Appendix A

Regulatory Aspects

APPENDIX A BACKGROUND INFORMATION RELATING TO THE FUNDAMENTAL INTERMITTENT STANDARDS

This Appendix provides further background information concerning the Fundamental Intermittent standards presented in Tables 2.2 and 2.3 of the UPM Core Manual.

A.1 Correction factors

The concentration, duration and frequency thresholds identified in Tables 2.2 and 2.3 of Section 2 of the UPM 3 manual relate to the toxicity at certain ranges of environmental conditions, notably pH and temperature for un-ionised ammonia. In addition, the synergistic effects of increased un-ionised ammonia toxicity due to low DO and increased DO thresholds when un-ionised ammonia concentrations are high must be considered. This approach results in site specific, toxicity based, thresholds identified by the use of the correction factors noted in the Tables. These correction factors take the form of either equations which apply the correction on a gradual basis, or as step changes, as supported by available information.

A.1.1 Correction for low temperatures and low pH

The toxicity of un-ionised ammonia is influenced by both pH and temperature, with an approximate doubling of toxicity (i.e. halving of lethal concentration (LC_{50} values)) for a unit drop in pH or a 10ºC drop in temperature. The un-ionised ammonia standards presented in Table 2.3 of Section 2 of the UPM 3 manual are for conditions of around pH 7, or above, and temperatures above 5ºC. If conditions are outside this range, the thresholds must be reduced by the correction factors shown below:

For pH <7, multiplicative correction factor = $0.0003(pH)^{4.17}$

For temperature <5ºC, multiplicative correction factor = 0.5.

To give an example, if a peak of un-ionised ammonia is being checked against the thresholds at a time when pH is 6.5, then the correction factor is calculated as:

$0.0003(6.5)^{4.17} = 0.74$.

Therefore, all the threshold concentrations of the un-ionised ammonia standards would be multiplied by 0.74.

Note that it is highly unlikely that these corrected thresholds will ever be critical. This is because at low pH and temperature conditions the proportion of total ammonia which is un-ionised is very small. For example, at 5ºC and a pH of 7, it requires about 16 mg/l of total ammonia to produce 0.02 mg/l of un-ionised ammonia.

A.1.2 Correction for combined DO and ammonia effects

Several studies have documented the synergistic toxic effects of ammonia and low DO occurring together, taking the approach of calculating ammonia toxicities at different DO concentrations. These show an increase in ammonia toxicity fairly consistently (in terms of LC_{50}) by a factor between 2 and 5 as DO concentration decreases from >8 mg/l to around 3 mg/l. These studies were all concerned with lethal effects, whereas the un-ionised ammonia thresholds discussed here are all well below those that would cause fish kills. However, there is no evidence to suggest that a similar relationship does not apply at lower concentrations, so, in the absence of such evidence, correction factors should be applied to the standards.

Correction factors for DO thresholds, when un-ionised ammonia levels are high, are given in Table A.1 and illustrated in Figure A.1 and correction factors for un-ionised ammonia thresholds, when DO levels are low, are given in Table A.2 and illustrated in Figure A.2.

The appropriate correction factor is dependent on the threshold being checked. Thus, if the 1 year RP 6 hour duration un-ionised ammonia threshold is being checked, the correction factor should be based on the DO concentration which is exceeded for 6 hours.

Table A.1 Correction factors to be applied to DO thresholds for high un-ionised ammonia conditions

Un-ionised ammonia concentration	Correction factor to be applied to DO thresholds in Table 2.2
less than 0.02 mg NH_3-N/l	no correction
0.02 - 0.15 mg NH_3-N/l	+ (0.97 x $\log_e$(mg NH_3-N/l) + 3.8) mg O/l
more than 0.15 mg NH_3-N/l	+ 2 mg O/l

Table A.2 Correction factors to be applied to un-ionised ammonia thresholds for low DO conditions

DO concentration	Correction factor to be applied to un-ionised ammonia thresholds in Table 2.3
5 mg O/l or higher	no correction
< 5 mg O/l	x $0.0126(\text{mg O/l})^{2.72}$

