A PRELIMINARY STUDY INTO THE CHANGE IN FAECAL INDICATOR CONCENTRATION OF ESTUARINE WATER ATTRIBUTABLE TO TIDAL INUNDATION OF SALTMARSH

Ian Dunhill.

Environment Agency (Southern Region)
Waterlooville Laboratory, 4 The Meadows, Waterberry Drive, Waterlooville, PO7 7XX
(ian.dunhill@environment-agency.gov.uk)

ABSTRACT
Programmes to improve compliance with the micro-biological parameters of the EU Bathing Waters Directive have demonstrated the importance of diffuse pollution. In North West England investigations have been undertaken to quantify the role of grazed saltmarsh which is in close proximity to bathing waters and is periodically inundated by the tide. Pathways investigated include both the re-suspension of faecal material from the marsh and the leaching of faecal indicators. Results have shown a marked cyclical pattern in the input of faecal indicators corresponding to flood and ebb tides. The magnitude of faecal contamination may be sufficient to represent a threat to compliance, particularly with the more stringent 'guideline' standards. The work has also required a reappraisal of the commonly accepted values for the decay rates of faecal coliforms. Further work is planned for summer 2003 and this will be reported at the conference. Samples were taken for faecal indicators from water known to have inundated the Ribble estuary saltmarshes. An increase in faecal indicator organisms was noted on the ebb when compared to the water quality of the flood. A series of problems with equipment and poor weather meant that a definitive survey was not carried out. The combined results from several surveys suggest that there is either a repeated cycle of faecal indicator organisms or that the tidal inundation of the grazed saltmarsh causes an increase in faecal contamination. Further survey work is required to clarify this.

Keywords: Diffuse pollution, Faecal indicators, Saltmarsh

INTRODUCTION
The Ribble estuary is situated in North West England and is in close proximity to a number of EU designated bathing waters (figure 1). In the Ribble estuary there are areas of saltmarsh, that are extensively grazed by sheep and cattle. Previous work (MSP 01-07) has shown that there is a significant standing load of faeces on the saltmarsh from these grazing animals. It has been speculated that the standing load of faeces on the saltmarsh has the potential to act as a significant source of faecal indicators to the nearby bathing waters. This study was designed to quantify what extent estuarine waters that inundate saltmarsh during spring tides pick up faecal indicators from the faeces deposited on the marsh by grazing animals.

Several surveys were attempted to try to quantify the difference in faecal indicator concentration between the flooding and ebbing tide in cases where the saltmarsh was inundated. Unfortunately difficulties such as bad weather or mechanical failure meant that no one-survey was completely successful.

METHODS
Three surveys were carried out; in August 2001, September 2001 and November 2002. On the 20-21st August 2001 during spring tides, a boat was anchored in the middle of one of the largest gullies on the south side of the Ribble estuary (figures 1 & 2), this gully has an approximate catchment area of 1km^2 saltmarsh. Samples were taken as the tide flooded and ebbed and the channel remained navigable (approximately 4 hours each day). Samples for faecal indicators (FI) were taken at 10-minute intervals. Analysis was carried out for; presumptive total coliforms (TC), faecal coliforms (FC) and faecal *streptococci* (FS) using standard Environment Agency methods. Results were expressed as colony forming units (cfu) per 100ml of sample. The current speed and direction were measured along with water temperature using a Sensordata SD6000 current meter, this took a reading every 5-minutes and was suspended under a tethered buoy. In addition a tubular 'keepnet' was used with its open end facing upstream, this retained any particles of faeces greater than the mesh size (approximately 5mm).

On the 17-19 September 2001 an EPIC automatic water sampler was used to take samples from a boat left at anchor in a gully on the east of the river Douglas estuary (figure 1). Sampling was programmed to take place at 30-minute intervals starting at the beginning of the flooding tide during the night. A current meter logged current speed and direction during the survey. Microbiological samples were obtained after the first high tide to inundate the saltmarsh tide on the 17/18th and during a subsequent tide on the night of 18-19th. The intervening high tide was used to retrieve the samples from the auto-sampler. The samples were in the auto-sampler for a minimum of 12 hours before collection and effective refrigeration. Failure of the auto-sampler lead to the sampling times being unclear.

