



CIS - WFD

Technical Background Document on Identification of Mixing Zones

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Disclaimer:

This technical document has been developed through a collaborative programme involving the European Commission, all the Member States, the Accession Countries, Norway and other stakeholders and Non-Governmental Organisations. The document should be regarded as presenting an informal consensus position on best practice agreed by all partners. However, the document does not necessarily represent the official, formal position of any of the partners. Hence, the views expressed in the document do not necessarily represent the views of the European Commission.

Explanatory Note

This document is designed to be read in conjunction with the EU Common Implementation Strategy document “Guidelines for the identification of Mixing Zones under the EQS Directive (2008/105/EC). It comprises additional supportive information to that provided in the Guidelines Document that the Drafting Group believes will assist practitioners working in this area to reach appropriate and robust decisions. The document also includes a “Frequently Asked Questions and Answers” section together with some useful examples.

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1. Frequently Asked questions

1) How should member states deal with metal-concentrations? Most effluent-data are expressed as total concentration, while the EQS is expressed as dissolved concentration.

It is recognised that metal concentrations in effluent data will normally be expressed as the total value. A precautionary approach is recommended such that in Tiers 1 and 2 the “total” emission data is treated as if it were a dissolved value to evaluate dispersion of the ‘total’ concentration. For those substances where the EQS is expressed as a dissolved value then comparison should be made with this value. (This effectively assumes 100% partitioning in the dissolved phase in the environment.) However, where there is evidence that partitioning could be different this could be taken into account at tier 3 or, where the partitioning is well understood, with the agreement of the Competent Authority, at Tiers 1 or 2.

2) What should Member States do if there is already an exceedence of the EQS in the receiving water body?

This is a consenting policy issue rather than a mixing zone question and while it is recognised as a real problem it should be dealt with under the River Basin Management Planning process directly. In plain terms this means that in circumstances where the upstream quality exceeds the EQS just upstream of the point of discharge a fundamental review of all permits above this point may be required.

3) How should Member States deal with discontinuous or intermittent discharges?

It is important to consider carefully the relevant statistics for the discharge concerned, including whether these should cover the whole time period or merely those times when a discharge occurs. It is important to ensure that such discharges are not screened out early if they present a risk to the overall status of the water body. Consideration at Tier 2 may not always be adequate and in such cases, where there remains a level of doubt, consideration at Tier 3 will allow the possible interdependence of effluent flow, quality and receiving water flow and quality (and possibly receptors) to be addressed.

4) Is there a possibility to incorporate (bio) degradation of a substance in the model?

It is certainly possible to consider biodegradation at Tier 3, and for fast decaying substances with a well-known loss rate, it may be possible to justify incorporation of the loss mechanism in Tier 1 and 2 level assessments at the Competent Authorities' discretion. Inclusion of such a loss is straightforward in some Tier 2 level models e.g. CORMIX. It is not normally possible to incorporate in Tier 1 since this is simply about dilution (not timescale) though where the loss is due to chemical reaction alone (and

can be characterised well by mixing) an adjustment based on the well-mixed concentration could be applied at the Competent Authority's discretion

5) *What should we do in the case of PBT-substances?*

One of the key criteria for inclusion on the priority list is whether a substance has persistent, bio-accumulative and toxic (PBT) properties. Such substances must be considered in this guidance. The document has been designed to lead the Competent Authority towards an approach where all relevant information is considered before reaching a decision. For this reason the guidance drew attention to the toxicological data sets used to derive the standards to ensure that the most appropriate data was considered and that all sensitive receptors potentially affected are protected

6) *Which variables can be set to a standard value? Not all input data are readily available.*

The danger with advocating reliance upon default or standard values is that it may not effectively deal with the variability of all cases. The tiered approach has been designed to try and eliminate clearly trivial discharges at an early stage but in most cases the quality of output will always depend upon the quality of the input material. Where data are lacking one option may be to identify the probable maximum and minimum values for the parameter concerned and then consider the size of difference that results when using these values. One can then scale the importance of finding the correct value.

7) *How should we deal with multiple mixing zones?*

This question is covered in detail in Chapter 12 of the Guidance document on Mixing Zones. Where the question refers to multiple substances in the same discharge the stringency will depend on the respective ratios of $[\text{CoC}]_{\text{effluent}}/\text{EQS}$ since all substances suffer the same dilution. However while this approach holds true instantaneously, there may be a need for further consideration for a discharge of multiple substances whose relative concentration changes with time and where the receiving body dilution changes in time.

2. Approach for dealing with natural background concentrations

Under Annex I Part B of Directive 2008/105/EC, the application of the EQS set out in part A is explained. At point 3 the following text is provided:

With the exception of cadmium, lead, mercury and nickel (hereinafter ‘metals’) the EQS set up in this Annex are expressed as total concentrations in the whole water sample. In the case of metals the EQS refers to the dissolved concentration, i.e. the dissolved phase of a water sample obtained by filtration through a 0.45 µm filter or any equivalent pre-treatment.

Member States may, when assessing the monitoring results against the EQS, take into account:

- (a) natural background concentrations for metals and their compounds, if they prevent compliance with the EQS value; and*
- (b) hardness, pH or other water quality parameters that affect the bioavailability of metals.*

The EQS values in Annex 1 part A of the Directive 2008/105/EC do not take account of natural background concentrations. For this reason, a correction for the natural background concentration can be carried out in the monitoring program where, at water body level, WFD standard cannot be met.

This means that a tiered approach is effectively followed; i.e. when WFD standards cannot be met at a water body level a correction may be carried out for natural background concentration, for example by adding the natural background to the limit value (EQS).

When the natural background concentration equals a value of $C_{\text{background-natural}}$ the limit value transfers in $C_{\text{limit}} + C_{\text{background-natural}}$. This means that the maximum allowable increase in concentration at the border of the mixing zone, at distance L, has to meet the following criterion:

$$\Delta C_L \leq C_{\text{limit}} - (C_{\text{upstream}} - C_{\text{background-natural}})$$

It is for the Competent Authority to decide whether or not to correct for biological availability and natural background concentration, and also decide the method for such a correction.

As an example, in the Netherlands, the hardness of water is taken into account to deal with the aspect “bioavailability” for cadmium. In the following table the limit values for cadmium (Cd) are presented.

Substance	EQS Fresh waters	EQS Other waters	MAC Fresh waters	MAC Other waters
Cadmium (CAS No 7440-43-9)		0,2	≤ 0,45	0,45
Class-1: < 40 mg CaCO ₃ /l	≤ 0,08		≤ 0,45	
Class-2: 40 mg CaCO ₃ /l < concentration < 50 mg CaCO ₃ /l	0,08		0,45	
Class-3: 50 mg CaCO ₃ /l < concentration < 100 mg CaCO ₃ /l	0,09		0,6	
Class-4: 100 mg CaCO ₃ /l < concentration < 200 mg CaCO ₃ /l	0,15		0,9	
Class-5: ≥ 200 mg CaCO ₃ /l	0,25		1,5	

It is not yet evident which natural background concentrations should be adopted. In the Netherlands the current approach is to use generic natural background

concentrations. For Cadmium a value of 0.2 ug/l is used in all inland waters and a value of 0.62 ug/l is used for other waters. These values will be incorporated in the Netherlands monitoring program.

Results from the monitoring are evaluated on a yearly basis and if necessary the methodology is adapted.

Information from the existing guidance on heavily modified water bodies can also be of importance for this guidance. In the following text box this information is presented.

Existing guidance on scale & heavily modified water bodies

CIS Guidance No 2 - Water Body Definition

The smaller the granularity of water body definition, the greater is the potential for stringency in environmental protection, depending upon how 2000/60 Article 4 is applied. However, the overall objective in setting water body boundaries is to allow accurate description of status. Issues associated with water body size have already been considered in the CIS process and have been left open for the determination of Member States based on the local specifics. (CIS Guidance No 2 3.3.1)

"Although effects of human activities will always vary no matter what the size of a water body, major changes in the status of surface water should be used to delineate surface water body boundaries as necessary to ensure that the identification of water bodies provides for an accurate description of surface water status. It is clearly possible to progressively subdivide waters into smaller and smaller units that would impose significant logistic burdens. However, it is not possible to define the scale below which subdivision is inappropriate. It is a matter for Member States to decide on the basis of the characteristics of each River Basin District"

The CIS Guidance No 4 on Identification and Designation of Heavily Modified and Artificial Water Bodies considers the cumulative impacts in heavily modified water bodies (HMWB):

5.5.4 3. Identification and description of **significant impacts on hydromorphology** [Annex II No. 1.5]:

The significant impacts on hydromorphology should be further investigated. Both qualitative and quantitative appraisal techniques can be used for assessing impacts on hydromorphology resulting from physical alterations (Examples in the toolbox). The elements examined should include the elements required by the WFD [Annex V No. 1.1: river continuity, hydrological regime, morphological conditions, tidal regime], as far as data are available.

Special attention should be given to cumulative effects of hydromorphological changes. Small-scale hydromorphological changes may not cause extensive hydromorphological impacts on their own, but may have a significant impact when acting together. To assess the significant impacts on hydromorphology, an appropriate scale should be chosen (see also Guidance of the WG 2.113). The following issues in scaling should be considered in assessing impacts and in the identification and designation of HMWB and AWB:

Scaling due to impact assessment changes according to the pressure and impact characteristics, i.e. some pressures have lower thresholds for wide-scale impacts than others;

Scaling may change according to the water body type and ecosystem susceptibility. Spatial and temporal scale (resolution of impact assessment) should be more precise in such water body types and specific ecosystems which are considered susceptible to the pressure.

