Discussion of an environment quality standard based assessment procedure for permitting discharge

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Abstract The 'combined approach' as a requirement of the EC Water Framework Directive pools an emission-based approach with an approach based on environmental quality standards (EQS) to improve European water quality. The implementation of the EQS-based approach poses problems of defining a reference water discharge, defining a distance, where the EQS are obligatory and thus have to be controlled after point discharge, considering incomplete mixing. To elaborate a simple assessment procedure including the aspects mentioned above is the point of discussion in this paper. On the basis of easily available data and references from several European countries, recommendations for an Austrian assessment procedure are presented.

Keywords Combined approach; mixing processes; point pollution; regulatory praxis; water quality objectives

Introduction

The EC Water Framework Directive 2000/60/EC (WFD) allots an integrated river basin-wide water quality protection for all European water bodies. By 2015, a good ecological state should be reached in all surface water bodies, taking into consideration biological parameters as well as hydro morphology, physical and chemical aspects, and hazardous substances. To reach this aim, the WFD defines a new strategy to reduce water pollution from point and diffuse sources. The 'combined approach' pools emission limit values (ELV) with environmental quality standards (EQS). Consequently, water pollution of point source emissions will be limited by both requirements in future, while until now, water quality management practice in most European countries was aligned to either one of these aspects.

This new European strategy guarantees a further advancement of water quality, combining the control of point source emissions by ELV explicitly with the specific response character of the receiving water, controlled by EQS.

Typical relations of ELV/EQS for physical and chemical water parameters range between 5 and 1 000 (Jirka *et al.*, 2003), due to different protection objectives. While the ELV-based approach aims to prevent aquatic organisms from acute lethal damage concerning the near field of the discharge, the EQS approach prevents aquatic organisms from long-term chronic stress in the whole water body. Ragas *et al.* (1997) highlighted the advantages and disadvantages of both approaches. Commonly, emission regulations by ELV represent a widely successful and practicable tool to prevent receiving surface waters from pollution. Nevertheless, in special cases like large point sources emitting to small receiving waters or a sequence of point sources emitting to the receiving water, the emission-oriented approach is insufficient. Beneath the possibility of regulating additional emission requirements by case-to-case ruling, the EQS-based approach guarantees a direct water body-related procedure including the ecological response character of the

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receiving water, and thus linking the responsibility of the discharger directly to the recipient. On the other hand, the appliance of the EQS-based approach only could lead to situations where dischargers would exploit the assimilative capacity of the water body until the EQS are reached. Furthermore, monitoring by the national water quality authorities would be more complicated with respect to the sampling site and the reference discharge (Jirka *et al.*, 2004). Thus, a combination of both approaches can stress their benefits, while their disadvantages mostly can be avoided.

Nevertheless, there are still many open questions regarding the implementation of the 'combined approach', especially with respect to considering a multitude of normative and practical aspects being connected with each other. The main normative considerations concerning an EQS-based approach are how to deal with multiple dischargers, mixing zone regulations, temporal variations, environmental compartments, mixture toxicity, and uncertainties of calculations. The most important practical considerations are which water quality models can be used and which data are available and needed for the assessment (Water Ministry of Transport, Public Works and Water Management, The Netherlands, 2003).

In several European countries, different regulations were applied to implement the 'combined approach' into national law (Austrian Ministry of Agriculture, Forestry, Environment and Water Management, 2004). In Austria the Federal Ministry of Agriculture, Forestry, Environment and Water Management defined, as the first step a list of EQS for a multitude of chemical substances (Austrian Ministry of Agriculture, Forestry, Environment and Water Management, 2003). In a further step, recommendations for a procedure were developed that constitute the control of EQS in surface water after point discharges.

This paper outlines the recommendations of an assessment procedure regarding the need for easy and practicable implementation by national authorities on the one hand and the relevance of physical-based mixing processes after point emissions on the other. With respect to the open questions mentioned above, the problems of defining clear 'mixing zone regulations' stating where in the water body relative to the point of discharge the EQS have to be obligatory and the need to consider 'temporal variations', which means the definition of a typical, easily available statistic discharge dimension this paper discusses.

