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Expert Panel



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Science Advisory Report No. 007 Edition 2

Methods for the measurement and modelling of power station cooling water plumes

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Table of contents

1	Introduction.....	1
2	Context and challenges	2
2.1	Context	2
2.2	Definitions.....	2
3	Regulatory considerations	4
4	Behaviour of cooling water plumes.....	5
4.1	Buoyant plumes.....	5
4.2	Plume behaviour in tidal flow	6
5	Modelling of plumes.....	8
5.1	Specific challenges.....	8
5.2	Boundary conditions and verification data for modelling.....	9
5.3	Modelling	10
6	Measurements of plume behaviour	12
6.1	Requirements.....	12
6.2	Monitoring.....	13
6.3	Other parameters	14
7	Discussion	15
7.1	Modelling strategies	15
7.2	Application of results	16
	References	18
	Acknowledgements	19
	Glossary	20
Appendix A	Definitions	21
A.1	Chemical Discharges	21
A.2	Illustrative examples of other (more generalized) approaches	22
Appendix B	EA informal guidance 2010, pending UKTAG decisions on TraC temperature standards 23	
B.1	Nuclear New Build – guidance on hydrodynamic modelling requirements.....	23
B.2	Nuclear New Build – guidance on permitting non-nuclear discharges	25
B.3	Nuclear New Build – guidance on temperature standards and environmental permit requirements 28	
Appendix C	Technical guidelines for the identification of mixing zones pursuant to Art. 4(4) of the Directive 2008/105/EC.....	31

List of tables and figures

Tables

Table 1 Typical annual discharges for an EPR	21
Table 2 Temperature standards for rivers	28
Table 3 Draft WFD standards against requirements for transitional waters to have good ecological status	29

Figures

Figure 1 Example GIS output from a survey of the discharge at Heysham power station.	Error! Bookmark not defined.
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1 Introduction

Since the last nuclear power stations were built in the UK, there have been many developments in techniques, technology, understanding of ecology and legislation. The trend has been towards much larger generating units likely to produce significantly larger discharges, with plumes affecting wider areas. Additionally, there has been a greater appreciation of the possible environmental effects, and, consequently, the introduction of more stringent regulatory controls. These include the adoption of the ecosystem approach, the introduction of new, primarily EU-led, legislation and increases in public and regulatory expectations. Because of the expected longevity of the new generation of power stations (>50 years), their effects have also to be considered within the context of climate change.

The cooling water plume from a direct cooled power station has several characteristics that make it unlike the most effluent plumes, specifically characteristics that merit consideration include:

- ▶ the return is (usually) of water abstracted from the same water body
- ▶ the volume is high, and can be significant as a proportion of the receiving water
- ▶ the elevated temperature will render it buoyant
- ▶ the main 'contaminant', heat, is a non-conservative property which is naturally lost to the wider environment

This report reviews the techniques for understanding, and characterisation of, cooling water plumes and their associated mixing zone, and suggests practical methods for their application. The methods for the treatment of results and the use of the output and significance for high discharge systems in relatively shallow water are emphasised, particularly with reference to background characteristics and zones of influence (mixing zones). Mixing zones are discussed theoretically and from a regulatory point of view. The approach can be used for assessing the fate of both the thermal and chemical components of the discharge. Nevertheless, because of the diversity of situations individual power stations may encounter, regulatory agreement to application of the suggested principles will be necessary.

2 Context and challenges

2.1 Context

An adequate supply of cooling water is a fundamental requirement of any thermal power station. The laws of thermodynamics dictate that for every megawatt of power generated approaching two megawatts must be discarded as low grade (low temperature) heat. Thus a nominal 1600 MW_e nuclear generating station must discard over 2500 MW_{th} into the environment as waste heat.

The high volume of the returned cooling water (typically 65 m³ s⁻¹ for an EPR) inevitably produces a significant plume of warm water around the discharge. Effectively dissipating the heat contained in the return cooling water is both critical to the operation of the power station, and constitutes an important influence on the marine environment of nuclear power station operation.

2.2 Definitions

A plume is an active mixing zone in the vicinity of a power station where the properties in the receiving water body are altered by the discharge from the power station outfall. It is normally recognised as a zone where temperature and/or levels of other contaminants are higher than the ambient water. There are normally three zones within the plume:

1. the near-field, where motion is dominated by the upward momentum and buoyancy induced by the discharge
2. a mid-field, where the plume motion changes to reflect the velocity of the ambient fluid
3. the far-field, where horizontal spreading and advection dominate

Regulators tend to adopt a more narrow definition of a mixing zone, and can be expected to adopt the version outlined in the 2010 EC Technical Guidelines (European Commission, 2010). *'A mixing zone is designated by the Competent Authority (Environment Agency (EA) in England and Wales, Environmental Protection Agency (SEPA) in Scotland) as the part of a body of surface water which is adjacent to the point of discharge and within which the concentrations of one or more contaminants of concern may exceed the relevant EQS¹, provided that compliance of the rest of the water body with the EQS is not affected'*.

Section 6.3 and Appendix A further consider the implications for factors other than temperature.

2.3 Challenges

The interaction between high volume cooling water discharges and tidal flows leads to complex flow patterns within the plume and mixing zone. As an example, observations over many years at operating power stations have demonstrated that buoyant discharges at the bed into a tidal current may divide into two branches of elevated concentration with lower concentration in between (Rodi and Weiss, 1982; Cooper, 1987). Potential mechanisms are discussed in section 4.1, but whatever the cause (or combination of causes) it demonstrates that modelling non-linear behaviour presents a major challenge to the modeller. The regulator thus needs a good appreciation of the capabilities of the models being used when assessing the significance of model outputs.

¹ Environmental Quality Standards

During operation, the plume location and characteristics need to be monitored by field data collection to assess both regulatory compliance and operational effectiveness (eg, residual heat build-up, re-entrainment of waste heat or toxic substance concentration). When describing the plume and mixing zone, the very different behaviours of the heat load and chemical constituents in a cooling water system need to be addressed:

- ▶ Heat is non-conservative, and is ultimately transferred to the atmosphere, being lost from the marine environment.
- ▶ Unstable, non-conservative, chemicals such as the total residual oxidants (TRO) will degrade down (often very rapidly) or be lost via volatilization; some residual components will remain in the aqueous or sedimentary phase although they may be benign.
- ▶ Many more-persistent chemicals are inherently conservative and their reduction to environmentally harmless concentrations is mainly through dilution, dispersion and sequestration (eg, into sediments).

3 Regulatory considerations

When considering initial dilution, secondary mixing is a regulatory concept in that it occurs in a spatial zone, determined by the regulator, where the diluting effluent must meet any standard(s) beyond the boundary of the mixing zone. This standard could be temperature, turbidity or a chemical parameter. Normally this would be set as some statistic (eg, 95th percentile, annual average, etc), based on local mixing estimates (modelled) and derived from (worst case) ambient current field measurements. This will involve more than density gradients in most cases (bed or shore-derived turbulence) but is near-field in the sense that it is usually within a few hundred metres of the discharge.

In regulatory terms, the far-field would be considered as the mixing effluent (plume) beyond the edges of the mixing zone (ie, where the element under consideration was still significantly above background). This does not transpose neatly across to the physical processes (above) but it is important to make clear how these two approaches relate to each other and that, ultimately, the licensing authority is likely to make a determination using these criteria. A pragmatic definition is that the whole area of sea where there is a detectable elevation of the parameter in question would be considered the plume.