This makes explicit reference to the need (of a Competent Authority) to consider both qualitative and quantitative appraisal techniques in coming to a decision of the cumulative impacts of HMWB that may be considered to be analogous to cumulative impacts of mixing zones.

This guidance also considers the concept of 'significance'.

6.4.5 What is significant?

It is not considered possible to derive a standard definition for "significant" adverse effect. "Significance" will vary between sectors and will be influenced by the socioeconomic priorities of Member States.

It is possible to give an indication of the difference between "significant adverse effect" and "adverse effect". A significant adverse effect on the specified use should not be small or unnoticeable but should make a notable difference to the use. For example, an effect should not normally be considered significant, where the effect on the specified use is smaller than the normal short-term variability in performance (e.g. output per kilowatt hour, level of flood protection, quantity of drinking water provided). However, the effect would clearly be significant if it compromised the long-term viability of the specified use by significantly reducing its performance. It is important to undertake this assessment at the appropriate scale. Effects can be determined at the level of a water body, a group of water bodies, a region, a RBD or at national scale. The appropriate scale will vary according to the situation and the type of specified use or sector. It will depend on the key spatial characteristics of the adverse effects. In some cases it may be appropriate to consider effects at more than one scale in order to ensure the most appropriate assessment. The starting point will usually be the assessment of local effects (Examples in the toolbox in the guidance).

Again this guidance emphasizes the need to consider scale of the water body and the other characteristics of it in deciding on the significance of impacts – analogous to considering the acceptability of a mixing zone within a water body.

3 Tiered approach

The calculation of the extent of a mixing zone is rather complex and a lot of specific data is needed. In order to focus the resources on those situations that might have a significant impact on water bodies, a tiered approach is proposed. The basic idea behind this approach is that discharges that do not have a significant impact on a water body are deselected. Calculation of the mixing zone is not necessary. In the following paragraphs this tiered approach is explained for the different types of water bodies; rivers, lakes, transitional waters and coastal waters.

3.1 Tier 0

At this tier 0 irrespective of the type of water body, it is checked if the effluent is liable to contain a contaminant of concern. If so, it is checked if the concentration of this contaminant of concern in the effluent is above the EQS for that contaminant. All discharges where no contaminant of concern is present above the EQS are deselected, because this discharge will not lead to an exceedance of the EQS in the water body.

3.2 Tier 1

At tier 1 all discharges where a contaminant of concern is present in a concentration above the EQS are checked if the discharge might have a significant impact on the receiving water body.

3.2.1 Tier 1, rivers

In Tier 1a a significance criterion is used to identify non-significant discharges. The criterion is defined as the proposed allowable increase in concentration after complete mixing due to the discharge, expressed as a percentage of EQS.

In order to check if this criterion is fulfilled one has to calculate the so-called process contribution (PC). This is defined as:

$$\frac{[CoC]_{eff} \times Q_{eff}}{(Q_{river} + Q_{eff})} = PC$$

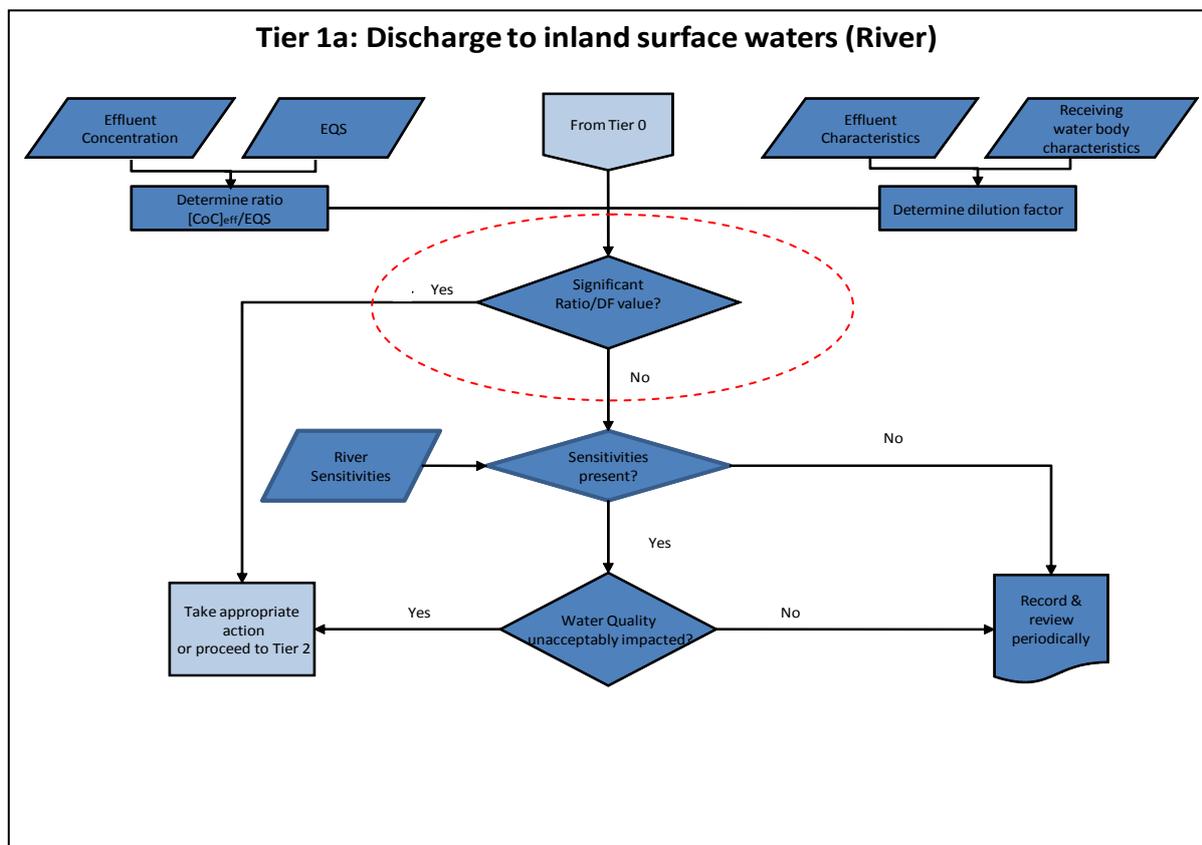
In the next step, the PC as a percentage of the EQS needs to be checked with the proposed allowable increase.

$$\frac{PC}{EQS} \times 100\% = \text{relative - increase}$$

If the increase is below the significance criterion as shown in table 8.0 of the report, this discharge is deselected if there are no sensitivities present in the vicinity of the point of discharge.

In the text below an underpinning of the proposed allowable increase is given.

For consistency the criterion chosen must ensure that any discharges eliminated in Tier 1 (and therefore not assessed in the subsequent tiers) would have met the criteria for Tier 2¹. We have therefore tested the threshold values using the Discharge Test for different water types. Mixing characteristics depend upon the flow of the water body, dimensions of the water body and bottom roughness of the water body amongst other factors.



For the assessments the following starting point were used:

- Calculations used an assumed upstream concentration of $0,5 \cdot EQS^2$;
- In the calculated example an EQS concentration of 3 ug/l and a MAC concentration of 9 ug/l was assumed;
- For fresh waters the assessment used Q_{90} net flows³ for the water body;

¹ This means that discharges have to meet the criteria of the MAC mixing zone at $0,25 \cdot$ width of the water body (max 25 m) and the criteria of the EQS-mixing zone at $10 \cdot$ width of the water body (max 1000m) of the discharge test

² At a water body or water basin numerous dischargers can be located. As a consequence dischargers at the end of the water body or water basin are confronted with elevated (upstream) concentrations. For example for a river like the river Rhine the number of significant discharges can increase to more than 100. Besides significant discharges also discharges, which are ruled out in TIER 1, can contribute to the upstream concentrations.

³ The flow which is exceeded during 90% of the time in a year

- For tidal waters the EQS assessment used Q_{90} net flows¹ for the water body and the average tidal flow corresponding with the Q_{50} net flow (both net flow and tidal flow were used for calculation accumulation and tidal flow was used for calculating plume mixing).
- For tidal waters the MAC assessment used Q_{90} tidal flow⁴ (for calculating plume mixing).

In Table 1 the results of assessment for fresh waters (rivers and canals) are presented. Changing the effluent flow or concentration values allows the load of the discharge to be varied as well. Two scenarios have been worked out, a low effluent-flow scenario ($0.25 \cdot \text{flow-river}/3600$) combined with a high effluent concentration⁵ and a scenario with a high effluent-flow ($5 \cdot \text{flow-river}/3600$) and low effluent concentration⁶.

