5. DISCUSSION & CONCLUSIONS

5.1 Discussion of Results

5.1.1 Concentration snapshots

Upon examination of Figures 4.1 – 4.24 it is evident that, in general, higher solute concentrations occur during the neap tidal cycle due to a smaller volume of water entering or leaving the bay. This is due to the reduced water depth and associated low current velocity values which tend to inhibit rapid dilution of the effluent during this period. Conversely, dilution of the effluent plumes is greatest on the spring tide at periods of relatively high current velocity i.e. at mid-ebb and mid-flood tide, when the volume of water entering or leaving the bay is at a maximum.

Figures 4.5 - 4.8 show faecal coliform concentrations for the different stages of the neap tide. It is evident that the maximum levels of faecal coliforms are experienced in the immediate vicinity of the outfall (i.e. within the first 10m grid square), as expected. At the four stages of the neap tide, faecal coliform levels within this area vary between 1.54 and 1.82 no./100ml. Away from the outfall in the vicinity of Lough Furnace and in the east of Newport channel the concentration of faecal coliforms within the water can be seen to decrease to values of less than 0.01 no./100ml. The maximum value of faecal coliforms during the neap tidal cycle (1.82 no./100ml) occurs at high water which seems unusual since the greater water depth should provide more dilution than at low water. However, looking at the current velocity vectors in figures 3.3 and 3.5 it can be seen that the current is significantly stronger near the outfall site at low water neap and this prevents the build up of faecal coliforms during this stage of the tide.

Faecal coliform concentrations for the different stages of the spring tide are shown in Figures 4.1 – 4.4. These are less than those of the neap tide (approximately 0.711 no./100ml - 0.860 no./100ml) and the concentration again reaches a maximum at high water. However, this relatively high concentration is confined to within approximately

25m of the outfall pipe and is quickly diluted with increasing distance from the source.

From Figures 4.9 – 4.24, similar patterns may be observed for copper and cadmium concentrations. The maximum values of copper and cadmium occur at neap high water and are equal to 87.5ng/l and 1.1ng/l respectively, whereas the maximum values during the spring tidal cycle are 41.5ng/l and 0.519ng/l.   Again the above solute concentrations decrease rapidly with increasing distance from the outfall.

5.1.2 Time-traces

The maximum values of copper, cadmium and faecal coliforms which occurred at the four observation points have been tabulated in the last chapter. The time-traces show a significant difference in the concentration of effluent recorded at sites A and B for the two different flow regimes. Simulation 1, which assumes no flow into Lough Furnace, indicates that a build up of conservative substances such as cadmium and copper will gradually occur over time. The increase in concentration between one high water spring tide and the next was approximately 0.05ng/l and 4ng/l of cadmium and copper respectively which is extremely small. For the second simulation no such build up was observed. This indicates that even a moderate flow into and hence out of Lough Furnace will prevent any build up of unwanted substances. Therefore, the possibility of conservative or biodegradable substances accumulating in Lough Furnace should not be a problem. The above simulations also assume that any cadmium or copper discharged from the outfall remains in the water column, whereas in reality these substances will tend to bind to the sediment closer to the outfall site and so even lower levels than predicted can be expected to reach Lough Furnace. The possible impact on the sediment is discussed further in section 5.2.2

5.1.3 DIVAST Simulations using second model

Looking at figures 4.44 – 4.59 it was found that the highest concentration of ammonia occurred during the neap tidal cycle, as expected. The highest value of 0.0194mg/l occurred during the neap tidal cycle at high water. This high concentration is confined to the outfall grid square and decreases rapidly away from the outfall site. It is also

quite a conservative estimate since diffusion due to wind is not considered. When the effect of the wind is taken into account the corresponding value was 0.0048mg/l.

5.1.4 Cormix Simulations

Simulations performed using the CORMIX model exhibit similar result patterns to those predicted using DIVAST. From Table 4.6 it may be observed that the maximum solute concentrations occur at neap tide, while effluent plumes experience significantly more dilution at spring tide. For example, the concentration of cadmium at a distance of 300m from the point of discharge is 0.287ng/l at spring flood tide and 0.802ng/l at neap flood tide. The corresponding values predicted by DIVAST are somewhat lower especially at a distance of 100m from the diffuser and during the neap tide. This can be explained by considering the fact that CORMIX models the density of the effluent and the thickness of the plume whereas DIVAST does not. Therefore, close to the diffuser and especially when the ambient velocity is low, vertical mixing will be limited and hence CORMIX will predict higher solute concentrations. Downstream when vertical mixing has occurred (particularly during the spring tide due to greater velocities) the predicted solute concentrations should become increasingly similar. However, CORMIX can only model effluent plumes in an idealised channel and for one tidal cycle and hence it is only really suitable for modelling near field effects such as the effect which the outfall configuration has on the effluent plume. For simulations over a prolonged period of time DIVAST is much more accurate since it models the actual bathymetry and tidal reversal effects. It can also model a much larger area than CORMIX.