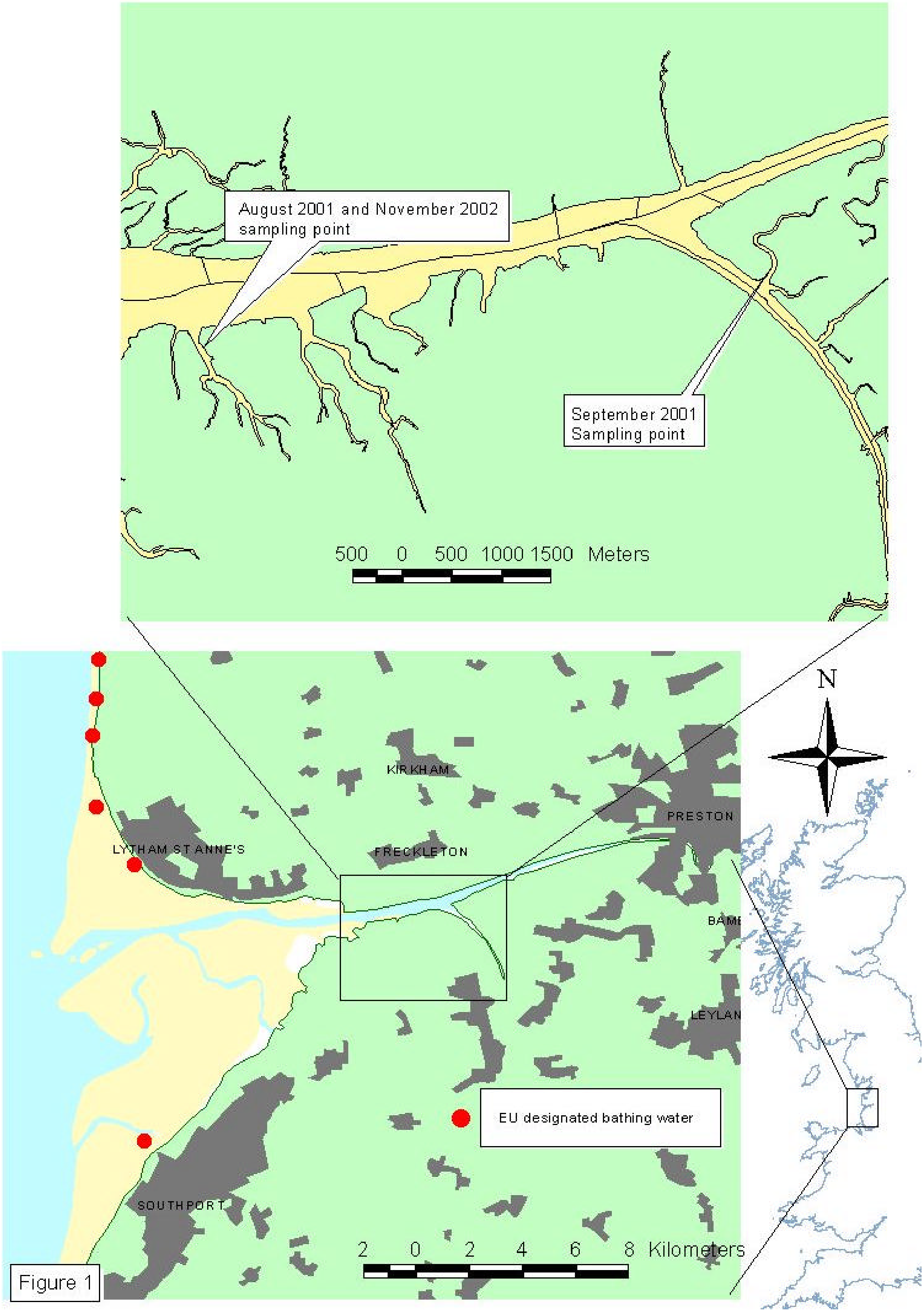


Figure 1 Study area and sampling points

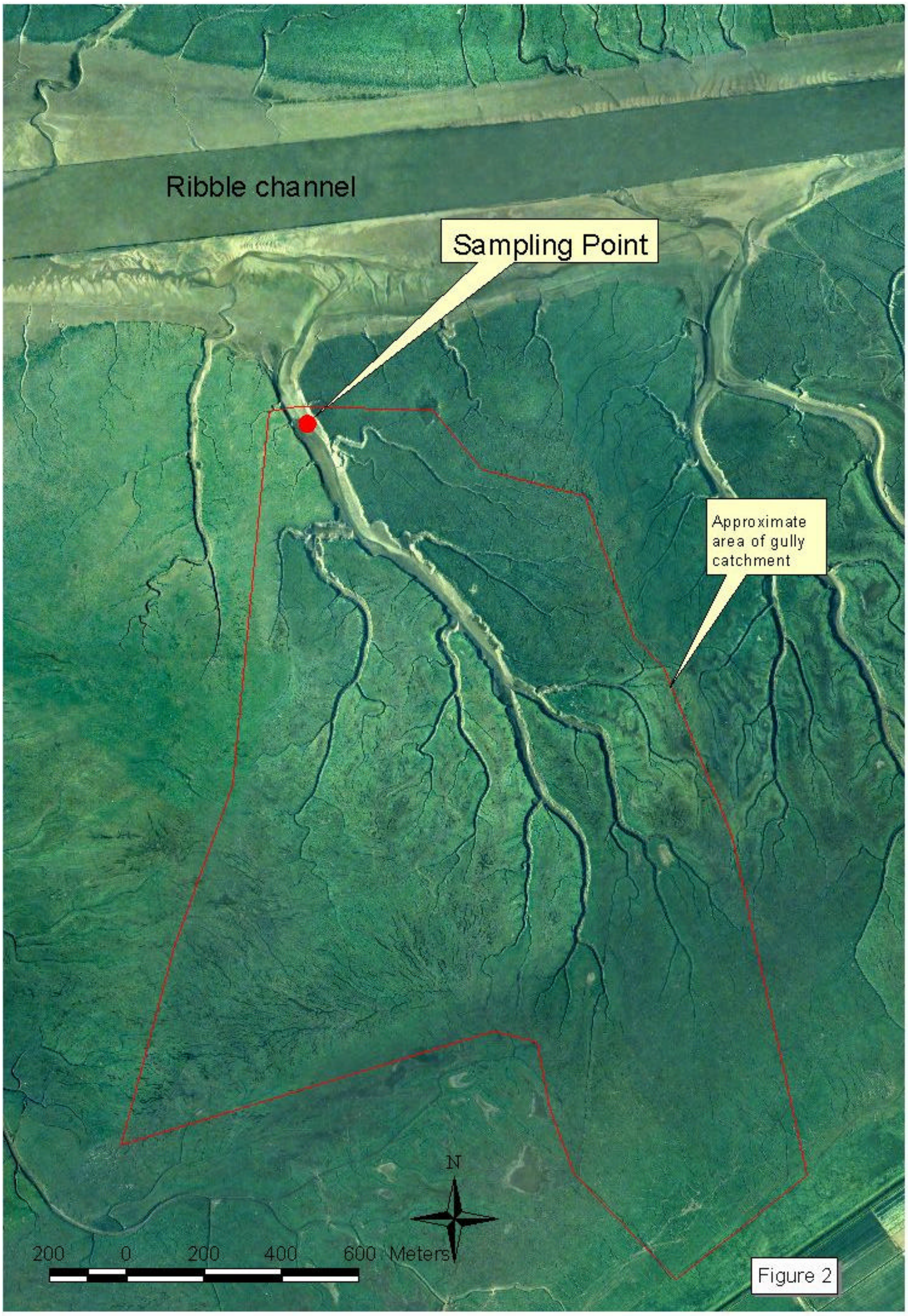


Figure 2: Catchment of sampling point

In November 2002 sampling was once again attempted, an anchored boat was left in the same location as the August 2001 survey. An Aquamatic auto-sampler was used to take samples every 30-minutes over a tidal cycle. Although the auto-sampler worked well, an engine failure on the shuttle boat prevented the retrieval of the samples in time for microbiological analysis to be meaningful. Samples were later analysed for salinity and conductivity using a YSI-556 hand held meter. Data from the current meter were also retrieved.