For a cross-shore discharge, where the effluent is channelled across the intertidal zone, and the location of the initial interaction changes at different states of the tide, there is an added complexity from a regulatory viewpoint². There would only be loss of heat to the atmosphere and the seabed, and no dilution until the receiving water mass is reached.

Discharges in the UK are usually licensed by the regulator from the point of discharge, ie, the end of the outfall; anything before that (heat losses, mixing with other streams, balancing, etc) is 'pre-treatment'. The end of pipe discharge standard will be calculated taking into account the amount of dilution available before the EQS is met at the edge of the mixing zone.

There are no statutory instruments in force in the UK for the definition of mixing zones. However, the Environment Agency issued three documents during 2010 to assist its own staff who might receive applications from new nuclear builds (NNB). These are reproduced in Appendix B, and apply to England and Wales. In Scotland, guidance on modelling and mixing zones is given by SEPA (2009) although this does not yet cover thermal plumes specifically.

In December 2010 the EU issued technical guidelines (European Commission, 2010) for the definition of mixing zones. Although they are simply 'guidelines' and there is no obligation on member states to adopt them, the preamble does state:

'It should be underlined that according to Article 4 of Directive 2008/105/EC, there is no obligation for Member States to designate mixing zones. If they decide to do so, it is expected that they will follow these guidelines.'

It may therefore be expected that the Environment Agency (and SEPA in Scotland) will in future adopt this EU guidance document as the basis for their own procedures. Although a comprehensive document, which provides a good basis for future policy, the new EU guidance does not specifically deal with the special case of very large volume discharges nor does it fully address the assessment of non-conservative pollutants. It does, however, offer a new definition of a mixing zone as stated in section 2.1.

² Both in terms of what has been and would be permitted, meaning that different regulators may take different views.

4 Behaviour of cooling water plumes

There has been a large literature generated by studies into the properties and movement of plumes, supported by theory and laboratory experiment, both into the atmosphere and into still and flowing water. However, extension of those findings into discharge plumes created in shallow tidal water is difficult because of the complications presented by the presence of two boundaries: the seabed and the sea surface, which causes turbulence and frictional shear by the rapidly changing tidal currents and by variable stratification.

4.1 Buoyant plumes

Much of the understanding has come from the observation of plumes caused by discharge of smoke or gaseous effluent into the atmosphere, which has enabled visualisation of the structures of the mixing processes, and the interaction of the effluent with the ambient media. Laboratory experiments and studies on thermal discharges into coastal waters have supported the basic concepts. These have led to the classical description of a plume discharging into water with a constant flow as containing three zones:

- ▶ **In the near-field**, the motion is dominated by the upward momentum of the discharge and buoyancy induced by the lower density of the fluid. The highly turbulent discharge interacts with the surrounding fluid, and the shear produces wave-like motions on the boundary of the rising plume. The breaking of these waves incorporates ambient fluid into the plume (a mixing process known as entrainment), thereby increasing its volume, and reducing its temperature, increasing its density, and diluting any contained pollutants (Fischer *et al.*, 1979; Lewis, 1997). Although the volume of the plume is increased, its momentum owing to the discharge velocity would effectively stay constant. However, the changing density gradually reduces the vertical buoyancy forces. Once the sea surface, or an internal density boundary, is reached, the vertical momentum is translated into horizontal momentum, and the plume begins to spread out.
- ▶ **In the mid-field**, radial pressure gradients are caused by the change in the direction of action of the momentum, and the horizontal density gradients. The plume spreads outwards, and thins as it does so, the spreading even penetrating a short distance into the prevailing current. The magnitudes of the vertical density gradient and velocity shear will determine the stability of the interface and the magnitude of the vertical mixing, and the direction of the shear will influence the subsequent movement of the plume. Loss of heat occurs through mixing of the plume with the ambient water and through exchange at the sea surface.
- ▶ **In the far-field**, the velocity shear at the base of the plume will have reduced to the extent that vertical turbulent mixing is minimal, and horizontal spreading and advection dominate. The spreading involves an outward movement of the near surface water, a downwelling at the edge of the plume where a front occurs, and a slower return flow above the interface. Thus the plume rapidly thins, the rate of spreading diminishes, and the boundaries of the plume become essentially parallel. The interface at the base of the plume is relatively stable, and mixing depends on the degree of turbulence in the water below. The heat loss is predominantly into the atmosphere, and depends on such factors as the temperature, humidity and wind speed.
- ▶ The bifurcation of a plume can occur, and is observed, in the mid- and far- field of discharges into the atmosphere and into water, both in nature and in the laboratory. This also happens for a jet discharging into a uniform crossflow. After a buoyant discharge has reached the surface, the plume can separate into two limbs with ambient water appearing between them. The mechanism requires that the spreading motion develops into a pair of counter-rotating helical vortices. These create a divergence in the flow at the surface in the middle of the plume, thereby bringing to the surface ambient fluid from below, in addition to creating convergence and downward motion at the outer

edges of the plume, where 'fronts' form (see, for instance, Fischer *et al.*, 1979). These vortices are similar to those formed by Langmuir circulation that creates 'windrows' on the sea surface under high wind conditions.

There are several mechanisms that have been proposed for generation of the vortices. In this instance, the vortices are part of a horseshoe-shaped vortex system caused by rotation around the rising plume in the near-field that persists into the far-field, gradually moving apart. Also the mechanism of spreading in the near-field, involving an outward flow at the surface and a return flow at the bottom of the plume, can be a factor leading to bifurcation of the plume. Additionally, shear resulting from separation of the flow round the rising plume can create a pair of rotating vortices within the plume that separate once the plume reaches the surface. It is also possible that all of these mechanisms may combine to produce bifurcation.

As a result of the bifurcation the spreading rate in the far-field is increased and the highest temperatures would occur towards the outer boundaries of the plume. There appear to be no conclusive results defining the conditions under which bifurcation appear but theory and experiments suggest that it is sensitive to a number of factors including discharge rate, buoyancy, outfall shape and diameter, and depth and velocity of the ambient fluid above the outfall (Andreopoulos *et al.*, 1986; Jirka and Akar, 1991; Smith and Mungal, 1998). In considering spreading of the plume observed at Sizewell, MacQueen (1978) concluded that vortices with a circulation related to buoyancy were more likely to contribute significantly than velocity shear at the outlet. For future large buoyant discharges into shallow water it is possible that bifurcation would be more likely to occur, especially at times of maximum tidal velocities.