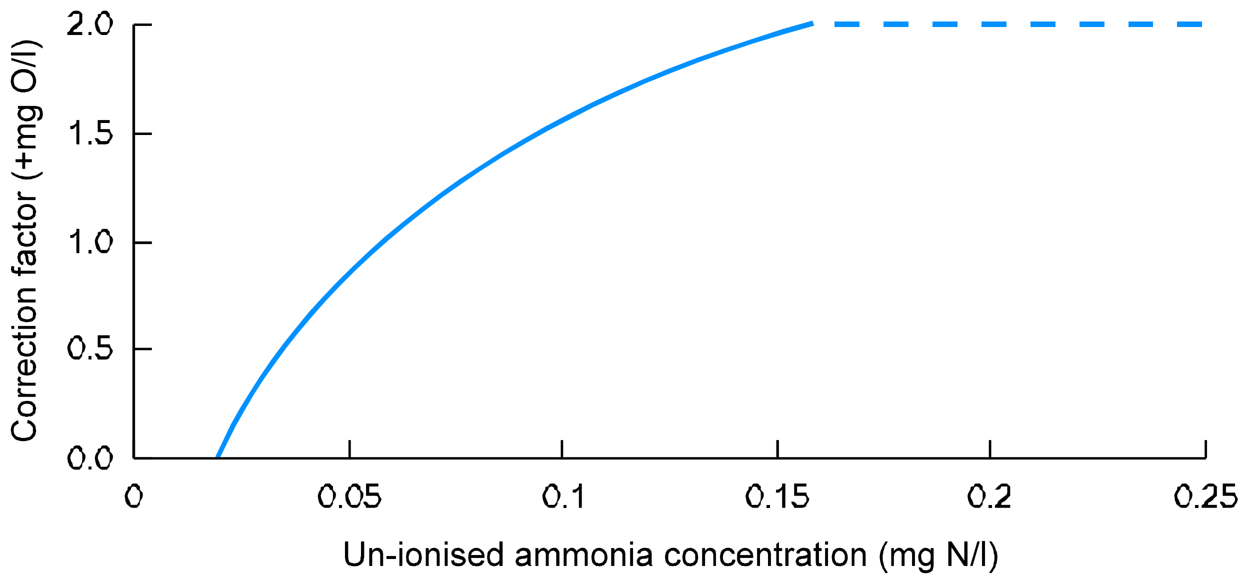

Figure A.1 Correction factors to be applied to DO thresholds for high un-ionised ammonia conditions