RESULTS

No single survey yielded a complete set of data. A composite of the August 2001 and November 2002 data yields the best compromise given the limitations of the other surveys.

August 2001

Figures 3 & 4 show the results of the August 2001 survey. At the point where samples were taken the time of HW is approximately the same as Liverpool (Alfred dock) and LW is approximately 2½ hours after Liverpool. The tides during the survey overtopped the saltmarsh for approximately one hour, during this period the entire area around the boat was inundated. On the 20th August local HW was at 13:01, with a tide height of 9.76m above chart datum. On the 21st HW was at 13:48 with a height of 9.82m above chart datum (Tidal calculations made using ‘Tides & Currents’ software, Nautical Software, Beaverton, OR, USA. Using Admiralty data. NB all tidal data is given as locally adjusted times and heights based on Liverpool Alfred dock unless otherwise stated.). Figure 5 shows a photographic sequence of the tidal inundation of the saltmarsh on the 20th August 2001.

Figure 3
Ribble Saltmarsh, 20th August 2001

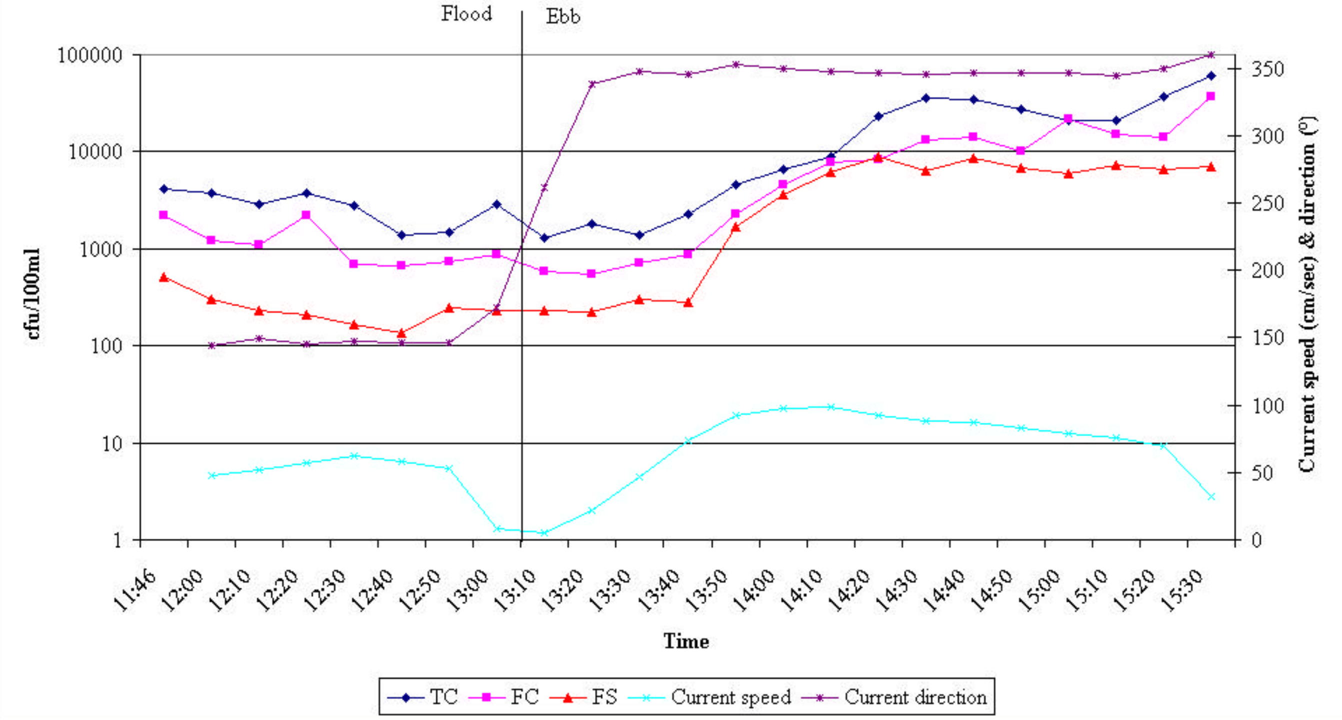
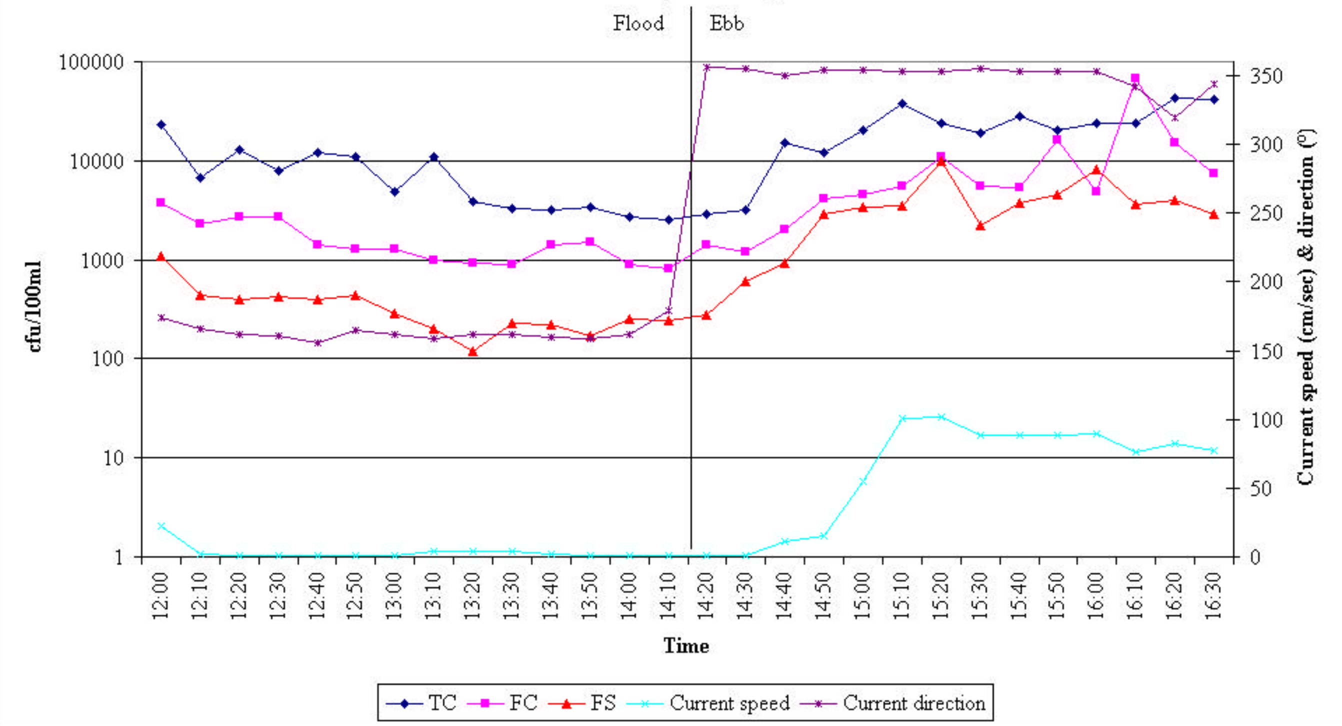