All the above values will now be discussed in relation to relevant water quality standards.

5.2 Water Quality Standards

5.2.1 Shellfish Waters

The Shellfish Water Directive (79/923/EEC) states that a mandatory value of <300 faecal coliforms/100ml applies "in the shellfish flesh and intervalvular fluid". As a

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footnote it also adds that – "however, pending the adoption of another Directive, on the protection of the consumers of shellfish products, it is essential that this value (i.e 300 faecal coliforms/100ml) be observed in the waters in which live shell fish directly edible by man." A further EC Directive 'laying down the health conditions for the production and the placing on the market of live bivalve molluscs' (CEC,1991c) reiterated the water quality parameters of the earlier Directive as well as additional guidelines for harvesting, transportation, and purification centers.

The Department of the Marine and Natural Resources (DMNR) is the competent authority in Ireland for classifying shellfish production areas and Regulations (S.I. No. 147 of 1996) implementing the directives were made by the Minister in 1996. The scheme of classification has three categories, corresponding with the criteria laid down in the directive, which can be summarised in Table 5.1.

Classification	Faecal coliforms/*E.coli* per 100g of shellfish flesh	Requirements
A	Less than 300 faecal coliforms or 230 *E.coli* consumption permitted	None - safe for direct human consumption
B	Less than 6000 faecal coliforms or 4600 *E.coli* in 90% of samples	Purification in an approved plant for 48 hours prior to sale for human consumption
C	Less than 60000 faecal coliforms	Relaying for a period of at least two months in clean seawater prior to sale for human consumption

†five-tube, three-dilution MPN test

Table 5.1 : Summary of scheme of classification of shellfish production areas operated by the Department of the Marine under Directive 91/492/EEC.

Therefore based on the 79/923/EEC Directive, a shellfish area which is classified as 'A', should have less than 300 faecal coliforms/100ml in the surrounding waters. In fact, this standard for the water quality has also been adapted by the UK government [6] as "a national minimum which meets the Directive's requirement to endeavour to observe the guide value". (i.e 300 faecal coliforms/100ml in the shellfish flesh).

International standards are even stricter however, with the World Health Organisation and the United Nations Environmental Programme [7] requiring that the faecal

coliform median or geometric mean must not to exceed 14 MPN/100 ml, and that not more than 10 percent may exceed 43 MPN/100 ml (MPN = Most Probable Number). These standards have also been adopted by the National Shellfish Sanitation Program (NSSP) in the US.

In comparing the above national and international standards for the production of shellfish with the results from the model, it is clear that discharging the given quantities of faecal coliforms from the proposed outfall in Newport Bay will have little or no impact on the surrounding water quality with regard to shellfish production. As mentioned in section 4.1, the highest concentration of faecal coliforms predicted by the model was 1.82 no./100ml at the outfall site. This value is an order of magnitude lower than the strictest requirements for faecal coliforms considered above.

5.2.2 Copper and Cadmium levels

Various permissible levels of Copper and Cadmium, are specified by national and international regulations. In this report the levels of Copper and Cadmium computed by the model are compared with relevant EU legislation and the World Health Organisation and OSPAR Ecotoxicological criteria.

The most stringent requirement for cadmium laid down by the EU permit a maximum of 5µg/l in the drinking water and surface water regulations. Since the toxicity of cadmium also depends on water hardness, different permissible levels are allowed depending on the water hardness. In fresh water the 24hr average values permitted by the World Health Organisation are: 0.012µg/l, 0.025µg/l and 1.05µg/l, for hardness values of 50, 100, and 200mg/l $CaCO_3$. For salmonid waters the values range from 0.4µg/l to 1.2µg/l. The most stringent limits according to the OSPAR Ecotoxicological criteria (table 5.2) range from 0.01 – 0.1µg/l.

Background levels of cadmium in Irish estuaries range from 0.034 – 0.096µg/l [8]. The maximum level of cadmium recorded anywhere in the bay due to inputs from the outfall was 1.1ng/l or 0.0011µg/l. This is well below the background level. Therefore,

there is no likelihood of any impact on the surrounding water quality due to the proposed discharge of cadmium.