Methods

EQS-based assessment procedure (administrative aspect)

Compliance with the regulations or exceeding of the EQS in surface water bodies can only be ensured by forecasting models. These can be simple balance models (on the basis of allegation alternates) or complex system models (with a higher effort on data, time, knowledge, and costs) (Ragas *et al.*, 1997). As documented in Figure 1, a water quality assessment procedure can be divided in two phases. On the basis of discharge data, water system data, and an emission inventory, the first assessment phase has to prove in a 'forward' model calculation if the predicted water quality will reach or exceed the EQS values. If the predicted water quality is lower or equals the EQS, then no further steps will be necessary (the best available technique (BAT) is sufficient). If the EQS fail, the resulting new ELV will have to be calculated in a reversed water quality modelling phase, starting from the EQS and the left assimilatory capacity of the water body. One important precondition is the knowledge of the emission inventory. If there are different dischargers, the EQS has to be diminished. This can be practised by the determination of a total maximum daily load (TMDL) concerning river sections or by a correction of the EQS in regard to the number or the share of discharges. However, it has to be avoided that single dischargers can use the whole assimilative capacity of the water body.

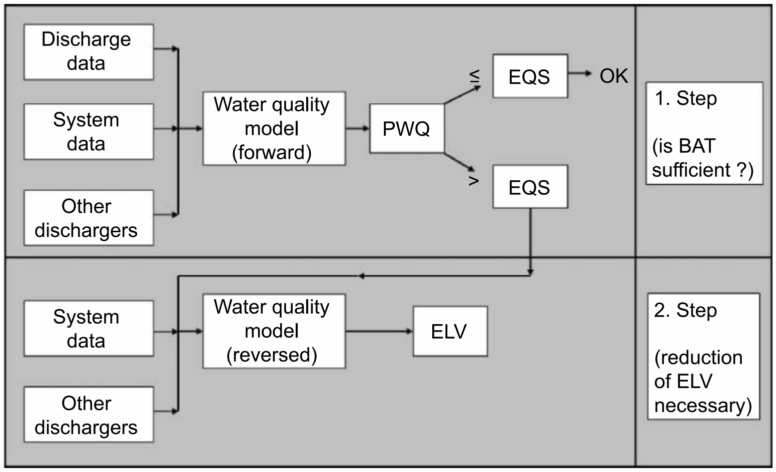

Figure 1 Schematic overview of an EQS-based assessment procedure, PWQ = predicted water quality; BAT = best available technique (adapted from Water Ministry of Transport, Public Works and Water Management, The Netherlands, 2003)

Reference water discharge (temporal aspect)

In the EC-WFD, EQS values are defined as average annual values (Irmer *et al.*, 1997). Therefore, an assessment of the EQS in the case of a point source emission has to consider a reference water discharge, which represents the intended dilution effect. This reference water discharge has to reflect the variability of runoff conditions (low water events) to guarantee a continual protection of the aquatic organisms. It may not lead to unrealizable requirements and it should be based on statistical, easily available data to maintain a practical EQS-based assessment procedure for the public authorities.

Examples from different countries demonstrate the variability in the interpretation of the required reference water discharge, ranging from mean water discharge over mean low water discharge up to simple undefined terms as 'low water situation' (Commissie Integral Waterbeheer, 2000; NRW – guideline, 2003). In this paper, an easy approach is presented to assess a reasonable reference water discharge based on the assumption of a point source emission. To guarantee the practical implementation of the approach, easily available discharge data from several Austrian rivers were used (Austrian Ministry of Agriculture, Forestry, Environment and Water Management, 2002).

'Mixing zone regulation' (spatial aspect)

In the case of a point source emitting to the receiving water, the WFD suggests neither a guideline, ruling where the EQS values in the water body are obligatory nor an instruction for the national authorities to develop such guidelines. However, physical-based regulations are essential to control EQS in surface water bodies for a practicable implementation of the 'combined approach'. In the absence of clear regimentations, extreme interpretations can be established where the EQS can be controlled. These are:

- at the point of emission (in this case the EQS values would displace the ELV values),
- below complete mixing, (accepting expanded regions where the EQS is not valid and aquatic organisms will be exposed to long-term chronic stress)

The goal of a clear 'mixing zone regulation' is to avoid this range of interpretation in terms of the 'combined approach' and to guarantee the comparability of monitoring results. This means to elaborate a compromise considering defined zones, where the EQS values are exceeded, taking into account the necessity to avoid acute toxicity and long-term chronic stress for aquatic organisms in most of the zones of the water body.

