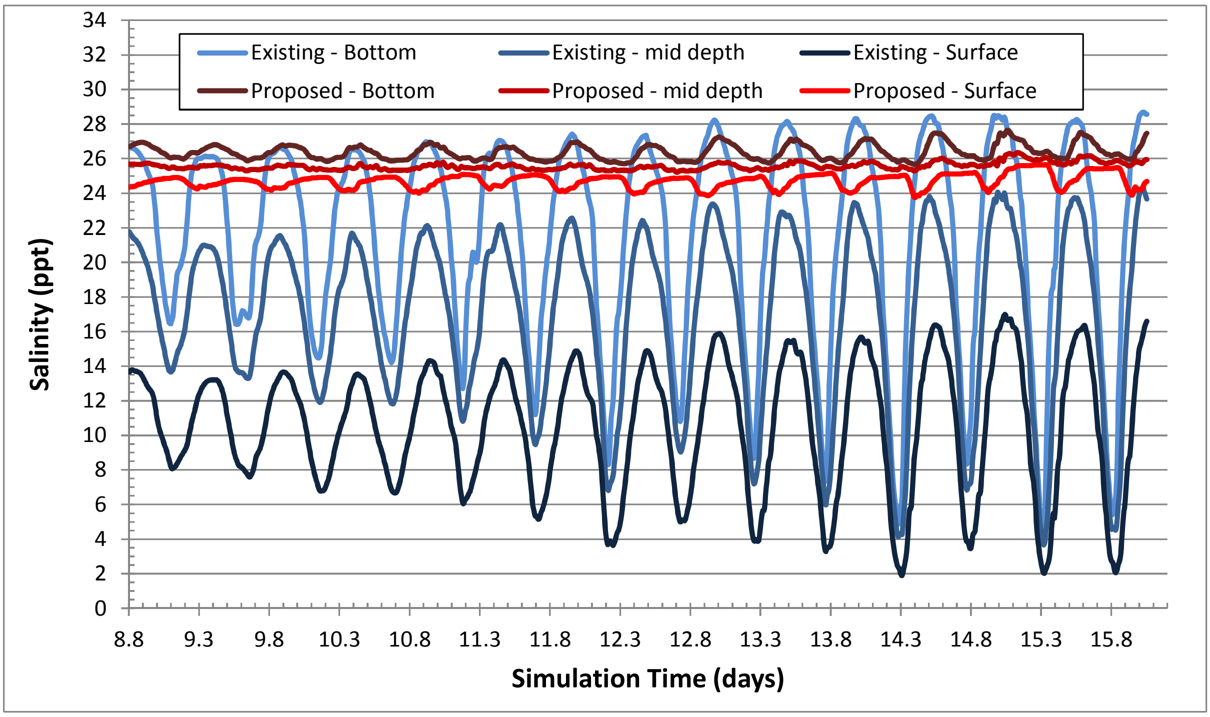


Figure 70 Time Series Output of Salinities for Site 5 existing and Proposed Cases neap to spring tide under 10-percentile Flow