4.2 Plume behaviour in tidal flow

Continuous discharge of a heated effluent into a tidal flow leads to complex movement of the plume because of the changing rate and direction of movement of the ambient fluid. A typical sequence would be:

- 1. Slack water after ebb.** Initially a plume injected vertically into or across the flow has no horizontal component of motion, and will rise to accumulate as a patch of low density water at the surface. There would be an accumulation of warmer water which would increase in thickness and diameter with time. Near-, mid- and far-field zones would form as described above, but with limited dimensions, and heat dissipation. As water depth over the outfall would be at a minimum, a boil may occur at the surface for large discharges. This would produce an elevation of the sea surface in the middle of the patch, and an outward pressure driving a radial surface flow.
- 2. Flood tide.** As soon as the tide begins to flood, the near-field rising plume would be deflected by the current and the magnitude of the initial dissipation of heat would increase because of the increasing plume length. The presence of a boil would become less likely. The patch would be moved away in the direction of the tidal current, and become elongated. The initial patch would spread out, but maintain some of its integrity as a nose of higher temperature, with high temperature gradients at its leading edge. At the trailing end the gradually extending plume would undergo fairly intense mixing because of entrainment. In the mid- and far-fields the discharge would become influenced by the regional tidal pressure gradient, and the plume spreading rate would be related to the tidal velocities. Consequently, the plume reaches a full width which will be greater at neap tides than at spring tides. In the mid-field at maximum current, the vertical momentum will have been dissipated, but velocity gradients beneath the plume and at its lateral boundaries will be strong, as the plume still travels relatively slowly within the ambient fluid. These will induce continued acceleration of the plume, and entrainment of water from within it into the more turbulent ambient fluid, causing the plume to lose volume and heat. The ambient fluid is likely to be more turbulent because of shear at the seabed. In the far-field the plume will be essentially integral in the flow, and will respond to the tidal driving forces. The velocity differences between the plume and the ambient fluid are likely to have decreased so that turbulent mixing dominates over entrainment. This produces an increase in momentum in the plume, but little increase in volume. Consequently, heat

dissipation is dominated by exchange with the atmosphere. Continued spreading of the plume involves a gradual decrease in thickness and increasing importance of mixing induced by surface waves.

3. **Slack water after flood.** With gradually decreasing tidal velocity, the width and thickness of the plume will increase in the near- and mid-fields, and the magnitude of heat dissipation will decrease. In the far-field the plume will be extended, wide and thin, with the likelihood of breaking up into ribbons and fingers because of variations in water depth and velocity resulting from bathymetric and seabed frictional differences.
4. **Ebb tide.** During the ebb tide the remnants of the plume will begin to be advected back across both the cooling water intake and the outfall, to interact with the continuing plume discharge in a similar manner to that occurring on the flood tide.

The presence of a coast or shallow water on one side of the plume will create frictional differences that affect the turning of the current; slack water and reversal of the current occurs earlier near the shore. This could lead to a penetration of part of the plume along the shore while the remainder is still going the other way offshore. When the tide turns offshore the head of the plume may have a complex outline. In addition, the influence of onshore or offshore winds will further affect the movement of the surface part of the plume.

In the short-term, movement of the plume is a complex interaction of the geometry of the outfall, the velocity and density of the discharge, the water depth and its spatial variation, the tidal velocities, seabed induced turbulence, density of the receiving waters, waves, winds and atmospheric temperature. Tidal motion may cause the plume to have a wide trajectory and influence a large geographical area in the long-term, particularly because of the spring and neap variation in tidal currents, and the influence of weather and waves. In addition, density gradients can cause a residual offshore surface current and a return onshore bottom flow. Although the total area affected at some stage of the tidal cycle may be relatively large, at any given time a much smaller area is affected.

5 Modelling of plumes

During the planning of the power station location, the optimum position of the outfall and distribution of the plume, its movement and characteristics, are determined by an iterative combination of mathematical modelling and field data collection, especially with respect to the hydromorphology of the area.

During operation, the plume location and characteristics need to be monitored by field data collection to assess both regulatory compliance and operational effectiveness (eg, residual heat build-up, potential re-entrainment of warmer water or toxic substance concentration).

5.1 Specific challenges

The anticipated discharges from NNB Power Stations (with two EPR units) will be of the order of $120 \text{ m}^3 \text{ s}^{-1}$. This is considerably more than the discharge from existing nuclear power stations, and presents a number of new modelling problems at coastal stations where water depth at the discharge point is limited, ie:

1. The outfall structures are likely to be large in order to retain reasonably low discharge flow velocities. Nevertheless, the grid size is unlikely to provide sufficient detail of secondary flows. The use of several outlet ports would create possible in-combination effects of several rising plumes.
2. There are likely to be large relative changes of water depth at the discharge point during the tidal cycle.
3. The large volume discharge is close to the bed.
4. The rising plume is likely to create a boil at the surface for long periods during the tidal cycle, producing complex spreading.
5. There is a high risk that the plume would bifurcate, in which case the details of secondary flow velocities will need to be resolved.
6. After slack water there is the possibility of recirculation (re-entrainment) of the plume into the cooling water intake.
7. In view of the high flow rates relative to tidal flows, plume interaction with intertidal areas and tributary estuaries is possible; hence wetting and drying of cells within the modelled area has to be well represented.

Under such demanding conditions, inclined or horizontal discharges may be used to maximize mixing and to direct the plume towards deeper water away from the coast. It may also minimize the risk of bifurcation. This will require detailed specification of the input conditions in the mathematical models, and may necessitate separate modelling of initial dilution.

The high rates of discharge are likely to create a plume with high density gradients to the ambient water. This requires a good turbulent mixing algorithm and a detailed vertical grid. Adequate specification of vertical mixing by both surface and internal waves is needed.

A key challenge in all modelling is the compromise between grid resolution and the extent of model domain. Ideally it would be preferable to get high resolution in order to resolve the necessary physics in the near- and mid-field, and a large domain to ensure the far-field is adequately captured without contamination from boundary effects. Models with grid refinement capabilities or capable of using irregular unstructured grids can help, but are generally very costly to run compared to simple regular structured grid models. Far-field

and mid-field models are likely to depend on accurate parameterisation of the near-field physics, especially if the hydrostatic assumption is invalid (Baptist and Uijttewaai, 2005). All the far- and mid-field modelling then relies upon the conditions imposed on the grid cell containing the discharge point. Since the volume and heat flux are given, the only degree of freedom is the choice of how the heat is distributed in the vertical. For example, all of the heat can be assumed to be in the top few vertical layers, or spread uniformly throughout the water column.

5.2 Boundary conditions and verification data for modelling

For setting up a mathematical model, boundary conditions are required for an extensive area, together with detailed information at positions within the area to be used for calibration and validation.

5.2.1 Boundary conditions

1. Local and regional bathymetry is required, with highest resolution in the near- and mid-field areas. Bathymetric data can be obtained from the Hydrographic Office, or from SeaZone HydroSpatial, and should comprise the fair sheets or sounding charts. Detailed bathymetry/topography, particularly in the near- and mid-field, should be obtained by swath echo-sounding, or by closely spaced conventional vertical echo-sounding.
2. The mathematical modelling will require information on the tidal harmonics for long periods of analysis, or observations and current velocities at the boundaries for shorter periods. The tidal harmonics should be available for nearby Standard or Secondary Ports.
3. The physical characteristics of the receiving water body, including density, temperature and salinity, must be known at a number of positions.
4. The positions of water body structures such as bridges and quays which will distort the dispersion patterns need to be established.
5. Data on river flows and extreme floods should be obtained from CEH Wallingford, or the local Environment Agency (EA) offices for England and Wales and Scottish Environment Protection Agency (SEPA).

5.2.2 Verification data

1. Tidal variation in water level and current velocity need to be known at a number of positions within the model for spring and neap tides, for various weather conditions, and if possible for extreme events.
2. Data on tidal heights should be available from port authorities and the National Oceanography Centre (NOC) in Liverpool.
3. The long-term variation of density and temperature in the receiving water must be determined in order to allow estimation of the vertical stability and heat losses from the plume to the surrounding water and to the atmosphere.