	Water (µg/l)	Sediment (mg/kg dw)	Fish (mg/kg ww)	Mussel (mg/kg dw)
As	1 – 10*	1 – 10†	nr	nr
Cd	0.01 – 0.1*	0.1 – 1†	fc	fc
Cr	1 – 10*	10 – 100†	nr	nr
Cu	0.005 – 0.05*‡	5 – 50†	fc	fc
Hg	0.005 – 0.05*	0.05 – 0.5†	fc	fc
Ni	0.1 – 1†	5 – 50†	nr	nr
Pb	0.5 – 5*	5 – 50†	fc	fc
Zn	0.5 – 5*	50 – 500†	nr	nr

* firm; † provisional; ‡ this bracket is within the range of background values for natural waters. This value should be compared with the bioavailable fraction in sea water; fc for future consideration; nr not relevant to the current monitoring programme; nd no data available or insufficient data available.
Cautionary note: These assessment criteria have no legal significance and should only be used for the preliminary assessment of JMP/JAMP chemical monitoring data with the aim of identifying potential areas of concern. When applied, the fact whether an EAC is firm or provisional should be taken into account.

Table 5.2 : **Overview of ecotoxicological assessment criteria. Source: OSPAR (1997b).**

The equivalent values for copper are; 0.5mg/l in the EU Drinking water Regulations, 0.05mg/l in the EU Surface water Regulations, 0.005mg/l in the Salmonid Waters Regulations, and a 24-hour average value of 5.6µg/l permitted by the World Health Organisation for fresh water. The strictest limits according to the OSPAR Ecotoxicological criteria are 0.005 – 0.05µg/l. The maximum recorded value of copper (87.5ng/l or 0.0875µg/l) satisfies all of these criteria except the OSPAR one. However, the following points should be kept in mind when determining whether or not this represents a threat to the surrounding marine environment.

- This maximum concentration is confined to within 10m of the outfall pipe and decreases rapidly with increasing distance from the pipe.
- In a footnote to table 5.2 it states that "this bracket (i.e. 0.005 – 0.05µg/l) is within the range of background values for natural waters" and "this value should be compared with the bio-available fraction in the sea water".
- Background levels for copper on the west coast of Ireland were found to be in the region of 0.31µg/l [8].

Since the maximum recorded value of copper (87.5ng/l or 0.0875µg/l) was well below this background figure then it follows that proposed outfall will have a

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negligible impact on the surrounding water quality even though the maximum value exceeds the strictest OSPAR criteria. If the maximum concentration of copper in the immediate vicinity of the outfall is to be within the OSPAR range then the concentration of copper in the effluent will need to be reduced by at least a factor of two.

With regard to the build-up of contaminants in the sediment, a conservative approach has been taken in predicting the concentrations. It is assumed that all the predicted heavy metal load in suspension will settle out on the sea bed at low or high water (see Figures 4.14 and 4.16 for copper and Figures 4.22 and 4.24 for cadmium). As noted previously in the text, the maximum predicted values for copper and cadmium are 87.5 ng/l and 1.1 ng/l respectively and these values are only predicted for a 10m grid square surrounding the pipe; concentrations decrease rapidly with increasing distance from the out fall. Examining the previously noted figures, the plume of higher concentrations extends in an east-west direction and covers a distance of ca 2 km; the width of the plume is restricted by the contours of the bay. For copper, the concentrations range from 87.5 ng/l to ca 20 ng/l. Given a water depth of 3.2m at low water and 4.8m at high tide (during the neap tidal cycle), the total amount of copper in the water column is 0.42 mg at high water, and 0.261mg at low water for each $1m^2$ area of seabed at the outfall pipe. At greater distance from the pipe i.e. ca 500 m, predicted values fall to 0.08 mg/m^2 and 0.052 mg/m^2 at high and low water respectively.

Assuming that all of this copper will settle on to the seabed the concentration of copper in the sediment needs to be calculated. The concentration of metals in sediment is specified in mg/kg. Again being conservative, it is assumed that all of the copper will remain in the top 1cm layer of sediment. Therefore, given a sediment density of 2kg/m^3 (note: muddy sediments have a density of 1.7 - 2kg/m^3 depending on consolidation) the total weight of sediment in a $1m^2$ area of seabed with a thickness of 1cm will be 20kg. The concentration of copper in the sediment is then calculated as 0.021mg/kg at high water and 0.0131mg/kg at low water in the vicinity of the outfall pipe.

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Over a 24hr period the amount of copper in the sediment is calculated as the sum of these two figures multiplied by two, i.e $0.068mg/m^3$. The permissible levels of copper in sediment vary greatly depending on the sediment type and the type of marine organisms which are likely to be affected. However, as a conservative estimate the Marine Institute considers a figure of >20mg/kg to represent 'elevated levels' of copper in the sediment [8].