The calculations show that it is the low-effluent-flow scenarios that are the most critical. In this case the MAC mixing zone is often the limiting factor. As a consequence the relative influence of upstream concentrations decreases compared to situations where the EQS-mixing zone is limiting (ratio $C_{\text{upstream}}/\text{MAC} < \text{ratio } C_{\text{upstream}}/\text{EQS}$). In case of the low-effluent concentration scenario the EQS can also be limiting. The high-effluent concentration scenario is the most stringent. For these reasons the results of this scenario are taken up in Table 1,

Table 1 Allowable increase of concentration after complete mixing for different fresh water types

watertype:	flow Q_{90}	width	depth	velocity	allowable increase of concentration after complete mixing (% EQS) ¹⁾	allowed number of (extra) comparable discharges ²⁾	allowed discharge
	[m ³ /s]	[m]	[m]	[ms/]			[kg/y]
rivers:							
small river/creek	1	10	1,5	0,067	7,9	6	7,5
big river	250	125	3,8	0,53	3,8	13	898,8
very big river	1200	400	4	0,75	1,2	42	1362,4
Canals:							
small	2	30	2	0,035	8	6	15,1
moderate	20	100	5,7	0,035	6	8	113,5
big	40	200	6	0,033	2,5	20	94,6
very big canal	100	300	15	0,022	1,3	38	123,0

¹⁾ the allowed discharge resulting in an increase of concentration expressed as % of EQS after complete mixing which can meet both MAC and EQS criteria
²⁾ number of (extra) discharges of the same magnitude which can be allowed without exceeding MAC or EQS criteria at water body or water basin level

where it can be shown that big rivers and canals allow the lowest percentages of increase of concentration (% of EQS) after complete mixing: 1.2 % for very big rivers and 1.3 % for very big canals. In the context of achieving WFD goals on a water body or basin scale it must be recognised that, in general, the number of discharges located on larger waters will be much higher than the number located on smaller waters.

⁴ The flow which is exceeded during 90% of the tidal period

⁵ The maximum effluent concentration where mixing zone criteria can be met, using an effluent flow of $0,25 \cdot \text{flow-river}/3600$ as a starting point

⁶ The effluent concentration where mixing zone criteria can be met, using an effluent flow of $5 \cdot \text{flow-river}/3600$ as a starting point

For tidal water a similar assessment has been carried out, with the results presented in Table 2.

Table 2 Allowable increase of concentration after complete mixing for different tidal rivers

watertype:	width	depth	velocity (average)	input for EQS-mixing zone			input for MAC- mixing zone	allowable increase of conc. after compl. mixing (% EQS) ³⁾	allowed number of (extra) comparable discharges	allowed discharge [kg/y]
				Q ₉₀ ¹⁾ flood	Q ₉₀ ebb	Q ₉₀ nett	Q ₉₀ ²⁾ flood			
	[m]	[m]	[m/s]	[m ³ /s]	[m ³ /s]	[m ³ /s]	[m ³ /s]			
<i>tidal rivers:</i>										
very big (Nieuwe Waterweg)	400	15	0,63	2710	4600	950	400	0,5	100	449,39
big (Nieuwe -Maas)	400	12	0,71	1680	2400	360	225	0,7	71	238,41
moderate (Amer)	300	6	0,10	103	241	70	30	4,8	10	317,88
small (Lek)	300	7	0,28	570	620	25	75	4,2	12	99,34

¹⁾ the flow wich is exceeded during 90% of the time
²⁾ The tidal flow wich is exceeded during 90% of the time

Table 2 shows that in general the allowed increase in concentration after complete mixing in tidal waters is smaller than the allowable increase in concentration for fresh waters. This is caused by the accumulation due to tidal movement.

For both tidal rivers and fresh water rivers the allowable increase can be related to the net flow of the water body. Table 3 shows an approach for the allowable increase after complete mixing for rivers (fresh waters and tidal rivers) and canals. A separate approach for canals and rivers has been set out as the range of flows for canals differs strongly from those for rivers. In addition the calculated increase in concentration for canals in the range of flows up to 100 m³/s differs from the calculated results for rivers.

Table 3 Proposed allowable increase in concentration after complete mixing for different water types, which can meet criteria for MAC- and EQS mixing zone.

Water types:	Net flow (Q ₉₀ -flow) [m ³ /s]	Proposed allowable increase in concentration after complete mixing as % EQS ¹⁾²⁾³⁾
Fresh water rivers and tidal rivers		
Small	≤ 100	4
Medium	100 < flow ≤ 300	1
Large	> 300	0,5
Canals		
Small	≤ 10	6
Medium	10 < flow ≤ 40	2,5
Large	> 40	1

¹⁾ based on net flow

²⁾ if increase in concentration after complete mixing exceeds the percentage taken up in Table 3 further assessment in Tier 2 or further is necessary.

³⁾ Tier 1 is the first filter in the assessment to discriminate between non-significant discharges, which can always meet the criteria in the discharge test in Tier 2, and other discharges. Criteria in a filter may not lead to a situation where discharges are ruled out in Tier 1, but when assessed in Tier 2 this would lead to a conclusion that discharges cannot meet the criteria of Tier 2 (discharge test). For this reason a worst-case approach seems to be appropriate.

The material presented in Table 3 is based on the criteria of the discharge test using the option ‘existing discharges’ (Tier 2). For big fresh water rivers the lower result for tidal rivers is used. In general the value calculated for to the upper flow-range is used as allowable increase in concentration after complete mixing for whole flow-range considered. For the discharges a high concentration scenario is used. As a consequence criteria for the MAC mixing zone will be limiting, resulting in a more stringent approach than in situations where criteria for the EQS mixing zone are limiting. Thus the proposal in Table 3 provides the worst-case approach. In the case of a new discharge situation where WFD criteria cannot be met at water body or water basin level due discharges originating from point sources the option “reduced discharges” of the Discharge Test should be selected to reduce the size of the EQS mixing zone. In this way the spreadsheet can be used as a controlling tool in order to reach the WFD goals. It has to be realized, that as a consequence criteria derived in Tier 1 will change as well. As a consequence other (smaller) discharges can be taken into consideration as well for identifying mixing zones.

In Tables 1-3 the allowable increase in concentration after complete mixing is worked out in detail for different water types. The question remains whether specification to this extent is necessary in Tier 1. In fact the possible options are:

- Detailed approach: separate criteria belonging to specific water types and corresponding flows (see Tables 1 and 2);
- An intermediate option (see Table 3);
- A simple practical more generic approach with a stronger emphasis on the worst-case characteristics of such an approach (see Table 4).

The proposal presented in Table 3 can also have potential consequences for the discussion concerning the ‘no deterioration principle’. Although the ‘no deterioration principle’ is not assessed in Tier 2, the result of Tier 1 criteria used to identify non-significant discharges can affect choices to be made for the methodology on how to deal the ‘no deterioration principle’. However the proposed criteria for big canals and rivers will probably not jeopardise the ‘no deterioration principle’.

From practical point of view a simple generic approach may be preferable. Table 4 presents such an approach. It must be recognised that the approach taken must be a worst-case, to ensure that the discharges ruled out in Tier 1 would not lead to exceedence of the criteria for Tier 2. However the consequence of such an approach is that more dischargers in smaller waters would have to be assessed in Tier 2. The drafting group recognised that the selection of this option may lead to a potential increase in workload.

Table 4 Generic approach for the allowable increase in concentration after complete mixing

Classification of water body	Net flow (Q_{50}) [m ³ /s]	Proposed allowable increase in concentration after complete mixing [% EQS]
small	≤ 40	2
moderate	$40 < \text{flow} \leq 300$	1
big	> 300	0,5

3.2.2 Tier 1, lakes

While a generic approach has been provided for rivers and riverine estuaries, a similar approach for lakes is difficult, if not impossible because the circumstances may be unique to that particular water body. For rivers the allowable increase of concentration after complete mixing, expressed as % of EQS, is related to the river flow. In the case of lakes the net flow originating from rivers or channels can be zero or very small. In stagnant situations rainfall during a year can contribute to the refreshment of the water. This is important when determining the increase of background concentrations in lakes.

Because of the specific dimensions of lakes (relative large width) the flow velocity due to rivers or channels (if present) flowing to and from the lake is normally very low resulting in relatively poor mixing characteristics. On the other hand local wind driven flows can stimulate mixing. This can vary from location to location. The residence time of substances discharged may be very long due to these low flows. In addition factors such as partition between suspended particulate matters and the water phase, degradation, evaporation etc. become much more important and may be decisive for the assessment. These aspects are not taken into account in Tier 1 and 2, and thus such aspects have to be dealt with in Tier 3.

Where there is no flow or rainfall (the ultimate worst-case scenario) the effluent concentration thus has to meet EQS because in theory the concentration reaches EQS due to lack of dilution by other streams, not taking into account processes such as partition, degradation and evaporation.

Where the flow (and flow velocity) in a lake can be calculated, the location of the discharge relative to such flow is important. The use of an average flow based on a mass balance here can be misleading because the actual mixing calculated can easily be either overestimated or underestimated.

To assess whether or not a discharge is acceptable the (initial) mixing characteristics of a discharge must be identified. Simple Tier 1 criteria, as derived for rivers, cannot be derived in the same way for lakes. Thus it is difficult, if not impossible, to identify simple criteria for lakes in Tier 1.

One of the most determining factors in this context is the type of initial mixing. Two types of mixing can be identified PLUME-mixing and JET-mixing. Mixing in the near vicinity of the point of discharge (the first m) can be described by either jet-mixing or plume-mixing. The mixing pattern with the highest calculated mixing-factor is used to describe the mixing in the first few m from the point of discharge.

