# USING 99-PERCENTILES OF RIVER WATER QUALITY TO DESIGN CONTROLS ON DISCHARGES FROM SEWERS

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**Summary**

The shapes of the statistical distributions of measurements of river water quality are essentially the same for all rivers.

99-percentile standards of river water quality should be used to set conditions for the discharges to rivers from sewers.

The standards recommended for discharges from sewers appear more lax than the equivalent standards used for discharges from sewage treatment works.

**Standards**

Two kinds of river quality target are used to calculate the conditions imposed on discharges from sewers and sewage treatment works:

We use **percentiles** of river water quality to work out the standards for discharges from sewage treatment works.

Another type of river quality statistic is used for intermittent discharges from sewers (for example, a concentration exceeded in the river for 6 hours only once every 12 months).

Some of the **Percentile Standards** of river water quality are listed below[1].

Table 1: Standards for River Quality Objectives (mg/l)

| River Ecosystem Class | BOD | | Total Ammonia | | Unionised Ammonia | |
|---|---|---|---|---|---|---|
| | 90-percentile | 99-percentile | 90-percentile | 99-percentile | 95-percentile | 99-percentile |
| RE1 | 2.5 | 5 | 0.25 | 0.6 | 0.0205 | 0.05 |
| RE2 | 4 | 9 | 0.6 | 1.5 | 0.0205 | 0.05 |
| RE3 | 6 | 14 | 1.3 | 3.0 | 0.0205 | 0.05 |
| RE4 | 8 | 19 | 2.5 | 6.0 | - | - |

The Urban Pollution Manual[2] recommends additional sets of standards, called Fundamental Intermittent (FI) Standards for rivers affected by intermittent discharges from sewers. Table 2 gives a set of nine FI Standards. Each combines a concentration, a duration, and a return period.

| Table 2: FI Standards for Unionised Ammonia (mg/l) | | | |
|---|---|---|---|
| Average Return Period | Duration | | |
| | 1 Hour | 6 Hours | 24 Hours |
| 12 per year | 0.150 | 0.075 | 0.030 |
| 4 per year | 0.225 | 0.125 | 0.050 |
| 1 per year | 0.250 | 0.150 | 0.065 |

**What do these Types of Standard Measure ?**

A **percentile** is the sum of all the time spent outside a concentration. It covers all events in which the concentration is exceeded, no matter how long any event lasts. The **FI Standards** deal with events of a particular duration. This form was chosen because it appears to match, better than percentiles, the way we express the outcome of the experiments on fish that are used to determine standards.

If we take one of the FI Standards, the 6 hour duration and the one year return period, the alternative of a percentile is not necessarily inferior. For a particular concentration, an exceedence lasting 5 hours clocks up 5 hours of the time spent in failure allowed by a percentile. But a 5-hour failure does not register as a violation of a 6-hour FI Standard. It is not obviously better to exclude this event (as in the 6 hour FI Standard), than to include it (perhaps with too much weight) in a percentile.

This is a simplification because the UPM approach applies a family of FI Standards, covering any range of durations from, say, 30 minutes to 24 hours, and a range of return periods. But there is also a family of percentiles covering the range from, say, the 99.999-percentile to the 80-percentile. For the impacts of discharges from sewage treatment works, only one percentile appears necessary, the 90-percentile or the 95-percentile of river water quality. Experience shows that, in the main, if one percentile standard is met, the others are too. Similarly for the FI Standards, it is expected that if one member of a family is met, then the others are too.

**How are the Standards Related Mathematically ?**

In 1998, the Water Research Centre reported on *Compatibility of River Quality Targets for Continuous and Intermittent Discharges*[3]. Central to this was a computer simulation of the hour-by-hour impact on river quality, over ten years, for 800 different hypothetical sites. The sites covered permutations of big, small, continuous and intermittent discharges, to big, small, dirty and clean rivers.

The results confirm first the relation within the families of statistics - the families of percentiles or the families of FI-style statistics. Second, the results establish that percentiles are related to the FI-style statistics. For example, for Unionised Ammonia, and a FI statistic for a 6-hour duration and one year return period the FI statistic is 1.6 times the 99-percentile.

The relationship means that if our models show that 99-percentile standards will be met in the river, then this also demonstrates that particular FI-style summary statistics will also be met. There is no need for different **types** of standards - either type will do for both intermittent and continuous discharges. There is no fundamental difference in the shape of the poorer quality tail of the statistical distribution of river water quality, whether this is caused by continuous discharges, intermittent discharges, or a combination of both.

These two facts:

the relation between the summary statistics; and,
its applicability to the impacts of discharges from sewage treatment works and sewers.

suggest that the 99-percentile standards in Table 1, which are used for continuous discharges from treatment works, can also be used to set conditions for intermittent discharges from sewers.

**Are the Standards Equally Strict ?**

So far, we have suggested only that the calculations can be done equally well either with percentile-type summary statistics, or with FI-style summary statistics. We have not said that meeting the 99-percentile standards in Table 1 is the same as meeting the FI Standards.