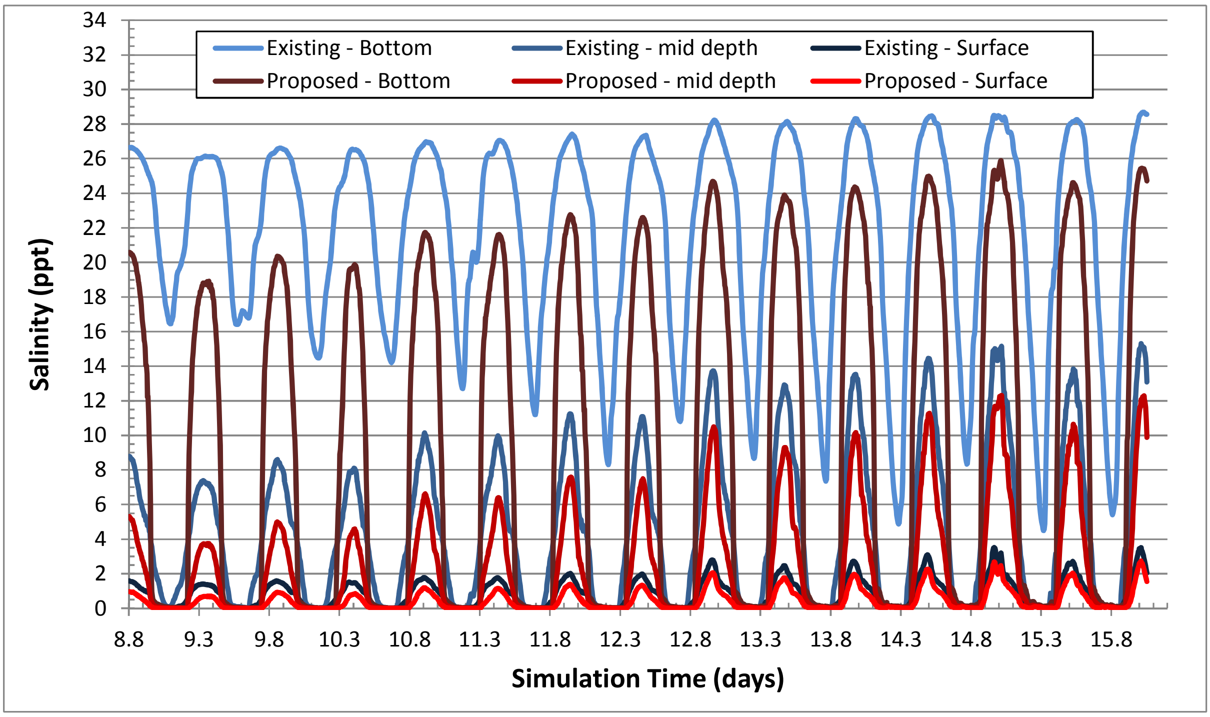


Figure 71 Time Series Output of Salinities for Site 7 Existing and Proposed cases neap to spring tide under 10-percentile Flow

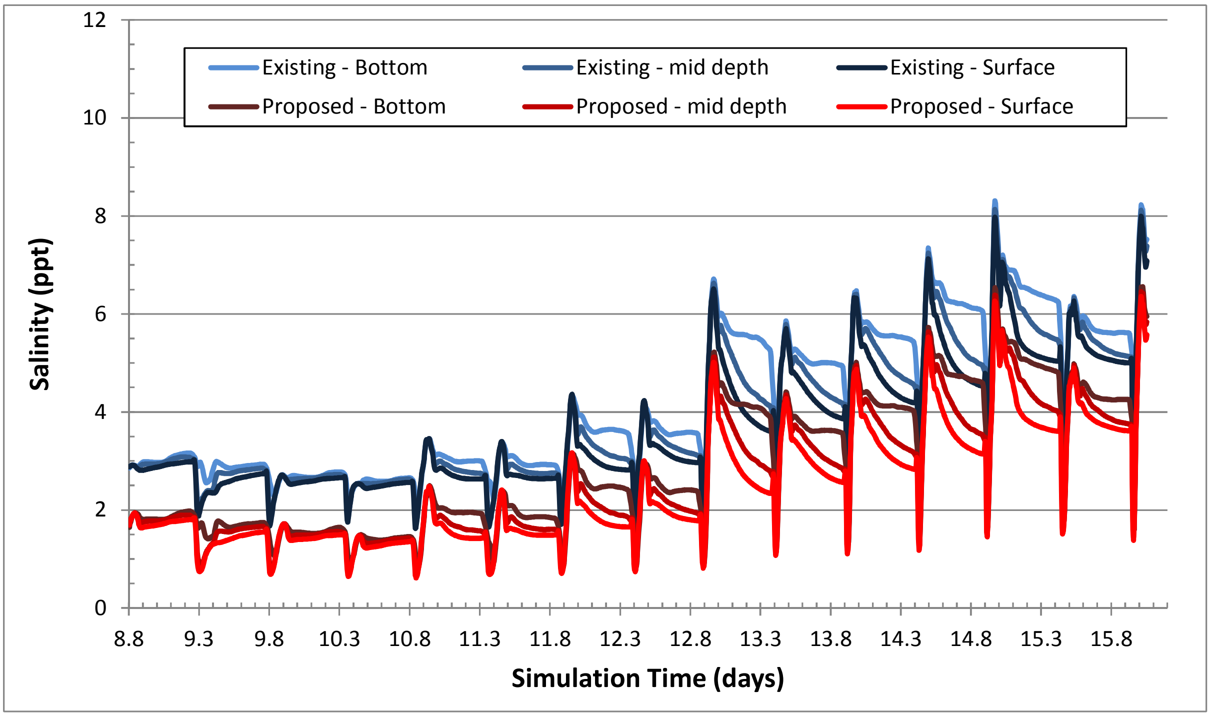


Figure 72 Time Series Output of Salinities for Site 9 in Lough Atalia Existing and Proposed cases neap to spring tide under 10-percentile Flow