A relative simple tool to identify initial mixing is the discharge test (TIER 2). Difference between either PLUME- or JET- mixing can result in a significant difference in initial mixing (greater than a factor of 10!). In specific cases of discharges at lakes where mixing is determined by PLUME-mixing, the MAC mixing zone is often limiting, while for JET-mixing, the AA-EQS mixing zone is usually limiting.

Dimensions of the effluent pipe and the flow of discharge are determining the discharge-velocity and are together with the flow of the water body decisive whether the initial mixing will be JET or PLUME mixing. In order to determine whether or not criteria can be met, information concerning rain fall, flows of other water bodies, flowing to and from the lake has to be available, the flow of the discharge and the dimensions of the effluent pipe has to be available. This means that relatively much information is needed to assess whether or not the criteria in Tier 1 (if available) can be met. From perspective of accuracy and simplicity doing the discharge test in Tier 2 as a first assessment, seems to be the most appropriate for lakes.

3.2.3 Tier 1, large estuaries and coastal waters

An approach similar to that used for rivers and riverine estuaries could also be established for other water types such as large estuaries or coastal waters. At the time of writing this area of work remains incomplete. It may thus require consideration at Tier 2 or 3.

3.2.4 Tier 1, harbours

Many factors determine the mixing pattern in harbours. Simple generic criteria for harbours cannot be given and it is not normally possible to provide a Tier 1 approach that will work in all cases but harbours are discussed in more detail in Annex 5. The net flow in harbours, as in lakes, can be very low and stagnant situations can develop. In tidal harbours eddy currents and exchange arising from density differences can occur. The presence of net flow mixing also depends on the size of the harbour, the location of the discharge and the presence of other discharges. Detailed information is needed to identify whether or not a discharge in a harbour is acceptable. For such an assessment the approach of competent authorities towards harbours⁷ in relation to the rest of the water body can also be an important factor.

A reliable assessment for harbours requires an estimate of the mixing zone to be calculated, and this may be done by using the updated Discharge Test⁸ in Tier 2 or by using a more complex model in Tier 3.

3.3 Tier 2 Assessment of mixing zone

At Tier 2 the dimensions of the mixing zone must be estimated to judge whether a discharge is acceptable. This requires an assessment using simple computation of the size of the mixing zone at Tier 2. In this paragraph methods to assess the mixing zone in Tiers 2 are described.

⁷ The best way to deal with harbours may not always be immediately evident. Sometimes the dimensions of the harbours can be used to provide the boundaries of the mixing zone (for example heat discharges), but it is important in such cases to avoid acute toxic effects. Therefore the dimensions of the MAC-mixing zone may be relevant.

⁸ An update of discharge test, as distributed in December 2009, will be available by internet in spring 2010. In this version mixing zones in (tidal and fresh water) harbours can be calculated as well mixing zones at coastal waters, open sea and (tidal) riverine estuaries. This is an open free version.

3.3.1 Tier 2, freshwater rivers

A simple approach for dilution as a function of the distance from the point of discharge can be derived from the Fischer equations, the most important of which are given below. An important limiting condition is that the flow of the effluent is negligible to the flow of the water body.

$$\varphi(x, y) = \frac{W}{a \cdot u \cdot \sqrt{\pi \cdot K_y \cdot \frac{x}{u}}} \cdot \sum_{n=-\infty}^{n=\infty} \exp \left[-\frac{(y - 2 \cdot n \cdot B)^2}{4 \cdot K_y \cdot \frac{x}{u}} \right] \quad [1]$$

At short distance ($X \leq L$) from the point of discharge the concentration at the riverbank ($y=0$) only the situation $n=0$ contributes to the concentration, for other values of n the e-power-function approaches a zero value. The equation changes in:

$$\varphi(L, 0) = \frac{W}{a \cdot u \cdot \sqrt{\pi \cdot K_y \cdot \frac{L}{u}}} \quad [2]$$

W = emitted load of a substance (g/s);

a = depth of the receiving surface water [m];

u = flow rate of the surface water (m/s);

B = width of the receiving surface water [m];

K_y = transversal dispersion coefficient in y direction

X = distance to the point of discharge (maximum L) [m];

$\varphi(x, y)$ = concentration at a distance x from the point of discharge and distance y from the bank of the receiving surface water.

With:

$$K_y = \max(0,6 \cdot u \cdot a \cdot \sqrt{10} / C_{chezy}; 0,001);$$

$$C_{chezy} = 18 \cdot \log((12 \cdot B \cdot a) / (B + 2 \cdot a) / k)$$

k = bottom roughness. In the Netherlands for rivers a value of 0.05 is used and for canals and lakes a value of 0.1 is used. In the discharge test, an option has been built in to calculate the bottom roughness for several water types.

With $W = Q \cdot \varphi_0$ where φ_0 is the concentration at the discharge point ($x=0$) and Q the flow of the emitted effluent the equation changes in:

$$\varphi(x, 0) = \frac{Q \cdot \varphi_0}{a \cdot \sqrt{\pi \cdot K_y \cdot u \cdot x}} \quad [3]$$

The dilution factor is given by $\varphi_0 / \varphi(x, 0)$:

$$M_x^{2D-plume} = \frac{\varphi_0}{\varphi(x, 0)} = \frac{a \cdot \sqrt{\pi \cdot K_y \cdot u \cdot x}}{Q} \quad [4]$$

The increase in concentration ΔC at distance L , as a consequence of the discharge is given by $\Delta C_L = C_{effluent} / M_x^{2D-plume}$

In Figure 1 an example of the dilution factor, the distribution pattern and concentration as a function of the distance to the point discharge, derived from the Fischer equations, is shown.

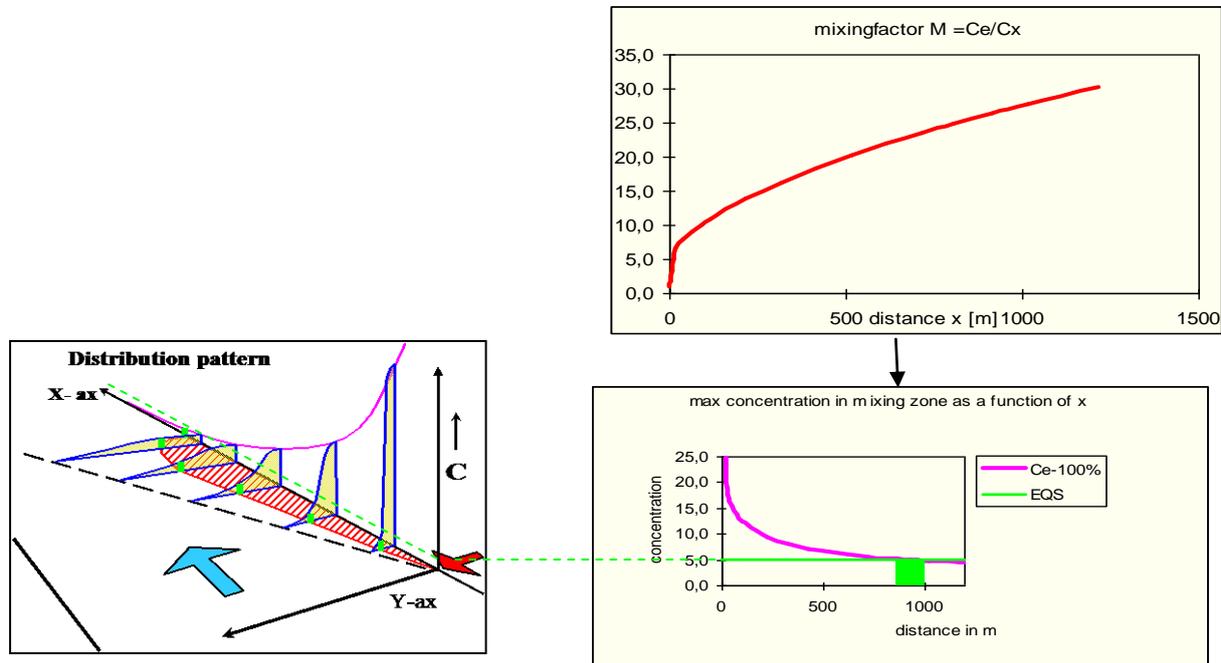


Fig. 1 Dilution, distribution pattern and concentration as a function of the distance to the discharge point.

A good knowledge of mixing in the vicinity of the discharge is important to evaluate whether or not acute toxic levels may be exceeded. Different models can be used to describe mixing in this area of the water system, such as Cormix, 3D models (non hydrostatic) or more simple approaches based on the Fischer equations. A simple approach based on the Fischer equations is described below:

For (initial) mixing adjacent to the point of discharge jet-mixing or plume-mixing may apply:

$$M_x^{3D-jet} = \frac{x}{5,6 * l_Q} = \frac{x}{5,6 * D * \sqrt{\pi/4}} \quad (\text{JET-mixing}) \quad \text{and} \quad [5]$$

$$M_x^{3D-plume} = \frac{2 * \pi * x * \sqrt{K_y * K_z}}{Q} \quad (\text{PLUME-mixing}) \quad [6]$$

Typical values for K_y are 0.01-0.015 (canals/lakes) and 0.01-0.05 (rivers). Typical values used for K_z are 0.001-0.01.