4. Data on waves may be available from various authorities, such as WaveNet³ or can be estimated from wave models run by the Met Office³.
5. Data on winds and atmospheric conditions should be obtainable from British Atmospheric Data Centre (BADC) or the Met Office and from local airfields, in terms of averaged conditions and extreme statistics.
6. Data on current velocities are essential⁴, particularly at the proposed intake and outfall positions. These should cover complete tidal cycles and be representative of spring and neap conditions at various wind states. Additional data may be obtained by anchored ship measurements, or from monitoring buoys.
7. Detailed data on current strength and direction can be obtained from ship-borne Acoustic Doppler Current Profiler (ADCP) surveys.
8. The local climate regime must be known including its diurnal and seasonal variation, covering any period during which there is a need for model calibration or validation. Additionally, climatic extremes and predicted future evolution need to be considered.
9. Calibration data for a plume model can be obtained from dye release or drogue tracking.

Additional information may be required on:

- ▶ The roughness of the seabed and the sediment distribution, this should be obtained from oblique sonar surveys, and from seabed grab-sampling;
- ▶ The near-surface bedrock and sediment structure, which may be necessary for determination of potential erosion or deposition; this may be obtained by acoustic sub-bottom profiling and by core sampling.

5.3 Modelling

There is a wide range of commercial models available and the choice of appropriate ones will depend on local conditions. An introduction to the selection and implementation of mathematical models is provided by Bartlett (1998). There are many aspects that need to be included for successful and relevant modelling, as an indicative check-list these include the following topics:

1. Mathematical modelling should be carried out using three dimensions.
2. Ideally the high resolution plume model should be nested within a coarser-scale regional hydrodynamic model, and the boundary conditions taken from it.
3. Appropriate grid sizes and time steps should be used, with increasing resolution close to the proposed outfall position. Alternatively, high resolution should be used everywhere.
4. Careful consideration must be made in the specification of wetting and drying of intertidal areas.

³ A number of sources are available; WaveNet (<http://www.cefas.co.uk/data/wavenet.aspx>), funded by the EA, is probably now a more comprehensive source for England and Wales than the Met Office

⁴ <http://www.ecmwf.int> and <http://badc.nerc.ac.uk/home>

5. Specification of the discharge may require a level of detail that cannot be achieved within regional scale models. Initial dilution models may be used for the near-field conditions. This should allow the discharge to be specified in the innermost cells of the wider model.
6. Appropriate mixing coefficients should be used, and sensitivity tests carried out to determine likely errors. The algorithms for surface cooling of the plume by the atmosphere are of particular importance and, if possible, the coefficients of heat transfer to the atmosphere should be adjusted frequently to take account of changing weather conditions.
7. Normal limits must be used for the acceptable comparison of the model output with field data.
8. Ideally two separate data sets should be used for calibration, and for validation of the models used.
9. The modelling should provide output scenarios for appropriate cooling water discharges at different states of the tide, different tidal ranges and different wind force and direction.
10. Future climate scenarios, particularly of wind, atmospheric and ambient water temperature, should be considered.
11. Any regulatory recommendations or requirements in terms of modelling approaches or sampling frequencies (eg, the SEPA Guidance on the use of numerical models) should be used.
12. Where possible also use secondary dilution (3D models) to estimate wider dispersion in the local sea area.
13. Use well-accepted initial dilution models where the criteria of depth, flow, discharge aperture and relative densities allow some estimate of dispersion and dilution.
14. Physical models used for assessment of outfall design may provide useful information on initial mixing of the plume provided appropriate scaling factors are used.
15. Once the outfall is in operation, surveys of the plume extent should be compared with the modelled estimates to improve operational use of the models.

Once adequately validated, the modelling should provide estimates of the trajectory of the plume at various conditions of tide, waves, wind and outfall discharge. The modelling should also provide estimates of the magnitudes of elevation of temperature (or absolute temperatures) at particular positions, and their duration. Care will need to be taken over interpretation of relative changes at the seabed and in the water column.

The modelling should allow estimation of the possible blocking of transit of migratory fish species by a water quality barrier, especially any associated dissolved oxygen sag. The simulations of the plume trajectory and characteristics can be used to modify the initial design of the power station if necessary. The results can be compared with results obtained from other sites, if there is confidence that sites are similar.

6 Measurements of plume behaviour

As discussed in the previous section, apart from some limited areas where information may already exist, extensive field data collection will be required for model parameterisation and calibration. However sophisticated the models used and comprehensive the data available for calibration are, no model can predict the actual behaviour of a plume with complete accuracy. It will therefore be necessary, post commissioning, to monitor actual plume behaviour, an exercise which may need repeating at intervals during the operation life of a power station to ensure changes - such as natural evolution of local morphology, climate change and man-made interventions - have not significantly changed plume behaviour.

This section reviews the minimum data requirements and some of the techniques available for their acquisition.

6.1 Requirements

A cooling water thermal plume is a complex entity, and monitoring has to be carefully designed if the results are to be of value.

- ▶ The position and characteristics of the plume are required in three dimensions, because it does not always reach the seabed; the characteristics include temperature, salinity and turbidity.
- ▶ The plume movement must be known at various states of the tide and in different weather conditions.
- ▶ Any regulatory recommendations or requirements in terms of sampling frequencies or ecological quality elements should be observed.

A minimum requirement is information on:

6.1.1 Ambient conditions

- ▶ Local measurements should be made of the tidal water level variation for comparison with modelled results and for reference during other measurements.
- ▶ Additional current measurements are required, especially including near-bed currents and vertical profiles of current velocity at the outfall position, and the discharge rates.
- ▶ Local wave data, particularly at the outfall position, should be obtained by wave-rider or appropriate instruments, and the statistics of maximum wave heights and periods derived.
- ▶ Variations in freshwater flow that may impact local currents and the density difference between plume and ambient flow should be characterised.
- ▶ Time-series of temperature, salinity and turbidity should be obtained at several appropriate fixed points, particularly those in sensitive areas, such as oyster beds. The duration should cover the plume monitoring.
- ▶ Air temperature, atmospheric pressure, wind force and direction, and solar radiation at a local weather station.

6.1.2 Within the plume

- ▶ Synoptic field surveys of temperature, salinity and turbidity should be carried out using towed sensors or vertical profilers at fixed stations.
- ▶ Repeated surveys are needed to cover lunar and seasonal cycles.
- ▶ These should include Horizontal field of temperature, salinity and current vectors.
- ▶ Vertical profiling of temperature and salinity.

For a rapidly evolving plume precise position fixing and near synoptic measurements are required.

6.2 Monitoring

Monitoring can be carried out in two ways:

- ▶ Lagrangian (monitoring within/with the flow)
- ▶ Eulerian observation (observe the passing flow from a fixed location).

Typically plume characterisation will employ a combination of these methods, with data from ship board sensors ship being combined with measurements taken at fixed locations with the results most conveniently presented within a Geographical Information System (GIS). Additionally, monitoring of plume trajectories can be obtained by tracking of drogues or injected dye tracers, and airborne remote sensing using thermal or colour wavelengths.

It is not practical to provide a generalised monitoring plan as each location will have its own characteristics and constraints. However some general rules will apply to any effective survey technique.

Position fixing by differential GPS, referenced to a base station at a precisely known location, can provide a fix within a few centimetres.

Current profiles can be measure by a ship mounted bottom tracking Acoustic Doppler Current Profiler (ADCP), the bottom signal compensating for ship movement during Lagrangian measurement, or drift when measurements are taken at a nominally fixed station.