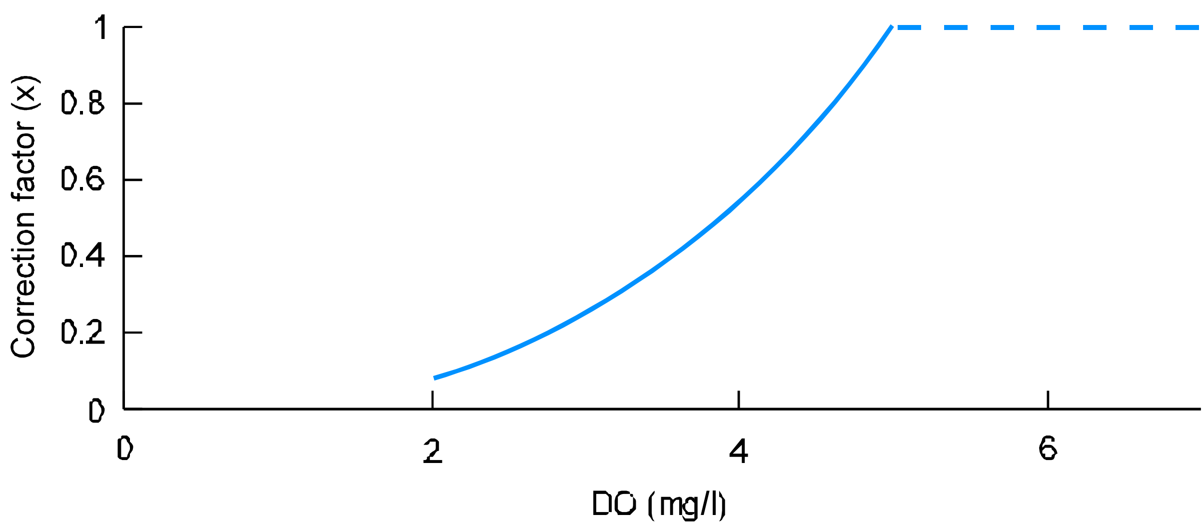

Figure A.2 Correction factors to be applied to un-ionised ammonia thresholds for low DO conditions

Figure A.3 illustrates the meaning of these correction factors by reference to a record of poor water quality downstream of a STW following a storm event. The STW has a history of causing intermittent pollution because of premature discharges from the storm tanks. The quality targets for the receiving water dictate use of the standards for ecosystems suitable for a sustainable cyprinid fishery.

On this occasion a short-lived but high peak of un-ionised ammonia (above 0.17 mg/l for 1 hour) occurred at a time of low DO. This was the most critical aspect of the event (it exceeds the 0.15 mg/l - 1 hour - 1 month RP threshold). If the DO had not dropped below 4.5 mg/l during this period, such a peak would have been allowable once a month, on average. However, because the DO did drop below 4.5 mg/l, the thresholds in Table 2.3b of Section 2 of the UPM3 manual must be corrected. Application of the correction formula for 4.5 mg/l DO gives:

correction factor $= 0.0126(4.5)^{2.72}$

$= 0.75$

Therefore, the thresholds in Table 2.3b must be multiplied by 0.75. As a result, the event breached the corrected three month RP threshold (3 month RP(1 hour) = 0.225 mg/l x 0.75 = 0.169 mg/l). Such an event must not occur more frequently than once every three months on average.

In the example given in Figure A.3, the un-ionised ammonia standards were corrected for low DO concentration occurring at the same time as the ammonia peak. However, as discussed in Section 2.3.3, if an ammonia peak and a DO sag do not occur at the same time during an event but are within 12 hours of each other, they should be considered coincident for the purposes of calculating correction factors. If the two events are more than 12 hours apart then the correction factor is not applied.

By way of a further illustration, consider the hypothetical situation shown in Figure A.4, for another river where the cyprinid fishery standards apply. During a storm-induced pollution event, un-ionised ammonia exceeded 0.07 mg/l for a period of 1 hour. A few hours later a DO sag occurred during which DO went below 4 mg/l for 1 hour. This was the most critical aspect of this event, and in the absence of elevated ammonia levels would be allowable once a month, on average. However, since the maximum un-ionised ammonia and the minimum DO occurred 6.25 hours apart, a correction factor should be applied to the DO thresholds to account for the recent elevated un-ionised ammonia.

The correction factor for the DO thresholds, for 0.07 mg/l un-ionised ammonia is calculated as:

$$0.97 \times \log_e(0.07) + 3.8 = +\ 1.2 \text{ mg O/l}$$

Therefore, 1.2 mg O/l must be added to the DO thresholds. The low DO episode now breaches the corrected 1 hour 1 year RP threshold. Such an event would only be allowable once a year, on average.