Figure 4
Ribble Saltmarsh, 21st August 2001



An Anderson-Darling test was carried out to assess the $\log_{(10)}$ transformed faecal indicator data for normality (H_o data are likely to be normally distributed Vs H_a data are unlikely to be normally distributed). The results of the tests suggested that these data were unlikely to be normally distributed with P-values of 0.003 (TC), 0.009 (FC) and 0.000 (FS). It was not deemed appropriate to analyse these data with parametric statistics. The Kruskal-Wallis test was therefore used to measure differences in these data.

Figure 5.
Picture sequence showing tidal inundation of Ribble saltmarsh

When a Kruskal-Wallis test was performed, there was no significant difference between the two sampling days, with P-values of 0.142 (TC), 0.643 (FC) 0.684 (FS). There was however a highly significant difference between the flood and the ebb FI concentration, with P-values of 0.000 for all values. Figures 3 & 4 show there was a clear increase in FI approximately one hour after the ebb had started. Figure 6 shows the difference between the flood and ebb tides. The ebb tide was approximately an order of magnitude more contaminated than the flood. Geometric mean values of the two days data are presented in the following table:

Table 1. August survey, geometric means (cfu/100ml) and ratio ebb:flood.

	Total coliforms	Faecal coliforms	Faecal streptococci
Flood	4,326	1,265	274
Ebb	14,593	5,941	2,794
Ratio	3:1	5:1	10:1

Unfortunately no salinity readings were taken so it was not possible to make a comparison between similar salinities on the flood and ebb.

September 2001

This survey took place around the autumnal equinox with HW at 00:11 18th September at 10.1m above chart datum and 00:56 19th September, 10.2m height above chart datum. This survey was planned to take place over three days, with samples taken by an auto-sampler. Unfortunately the sampler did not work correctly, although samples were taken. It was not possible to be sure about the absolute timing of these samples. Salinity readings were taken of the samples obtained. Assuming that the period around high water coincides with the salinity maxima, an educated guess can be made as to where an individual sample was taken on the tidal curve. The malfunction in the auto-sampler lead to paired samples being taken over a period of three hours, rather than single samples over 6-hours. Given the salinity readings samples appear to have been taken on the flood only.

Faecal indicator results were high with several TC samples >LOD ($1.x10^5$ cfu/100ml). If the > results are assumed to be =LOD the geometric mean FI values were 36,073 (TC), 5,277 (FC) and 397 (FS). Figure 8 shows the plots from the September survey. It is thought that the lines represent pairs of samples rather than individual samples the timing of these pared samples relative to HW remains unclear. Figure 7 shows the FI plotted against salinity. The lower salinity results had a high FI concentration indicating that cleaner seawater was mixing with more contaminated freshwater.

November 2002

This survey took place at the same location as the August 2001 survey. A new auto-sampler was used for this survey that provided a date/time stamp for samples. Whilst the sampler worked well, an engine failure on a boat used to retrieve samples meant that the samples were retrieved several days later than planned, making microbiological analysis invalid.

The survey took place on a spring tide with a height of 10m above chart datum.

The salinity (figure 9) showed a steep increase on the flood, followed by a more gradual decrease on the ebb. By combining the current meter and salinity data, an estimate can be made of when a body of water with a given salinity passed the monitoring point on the flood and then back on the ebb, this is summarised in the following table:

Table 2, Time (in minutes) from HW for a water body with a given salinity to pass sample point.

Salinity	Flood	Ebb
18	-145	+155
22	-115	+105
24	-95	+55

The maximum salinity reading was 26.01; this salinity was reached just before HW but had only been marginally increasing since HW–80 minutes. The ebb was accompanied by a gradual decrease in salinity readings. The current meter appeared to stop correctly reading approximately 2½hours after HW, presumably after the water depth became to shallow for it to operate. The salinity slowly decreased over the next few hours before a minimum reading was recorded on the last sample, 5½hours after HW.