In the USA, mixing zone regulations are implemented into national law. The assessment of the innocuousness of the emission has to be adduced by the polluter (polluter pays principle) using more or less complex models (US-EPA, 1991). In the EQS-based assessment of the Netherlands, additional measures can be decreed if the emission will raise the concentration after a certain distance (10 fold the water body width, with a 1,000 m maximum) by 10% of a substance specific maximum tolerable risk (MTR) (Commissie Integral Waterbeheer, 2000). The approach presented in this paper tries to consider the variety of possible cases of mixing zones and transfers them into simple regimentations.

Mixing processes for point sources in rivers

Mixing of a point source discharge in a river is affected by the interaction of the streaming conditions in the river and the emission characteristics. Assuming a so-called 'passive source', where the momentum of the discharge as well as effects of buoyancy can be neglected, mixing is controlled by advective and turbulent diffusive flow properties. In the past four decades, mixing processes have been the subject of intensive research (e.g. Fischer *et al.*, 1979; Rutherford, 1994). The 3-D mixing processes can be separated into a vertical, a longitudinal, and a transversal dimension.

The distance where complete vertical mixing of the plume appears (L_{mv}) can be determined by the method of images where the concentration of the riverbed reaches 90% of the surface concentration (Fischer *et al.*, 1979):

$$L_{mv} = 0.4\frac{Uh^2}{E_z} \tag{1}$$

$U =$ mean velocity, $h =$ water depth, $E_z =$ vertical eddy diffusivity.

The distance where complete transversal mixing over the river cross-section takes place (L_{mh}) can be calculated using Equation (2):

$$L_{mh} = 0.4\frac{UB^2}{E_y} \tag{2}$$

$B =$ width of the river, $E_y =$ horizontal eddy diffusivity.

Jirka *et al.*, (2003, 2004) deduced empirical formulas from the above equations:

$$L_{mv} \approx 50\,h \tag{3}$$

$$L_{mh} \approx 7\left(\frac{B}{h}\right)B \tag{4}$$

and characterizes the border conditions where these simplifications are valid. The empirical Equation (4) describes the point of complete transversal mixing assuming a point source discharge form the river bank. Situating the point of discharge in the middle of the river would affect a fourfold faster complete transversal mixing (B replaced by B/2).

The longitudinal mixing depending on fluctuations in discharges is not discussed in this paper.

Results and discussion

Recommendations to define the reference water discharge

In the Austrian administration, an EQS assessment based on a simple mixing calculation has been practised in certain cases since 1991 (Austrian Ministry for Environment, Regional Development and Agriculture, 1991). The reference water discharge used in this assessment varies between the discharge that has been exceeded in 85% or even 95%

(Q_{85} and Q_{95}) of two following years. The EC-WFD rules the achievement of the EQS as an annual mean, which would argue for the mean annual discharge (MQ) to be used as the reference discharge. Certainly, using either Q_{95} or MQ as the reference discharge would lead to a significant difference in the maximum tolerable load (MTL) that may be emitted from a point source (deviations of 100%–600% in Austrian rivers were calculated by the Austrian Ministry of Agriculture, Forestry, Environment and Water Management, 2004). Figure 2 shows the variability of the hydrology in a river, illustrated in a frequency distribution of the annual discharge. Furthermore, a fictive point discharge is assessed illustrating the different resulting concentration distributions in the river Ybbs after calculating the ELV with different reference water discharges.