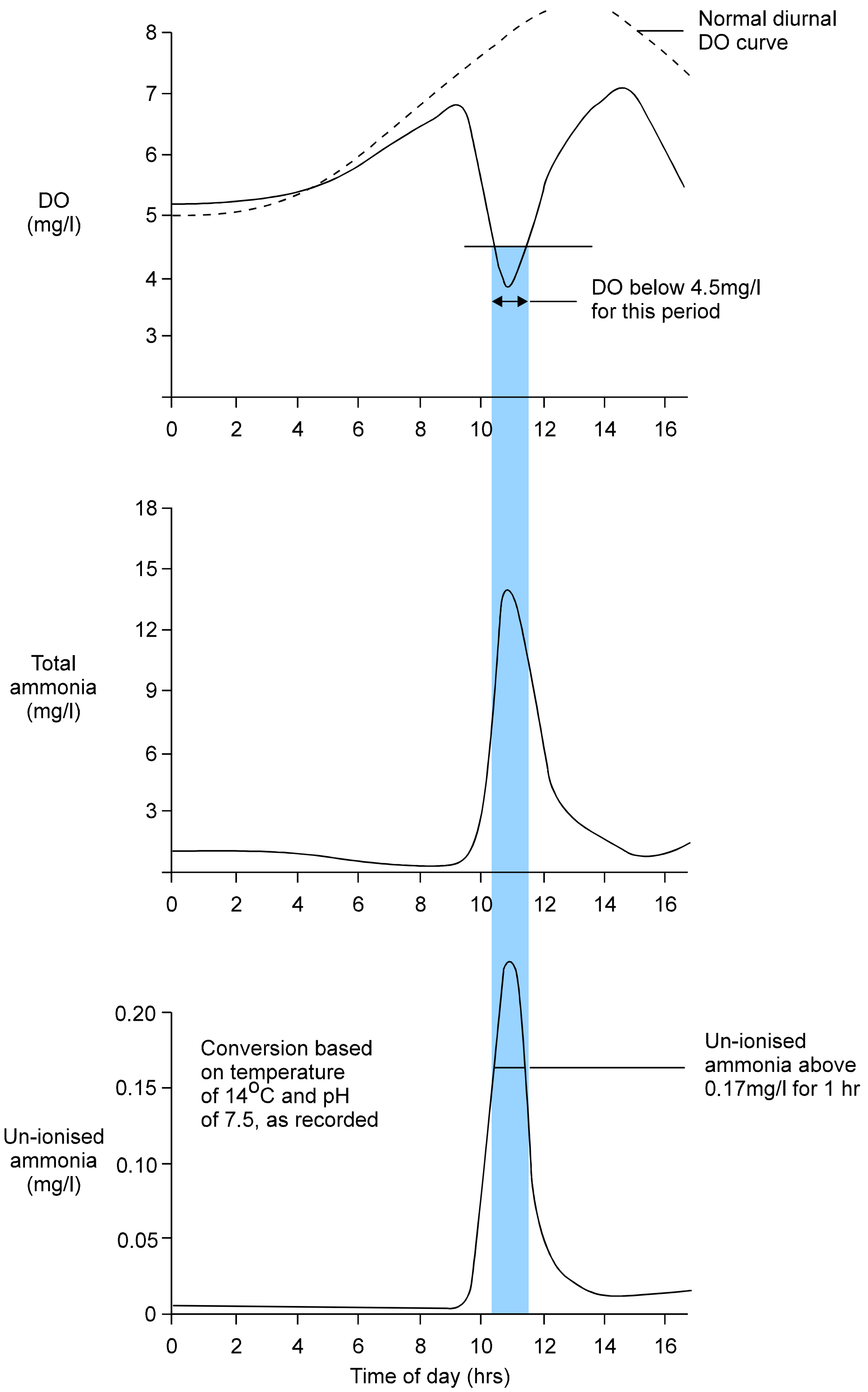

Figure A.3 Example of a storm induced pollution event producing high ammonia and low DO levels simultaneously