However at a certain distance downstream of the discharge point the 3D-equations (Jet or plume) can be replaced by 2D-plume equation for mixing [4]. For plume-mixing the distance where 3D-may be replaced by 2D-plume-mixing is given by

$$x = \frac{a^2 \cdot u}{4 \cdot \pi \cdot K_z} \quad [7]$$

$$x_{\max}^{\text{jet}} = \frac{7 \cdot \ell_Q \cdot w_0}{2 \cdot u} \quad \text{with } w_0 = \text{the maximum velocity in the effluent stream.} \quad [8]$$

It should be noted that when the velocity in the effluent stream increases the distance x (where jet-mixing dominates the mixing pattern), increases as well.

In situations where jet mixing dominates in the near vicinity of the discharge point a correction has to be made for the 2D-plume mixing behaviour. The distance x has to be corrected with a value 'x_{move}' and equation [4], describing 2D-plume mixing, changes in:

$$M_x^{2D\text{-plume}} = \frac{\varphi_0}{\varphi(x,0)} = \frac{a \cdot \sqrt{\pi \cdot K_y \cdot u \cdot (x + x_{\text{move}})}}{Q} \quad [9]$$

The distance 'x_{move}' is given by:

$$x_{\text{move}} = \frac{\left(\frac{x_{\max}^{\text{jet}} \cdot Q}{5,6 \cdot a \cdot \ell_Q}\right)^2}{\pi \cdot K_y \cdot u} - x_{\max}^{\text{jet}} \quad [10]$$

Factors dominating the initial mixing are:

- the flow rate of the effluent stream;
- the flow rate of the surface water;
- the horizontal position of the discharge point (at the bank of the water body or at a certain distance from the bank of the water body);
- the vertical position of the discharge point (at the surface of the water or at medium depth or at the bottom).

Furthermore bed "roughness" plays a role in mixing and detailed data may be required for complex 3D models to assess the mixing accurately, but more often coefficients, based on the general bottom characteristics, will be adequate.

In general the dilution factor at the maximum length (L) of the mixing zone is given by equation [4].

3.3.1.1 Dealing with specific situations

Protection of Migratory Species

In situations where the receiving water body has a narrow channel or may be subject to low flows there is a risk that the mixing zone will occupy a major part of the cross-

section which can have adverse consequences for the passage of migratory species.

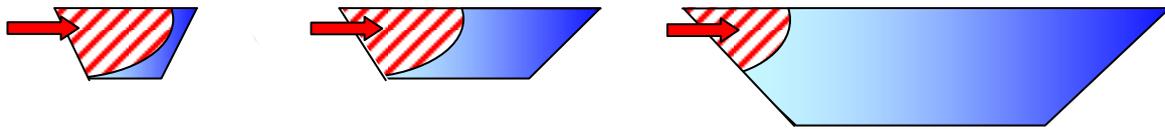


Fig. 17.2 Migration: serious problem

migration may be affected

migration: no problem

The extent of exceedence of concentration with potential to impact on migration success is shown by the striped sections in Figure 2 above

To prevent such problems the width of the mixing zone may be limited. In some countries a limit is placed upon the proportion of the channel width occupied by the mixing zone, for example in the Netherlands the mixing zone is limited to 25% of the cross-section of the water body. In the discharge test criteria are chosen in such a way that when mixing zone criteria can be met in streaming water bodies at distance L , the cross section taken by in the mixing zone, bounded by EQS, (in general) will not be greater than 25%.

Sensitive situations

Where shellfisheries, drinking water abstractions, or other areas of special ecological significance are located in the vicinity of the discharge point, it is important to ensure that these form part of the overall appraisal process when determining the mixing zone. The distance between such features and the discharge point can be of great importance, especially when the distance is less than L or 10 times the width of the water body.

3.3.2 Tier 2, riverine estuaries

The approach for mixing zones in tidal waters, i.e. riverine estuaries, has been developed from that used for fresh waters. The situation in tidal waters may often be more complex as the boundaries of the water body are less easily defined and the flow direction can change, depending on the tide. This may affect the positioning of the mixing zone. In such situations the mixing zone may lie downstream during the ebb period and upstream during the flood period (see Figure 3).

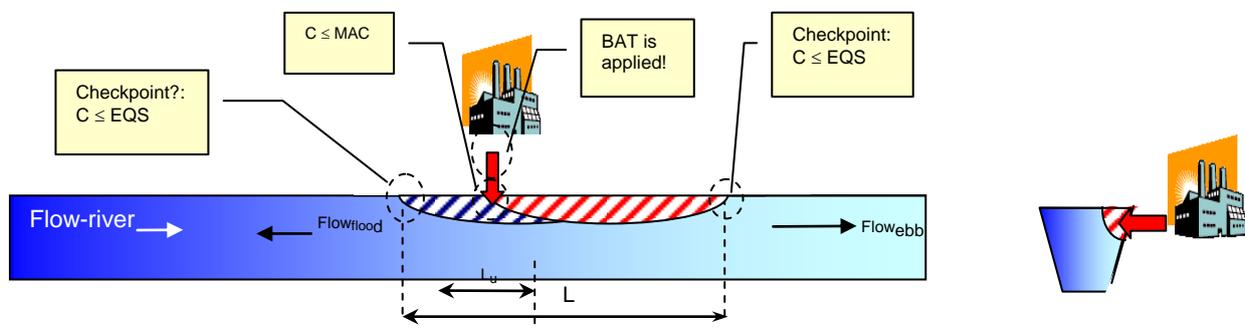


Figure 3 Mixing zones in tidal flowing waters

Using the same starting point as for fresh waters a maximum length of mixing zone may be proposed. This could be a distance of $10 \cdot B$ (width of the water body) with a maximum length of L m⁹. The position of the mixing zone depends on the ratio between the total flood volume (Q_{flood}) and the sum of the flood volume and the total net volume of the river flow during the tidal period. The maximum length of the mixing zone upstream (L_u) is given by the following equation:

$$L_u = (Q_{\text{flood}} / (Q_{\text{ebb}} + T \cdot Q_{\text{netto}})) \cdot L / 2 \quad [11]$$

With:

- Q_{flood} = the total tidal volume during the flood-period;
- Q_{ebb} = the total tidal volume during the ebb-period ($= Q_{\text{flood}} + T \cdot Q_{\text{netto}}$);
- L = total length of the mixing zone ($10 \cdot B$ (width of the water body) with a maximum of L m);
- L_u = length of the mixing zone upstream of the discharge point;

The length of the mixing zone downstream is given by $L_d = L - L_u$

Equation [11] can be used as a general description of the position of the mixing zone for fresh waters as well as salt waters. When the flood volume approaches zero $L_u = 0 \rightarrow L_d = L$ (the fresh water situation). For the situation where the net river flow approaches zero the equation changes in that: $L_u = L_d = L/2$. In this case the discharge point lies in the middle of the mixing zone, with boundaries at $L/2$ m upstream en $L/2$ m downstream. This approach helps smooth the way the transition of one water body, i.e. characterized as tidal water to another water body, characterized differently, is effected.

While more complex, the general approach followed does not differ greatly from that in fresh waters. The first step is to evaluate whether or not the emission leads to a problem in terms of water quality using a simple assessment to calculate concentrations in the mixing zone shown below.

One important aspect when describing mixing in tidal areas is the change of flow direction due to tidal movements. As a consequence, accumulation of the discharged substance can occur because water, already influenced by the discharge, passes the discharge point more than once due to the change of flow direction. In this way the background concentration can increase. This effect must be taken into account. The number of tidal movements the 'influenced water' needs to leave the area where it can be influenced by the discharge can be given by the following equation:

$$n = \frac{Q_v}{Q_n} \quad [12]$$

With n = the number of tidal movements and Q_n = the net river flow [m³/s] and Q_v = the flood flow [m³/s]. The number of tidal movements (n) is rounded off to above in whole numbers.

The mixing factor (complete mixing) is given by:

⁹ In the Netherlands the maximum length for tidal waters is similar to the maximum length of the mixing zone in fresh waters and equals a distance of 1000 m.

$$M_{tidal} = \frac{Q_v + Q_{effl} * n * 2}{Q_{effl} * n * 2} \quad [13]$$

With this mixing factor the increase of the background concentration can be calculated.

$$\Delta C_{background} = C_{effluent} / M_{tidal} \quad [14]$$

The increase in concentration ΔC as a consequence of the discharge at the checkpoint (L) is given by:

$$\Delta C_L = \Delta C_{background} + C_{effl} / M = C_{effluent} / M_{tidal} + C_{effl} / M_x^{2D-plume} \quad [15]$$

with C_{effl} = effluent concentration.

Due to tidal movement the pathway of water 'influenced by the discharge' may be relatively long before it leaves the 'area of influence'. As a consequence the plume broadens. This raises the question whether or not the mixing zone will occupy a major part of the cross-section of the water body. However when the distance covered increases the mixing-factor increases as well. The cross-section of the mixing zone bounded by EQS in tidal waters does not reach 25% cross-section of the water body when EQS is met at checkpoint L. In cases where substances with a low ratio of MAC/EQS are discharged the MAC assessment is often limiting. When a discharge can meet the MAC criteria in the near vicinity of the point discharge, the maximum cross-section of the EQS-mixing zone will be (much) lower than 25%.

Stratification can occur due to differences in density and/or temperature. When the emission takes place in only one layer and the densities of the effluent and layer are comparable, an approach can be followed where mixing is described only in that layer. As a consequence the depth (a) has to be adapted. However because mixing often also affects another layer this approach can be seen as a worst-case approach. If an emission complies with the EQS using this approach a further evaluation is not necessary.