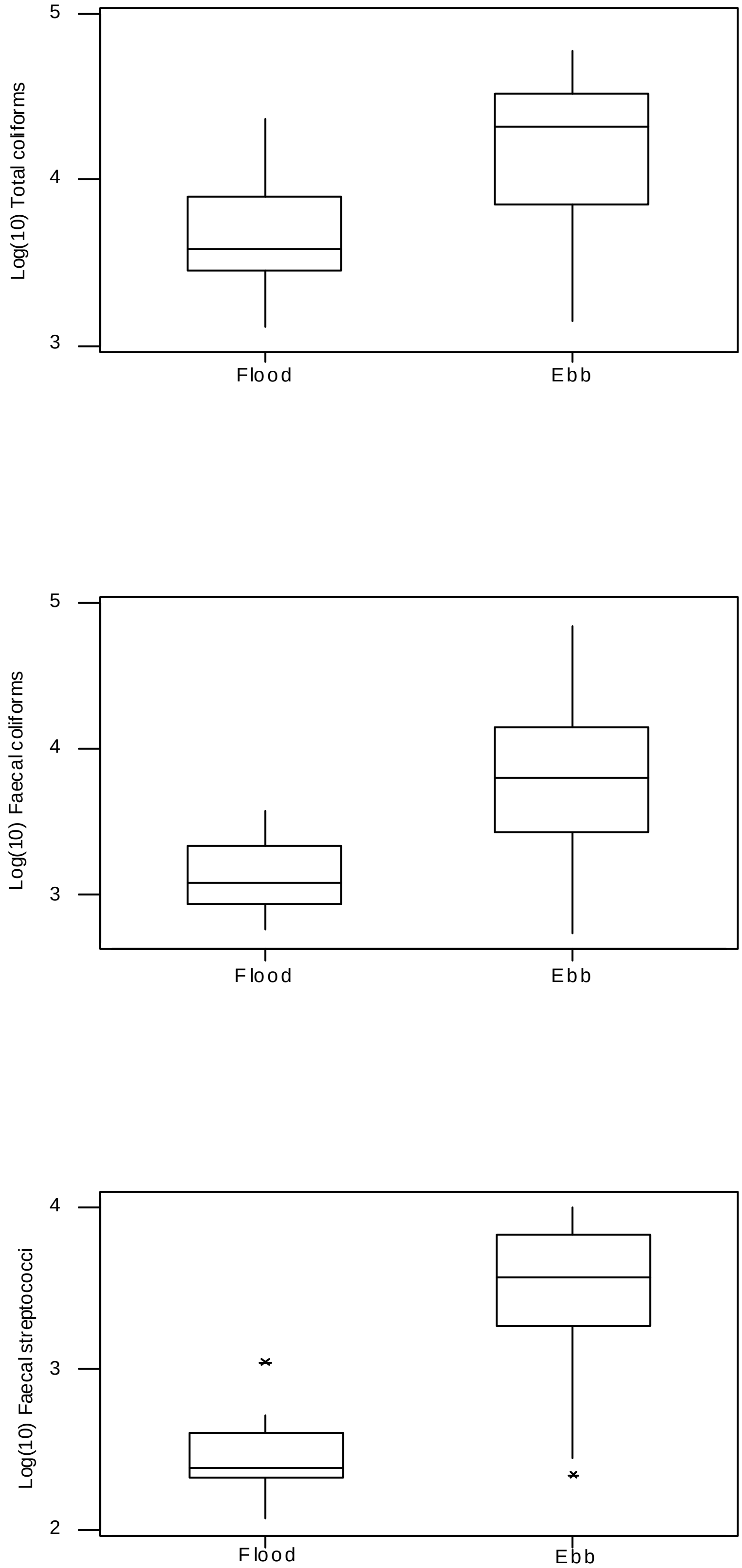


Figure 6. Boxplots showing difference in FI between flood and ebb tides (combined data for both days), August 2001 survey.

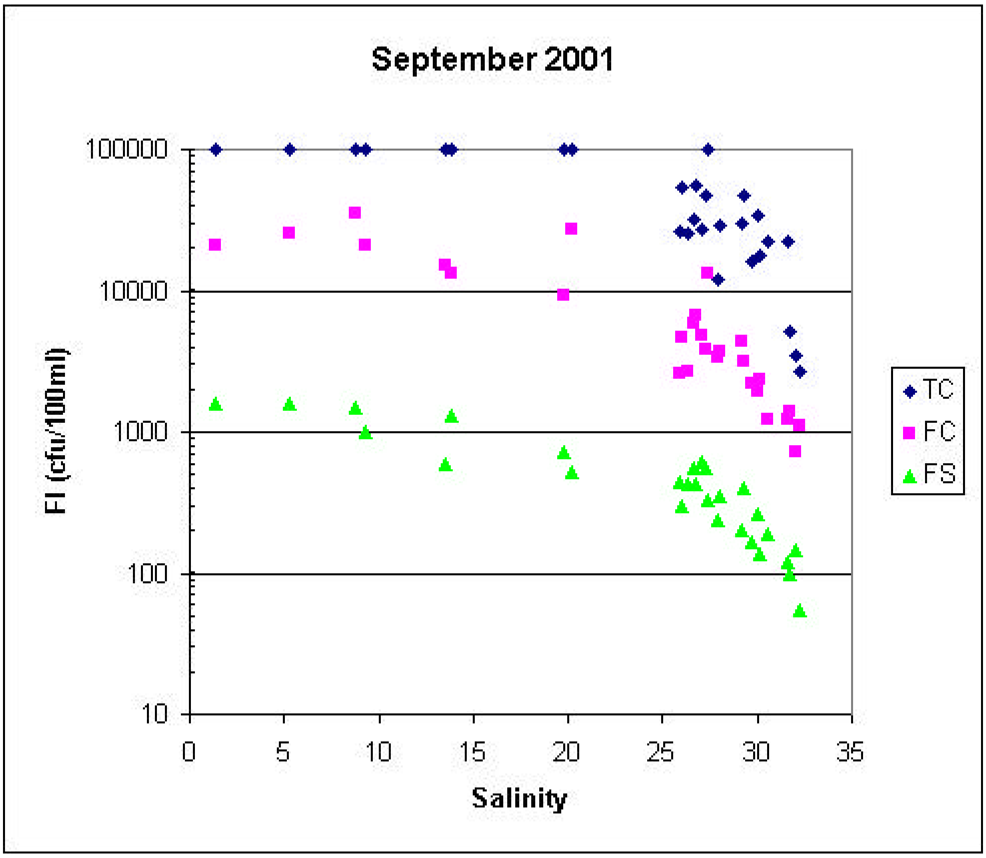
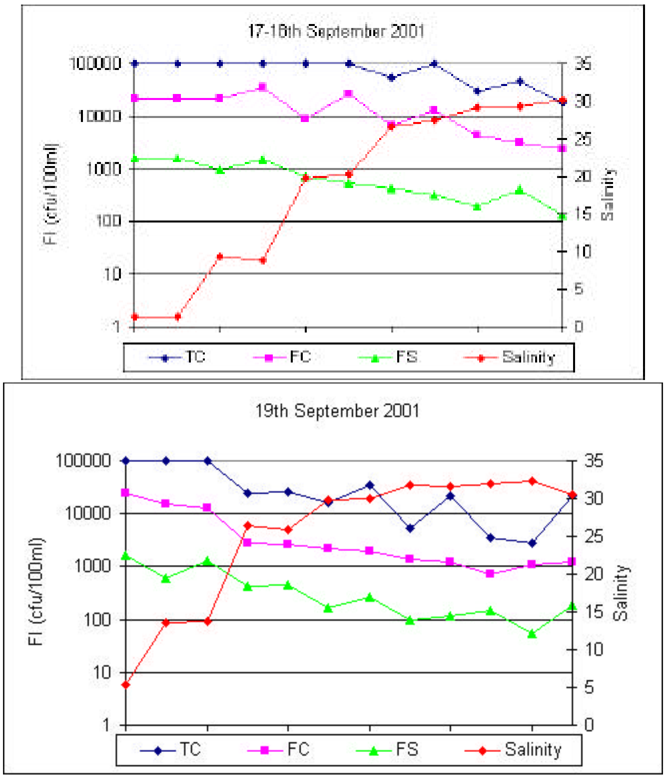