It is difficult to compare all the percentile standards in Table 1 with the FI Standards. This is because the UPM uses no standards for BOD and Total Ammonia. A comparison is available for Unionised Ammonia. Table 3 gives the 95-percentiles that are the statistical equivalent of various FI Standards.

Table 3: 95-percentile Equivalents of FI Standards for Unionised Ammonia

| Average Return Period | Duration | | |
|---|---|---|---|
| | 1 Hour | 6 Hours | 24 Hours |
| 12 per year | 0.051 | 0.052 | 0.088 |
| 4 per year | 0.033 | 0.037 | 0.052 |
| 1 per year | 0.048 | 0.050 | 0.068 |

The first point about Table 3 is that, within the uncertainty in estimating standards and summary statistics, all 9 entries are effectively the same at around 0.05 mg/l. This underpins the suggestion that there is a particular shape to the statistical distributions of water quality, generally, and that this shows up in the family of FI Standards. This supports the expectation that if one FI Standard is met, then others in the family will be also be met.

Table 3 also underpins the suggestion that if a 95-percentile of 0.05 is met, then **all** the FI Standards, and other percentile expressions of the 0.05 standard, will be met as well.

The third point about Table 3 is that the value of 0.05 appears to be 2.5 times more lax than the 95-percentile of 0.02 used for River Quality Objectives, the Directive on Freshwater Fish, and propounded by EIFAC[4]. This suggests that Table 1 is too strict, or the FI Standards too lax.

In the UPM approach, the standard for Unionised Ammonia in the river, varies, hour-by-hour, according to the calculated concentration of Dissolved Oxygen in the river. (Similarly, the standard for Dissolved Oxygen varies with the calculated concentration of Unionised Ammonia).

This means, for example, that the 2.5-fold relaxation in the EIFAC Standard would be taken up by the UPM calculations if the river spent a lot time with a pH of 6.5 (producing high values of Unionised Ammonia) when the Dissolved Oxygen was less than 4.0 mg/l. This interacting action of the FI Standards will sometimes offset some of the 2.5-fold relaxation.

But we should look at the risks of a process that needs to model, in a synchronised manner, the hour-by-hour changes in two determinands that so difficult to handle (Unionised Ammonia because of sensitivity to pH; Dissolved Oxygen because of the volatility of the Streeter-Phelps formulation; and both because they depend on the estimates of Total Ammonia and BOD).

**Which Standards Should We Use ?**

Given that we can do the sums either with 99-percentiles of river water quality or with FI-style statistics, there are reasons for choosing the former that can be set against the advantages of the more fundamental nature of the FI Standards. Chief of these benefits is that 99-percentiles are estimated in models with more precision than their FI counterparts. Also, percentiles can be calculated by simpler models, with less need to gather special data.

If we accept that percentiles are relevant, and if we acknowledge the past success of Table 1 and the import of *Compatibility of River Quality Targets*, we can factor in the added simplicity of modelling BOD and Total Ammonia instead of Unionised Ammonia and Dissolved Oxygen.

**Conclusions**

This paper has helped explain our success in setting standards for discharges from sewage treatment works, and suggests that this success can be extrapolated to discharges from sewers.

We should require that discharges to rivers, from sewage treatment works and sewers, are designed to comply with the 99-percentile standards in Table 1. This is because there is no fundamental difference between the impacts of continuous and intermittent discharges on the shape of relevant parts of the distributions of river water quality.

**References**


1 Department of the Environment (1994). *Water Quality Objectives: Procedures Used by the National Rivers Authority for the Purpose of the Surface Waters (River Ecosystem) (Classification) Regulations 1994.*

2 Foundation for Water Research (1998). *Urban Pollution Management.* Manual. FR/CL 002. November 1994. Updated in October 1998.

3 Foundation for Water Research (1998). *Compatibility of River Quality Targets for Continuous and Intermittent Discharges.* FR/CL 008. March. Extended (in a Draft Report) in 1998.

4 European Inland Fisheries Advisory Committee (1973). *Water Quality Criteria for European Freshwater Fish. Report on Ammonia.* Water Research, 7 111-22.

## DISCUSSION

### Question Graham Squibbs NWW

I am concerned about the statement that fundamental standards and 99%ile standards are the same. From our experience we have situations where FI standards suggest one spill per annum solutions against 99%ile of 15 spills per annum. We also have examples where we have no problems with meeting FI standards but have to put 3000 $m^3$ of storage in the network to achieve 99%ile standards. Our work would suggest that for flat watercourses FI standards are more extreme and for steep catchments 99%ile standards are more extreme. They are not the same.

### Answer

I do not say the standards are the same. I say that the calculations can be done equally well with standards expressed as 99-percentile or standards expressed in the form of the FIS. That is the same degree of control can be expressed either way. This is not a very startling result except that percentiles are so much more easily modelled.

For the few standards where it is possible to make a close comparison of particular 99-percentile standards and particular FIS standards, I agree that the FI standards are more lax than the percentiles. This produces the dilemma that schemes designed to FI standards will fail the criteria used normally for continuous discharges. I have never found that in FI standards.