Vertical structure of (for example) salinity and temperature can be measured by rapid drop profilers which provide near synoptic vertical readings, at least in the shallow waters encountered in most power station investigations.

Information on *local* tidal elevation is necessary, and tide gauges/pressure transducers deployed should be referenced to a station that is part of the National Tide-Gauge Network.

Short and long- term data for ambient conditions are conveniently provided by instrumentation packages at fixed locations, either shore-based or mounted on buoys.

It is obvious that the measured plume extent will be taken over what could be a considerable time period and will not show instantaneous distributions. This will be compared with the modelled results which will be for defined instants. Also there will need to be interpolation of the contour locations between the monitoring profiles. Consequently, careful interpretation of the comparison between the monitoring and the modelled results is required. However, almost instantaneous distributions at the water surface can be obtained from remote sensing imagery.

An example of the thermal plots that can be provided by using these methods is given below.

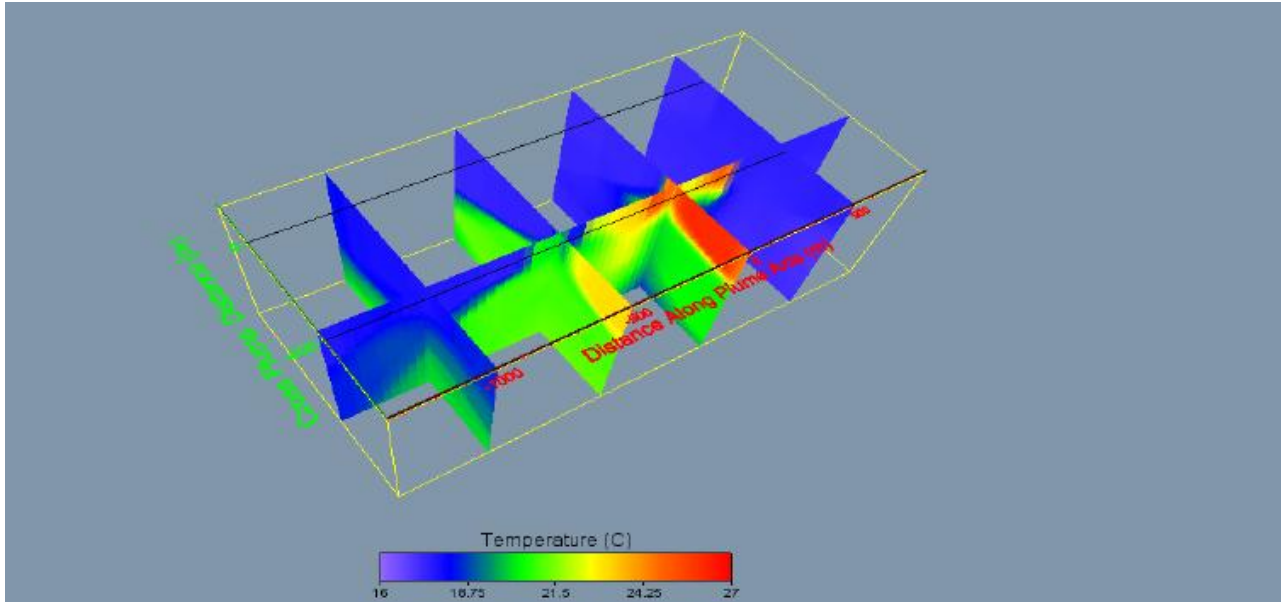


Figure 1 Example GIS output from a survey of the discharge at Heysham power station © British Energy Generation Ltd.

6.3 Other parameters

The heat load is not the only potential contaminant in cooling water and demonstrating the distribution of various chemical parameters will be necessary. Principal amongst these will be:

- ▶ total residual oxidants
- ▶ chlorination by-products
- ▶ hydrazine
- ▶ other process chemical (see Appendix A and BEEMS Science Advisory Report No. SAR009)

Many of these constituents are unstable and require measurement in situ. Although there are obvious benefits in a combined survey to measure both the physical and chemical behaviour of a plume, the danger of compromising both must be recognised.

7 Discussion

7.1 Modelling strategies

Despite the difficulties of modelling the discharge plumes and the distribution of effluent, it is the only method of estimating their possible impact. Models of discharge plumes depend upon the quality of the general hydrodynamic models within which they are embedded. Errors, which are largely unquantifiable, arise from three causes:

- ▶ The representation of the physical processes will be incomplete because not all of the processes are understood and cannot be adequately parameterised. It is important to remember also that the output from a mathematical model is averaged over a finite space – the grid cell – and over time – the time step. Within the grid cell area in particular there may be considerable variations in velocity, temperature and other properties. The model will provide a smooth plume outline with a continuous change in temperature, which will contrast with actual measurements. Therefore, comparison with observations will not be direct and potential errors may be large.
- ▶ The accuracy of calibration and validation will also depend on the quality of the field data used. It is not possible to obtain exact correspondence between the data and the models, even for the most fundamental variable, the water levels. Criteria have to be used to establish a level of acceptability.
- ▶ Not all of the independent variables can be represented at once. For instance, winds, atmospheric conditions, waves, tidal variations and surges may all occur at the same time, but they cannot all be represented together. Consequently, different combinations of typical conditions need to be chosen and extreme values considered to obtain the extent of likely effects.

Nevertheless, used with discrimination the results can be viewed as acceptable estimates of what is a complicated natural system with the addition of human interference. However, there are likely to be significant differences in the ways in which various physical processes are characterised within different models, which may lead to important differences in the estimates. These differences have not always been apparent in the past when only a single model may have been used but comparisons by Baptist and Uijtewaal (2005) and by Fernand (2011) indicate there are benefits from using two models. For example, the heat distribution in a plume depends on the algorithm for heat transfer into the atmosphere, and different models use different formulations. Although each algorithm may represent experimental data reasonably well for certain parameter ranges, important differences may arise in practical modelling. Consequently, it is generally of value to run two or more different models with the same input data within a robust quality assurance framework, because each model will represent the processes in different ways. Comparison will allow assessment of the possible errors and help exploration of dependencies on the various parameters. This approach has been termed 'ensemble modelling'.

There is a logical progression of models from a large scale, coarse grid, which can represent the general regional conditions, to smaller scale local models that consider more detailed processes and interactions. A likely sequence of models would be:

- ▶ A regional model to provide the boundary conditions for the more detailed model of tidal and weather induced water level variations and flow velocities. This would, for instance, be of the whole of the North Sea, or Celtic Sea, with inputs of the regional wind field and atmospheric conditions. This may be either 2D or 3D.
- ▶ A more detailed model of the area of specific interest, with more detailed bathymetry and coastal topography. This would have local wind and atmospheric conditions imposed on it and may include such things as waves. This would have to be 3D.

- ▶ The plume model would be embedded in the detailed model with enhanced detail in the outfall area. This model would benefit from special modelling of the plume near field to specify the discharge conditions at the outfall. Additionally, models involving particle tracking may also be helpful in defining the plume trajectory.