One characteristic of the water discharge frequency distribution is the asymmetry with a significant overbalance of low water discharges. This results in discharges falling below the mean annual discharge in about 70% of a year. Consequently, the maximum acceptable load of a point discharge assessed with a mean annual discharge (MQ) presumably would tolerate a violation of the EQS in the water body in 256 days of the year (Figure 2), assuming a constant emission of this load. Thus, the effective mean annual concentration (c1) would significantly exceed the EQS (e.g. $1\ \mathrm{mg/m^3} = \mathrm{c3}$ in the example). Calculating the maximum acceptable load using the Q_{95} as the reference discharge would result in an optimized water quality protection (EQS violated in only 5% of the year), but the effective mean annual concentration of a specific substance would be lower, as specified by the EQS, values (c2).

In order to calculate at which maximum acceptable load the EQS will be met as an annual mean, it is necessary to define the discharge where the mean concentration (Q_{mc}) is met:

$$Qmc = N/(\sum 1/q_i) \tag{5}$$

Q_{mc} = discharge at mean concentration, q_i = daily discharges, N = number of values.

In regard to the asymmetry of the discharge frequency distribution, this discharge will be found between Q_{50} and Q_{60}. Considering the variability of discharges in different years, it is recommended to calculate Q_{mc} from annual data with the lowest water discharges (Q_{mcLQ}). In Table 1, a comparison is shown of statistical annual water discharges for different rivers representing typical Austrian river types with the Q_{mc} and Q_{mcLQ}.

Conclusions can be drawn that the statistical discharge Q_{70} coincides with the calculated Q_{mcLQ}. Maximum deviations range between −4% and 29%. Thus, the Q_{70} is a suitable, easily available reference for water discharge, aggregating the different needs

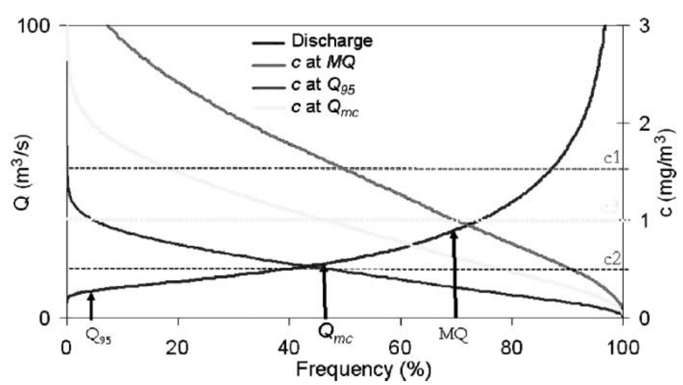

Figure 2 Resulting concentration frequency distributions in River Ybbs, after point discharge of ELV, calculated with different water discharges

Table 1 Table1 Comparison of Q_{mc} and Q_{mcLQ} with easily available statistic discharge data (Q in m^3/s; factor f is characterizes the deviation from Q_{mcLQ})

River	Danube 1971–1996		Traun 1980–1997		Inn 1971–1999		Ybbs 1971–1996		Thaya 1977–1999		Wulka 1971–1997	
	Q	F	Q	F	Q	F	Q	F	Q	F	Q	F
Q_{mcLQ}	1208	1.0	73.3	1.0	24.7	1.0	13.4	1.0	3.4	1.0	0.5	1.0
Q_{mc}	1597	1.3	86.2	1.2	30.7	1.2	18.8	1.4	5.5	1.6	0.8	1.5
MQ	1877	1.6	127.7	1.7	58.3	2.4	30.3	2.3	9.3	2.7	1.1	2.1
Q_{70}	1340	1.1	70.5	1.0	29.1	1.2	14.6	1.1	4.5	1.3	0.7	1.3
Q_{95}	933	0.8	36.6	0.5	10.1	0.4	9.5	0.7	2.7	0.8	0.4	0.8

(protection, use, control) that have to be considered in an EQS-based assessment, while MQ and Q_{95} both show disadvantages in being used as a reference discharge if EQS are defined as yearly averages (see calculated deviations from Q_{mcLQ}).

Recommendations for defining a 'mixing zone regulation'

Until now, complete mixing was assumed with regard to controlling EQS values in Austria. However, such a procedure includes certain arbitrariness with respect to the significance of monitoring results because the mixing behaviour and the point of monitoring will determine the measured concentration while mixing is incomplete.