Table 16 Salinity Concentrations for neap to spring tides under 1-percentile flood flow in Corrib – Existing Case (without development)

Reference Sites	Surface Layer (5)			Mid-depth Layer (3)			Bottom Layer (1)		
	max	min	mean	max	min	mean	max	min	mean
1	17.80	10.43	13.47	29.34	26.69	28.56	30.91	29.65	30.50
2	17.78	7.35	13.51	28.01	20.42	25.83	30.47	27.67	29.74
3	15.60	3.38	10.09	26.88	12.51	21.48	30.12	22.59	28.78
4	15.74	4.41	10.25	22.31	6.72	15.08	27.32	9.93	20.37
5	14.61	1.75	7.17	22.27	3.23	13.24	27.88	3.92	18.74
6	12.25	1.57	6.51	25.87	8.28	18.61	30.63	26.01	29.87
7	1.97	0.00	0.26	9.52	0.00	1.53	25.82	0.00	7.36
8	4.48	0.04	1.49	6.53	0.08	1.78	13.60	0.27	2.45
9	5.09	0.31	1.63	5.20	0.33	1.80	5.34	0.38	2.05
10	4.27	0.61	1.48	4.74	0.65	1.68	5.06	0.81	1.98
11	3.82	0.72	1.52	4.00	0.73	1.60	4.41	0.73	1.66
12	2.56	1.04	1.56	2.56	1.04	1.59	2.86	1.04	1.63

Table 17 Salinity Concentrations (ppt) for neap to spring tides under 1-percentile flood flow in Corrib – Proposed Case (with Harbour Extension)

Reference Sites	Surface Layer (5)			Mid-depth Layer (3)			Bottom Layer (1)		
	max	min	mean	max	min	mean	max	min	mean
1	16.63	8.25	11.97	29.34	24.72	27.71	30.89	29.31	30.43
2	24.42	16.68	19.87	27.72	23.54	25.94	29.91	25.78	28.25
3	24.32	20.72	22.56	26.53	24.70	25.49	28.86	25.73	27.35
4	25.60	21.62	23.10	25.63	23.78	24.25	26.69	24.44	25.27
5	24.53	22.44	23.52	25.43	24.13	24.52	26.85	24.60	25.48
6	9.59	0.11	4.73	23.12	0.46	12.99	30.38	3.12	26.94
7	1.25	0.00	0.09	6.32	0.00	0.51	22.52	0.00	3.03
8	3.24	0.00	0.64	4.44	0.00	0.78	9.91	0.00	1.09
9	3.54	0.02	0.66	3.63	0.02	0.78	3.72	0.02	0.94
10	2.62	0.08	0.57	3.11	0.08	0.68	3.43	0.11	0.87
11	2.29	0.14	0.60	2.41	0.14	0.63	2.74	0.14	0.65
12	1.22	0.29	0.62	1.21	0.29	0.63	1.31	0.29	0.65

Table 18 Difference in Salinities (ppt) between the Existing and Proposed Case for neap to spring tides under 1-percentile flood flow in Corrib

Reference Sites	Surface Layer (5)	Mid depth Layer (3)	Bottom Layer (1)	Depth averaged
1	-1.5	-0.85	-0.07	-0.81
2	6.36	0.11	-1.49	1.66
3	12.47	4.01	-1.43	5.02
4	12.85	9.17	4.9	8.97
5	16.35	11.28	6.74	11.46
6	-1.78	-5.62	-2.93	-3.44
7	-0.17	-1.02	-4.33	-1.84
8	-0.85	-1	-1.36	-1.07
9	-0.97	-1.02	-1.11	-1.03
10	-0.91	-1	-1.11	-1.01
11	-0.92	-0.97	-1.01	-0.97
12	-0.94	-0.96	-0.98	-0.96