If the 'worst-case' approach identifies a potential problem then a more complex approach can be followed. For example a 3D or Cormix model may be used to evaluate the emission.

Further consideration of the approach in specific industrial areas, such as harbours or ports, is covered later in this annex.

3.3.3 Tier 2, lakes

In this paragraph methods to assess the mixing zone used in Tiers 2 are described. In Tier 2 steps are described to assess the mixing zone using simple computations of the size of the mixing zone.

The same instrument used for rivers can be used for lakes. However the definition of the dimensions of the mixing zone can differ from the definition used for rivers (see section 12). Constants used in equation [5] for calculating the mixing factor, can differ from the constants used for rivers.

For lakes a typical value of K_y varies from 0.01-0.015 and for rivers this value varies from 0.01-0.05.

A major difference between lakes and rivers is the streaming velocity. In general lakes are much less free-flowing than rivers. The mixing zone can be represented by a half a circle. In most cases the width of a lake is large. Making the length of the mixing zone proportional to the dimensions of the water body, i.e. the area of the water body, length and width of the water body, seems to be logical¹⁰

3.3.4 Tier 2 - Large estuaries and coastal waters

In this annex methods to assess the mixing zone used in Tier 2 are described. In Tier 2 steps are described to assess the mixing zone using simple computations.

Although the streaming velocity in large estuaries is usually not very high the formulas derived for tidal riverine estuaries can be used for simple calculation of the mixing as a function of the distance to the point of discharge. In this case the influence of tidal movement and the accumulation due to tidal movement can be taken into account.

For emissions at sea (open sea and along the shoreline) the adoption of an approach, which equates the mixing zone to the dimensions of the water body, cannot be used. This would result in large volumes where EQS is exceeded. In both situations the width (B) is not limiting and the length of the mixing always is L. In the Netherlands an approach based upon maximum volume is used for calculating the extent of the mixing zones in open sea and emissions along the shoreline.

For emissions along the shoreline the total length of the mixing zone is L m. Equation [11] leads to a mixing zone positioned between a point L/2 m downstream and a point L/2 m upstream of the point of discharge¹¹. When using a maximum length of 1000 m for the mixing zone this leads to a mixing zone defined as half a circle with a radius of 500 m. For the average depth at the shoreline a value of 5 m is assumed. This results in a maximum volume of the mixing zone:

$$V_{\text{mixing-zone}} = \pi / 2 * (500)^2 * 5 = 1,96 * 10^6 \quad [\text{m}^3] \quad [16]$$

¹⁰ In the Netherlands the length of the mixing zone for lakes is proportional to the dimensions of the water body. The length L of the mixing zone is given by the following equation: $L_{\text{mixingzone}} = \frac{\sqrt{A}}{4}$

¹¹ In the Netherlands a distance of 1000 m is used as maximum length L of the mixing zone for large waters, with a width of 100m or more.

For emissions in the open sea this same maximum volume approach can be used. In such circumstances the depth of the water can increase by orders of magnitude and the mixing maybe extensive due intensive currents. An approach only based on meeting EQS outside the mixing zone and assuming vertical mixing, without setting limits to maximum volume of the mixing zone results in a mixing zone comprising an enormous volume of water. When applying the combined approach, BAT would normally be sufficient.

3.3.5 Tier 2 - Harbours

In Tier 2 steps are described to assess the mixing zone using simple computations of the size of the mixing zone.

In this appendix methods to assess the mixing zone used in Tier 2 are described.

In tidal harbours we must establish whether stratification can occur. In many tidal harbours this will happen but considering stratification and density differences the component flows can be identified. This can affect the mixing very markedly. The Mampec-Silthar model gives equations for the tidal and horizontal exchange between harbour and the water body and the exchange due to density differences.

Tidal exchange can be given by:

$$Q_t = (A * T_d) / T \quad [17]$$

With:

Q_t = tidal exchange (m³/s);
 A = surface of the harbour [m²];
 T_d = tidal difference [m];
 T = tidal period [s].

Horizontal exchange can be given by the equation of Graaf and Rainalda:

$$Q_h = 0.02 * a * B_h * V_{\max-riv} / \pi * Q_{ah} - 0.2 * Q_t \quad [18]$$

With:

Q_h = horizontal exchange [m³/s];
 A = depth harbour [m];
 $V_{\max-riv}$ = maximum flow rate of water body [m/s];
 B_h = width of the mouth of the harbour [m];
 Q_{ah} = average flow harbour [m³/s].

The exchange due to density differences can be given by:

$$Q_{\Delta\rho} = 0.7 * (0.125 * a * B_h * (\Delta\rho / \rho * 9.81 * a)^{0.5} - Q_t \quad [19]$$

With:

$Q_{\Delta\rho}$ = flow due to density differences [m³/s];
 $\Delta\rho$ = Density difference [kg/m³];

ρ = density [kg/m³];
 Q_t = the tidal flow in the harbour;
 a = the depth of the harbour.

The total exchange is given by

$$Q_{\text{tot}} = Q_t + Q_h + Q_{\Delta\rho} \quad [20]$$

Equation [20] gives information about the total exchange between the harbour and the water body. In tidal harbours, the gradual accumulation of background concentrations [see equation 13] has to be taken into account. This information can be used as input for the calculation of the mixing factor as a function of the distance to the point of discharge based on the plume-mixing equation [4 and 9].

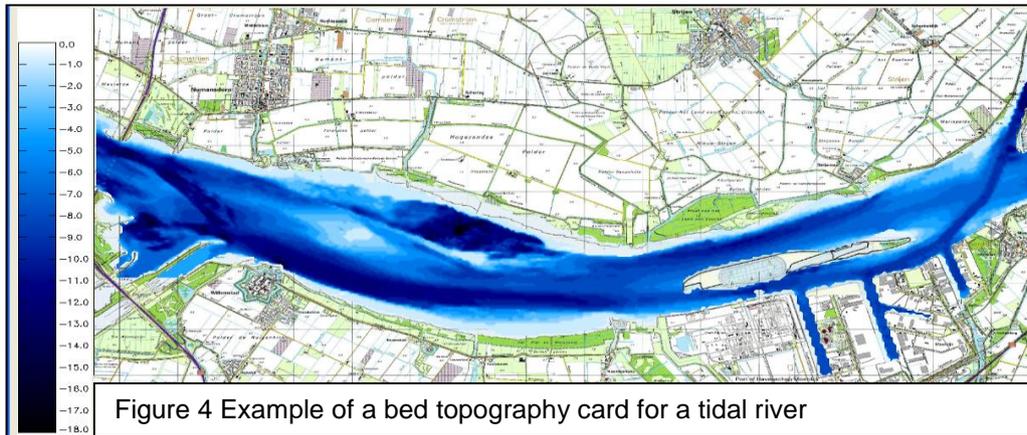
The impact of mixing zones on migratory species may require consideration in harbours but this will depend upon the type of emission and will usually only be required where the harbour(s) are connected to rivers or canals that support such migratory species. Fish are often unable to detect the presence of many polluting substances in their environment and thus as a consequence they do not necessarily change their routes or pathways. This is, however, not the case for all emissions, e.g. emissions of heat or acids which can cause an impact to limit their migrations. In such circumstances the same approach as used in fresh waters may be adopted.

3.4 Tier 3 Complex assessment

When simple assessment of the mixing zone results in an exceedence of EQS at checkpoint L, two options are possible:

- Take action to reduce the size of the mixing zone;
- Assess the mixing zone using complex models;

Different mathematical models, varying from complex 3-dimensional or empirical models (CORMIX) to more simple 2-dimensional approaches based on the Fisher equations, may be used to calculate the dilution of the discharged effluent as a function of the distance from the discharge point. The choice of approach depends on the individual situation. Clearly complex 3D models will require extensive input data to describe the situation in a reliable way (bed topography, tidal and net river flow, interactions with tributaries etc.). In order to model complex situations such as that shown in Figure 4 this data requirement may be demanding with data broken down into a network of individual small area units or grids, i.e. the bed topography, has to be gathered grid by grid as input for the calculations.



The dimensions of the model-area are important, as at the boundary of the model-area the influence of the emission has to be negligible. In modeling terms the area in the vicinity of the discharge point is often described in great detail with a fine grid while at a greater distance from the outfall a more general representation may be adequate. More than one model may be needed if the influence of the discharge is not negligible at the boundary of the modeled area. This has consequences for the necessary computer time and costs as modeling in this way can become a complex exercise. The principles described above hold for the modeling of mixing zones in all kinds of waters types, such as rivers, tidal rivers, lakes and estuaries.

In case of tidal waters special attention has to be paid to density differences between the discharge and the receiving surface water, due to differences in salinity or temperature. Also the tidal movement has to be taken into account. These aspects can impact the distribution pattern.

In case of discharges at harbours also others discharges at the harbour have to be taken into account because these can influence the streaming velocity in the harbour. For harbours the effects of ship movements may also be a significant factor in determining the size and location of mixing zones.