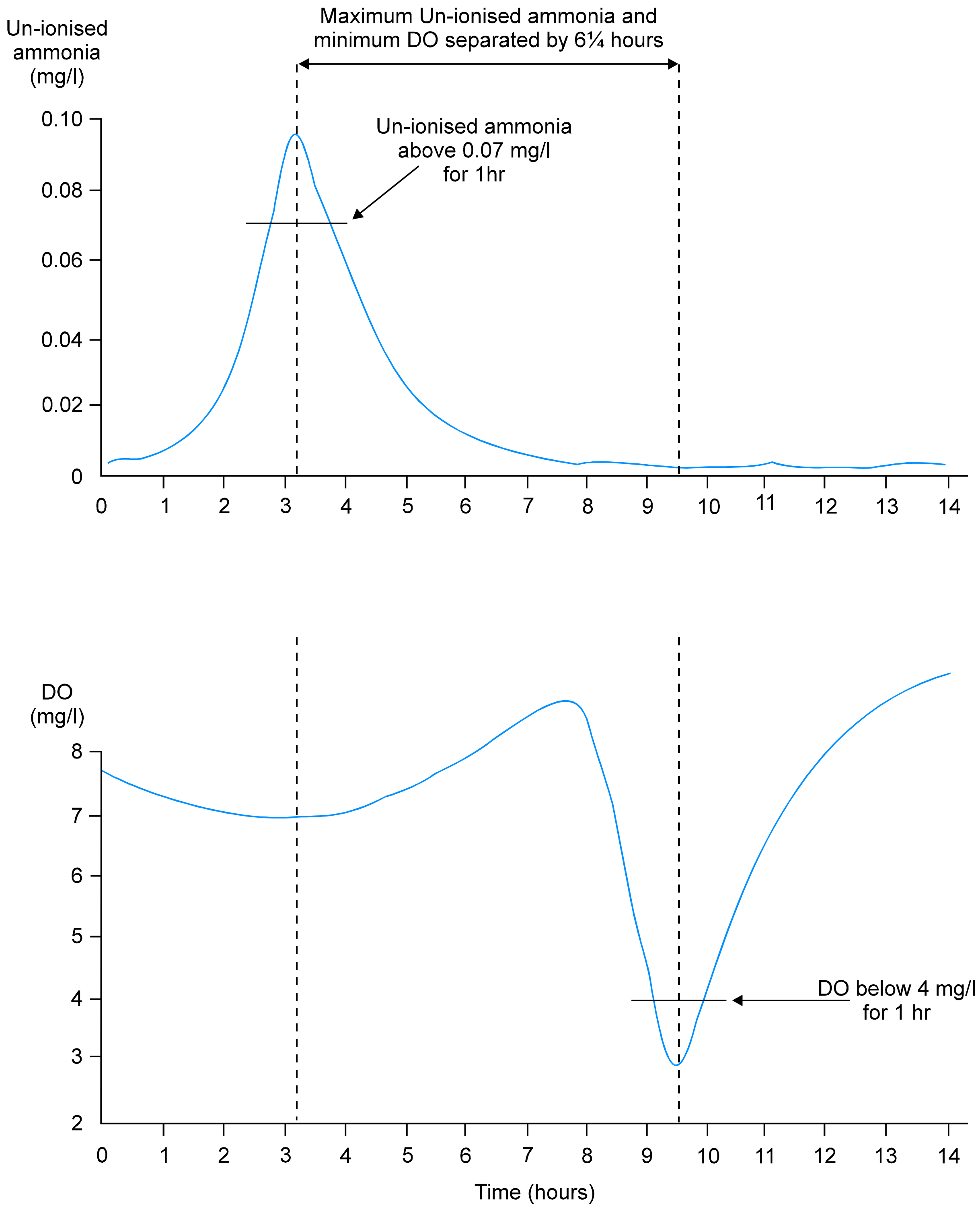

Figure A.4 Example of non-simultaneous high ammonia and low DO levels

A.1.3 Multiple correction factors for un-ionised ammonia standards

It is possible that receiving water conditions require the application of more than one correction factor. For example, if pH was less than 7 and DO was less than 5 mg/l, both the relevant correction factors for the un-ionised ammonia standards would be invoked.

There is a lack of information to determine how, for example, low pH and low DO combinations influence un-ionised ammonia toxicity. As a practical guideline, it is recommended that, where more than one correction factor is required, only the one giving the more stringent standard (i.e. giving the smallest multiplicative correction factor) is used.