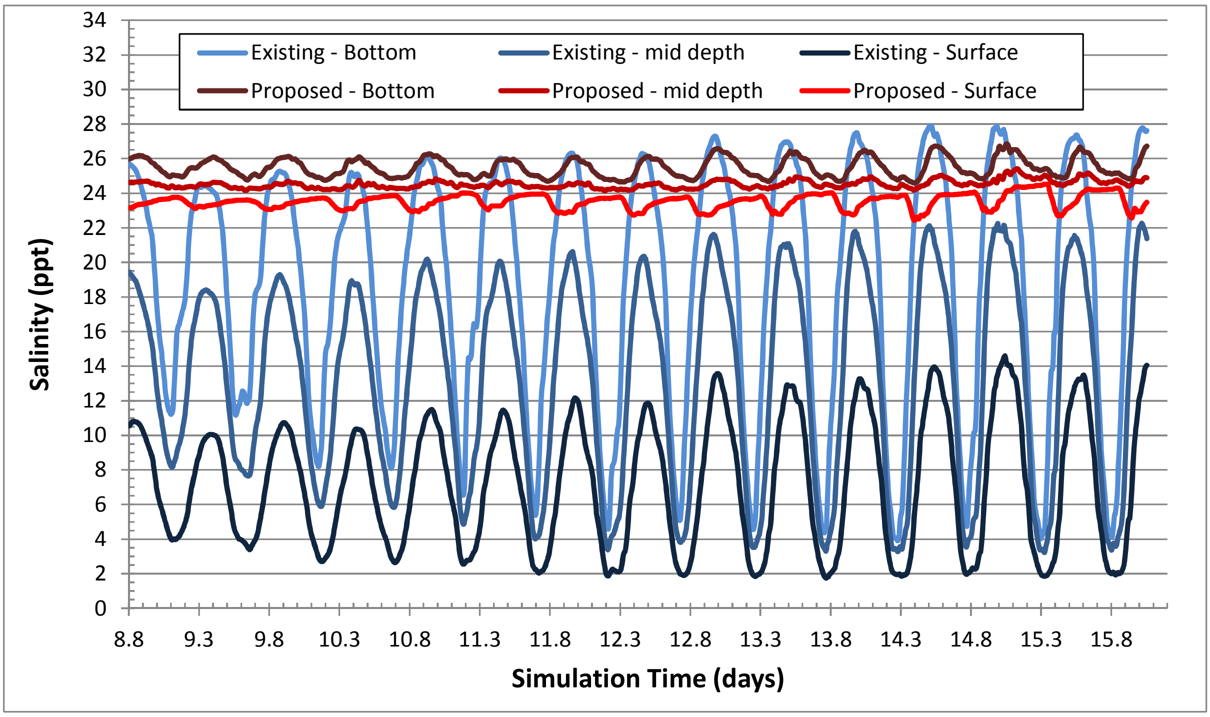


Figure 73 Time Series Output of Salinities for Site 5 existing and Proposed Cases neap to spring tide under 1-percentile Flood Flow