Due to resuspension and sediment transport it is unrealistic to assume that the copper concentration in the sediment will increase by this amount mentioned above each day. Particularly considering the assumption at the start of this section (which is clearly very conservative) that all of the copper in the water column will bind to sediment at low and high water. Nevertheless, assuming that this is indeed the case, it would take a period of 293 days of this kind of accumulation before the level of copper in the sediment could be considered 'elevated'. It should be remembered that these figures apply to within 10m of the outfall pipe and that the above figures would decrease significantly with increasing distance from the outfall. Also the spring tidal cycle was not taken into account, during which period the concentrations would be less than half those present during the neap tidal cycle.

Based on the above calculations the corresponding value for cadmium is 0.000855mg/kg over a 24hr period. The equivalent concentration of cadmium which is considered by the Marine Institute to represent 'elevated values' is >1mg/kg. It would take 1192 days of accumulation before this figure would be reached.

The above concentration predicted for a 24hr period are extremely low values and are ca 2 – 3 orders of magnitude lower than the naturally occurring background levels (i.e. 0-5mg/kg for copper and <0.05mg/kg for cadmium [8]). Given these extremely low levels of additional contaminants to the marine sediments, there will be no negative impact on the sediment biota in the short term. In the longer term it would be advisable to monitor the situation by taking sediment samples every two weeks initially and then monthly to establish if there is any build up of these substances in the sediment. Based on the conservative approach used above however it is unlikely that this will be an issue.

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The model predicts that only extremely low levels of conservative contaminants will reach the lower reaches of Lough Furnace (see previously referenced Figures above). Levels of ca 0.01 ng/l are indicated by the model for the area and the model predicts that no contaminants will get into the lake proper. It appears therefore that Lough Furnace will experience no likely ecological damage from the outfall. Similarly low levels of contaminants are predicted for the lower reaches of Newport River and this indicates that ecological damage to this part of the SAC is extremely unlikely.

5.2.3 Ammonia levels

Various permissible levels of nitrogen, in its different forms, are specified by national and international regulations. In this report, the levels of ammoniacal nitrogen computed by the model are compared with relevant EU legislation. The EU Directive on water quality associated with freshwater fisheries, 78/659/EEC, stipulates that the maximum permissible levels of total ammonia, as N, is 0.3 mg/litre, which is considered to be that which would contain the limiting amount of un-ionised ammonia which is most harmful to freshwater aquatic life. This value was not exceeded during the simulations. In fact the highest recorded value (i.e. 0.0194 mg/l), which was conservative since it took no account of diffusion due to the wind, was more than fifteen times less than the permissible value.

Conclusions

The effects of discharging the given quantities of faecal coliforms, copper, cadmium, and ammonia at the proposed outfall site in Newport Bay. are presented below:

- The maximum allowable level of faecal coliforms permitted by national and international standards for shellfish waters was not exceeded at any location in the bay at any time during the model study. The actual concentrations observed at the shellfish site were in fact several orders of magnitude lower and hence should not have any adverse effects on the quality of the shellfish being harvested.

- The maximum levels of copper and cadmium, as specified by the EU Directives on Water Quality Standards and by the World Health Organisation were well above the levels predicted by model, confirming that there should be no impact on the water quality resulting from the proposed discharge.

- The concentration of copper at the outermost points of the plumes shown in figures 4.9 – 4.16 (i.e. 20 ng/l) is within the range specified by the OSPAR Ecotoxicological criteria (i.e. 0.005 – 0.05 μg/l).

- The proposed discharge of copper is 0.08 μg/l, whereas a concentration of less than 0.04 μg/l would be required if the maximum concentration at the outfall site (i.e. within the initial 10m by 10m grid spacing) is to fall within the range specified by the OSPAR Ecotoxicological criteria.

- Background levels for copper on the west coast of Ireland were found to be in the region of 0.31 μg/l, which is much higher than the maximum concentration predicted at the outfall site.

- The concentration of cadmium at the outermost points of the plumes shown in figures 4.17 – 4.24 (i.e. 0.25 ng/l) is 40 times lower than the most stringent limit according to the OSPAR Ecotoxicological criteria of 0.01 μg/l.

- The proposed discharge of cadmium is 0.001 μg/l, whereas a concentration ten times higher than this, 0.01 μg/l, would be required to achieve the maximum concentration (as per the OSPAR Ecotoxicological criteria) at the outfall site just outside the initial mixing zone (i.e. 10m by 10m grid spacing).

- The levels of copper and cadmium likely to bind to the sediment are very small and will have no impact on the marine environment in the short term. In the longer term it would be advisable to take sediment samples at various locations around the bay until it can be established that there is no significant long term build up. Based on the model results however, it is highly unlikely that there *will* be any adverse effects in the long term.

- The maximum level of ammoniacal nitrogen as specified by EU Directive 78/659/EEC was not exceeded at any of the observation sites in the bay at any time during the model study. The maximum predicted value was more than fifteen times less than the permissible value.