For example, if pH was 6.7 and DO was 4 mg/l during a time when an ammonia peak occurred, the correction factors would be calculated as:

correction for DO = $0.0126(4)^{2.72} = 0.55$

correction for pH = $0.0003(6.7)^{4.17} = 0.84$

Therefore, the more stringent DO-invoked correction factor would be used, although at pH 6.7 there would be virtually no un-ionised ammonia associated with the ammonia peak.

A.1.4 Un-ionised ammonia standards expressed as total ammonia

In freshwaters, the relationship between un-ionised ammonia and total ammonia is dependent on temperature and pH. For illustration, Table A.3 shows the threshold values of the Fundamental Intermittent standards for un-ionised ammonia translated into total ammonia values for a range of different pH and temperature values.

Clearly, under certain pH and temperature conditions, the un-ionised ammonia thresholds translate into very high allowable total ammonia concentrations. In terms of toxicological information, the un-ionised form of ammonia is generally recognised as being by far the most toxic, although there is some uncertainty about how toxic the ionised form is. That said, a number of studies have demonstrated that fish can survive very high concentrations of total ammonia (100s of mg/l) at low pH and temperature (when there is little of the un-ionised form).

It should also be recognised that the high allowable equivalent total ammonia concentrations shown in Table A.3 are higher than concentrations likely to be found in dry-weather flow sewage. Therefore, in practice they will never be reached in a receiving water, particularly after rainfall dilution and receiving water mixing.

Table A.3 Translation of un-ionised ammonia standards into allowable total ammonia.

		Salmonid fishery standards			Cyprinid fishery standards			Marginal cyprinid ecosystem standards		
Fundamental Intermittent standards (mg N/l un-ionised ammonia):										
		1 hr	6 hr	24 hr	1 hr	6 hr	24 hr	1 hr	6 hr	24 hr
	1 m	0.07	0.025	0.018	0.150	0.075	0.030	0.175	0.100	0.050
	3 m	0.095	0.035	0.025	0.225	0.125	0.050	0.250	0.150	0.080
	1 y	0.105	0.040	0.030	0.250	0.150	0.065	0.300	0.200	0.140
Translated into allowable total ammonia (mg N/l) based on pH and temperature:										
pH 8; 15ºC	1 m	2.4	0.94	0.68	5.6	2.8	1.1	6.6	3.8	1.9
	3 m	3.6	1.3	0.94	8.4	4.7	1.9	9.4	5.6	3.0
	1 y	3.9	1.5	1.1	9.4	5.6	2.4	11	7.5	5.3
pH8; 5ºC	1 m	5.3	2.0	1.5	12	6.1	2.4	14	8.1	4.1
	3 m	7.7	2.8	2.0	18	10	4.1	20	12	6.5
	1 y	8.5	3.2	2.4	20	12	5.3	24	16	11
pH7; 15ºC	1 m	24	9.2	6.6	55	27	11	64	37	18
	3 m	35	13	9.2	82	46	18	91	55	29
	1 y	38	15	11	92	55	24	110	73	51
pH7; 5ºC	1 m	52	20	14	120	60	24	140	80	40
	3 m	76	28	20	180	100	40	200	120	64
	1 y	84	32	24	200	120	52	240	160	112

A.2 History of the development of the Fundamental Intermittent standards

Originally, single sets of Fundamental Intermittent standards were developed, for un-ionised ammonia and DO, for the protection of all river aquatic life, except the most sensitive early life stages of salmonid fish. Early versions of these Fundamental Intermittent standards were first disseminated in NRA R&D outputs, initially as interim reports PRS 2498-M for DO (Milne and Seager, 1990) and NR 2682/1 for ammonia (Milne and Seager, 1991). Following discussion, the ammonia standards were revised, and both sets of standards were reported in the NRA R&D Note 123 (Milne *et al,* 1992).