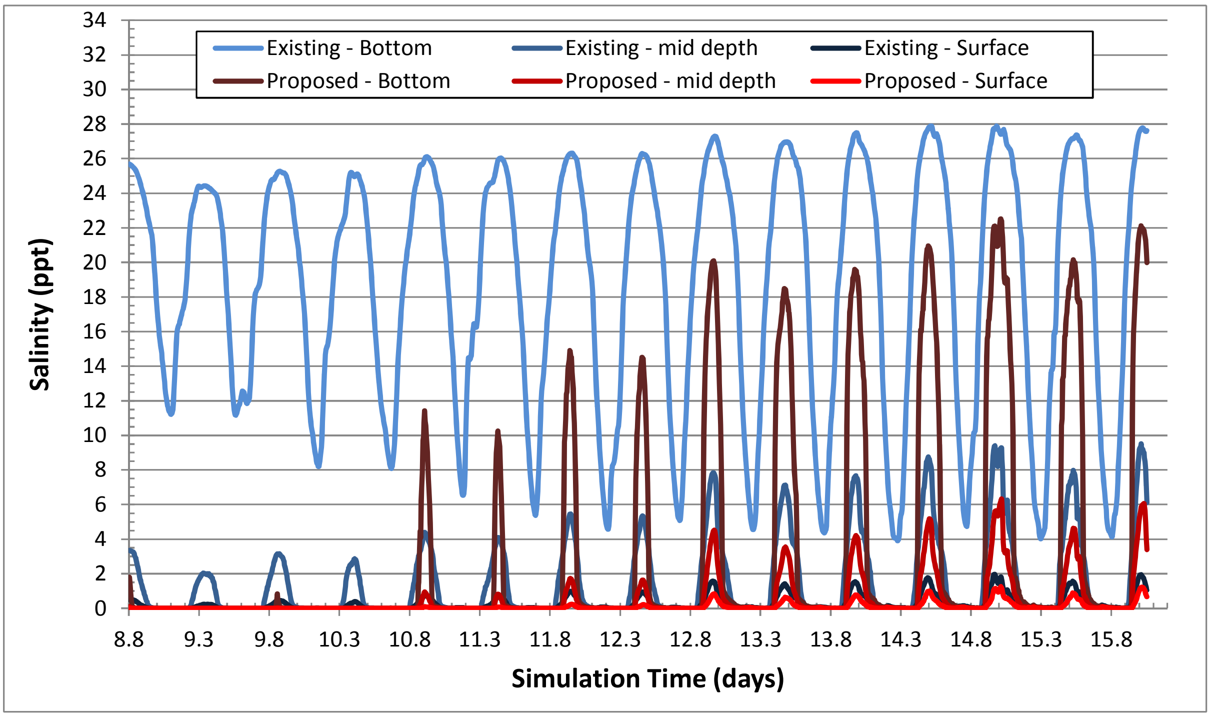


Figure 74 Time Series Output of Salinities for Site 7 Existing and Proposed cases neap to spring tide under 1-percentile Flood Flow

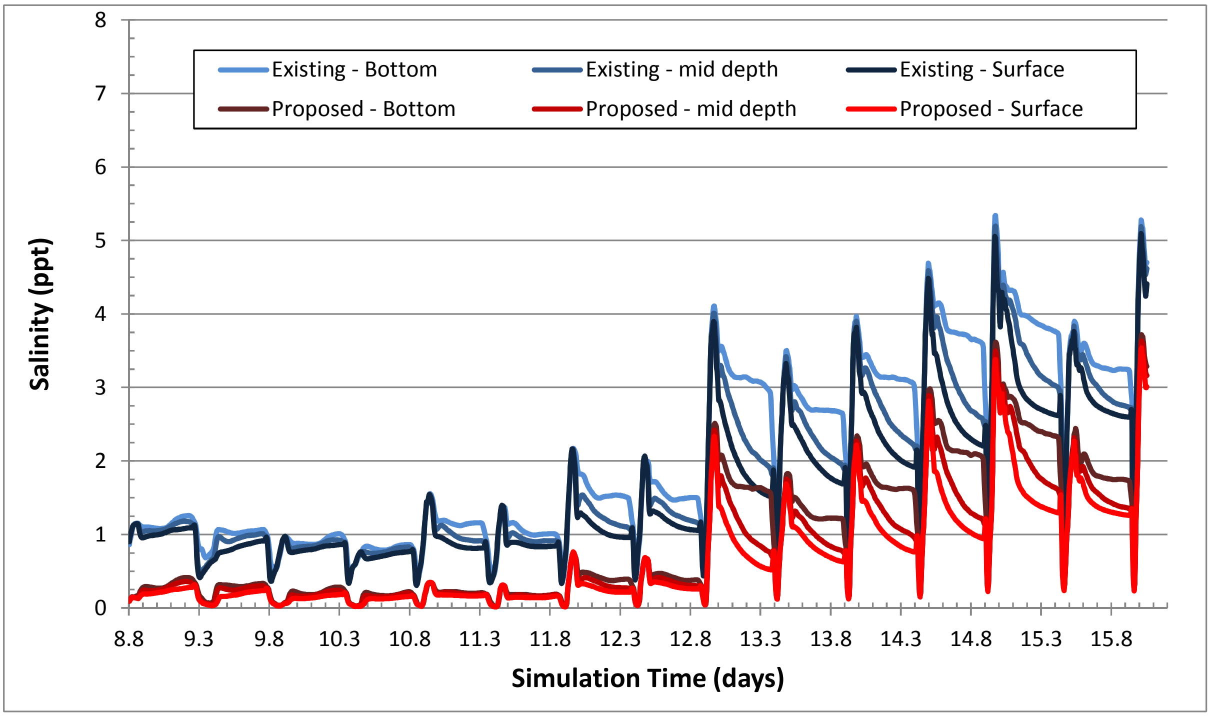


Figure 75 Time Series Output of Salinities for Site 9 in Lough Atalia Existing and Proposed cases neap to spring tide under 1-percentile Flood Flow