As can be concluded from Equation (3) the vertical mixing is a relatively fast process, even for rivers with a high water depth like the Danube (Table 2), and thus negligible. In contrast, complete transversal mixing can be reached after tens and hundreds of kilometres, depending on river morphology and flow conditions. As Table 2 illustrates, the point where complete transversal mixing occurs shows significant variations, depending on river water depth (factor 2 to factor 4). This implies that in a 'mixing zone regulation' in an EQS- based assessment, water depth has to be an additional consideration.

Considering the phenomena of incomplete mixing in an EQS-based assessment necessitates defining where after the point of discharge the EQS are allying and monitored. Practically, this can be a fixed distance (e.g. 500 m or 1,000 m) or a calculated distance following deterministic formulas, like in the Dutch approach (Commissie Integral Waterbeheer, 2000) considering the width of the receiving water ($L = 10B$). We modified this approach with $L = 200\,m + 10B$. Thus, in a concrete EQS-based assessment, the mean width of a river would determine where the EQS have to be adhered (e.g. a river of 20 m width in a distance of 400 m). In a second step, it is estimated which width of a river (B) will be mixed actually in the distance of 400 m, using simple nomograms (Figure 3) based on Equation (4). Considering the importance of discharge (previous section), the water depth at Q_{70} is used (e.g. a water depth of $Q_{70} \approx 1.25$ m) to calculate

Table 2 Complete vertical (L_{mv}) and transversal (L_{mh}) mixing considering water depth fluctuations

River morphology	Danube (1996–1999)	Traun (1994–1998)	Inn (1994–1998)	Ybbs (1971–1999)	Mur (1974–1998)	Wulka (1971–1997)
Width [m]	280	90	180	50	80	7
Lowest water depth [m]	1.59	0.74	2.15	1.62	1.14	0.56
Highest water depth [m]	6.24	3.05	4.96	3.85	4.85	2.21
L_{mv} at lowest/highest water depth [m]	80	37	108	81	57	28
	312	153	248	193	243	111
L_{mh} at lowest/highest water depth [km]	345	77	106	11	39	0.6
	88	19	46	5	9	0.2

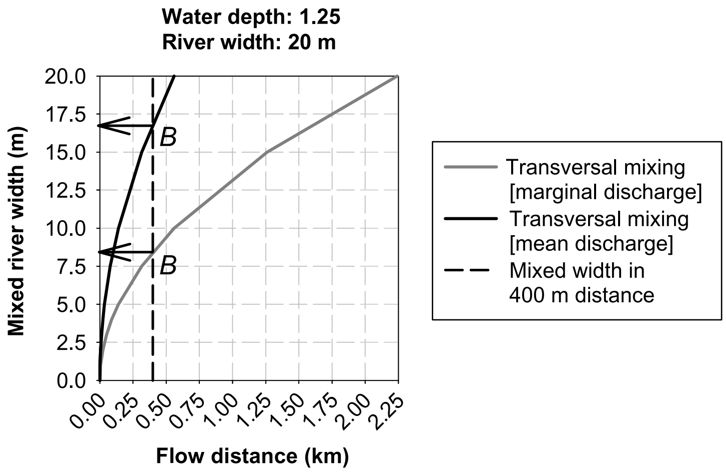

Figure 3 Nomogram showing transversal mixing (assuming a random and a central point of discharge) for a river 20 m wide at a water depth of 1.25 m at Q_{70}

at which distance a complete transversal mixing can be expected ($L_{mh} = 2240$ m considering a random point of discharge and $L_{mh} = 560$ m in the case of a central point of discharge).

From these simple estimations, it can be decided whether or not we have to consider incomplete mixing. In the presented example (water depth at $Q_{70} = 1.25$ m, river width = 20 m) in the case of a random point discharge only 8.5 m will be mixed in a distance of 400 m (incomplete mixing), while a point source discharging in the middle of the river would result in a mixed river width of 17 m and complete mixing will be reached after a further flow of only 160 m (Figure 3). To guarantee that the EQS are met after a distance of 400 m, the ELV have to be calculated with a reference discharge Q_{70} modified by a factor (Q_r) resulting from the actual mixed river width (B_{am})/river width (B) (8.5/20 = 0.425, in the case of a random point of discharge and 17/20 = 0.85 in the case of a central point of discharge).