Once adequately validated the modelling should be used to examine different aspects of the problem, for instance, daily, monthly and seasonal variations. A possible sequence to provide information on the likely variation of background water temperature to inform consideration of plume-induced temperatures, would be:

- ▶ The seasonal variation of water conditions, using observed tides and surges, and atmospheric conditions taken from a long time-series run of a model, together with extreme measured temperatures and salinities where possible.
- ▶ The tidal variation over spring to neap tides at various seasons and for extreme conditions chosen from the above seasonal results.
- ▶ The effect of extreme atmospheric conditions of an historic hot summer to simulate the long-term situation under climate change.

Application of the plume models would then be based on assessment and the understanding of possible extreme temperatures coming from the above sequence of models, in comparison with the statistics of observed temperatures. The results should provide estimates of the contoured distribution of temperature and the trajectory of the plume at various conditions of tide, waves, wind and outfall discharge. Again, several models may be necessary to ensure adequate consideration of all the variables, especially waves, and for representation of such factors as the atmospheric exchange algorithms.

The modelling should also provide estimates of the magnitudes of elevation of temperature (or absolute temperatures) at particular positions and their duration. Care will need to be taken over interpretation of relative changes at the seabed and in the water column. Furthermore, the modelling should allow estimation of the possible blocking of transit of migratory fish species by a water quality barrier.

7.2 Application of results

Over the timescale of many tidal cycles, the position of the plume will vary according to the changes in trajectory during the lunar spring-neap cycle, as well as the influence of wind and residual flows. The plume will thus cover a zone of influence (ZOI) – an envelope in which temperature may be at times elevated. Over much of the area the temperature will only be raised briefly and by a small amount; a lesser area will experience significantly elevated temperatures. The region determined by the regulators within which it is specified that the elevation in temperature is of environmental concern is the mixing zone. This should be much smaller than the ZOI. The ZOI will differ for different constituents (eg, temperature, chemical additives) depending on the various loss and decay processes

In terms of assessing the effects of the plume on the ecology, it is necessary to consider the likelihood of the plume affecting a particular point within its trajectory and the maximum temperatures and the duration to which the ecology is exposed. Those temperature fields can then be linked to the thermal tolerances and lethal/sub-lethal responses of the species in the receiving area (BEEMS Science Advisory Report No. 008).

Definition of the limits of the mixing zone in terms of the plume modelling should depend upon specification of the critical magnitude, frequency and duration of the temperature increase, and this will depend upon the statistics of the hydrodynamic and atmospheric variability. However, because of the many variables that act simultaneously, it is not usually possible to consider the likely temperature occurrences statistically in terms of joint-probability, or to define the modelled circumstances that best represent them. Under these circumstances, specific situations that may act as worst or most hazardous cases have to be agreed as the best definition of the mixing zone.

As outlined above, modelling the ZOI should encompass a full range of tidal and weather situations, but because of the decreased duration and increased mixing, extreme events should be of lesser importance in affecting the biology. The peak influence within the water column will obviously be close to the outfall site, but displaced according to the residual currents and the winds. At the seabed, the peak would depend upon how the plume interacts with the changing water depth, and the proximity of intertidal areas may be significant. As the ecology most at risk of damaging exposure will be at the seabed, one of the prime functions of the plume is generally to ensure that the heated water is retained near the surface for as long as possible. Consequently, the effects at the bed and near the surface need to be treated separately.

Therefore, it is proposed that the mixing zone should be defined, according to the critical temperature (BEEMS Science Advisory Report No. 008) within the plume extent modelled after the flood tide in one direction, and after the ebb tide in the other direction. Although at spring tides the extent of the plume will be greater than at neap tides, the temperatures should consequently be less. Also at spring tides the duration of exposure of a particular position on the seabed would be less. Nevertheless, the greatest mixing zone extent of springs and neaps should be used. Although the temperatures will be higher towards slack water, these should be within the plume extents specified above.

This approach should be modified to encompass the alterations to the mixing zone extent caused by wind, and wave breaking effects, and by seasonal extremes, with the maximum modelled extent taken as the accepted limit. The same criteria should be used for the surface and for the seabed, though the results will obviously differ.

For the water column there is also the question of the risk of creating a thermal or water quality barrier and thus blocking the passage of migratory species. In confined waters, such as an estuary where waters exceeding the critical temperature could extend across cross section, the modelling should define tides when excessive blockage (>25%) is created for durations of either spring or neap tides exceeding 15%. Such issues extensively discussed in BEEMS Science Advisory Report No. 008 on thermal standards.

Obviously, local conditions will be important and modifications may be needed to the above proposals that would be agreed by discussion with the regulatory authorities.

Before embarking on extensive (and expensive) modelling the environmental drivers must be fully understood and appreciated. To understand the impact of a discharge on the ecosystem there is as little value in modelling to a precision which is not required, as there is in making key decisions based on a model inadequate for the purpose.

Models must never be accepted unquestioningly but may be regarded as a valuable useful guide to actual plume behaviour. Post-commissioning measurement and monitoring of the real plume should always be carried out to both confirm any environmental consequences but also to refine the models for use in any future 'what-if' scenario testing.

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Glossary

Boil – Surface elevation created by rising plume reaching water surface

EPR – European Pressurised Reactor

Far-field – Part of the plume at some distance from the outfall, where mixing is limited and cooling occurs by losses to the atmosphere

Initial dilution – Loss of temperature caused by mixing of the plume by entrainment with ambient water

Mid-field – Part of the plume where both entrainment and loss of heat to the atmosphere occur

WMe – Electrical Energy (in Megawatts)

MWth – Thermal energy (in Megawatts)

Mixing zone – Part of the plume where the temperature exceeds the designated environmental standard

Near-field – Part of the plume adjacent to the outfall where the plume rises towards the surface

Primary mixing – mixing occurring within the mixing zone

Secondary dilution – Dilution/mixing occurring outside the mixing zone

Secondary mixing – Secondary dilution

Zone of influence – Area that the plume may affect at some point within the duration of many tides

Appendix A Definitions

A.1 Chemical Discharges

The cooling water discharge will also contain a variety of chemicals added within the station. In most locations chlorine is added to prevent fouling in the condensers. Additionally, a range of inorganic and organic chemicals will be released during routine purging (blow-down) or intermittent flushing of the primary cooling circuit of an EPR or PWR and discharged via the cooling water circuit

Excluding any radionuclides, the principal components are:

Cooling water treatment:

- ▶ residual oxidants formed during chlorine addition (total residual oxidant (TRO))
- ▶ non-oxidising chlorine by-products (CPBs).

Other chemical components:

- ▶ boric acid, added to the coolant as a neutron absorber
- ▶ lithium hydroxide, added to the coolant to offset the acidity of the boric acid to prevent equipment corrosion
- ▶ hydrazine, used as an oxygen scavenger in the feedwater
- ▶ metals from corrosion products
- ▶ morpholine and ethanolamine, used to adjust pH of secondary circuit water to minimise corrosion
- ▶ trisodium phosphate, used in some auxiliary cooling and heating circuits as a corrosion inhibitor
- ▶ detergents used in the laundry to clean work clothes

Although the dilution offered is high and concentrations will be very low, the quantities discharged are not necessarily trivial.

Table 1 Typical annual discharges for an EPR

Released chemicals	in kg/yr
Boric acid (boron)	2,000
Lithium hydroxide	less than 1
Hydrazine	7
Morpholine	345
Ethanolamine	250
Nitrogen compounds (as N) excluding hydrazine, morpholine and ethanolamine	2,350
Phosphate	155
Detergents	630
Metals	16

These non-trivial discharge levels are not necessarily an environmental problem, but their impact needs evaluating as part of a site assessment. Some elements of the discharge (eg, TRO and hydrazine) are unstable and their decay characteristics will require modelling. Others (eg, CBPs and phosphate) are far more stable and should be treated as conservative pollutants.