Figure 7, September 2001 FI Vs salinity.



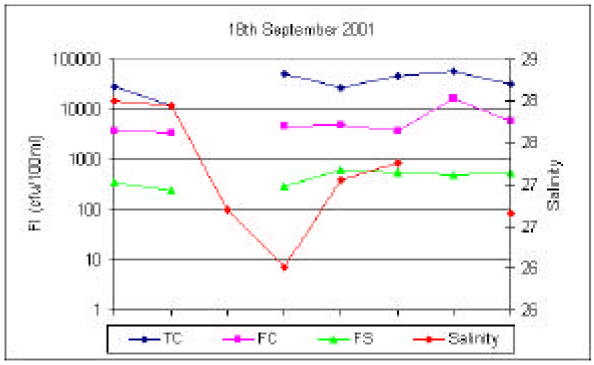
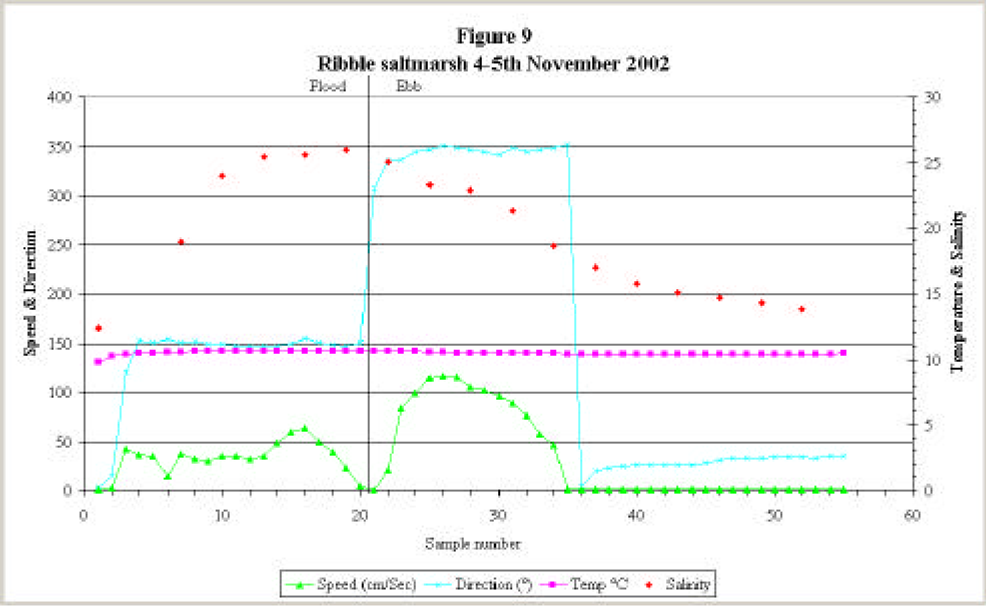


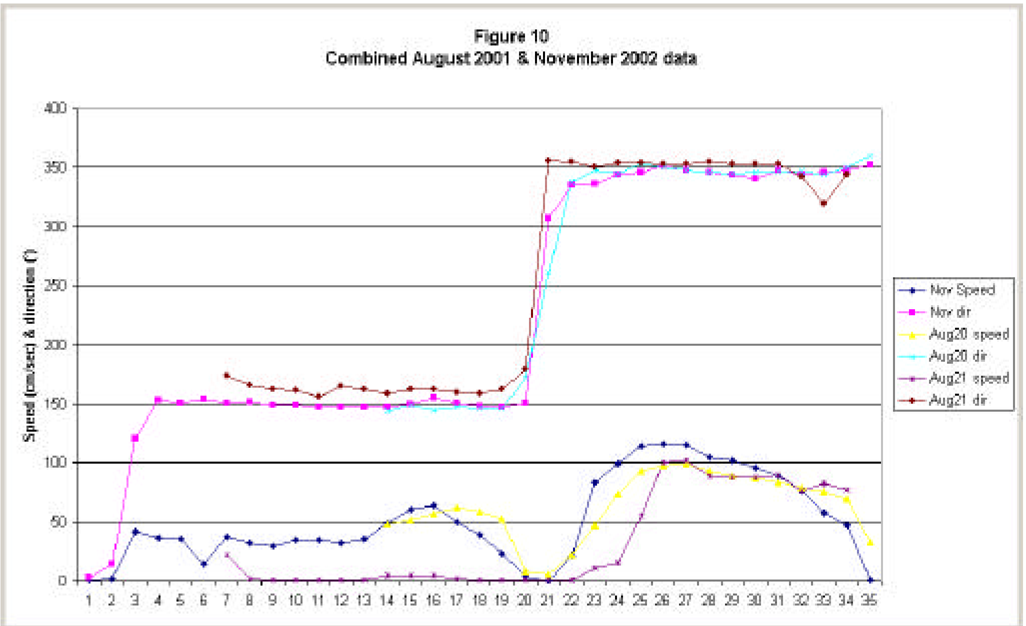
Figure 8. September survey, linear plots of FI and salinity.