3.5 Tier 4

For the purposes of this guidance 'Investigative Studies' can include a wide range of activities including:

- a) Chemical concentrations (of PS/PHS or other determinands under consideration)
Bathymetry, sediment characteristics, water velocity, water level, dispersion characteristics (e.g. dye tracer studies) (relevant to the set up, calibration and validation of modelling)
- b) Receptor characterisation (focusing on biological aspects of the receiving waters including bed, banks, water column biology as it varies with time within the projected impact zone of the discharge and wider throughout the water body)
- c) Evidence of impairment of receptors (focusing on evidence of extent of change in biology associated with the operation of the discharge – one way of doing

this would be to compare the biology in zones impacted by discharge with that in control zones (which could be the same zone prior to the occurrence of the discharge or could be a valid control zone situated elsewhere)

- d) Literature reviews or new laboratory-based ecotoxicity studies (e.g. for case-specific important receptors for which directly applicable or useful proxy data is not readily available)

Although presented as Tier 4, investigative studies may also contribute in any of Tiers 0-3. If information is available it can be used by the competent authority in reaching a decision and this Guidance is not intended to deter any party from gathering and using relevant information to support this process. As a general rule, guidance should not preclude or discourage the use of site-specific data where an applicant chooses to obtain it, since such data can only improve the database on which regulatory decision-making can be founded. In many cases, the onus may be on the discharger to provide such work, if otherwise the Competent Authority would be minded to regard a proposed extent of EQS exceedence as unacceptable.

4 Experiences in the USA

From INERIS guidance 2007 prepared for DG Env. Working Group E.

In the USA, water quality models are routinely used before granting discharge permits. Models are used to predict future water quality, check compliance with EQS and, if necessary, derive additional emission limit values (Ragas, 2000¹²).

USA is the only country with well-defined recommendations in several guidance documents¹³ for the development of mixing zones and the use of mixing zone models, although these are not mandatory. For the US Clean Water Act, "allocated impact zones" (AIZ) are defined based on mixing zones, but whether to establish a mixing zone policy is a matter of State discretion (US-EPA, 1994¹⁴). Consequently, implementations of mixing zones vary greatly between States, from using sophisticated mixing zone models¹⁵ to just calculating a dilution factor (Ragas, 2000). Anyway, any State policy must be consistent with the Clean Water Act and approved by the Regional EPA administrator.

Water quality criteria apply at the boundary of the allocated impact zone. They can be exceeded inside the allocated impact zones as long as acutely toxic conditions are prevented (see below for the definition of the zone of initial dilution).

The shape should be a "simple configuration that is easy to locate in the body of water and avoids impingement on biologically important areas". Furthermore, "shore hugging plumes should be avoided" (US-EPA, 1994).

¹² Ragas, A. (2000). Uncertainty in Environmental Quality Standards. Doctoral dissertation. University of Nijmegen. http://webdoc.ubn.kun.nl/mono/r/ragas_a/unceineng.pdf

¹³ see: <http://www.epa.gov/waterscience/standards/mixingzone/>

¹⁴ US-EPA. (1994). Water Quality Standards Handbook: Second Edition. US-EPA, Office of Water, Washington, DC. <http://www.epa.gov/waterscience/standards/handbook/>

¹⁵ Application of the CORMIX model is predominantly preferred.

The extent should "be limited to an area or volume as small as practical that will not interfere with the designated uses or with the established community of aquatic life" (US-EPA, 1994).

For streams and rivers, States generally limit mixing zones by widths or cross-sectional areas and allow lengths to be determined on a case by case basis. In the case of lakes, estuaries and coastal waters, some States specify the surface area that can be affected by the discharge (including the underlying water column and benthic area). In the absence of specific mixing zone dimensions, the actual shape and size is typically negotiated on a case-by-case basis (Jirka et al., 1996¹⁶).

The completely mixed conditions are usually defined as the location where the concentrations across a transect of the water body differ by less than 5% (US-EPA, 1991¹⁷). But, in practice, limiting boundaries defined by dimensions equal to the water depth measured horizontally from any point of the discharge installation (i.e. circular shape) are accepted by the US-EPA provided they do not violate other mixing zone restrictions (Jirka et al., 1996).

Indeed, the mixing zone should be placed and dimensioned to prevent adverse impacts to non-motile benthic and sessile organisms, and to protect free-swimming and drifting organisms. Furthermore, the use of mixing zones is not permitted where they may endanger critical areas including ecologically critical habitats (e.g. areas of feeding and breeding, shellfish growing areas, salmonid spawning and rearing, shoreline habitat, mouths of tributaries, shallows) but also drinking water supplies, recreational areas, etc. Denial of mixing zone should be considered when discharge contains bioaccumulative, carcinogenic, mutagenic or teratogenic substances with high level of concern. Also, another consideration for denial is when an effluent is known to attract organisms (e.g. warmer effluent) (Schnurbusch, 2000¹⁸). Also, visible slicks and aesthetic problems should be avoided

In addition to the allocated impact zone, US-EPA defines a smaller zone (the so-called "zone of initial dilution") in the area immediately surrounding the outfall and in which the standards for acute effects can be exceeded. The acute zone of initial dilution is nested inside the chronic allocated impact zone. The concentration at the border of the toxic dilution zone is the water quality standard that prevents acute toxicity, i.e. the "criterion maximum concentration" (CMC) which is quite equivalent to the EU maximum admissible concentration (MAC). The zone of initial dilution must comply with one of the 4 following conditions (Jirka et al., 1996):

- meet the CMC within the pipe itself, or

¹⁶ Jirka, G., Doneker, R. and Hinton, S. (1996). User's manual for Cormix: a hydrodynamic mixing zone model and decision support system for pollutant discharges into surface waters. DeFrees Hydraulics Laboratory School of Civil and Environmental Engineering, Cornell University, Ithaca, New York 14853-3501. <http://www.epa.gov/waterscience/models/cormix/users.pdf>

¹⁷ US-EPA. (1991). Technical Support Document for Water Quality-based Toxics Control. US-EPA, Office of Water, Washington, DC.

¹⁸ Schnurbusch, S. (2000). A mixing zone guidance document prepared for the Oregon department of environmental quality. A project submitted in partial fulfilment of the requirements for the degree of Master of Environmental Management. Portland State University. http://www.epa.gov/waterscience/standards/mixingzone/files/OR_MZ_Guidance.pdf

- meet the CMC within a short distance from the outfall by applying specific geometric restrictions¹⁹, or
- it should be demonstrated that drifting organisms will be exposed to the CMC for less than 1 hour no more than once every 3 years on average, or
- exit velocity must exceed 3 m/s.
-

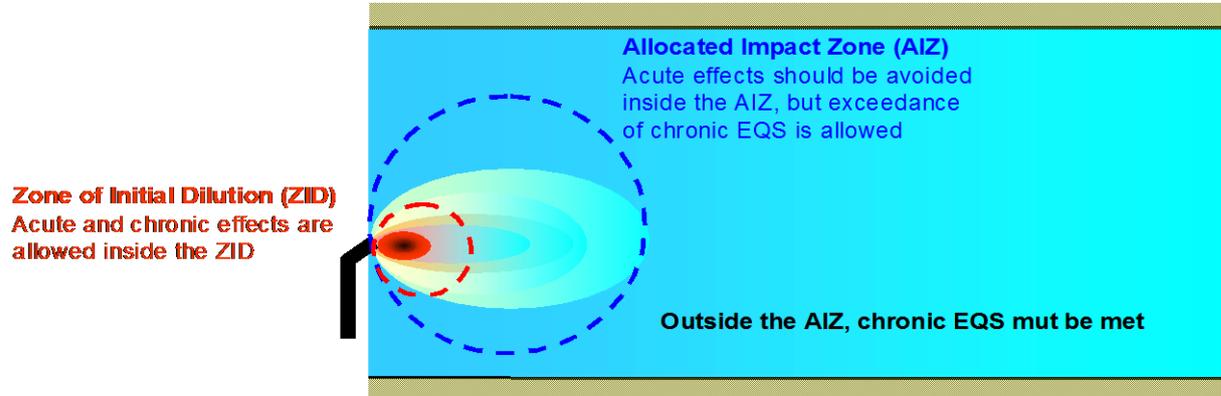


Figure 5: Regulatory mixing zones in the USA

The small red circle represents the Zone of Initial Dilution (ZID); the bigger blue circle represents the Allocated Impact Zone (AIZ)

5. Discharge characteristics

The discharge characteristics influence the effluent trajectory and the degree of mixing in the vicinity of the outfall. Discharge characteristics that favour turbulent mixing will maximise initial dilution. They are related both to the flux characteristics of the discharge (discharge flow rate, discharge velocity and density of the discharged fluid) and to the design of the effluent outfall (outlet diameter, diffuser/port configuration, position and orientation of the flow entering the ambient watercourse)²⁰

The discharged flux is mainly characterised by 3 physical parameters:

- Flow rate. The flow rate of the effluent is defined as the mass of fluid discharged per unit time (mass/time). It is a critical parameter for assessing the level of contamination.
- Velocity. The exit velocity of the effluent is distinct from the flow rate and corresponds to the speed of discharge of the effluent (distance/time). A high

¹⁹ These geometric restrictions should ensure a sufficient dilution under all possible circumstances, including situations of severe bottom interactions and surface interaction:

- meet the CMC within 10% of the distance from the edge of the outfall installation to the edge of the AIZ in any spatial direction,
- meet the CMC within the distance: $50\sqrt{\text{crosssectional area of the discharge outlet}}$
- meet the CMC within distance of 5 times the local water depth in any horizontal directions

²⁰ Schnurbusch, S. (2000). A mixing zone guidance document prepared for the Oregon department of environmental quality. A project submitted in partial fulfilment of the requirements for the degree of Master of Environmental Management. Portland State University.

velocity discharge relative to the ambient velocity will favour turbulent mixing²¹.