A.2 Illustrative examples of other (more generalized) approaches

The following is taken from a draft document 'Technical guidelines for the identification of Mixing Zones pursuant to Article 4(4) of the EQS Directive (2008/105/EC)' (Appendix C of this report). The document states in its Executive Summary:

'Water quality in Europe has improved dramatically in recent years aided by the adoption of an underpinning philosophy to reduce, or where possible, eliminate pollution. At a European level, this concept, the so called "combined approach", forms the basis for Water Framework Directive (2000/60/EC).'

'Compliance with environmental quality standards (EQS) is an essential part of this strategy and effluent discharge control regimes are normally designed to ensure that concentrations of polluting substances in the receiving water do not exceed the EQS. However, if the concentration of the contaminant of concern in the effluent is greater than the EQS value at the point of discharge there will be a zone of EQS exceedence or a 'Mixing Zone' in the vicinity of the point of discharge. Understanding this exceedence is important as it enables the Competent Authority first to identify whether such a mixing zone is acceptable and then identify the need and appropriate location for monitoring points. This guidance has been designed to assist Member States to designate and assess the acceptability of mixing zones using a Tiered Approach to provide an appropriate level of scrutiny. This guidance must be used in the determination of mixing zones for substances listed in Annex 1A of Directive 2008/105/EC.'

Appendix B EA informal guidance 2010, pending UKTAG decisions on TraC temperature standards

B.1 Nuclear New Build – guidance on hydrodynamic modelling requirements

B.1.1 Introduction

There are plans to build a number of new nuclear power stations in England and Wales over the next decade or so.

All of these power stations will be located on the coast to enable sea water to be used as the prime coolant. At each site, sea water will be extracted, used for cooling and returned to the sea with temperatures elevated by about 10°C. Flow rates will be of the order of 100 m³ s⁻¹ (cumeecs), so potentially the thermal, and consequential ecological, impact on the receiving water will be large according to the dilution and dispersion available.

This thermal and ecological impact on the receiving waters cannot be avoided, but it must be minimised.

Whilst the thermal impact of the discharge is of prime interest, the discharge may have secondary impacts, such as:

- ▶ changes in speciation of ammonia as a result of the elevated temperatures
- ▶ changes in salinity as a result of the abstraction/discharge regime
- ▶ changes in DO as a result of elevated temperatures
- ▶ discharges of anti-fouling agents and their by-products
- ▶ discharges of other process chemicals

Hydrodynamic modelling forms an essential part of the scheme design. It is needed to ensure that:

- ▶ the abstraction is located so as to minimise ecological and fisheries impacts
- ▶ the abstraction and discharge points are located such that interaction between the two is minimised
- ▶ the impact of the thermal plume is understood and minimised, particularly in sensitive areas
- ▶ any secondary impacts are understood and minimised, particularly in sensitive areas

This paper aims to outline Agency requirements for the modelling that must be undertaken. It does not attempt to specify in detail the type of model to be used or the modelling runs that are required – the discharger is expected to produce the detailed specification for the modelling. This specification should be agreed with the Agency on a site-by-site basis.

Note that the use of the term ‘mixing zone’ below refers to the part of a body of surface water within which a standard is exceeded. In tidal waters this can be temporally and spatially variable.

For example, if the particular standard under consideration is a maximum elevation of temperature of no more than 2°C above ambient, then the ‘mixing zone’ is the volume of water, in 3-D, within which the water temperature can be reasonably expected to be 2 or more degrees above ambient at some time during the lifetime of the plant. In this example, the ‘mixing zone’ is the 3-D envelope around the discharge point encompassing all locations where, when the discharge is at its maximum permitted temperature, the instantaneous temperature elevation may be above 2°C at some time. It will be much larger than any instantaneous zone within which the temperature elevation is 2°C or more.

Alternatively, if the standard under consideration is a 98th percentile temperature of 23°C over a year, then the ‘mixing zone’ is the 3-D envelope around the discharge point encompassing all locations where the

temperature is predicted to exceed 23°C for more than 2% of the time. The size of this ‘mixing zone’ may be small when compared to the worst-case instantaneous impact of the discharge.

Clearly, the ‘Zone of Influence’ (of elevated temperature) will extend beyond the ‘mixing zone’ as it is defined here.

B.1.2 Agency requirements

Our requirements for the thermal plume modelling (and post-project appraisal) are summarised as follows:

- ▶ modelled output to provide information in 3-D
- ▶ model(s) must be suitable for the application(s)
- ▶ not be limited to the use of one model – different model types can support and complement each other, eg, an excess temperature model looking at different discharge temperature elevations, run over relatively short periods for a number of different scenarios, and a long-term absolute temperature model
- ▶ model(s) must be demonstrated to be suitably calibrated and validated – validation should be against existing thermal plumes if possible, including the use of aerial or satellite imaging
- ▶ model(s) to comply with Agency standards for hydrodynamic model calibration/validation
- ▶ model(s) to be independently audited – audit report(s) to be provided
- ▶ model(s) to be available for use over a period of at least 10 years from the date of commissioning of the power station, and beyond that for as long as there is (are) no suitable alternative(s) available
- ▶ agency will require access to the model(s) over the lifetime of the power stations
- ▶ output to represent both absolute temperature and excess temperature above background, both in the near-/mid-field and in the far-field⁵
- ▶ results to include the effects of tidal currents, residual currents, wind driven currents, turbidity, solar insolation, cloud cover, air temperature, surface cooling including the effect of wind, river flows, river temperature, thermal and saline stratification, seasonal effects (including short-term extreme temperature events) and sedimentation and erosion
- ▶ results to cover a range of plausible scenarios of climate-change driven rises in air and sea temperatures and sea-levels over the planned life-time of the station
- ▶ results from alternative abstraction and discharge locations, including options to discharge near-bed, mid-water-column or near-surface and utilising different outfall designs, as appropriate
- ▶ maps to show locations of designations, sensitive waters, relevant sensitive receptors, etc
- ▶ ‘mixing zones’ appropriate to the various thermal standards to be presented in 3-D, based on the statistics of the standard (eg, annual average, maximum, 98th percentile)
- ▶ where a mixing zone relates to an instantaneous statistic (such as maximum value), then as far as is practicable, some indication of the variation of the duration of exceedence over the mixing zone
- ▶ in addition to the presentation of the overall mixing zones, various instantaneous representations of the temperature field are needed to enable an understanding of typical conditions
- ▶ detailed impact assessment inside the mixing zones (and outside if considered appropriate) for all relevant receptors (flora and fauna throughout the water column, on and within the seabed, and in the inter-tidal zone) to be assessed and discussed
- ▶ relevant statistics of the mixing zones, eg, area, volume, proportion of estuarine cross-section, proportion of time threshold value exceeded
- ▶ post-scheme appraisal within five years of commissioning to validate (or not) the model predictions – based on field observations, satellite or aerial imaging, etc
- ▶ if necessary, the re-calibration and validation of the model(s) following post-scheme appraisal.

Our requirements for the modelling of secondary impacts are essentially the same. Any models used will need to incorporate water quality modules suitable for the processes being modelled.