The concentration/duration thresholds reported in R&D Note 123 were seen as absolute limits never to be exceeded. However, this interpretation does not lend itself to use in conjunction with the UPM modelling procedures, since compliance can only be ascertained easily in terms of frequencies of exceedance of thresholds. Therefore, the thresholds reported in R&D Note 123 were revised such that they could be interpreted as thresholds not to be exceeded more frequently than shown. It was in this revised form that the Fundamental Intermittent standards were presented in the original UPM Manual. Although those values were different from those shown in R&D Note 123, they were intended to provide the same level of protection and were based on the same research. In other words, the single sets of standards were designated as affording protection to all river aquatic life except the most sensitive life stages of salmonid fish.

These original single sets of standards have now been expanded to include two additional levels of protection. One of the additional sets of standards affords a higher level of protection than the original set (designated as protection for ecosystems suitable for sustainable salmonid fisheries), the other a lower level of protection (designated as protection of marginal coarse fishery ecosystems). The original sets of standards sit between these two new levels and are designated as affording protection to ecosystems suitable for sustainable cyprinid fisheries.

A.3 Scientific basis for the standards

The Fundamental Intermittent standards for DO and un-ionised ammonia were derived on the basis of ecotoxicological information from a range of sources. Literature reviews were carried out on the general ecotoxicological effects of low DO and high ammonia, and in particular the effects of short-term (<24 hours), intermittent exposure. In addition, an experimental programme was undertaken, consisting of laboratory and field studies of both lethal and sublethal effects of low DO and ammonia on fish and invertebrates. Details of this work are reported in R&D Note 123 and summarised here.

The standards presented here are based on the objectives of no long-term detrimental effects on the specified aquatic ecosystem and no fish mortality for events up to one year RP. The standards cover exposure durations of one, six and 24 hours.

For DO, the important factors defining the standards are as follows. Fish recover very rapidly following sublethal exposure to low DO, with little evidence of long-term effects, even when the dose is close to the lethal concentration. Also, the DO concentration and exposure duration are more important factors than the exposure frequency. Invertebrates can show large-scale drifting responses to relatively mild oxygen depletion but populations recover within several weeks (if a colonisation source is available).

In contrast, sublethal exposure to ammonia can cause permanent damage to fish, particularly to gills, and can reduce growth rates. Experimental evidence suggests that event concentration, duration and frequency are all important factors in determining toxic effect. Frequency appears to become a dominant factor when it is high (greater than once per week). All the available data indicate that fish are more sensitive to ammonia than either invertebrates or plants, in terms of both lethal and sublethal responses. Therefore, the standards are based solely on data on toxicity to fish, with the assumption that this will afford adequate protection for other organisms.

For both DO and ammonia, the one-month RP standards would cause some physiological stress to fish (species associated with the specified ecosystem type) but no long-term effects. For DO there would be little invertebrate drift.

The three-month RP standards would cause a greater degree of physiological stress to fish. The DO levels would possibly cause avoidance responses by fish and would cause moderate invertebrate drifting. The ammonia levels are below those affecting fish growth in the laboratory for the sustainable salmonid and sustainable cyprinid fishery standards.

The one-year RP standards would cause stress in fish but would avoid mortality for fish associated with the specified ecosystem type. For DO, the degree of invertebrate drifting could be large for short events (one hour). For ammonia, the standards are well below threshold concentrations which cause mortality in the laboratory in fish species associated with the specified ecosystem type.

The ‘marginal cyprinid fishery ecosystem’ standards should avoid mortality of adult cyprinids, except possibly the most sensitive species, but may not fully protect sensitive life stages of some species although there is little information on this. Sensitive invertebrates would not be expected to tolerate the DO conditions allowed by these standards.

A.4 Salmonid spawning grounds

The one, all be it unlikely, situation where the DO standards may not provide adequate protection is where CSO discharges impact directly on salmonid spawning grounds. The problem centres around intergravel oxygen depletion relative to the water column DO concentration. This effect has been measured but is not well documented; the relationship between the DO concentration and supply in the gravel and the overlying water is complex (EPA, 1986 see UPM2 References, Section 1.8).