As can be concluded from nomograms considering manifold river width and water depth, incomplete mixing after $L = 200\,m + 10B$ will occur prior in rivers $>$10 m width (concerning a random point of discharge) and in rivers $>$20 m width (concerning a central point of discharge). It is obvious that this approach highly simplifies mixing processes. For more complex cases of point discharges (e.g. special discharge constructions or differences in density), it is recommended to use more detailed mixing models.

Recommendations to develop an EQS-based assessment procedure

A practicable EQS-based assessment procedure should minimize efforts and costs, should be easy to handle and aggregate the different needs: protection, use, and control. Therefore, an iterative procedure with growing complexity is useful.

The first step of such an assessment can be a rough screening. All point discharges with concentrations $<$EQS can be excluded from a possible EQS-based assessment. If the concentration are $>$EQS, it has to be tested if a detailed assessment is necessary (phase 2). In rivers $<$10 m width it can be calculated with the help of a simple allegation alternate if the point discharge will result in concentrations $>$EQS using Q_{95} (assuming complete mixing). In rivers $>$10 m width, Q_{95} is modified by a factor $10/B$ considering incomplete mixing. In general, the river background concentration is neglected in this assessment phase compensated by the rigorous discharge criteria Q_{95}. If the river is heavily loaded by other emitters, the EQS that shall not be exceeded by a point discharge even can be reduced. If the calculated concentrations are $<$ the EQS the assessment procedure stops. In case they exceed the EQS, the ELV have to be reduced in a third phase.

The calculation of a reasonable ELV by means of an EQS-based assessment (phase 3), needs to consider (1) a reference water discharge, (2) a defined distance, where the EQS have to be monitored after point discharge, and (3) a mixing zone regulation. As has been discussed before, the Q_{70} is a proper reference water discharge. The deterministic equation $L = 200\,m + 10B$ allows to estimate the distance where the EQS values have to be obligatory and incomplete mixing is considered by the possibility of reducing Q_{70} with B_{am}/B.

In a further intermediate step, the concentration upstream (C_{up}) has to be evaluated. With the help of a simple allegation alternate (Equation (6)) using the calculated water reference discharge (Q_r), the maximum admissible load (L_{max}) is calculated, which does guarantee not to exceed the EQS after a distance L.

$$L_{\max} = (Q_r + Q_{em})C_{EQS} - Q_r C_{up} \quad (6)$$

Q_{em} = discharge of the point emission, C_{EQS} = EQS concentration.
Should L_{max} exceed the ELV, no further reduction of the ELV is necessary. In case it falls below the ELV, the ELV has to be reduced to $\leq L_{max}$. In this case, more complex models can be used for a more detailed calculation of a proper ELV.

Conclusions

The 'combined approach' as a new requirement of the EC-WFD will guarantee a further improvement in European water quality. However, the implementation of an EQS-based approach discloses new challenges, whereof one is to consider complex processes without overcomplicating the assessment procedure. Another recommendation is to enable this assessment on the basis of easily available data.

It has been shown that considering physical-based mixing processes, as well as different discharges and water body dimensions, does not necessarily lead to complicated and time consuming assessment procedures. In regard to the EC-WFD recommendations, the Q_{70} is a proper reference water discharge for an EQS-based assessment, more capable of combining the needs of water protection and water use than the MQ or the Q_{95} (with regard to EQS these are defined as yearly averages). The appointment, where an EQS has to be obligatory and thus monitored after a point discharge can be estimated by deterministic equations, comprising a reasonable compromise of considering incomplete mixing in the near field of the point discharge and the protection of aquatic life against long-term impacts in most regions of the water body. Furthermore, a practical assessment procedure has been developed defining simple evaluation steps on the basis of an easily available dataset. However, this assessment procedure integrates the needs of water protection, water use, and the practicability of water quality monitoring; it is obvious that in special cases, the use of more complex models is highly recommended.

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