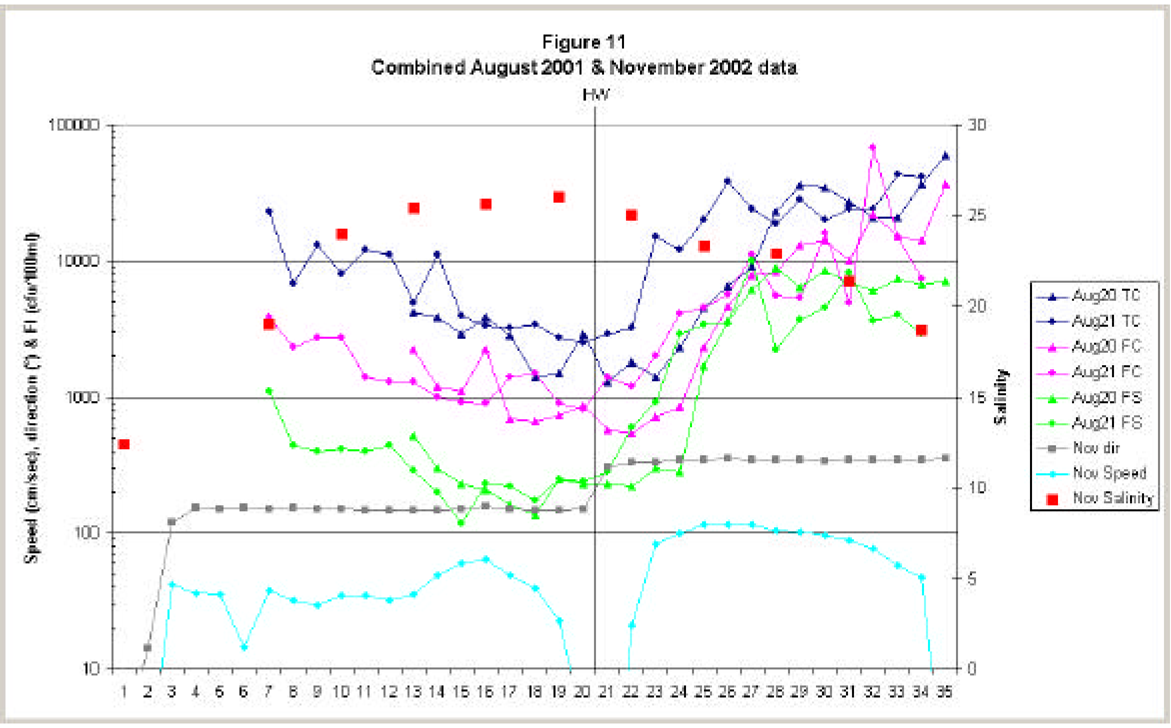
Combined data

It is possible to combine the FI data from the August 2001 and the salinity data from the November 2002 surveys to make a composite plot. The time of HW for the two data sets can be matched using the current meter data (figure 10). The direction readings match well and show the point when the tide turned, this allows the HW from the two surveys to be synchronised. The current speed varied between the different surveys, given variations in tide between surveys this is to be expected. The FI concentration (figure 11) fell as the tide flooded and rose as the tide ebbed.

The salinity can also be plotted against the FI concentration (figure 12). This plot shows a similar trend to figure 7 (September 2001 survey) in that the FI values at salinity values >24 do not appear to follow the same trend as observed at lower salinities.







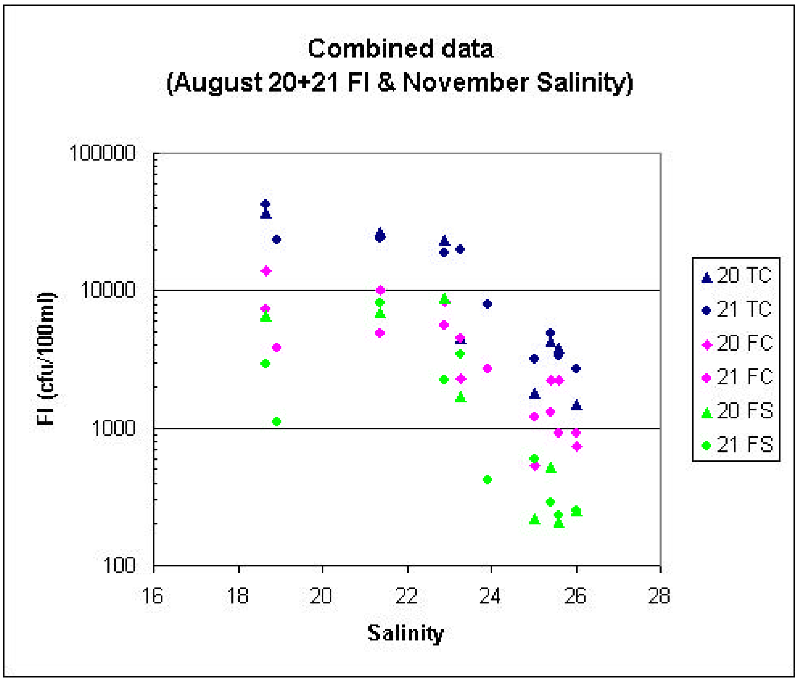
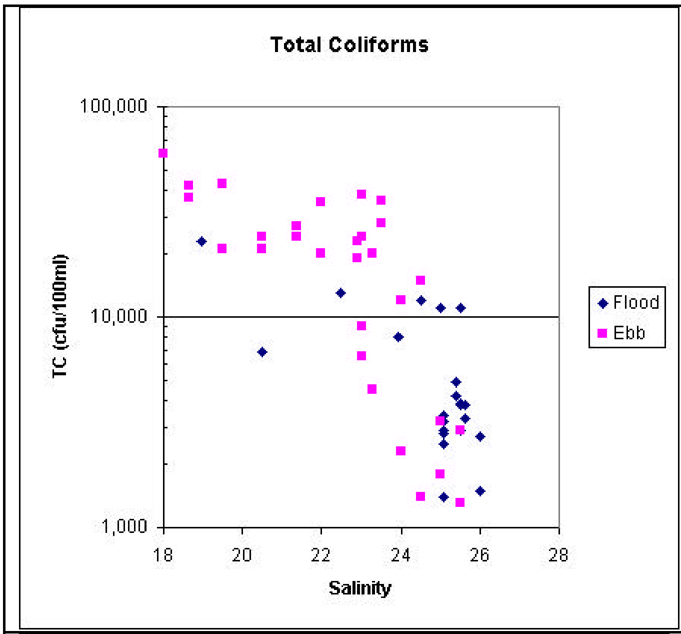
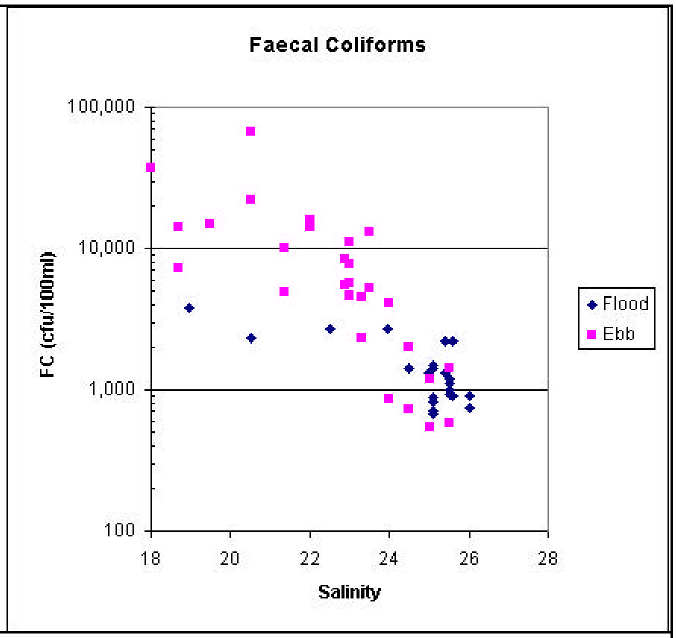