The DO supply to developing salmonid eggs and larvae depends on the balance between the rate of oxygen supply and the rate of depletion. The former is dependent on the DO concentration of the overlying water, and/or any upwelling ground water, and the rate of water flow-through, while the latter is a function of the respiration of gravel-dwelling organisms and of degradation processes.

Intergravel DO concentrations can show large spatial and temporal variability. Data cited by the EPA (1986 see UPM2 References, Section 1.8) indicate that even within a single redd (salmonid ‘nest’) the DO concentration can vary by 5 or 6 mg/l at a given time. Overall, the average DO concentration within redds was about 2 mg/l below that of the overlying water and the minima about 3 mg/l below. The EPA (1986 see UPM2 References, Section 1.8) cites another study that found mean DO concentrations in redds were between 2.1 and 3.7 mg/l lower than the stream water. Coble (1961) found mean reductions in DO concentration between stream and intergravel water of around 5 mg/l though this was for artificially constructed redds.

On the basis of the two studies of natural redds (and in the absence of other data), the EPA concluded that the intergravel DO concentration should be considered to be at least 3 mg/l lower than the concentration in the overlying water. On these grounds, the EPA formulated standards for early life stages which were 3 mg/l higher for species with intergravel development than for those with development within the water column. In its summarising of DO concentrations judged to correspond to various qualitative effects, the EPA considered that there was no difference between embryo and larval stages of salmonids and other life stages once the intergravel oxygen depletion effect had been taken into account.

Subsequently, a NRA/MAFF R&D Project (National Rivers Authority 1996 see UPM2 References, Section 1.8) showed intergravel DO concentrations in four rivers were, on average, about 5.0 to 6.5 mg/l lower than river column DO concentrations.

As mentioned above, the flow-through of water in the gravel is important for salmonid embryo survival (Coble 1961, EPA 1986 see UPM2 References, Section 1.8). Flow-through is dependant on the size of interstitial spaces, which may be restricted by the proportion of fine solids within the gravel; siltation can be an important factor limiting production in salmonid streams. Where salmonid spawning rivers receive urban wet-weather discharges, siltation is likely to be an important factor due to the high solids loadings associated with these discharges, especially as these solids will have a high BOD.

The information discussed above relates to ‘average’ intergravel DO concentrations, or minima, from spot recordings. There is little information on the dynamics of the relationship between intergravel and stream DO concentrations and no information on the likely within gravel effects of short-term DO depletion in the overlying stream. In the absence of such information, it is recommended that the EPA approach is taken and a factor of 3 mg/l used to account for intergravel DO depletion. Based on this, to protect salmonid spawning grounds, the Fundamental Intermittent standards for DO should be revised as follows. For the period of spawning to 30 days post-hatching (roughly November to March inclusive), all thresholds should be increased by 3 mg/l.

Note that this revision is relevant to spawning areas only. For other zones of salmonid rivers the normal standards apply.

A.5 Water Framework Directive

With the implementation of the Water Framework Directive (2000/60/EC) (WFD) and its new water quality and ecological standards, the UPM 2 standards (fundamental intermittent standards and 99 percentiles) were subject to a detailed review in 2011-2012 (Water Research Centre: Review of urban pollution management standards against WFD requirements, B Crabtree, J Horn and I Johnson).

The review concluded that the UPM2 FIS are “fit for purpose” and no modifications are required. For most concentration/duration/frequency combinations, the standards for both dissolved oxygen and unionised ammonia provide a margin of safety for salmonid and cyprinid fisheries. They should also provide a degree of protection against potential effects of reduced dissolved oxygen and elevated unionised ammonia concentrations for which toxicity data is not currently available. Therefore, when a fishery meets the relevant standards, no long-term behavioural and physiological effects and no short-term fish and macroinvertebrate mortality should result from irregular wet weather pollution events with at least an annual return period. Therefore, meeting the UPM2 FIS should ensure that the good quality status of a water body is not compromised.

To date, the vast majority of the practical experience of implementing the UPM procedure (particularly in the UK) has been obtained in rivers. However, the UPM2 FIS for cyprinid standards should also be applicable to still waters such as lakes.