- Buoyancy. Buoyancy corresponds to the tendency for the effluent flow to rise (positive buoyancy) or to fall (negative buoyancy). Buoyancy (mass*acceleration/time) is a function of the acceleration due to gravitational forces. It arises from the density difference between the effluent and the receiving water. Since buoyancy depends on this density difference it may vary depending on the environmental conditions (e.g. seasonal variations on temperature may modify the density profiles in the receiving waters).

At the vicinity of the outfall, the physical mixing is principally driven by the entrainment of the ambient water into the discharge jet. No ambient water can be entrained into the area immediately away from the jet outfall. This area is termed the zone of flow establishment (ZOFE) and extends to about 6 jet diameters from the jet orifice. But immediately outside of the ZOFE the entrainment rate is high and turbulent mixing occurs. The faster moving jet causes the ambient water to speed up. The viscous shear between the two fluids causes the ambient water that is entrained into the jet to be replaced by the discharged effluent and vice versa. At the edge of the jet, turbulent eddies carry ambient water into the discharged fluid. The more turbulent the mixing, the faster the dilution will be (Schnurbusch, 2000).

A drifting organism could not be entrained into the ZOFE and therefore would not be introduced to 100% of the effluent. But, due to the entrainment phenomenon, it would likely be entrained into the turbulent mixing area. The exposure time during which the drifting organisms would be trapped inside this turbulent mixing area can be estimated from the entrainment velocity. A rule of thumb is that the entrainment velocity is about 1/10 of the jet velocity (Schnurbusch, 2000). The entrainment velocity is also to be compared with the swimming velocities of fish and their ability to avoid the discharge.

6. Design and construction of outfalls

The design of the effluent outfall may indirectly modify the discharge characteristics:

- The outlet diameter triggers the flux velocity.
- The configuration of the diffusers may also modify the degree of mixing. For example multiport diffusers, made of an arrangement of multiple ports submerged along a diffuser line, are specifically designed to favour a turbulent and more rapid mixing.
- Position of the port. The discharge plume will eventually interact with the boundaries of the receiving environment: surface boundary, intermediate stratification boundaries (pynoclines²²) and the bottom of the water body. A rapid mixing will be favoured if it occurs far from these boundaries. It partly

²¹ For example, the revised US 1991 Technical Support Document for water quality-based toxics control recommends for new discharges a minimum exit velocity of 3 meters per second in order to provide sufficiently rapid mixing (US-EPA, 1991).

²² If there is a large enough density difference between the ambient and the mixed effluent (i.e. high buoyancy) a vertical spreading will occur (i.e. convection motion). A highly buoyant effluent will eventually reach a vertical boundary (e.g. water surface (positive buoyancy), water bottom (negative buoyancy), or pynocline) and then will cause the effluent plume to spread laterally and become thinner (Schnurbusch, 2000).

depends on the elevation of the port above the bottom²³. For example, surface discharges are the least favourable for initial mixing. In particular, surface discharges at the shoreline of a water body may yield to high surface concentrations along the shoreline and induce an impact. Submerged discharges are generally preferable for rapid mixing but they are not necessarily applicable for water bodies of insufficient depth, subjected to periodic dredging or to considerable scour or deposition (US-EPA, 1991). Dilution is generally maximised if the discharge is located at mid-depth. The lateral position of the discharge point is also a potential factor: e.g. if the source is located in the centre of the river the distance for complete mixing is reduced.

- The orientation of the port influences the trajectory of the flow entering the ambient watercourse. By maximising the velocity discontinuity between the discharged fluid and the ambient water it may be possible to cause an intense shearing action and a turbulent mixing.

7. Mandate for Drafting Group on Mixing Zones

This mandate was presented to (and ratified by Water Directors at their Paris meeting on 24-25th November 2008).

<u>Version no.:</u> 2.0	Date: 11 November 2008
<u>Authors:</u> DG ENV, the Netherlands, United Kingdom, France	

Background: On the 17th of June 2008 a second reading agreement between the European Parliament and the Council on the Environmental Quality Standards (EQS) Directive was achieved.

The Council formally approved the text²⁴ and now it is under the legal/linguistic finalisation. The publication in the Official Journal is expected at the end of this year, at the latest. During the last meeting of the WG E (March 2008) on priority substances the need for a detailed guidance document on mixing zones was discussed.

Time table for finalisation:

- Endorsement by the Water Directors during their meeting on 24-25 November 2008.

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I. Introduction

The concept of "**mixing zones**" has been introduced by the new EQS Directive and is a regulatory option to allow concentrations of one or more substances to exceed the relevant EQS in the proximity of outfalls. The compliance of the rest of the body of surface water with those standards must not be affected.

INERIS have already prepared a background document on mixing zones for consideration by WG-E. The purpose of the document was to provide a review based on existing

²³ The buoyancy of the effluent is also an important parameter.

²⁴ <http://register.consilium.europa.eu/pdf/en/08/st10/st10732.en08.pdf> (under legal/linguistic finalisation)

approaches for how Member States can delineate the administrative mixing zone in order to ensure the protection of the aquatic life and human health and ensure compliance for the rest of the water body with the EQS.

II. Objectives

The aim of the Drafting Group is to establish activities on mixing zones in order to support the work of the WG E on Priority Substances and therefore of the Common Implementation Strategy of the WFD 2000/60/EC.

The Drafting Group will focus on the development of a technical guidance document (TGD) for the identification of mixing zones as request of the Article 4(4) of the EQS Directive. The TGD will outline strategies to reduce the extent of the mixing zones. The TGD will be tested using different types of water categories with different hydromorphological characteristics.

III. Organisation

The first meeting took place on the 7th of May in Brussels (DG ENV) in order to discuss the fundamental principles of the way of writing of the guidance. The next meeting held on 22nd - 23rd of September 2008 was organised in Paris by the Ministry of Ecology, Energy, Sustainable Development and Territorial Development from France to discuss the first draft of the Drafting Group's mandate and the content of first draft of the guidance.

The Drafting Group on mixing zones (UK, NL, FR, DK and DG ENV) will be lead by the United Kingdom (John Batty) and co-lead by the Netherlands (Gerrit Niebeek) and DG ENV (Madalina David).

Technical meetings of the Drafting Group will be decided on an *ad hoc* basis or scheduled in advance.

The leader of the group will present the updates at the WG E meetings. In the next step the progress reports will be presented to the SCG, Water Directors and Article 21 Committee.

IV. Participants

A list of participants will be established for the active contribution to the Drafting Group. On the other hand all the members of the WG E on Priority substances are invited to comment on draft guidance/reports.

V. Contact person/s

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VI. Links with other activities

The Drafting Group on Mixing zones will work under the umbrella of the WG E on Priority Substances, with close links with the Chemical Monitoring Activities. Similar expert groups working for international marine conventions (OSPAR, Helsinki, Barcelona) or international river conventions (Danube, Rhine) and for other pieces of Community legislations (e.g. REACH, IPPC Directive, Pesticide/Biocide Directive) should be consulted.

VII. Type and intensity of the work

Contribution to the drafting of technical guidance will take the form of *ad hoc* meetings or e-mail exchanges for sharing experience, collection and compilation of the information, correction of the text and discussions of the specific issues. The Commission's consultants shall support the Drafting Group. The WG E members are invited to contribute to this work.

VIII. Timetable

Presentation of approach to WG-E	October 2008
SCG and Water Directors agree mandate	November 2008
Drafting group 1 st working draft to DG Environment	December 2008
Revisions and consultation with WG E	February 2009
Presentation of consolidated 1 st draft to WG-E meeting	March 2009

Start the testing of the guidance	March 2009
Amend document to reflect Member States written comments	June 2009
Final version agreed at WG-E	October 2009
SCG and Water Directors adopt final version	November 2009
Article 21 Committee's endorsement	November 2009/Spring 2010

List of symbols

A	=	area of water body, harbour etc.	[m ²]
B _h	=	Width of mouth of a harbour	[m]
ΔC _L	=	increase in concentration at distance L from the point of discharge	[ug/l]
CoC	=	compound of concern	
EQS	=	Environmental Quality Standard	
WFD	=	Water Framework Directive	
K	=	bottom roughness	[m]
MAC	=	Maximum Allowable Concentration	
PC	=	process contribution	[ug/l]
Q _t	=	tidal exchange flow in a harbour	[m ³ /s]
Q _{Δρ}	=	(exchange)flow between water body and harbour due to density differences	[m ³ /s]
Q _{river}	=	flow of the river	[m ³ /s]
Q _{effluent}	=	flow of the effluent	[m ³ /s]
Q ₅₀	=	flow of the water body which is exceeded during 50% of the year	[m ³ /s]
Q ₉₀	=	flow of the water body which is exceeded during 90% of the year	[m ³ /s]
Δρ	=	density difference in the (tidal) waters during tidal cyclus	[kg/m ³]
φ(x,y)	=	concentration at a horizontal distance x from the point of discharge and distance y off the (river)bank	
K _y	=	transversal dispersion coefficient in y direction	
K _z	=	vertical dispersion coefficient in z direction	
U	=	streaming velocity or flow rate of the water body	[m/s]
X	=	distance x from the point of discharge	[m]