Figure 12 salinity Vs FI, combined August 2001 & September 2002 data.





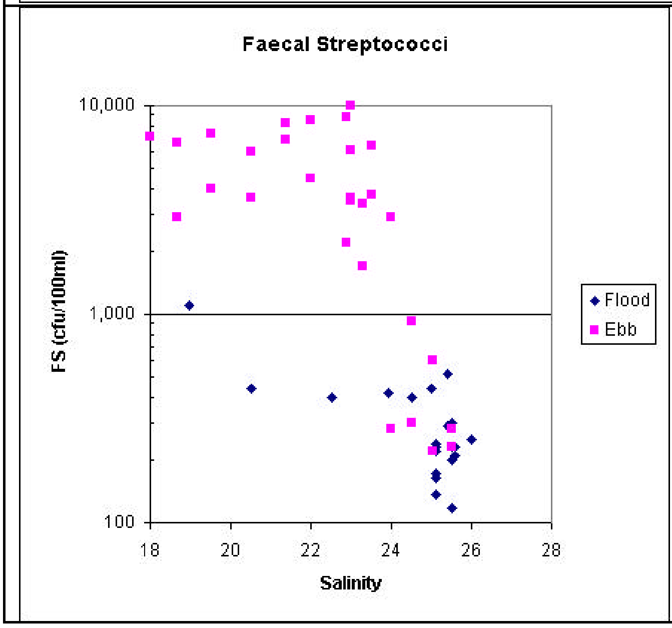


Figure 13 Salinity vs Total Coliforms, Faecal Coliforms and Faecal Streptococci

DISCUSSION

When the data from the August 2001 and November 2002 are combined they show clear trends in both FI's and salinity. The asymmetry in the tidal curve is reflected in the salinity which shows a rapid increase on the flood and a more gradual decline on the ebb. The flood brings higher salinity, less contaminated water to the sampling location. For about an hour at high water there was little change in FI concentration or salinity before the ebb shows a marked increase in FI coupled with a decrease in salinity. It is possible the relatively constant readings in salinity and FI observed during the slack water period may not be representative of the whole water column and that denser more saline water at depth had a differing FI concentration. There was a marked increase in FI after approximately 30 minutes into the ebb, which was significantly greater than FI concentration measured on the flood.

In an attempt to clarify the relationship between the FI on the flood and ebb using available data, the effects of salinity on the FI concentration have to be accounted for. FI concentration from the August 2001 survey was plotted against salinity from the November 2002 data (figure 13). Salinity values were interpolated along a curve drawn between measured salinity readings for a given time ± from HW where no salinity measurement was taken. There are too many assumptions and simplifications in these plots to make an absolute definition of the relationship between FI concentration in the flood and ebb tides. However figure 13 shows that once the change in salinity has been considered, there does appear to be a higher concentration of FI in the ebb than on the flood, it is hoped that further survey work can clarify this relationship. It may be that this increase it is attributable to the inundation of the saltmarsh and pick up of animal faeces or this may be part of a tidal cycle of FI. The absence of measurements over the complete tidal cycle mean that without further survey work this question cannot be answered.

Previous work (MSP-01-07) has shown that tides greater than 9.4m above chart datum at Fleetwood will cover the entire area of saltmarsh, this tidal height is exceeded for 15% of all tides, whilst a partial inundation (8.4m above chart datum) is exceeded for 56% of tides. This work also showed that the inundation of the marshes did not necessarily remove the faeces present. The absence of visible faeces in the net during the August 2001 survey indicates that during the time of the survey it was unlikely that large quantities of floating faeces had been removed from the saltmarsh during the tides measured. The net deployed during the September 2001 survey did catch sheep faeces; it is possible that the difference could be due to the locations of the two nets. Longton marsh where the September survey was undertaken is known to be one of the most heavily grazed areas of marsh whereas Banks marsh (where the August 2001 survey took place) has a much longer sward indicating a lower grazing density.

During the surveys a large number of birds were noted to be feeding on the saltmarsh. The Ribble estuary is known to be a major haven for birds and some of the saltmarshes are specifically managed by English Nature to encourage this. If there are large numbers of birds, it follows that there will be a large quantity of bird faeces deposited with associated elevated levels of FI's. Calculation a standing load of FI's on the saltmarsh would need to make an estimate of FI's from avian sources as well as faeces from grazing animals.

CONCLUSIONS

From the limited data gathered, it appears that there is an increase in FI in the water entering and exiting from gullies on the Ribble salt marsh between the flood and ebb tides. It is possible that this increase represents contamination picked up from the saltmarsh although the possibility that this increase is merely due to a tidal cycle that was not fully quantified during the surveys cannot be ruled out.

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