⁵ In the near/mid-field, jet and buoyancy processes dominate the mixing. In the far-field, horizontal and vertical advection and dispersion processes dominate.

B.2 Nuclear New Build – guidance on permitting non-nuclear discharges

B.2.1 Introduction

This guidance relates to all the potential water quality issues arising from operational discharges from NNBs, particularly with respect to the thermal plume and chemicals added to the main cooling water discharge, eg, process chemicals, products of electro-chlorination, etc.

Guidance on the permitting of discharges arising from the construction phases are covered in a separate NNB note. Similarly, other operational discharges that may be separate from the cooling water discharge, eg, on-site sewage treatment, are covered by our existing guidance on the Environmental Permitting Regulations 2010, which is available at <http://www.environment-agency.gov.uk/business/topics/permitting/default.aspx>

The guidance in this document is not exhaustive, but is intended to provide:

- (a) a summary of the relevant factors which may need to be considered in the supporting information to an environmental permit application, and
- (b) an overview of the process of assessing the impact of the cooling water discharge including any additional process chemicals.

In simple terms, the impact of any cooling water discharge and the added constituents/chemicals needs to be considered in relation to defined targets. However, there can also be additional considerations with respect to direct or secondary impacts on the local ecological functioning, sensitive faunal and floral species and the behaviour of both chemical and microbiological contaminants. The assessment of the discharge against the targets will involve some definition of a mixing zone, which is the volume of water where the target value is exceeded.

B.2.2 Targets

Relevant targets for the assessment of the cooling water discharge are defined for chemical constituents mostly by EQSs (statutory and operational) and Predicted No Effect Concentrations (PNECs) (where available). With regard to temperature, standards have been defined as a temperature difference above ambient, as well as a maximum temperature as a percentile of time. Guidance on the application of temperature standards to thermal discharges in transitional and coastal waters are covered in a separate NNB note.

B.2.3 Mixing zones

Mixing zones will need to be defined using modelling of varying complexity, depending on the extent that any substance exceeds the EQS or PNEC, or the temperature exceeds the defined targets. Guidance on mixing zones and the use of numerical models to assess mixing zones for NNB discharges is covered in a separate NNB note.

The extent and impact of any mixing zone will need to be considered at various scales in the information supporting the application, including the following:

- ▶ the overall area of any designated water body, eg, WFD water body, conservation area;
- ▶ current legitimate uses made of the receiving water such as recreational fishing, water sports, navigation, etc;
- ▶ the local area of designated habitats or conservation features;
- ▶ the local area of particularly sensitive conservation species or commercially exploited species, eg, oyster and mussel shellfisheries;
- ▶ the local area of fish- or bird-prey species in sites designated for birds and/or fish
- ▶ the local cross-sectional area of an estuarine or river channel (in relation to fish passage)

In the above list, local area should be defined and agreed in discussion with relevant conservation bodies. It will be very site-specific, and there is no specific criterion to define the extent of any local area in this context.

In addition, where a target includes a time element, usually as a percentile of time, then the modelling of the discharge will need to cover an appropriate timescale. This is particularly relevant to temperature and contaminants and parameters influenced by temperature, eg, dissolved oxygen. An appropriate timescale is a year, in order to include seasonal variations in air and water temperatures, and other climatic factors, eg, wind stress and light climate. Other significant variables that show seasonality include river flow, salinity, pH and tidal range, and the range of variation in these should be defined and considered in any assessment. As the climate varies between years, a representative (average) year should be defined from a number of years. An appropriate period in this context would be the preceding 10 years.

B.2.4 Other relevant impacts

B.2.4.1 General

The range of other impacts from the cooling water discharge is potentially extensive, but clearly is site-specific, depending on:

- ▶ the location and nature of any statutory international or national designations
- ▶ the location and nature of any protected species
- ▶ the location and nature of any local designations

in relation to the proposed discharge location.

Again, consideration of the potential impacts needs to include the effects of temperature, as well as the chemicals added to the discharge.

Designations in this context include both conservation designations, eg, SACs, SPAs, RAMSAR sites, SSSIs, etc, as well as water quality and other designations, eg, WFD water bodies, shellfish production areas, sensitive areas under the UWWTD, bathing waters, etc.

Marine licences for the construction and installation of structures below Mean High Water Spring (MHWS) tide level, eg, for an outfall, are obtained from the Marine Management Organisation. The Environment Agency is a consultee to these licences, and any impacts relating to the construction and installation of structures below MHWS will need to be considered in the context of these licences.

B.2.4.2 Biological aspects

The cooling water discharge can impact on a range of biological aspects, and there are also often critical times in the year for various biological processes. Biological factors that may need to be considered include:

- ▶ direct impact of temperature on selected species, both in terms of the average water and seabed temperatures and short-term extreme temperature events
- ▶ periods of fish migration (both adults and juveniles)
- ▶ migration patterns of significant bird- and fish-prey species
- ▶ reproduction and spawning of fish, shellfish and significant fish- and bird-prey species
- ▶ phytoplankton blooms
- ▶ critical periods in the larval development of the local populations of zooplankton and ichthyoplankton
- ▶ microphytobenthos productivity
- ▶ macroalgal and seagrass growth
- ▶ benthic invertebrate spat fall
- ▶ microbial processes both within the water column and the sediments
- ▶ contaminant uptake by macroalgae and benthic invertebrates

B.2.4.3 Water quality aspects

Certain water quality parameters are directly influenced by temperature, including ammonia speciation and the proportion of unionised ammonia and dissolved oxygen saturation. The impact of temperature on ammonia speciation and dissolved oxygen (DO) saturation should be quantified, and the resulting levels compared with defined targets for unionised ammonia and DO concentrations.

The pH may also be altered within the discharge, either through decreased CO₂ solubility or through the addition of chemicals. The potential impact of pH changes in the discharge needs to be addressed, particularly in relation to ammonia speciation.

Other factors that may need to be considered include:

- ▶ the salinity of the discharge compared with ambient salinities
- ▶ the impact of temperature, pH and salinity changes on the partitioning of contaminants between suspended sediments and the water column
- ▶ the partitioning of contaminants between bed sediments and the water column

It should also be borne in mind that there is an interaction between several of the biological and chemical impacts, eg, if primary productivity is enhanced through increased temperatures and nutrient loads, this may impact adversely on DO concentrations, as well as other biological processes.

B.3 Nuclear New Build – guidance on temperature standards and environmental permit requirements

B.3.1 Introduction

Water quality standards for temperature are needed to determine environmental permits that limit the thermal impact of cooling waters from new nuclear power stations on estuarine and coastal waters.

B.3.2 Regulatory background

The Ministerial Directions of December 2009 to the Environment Agency on water quality standards, (The River Basin Districts Typology, Standards and Groundwater threshold values (Water Framework Directive, England and Wales) Directions 2009)⁶, do not include statutory standards for temperature in estuarine or coastal waters:

Table 2 Temperature standards for rivers

Column 1	Column 2		Column 3		Column 4		Column 5	
	High		Good		Moderate		Poor	
River temp type	Non-cyprinid	Cyprinid	Non-cyprinid	Cyprinid	Non-cyprinid	Cyprinid	Non-cyprinid	Cyprinid
River temp (°C) as an annual 98 th percentile standard	20	25	23	28	28	30	30	32
Increase or decrease in temp (°C) in relation to the ambient river temp, as an annual 98 th percentile standard	2	2	3	3	-	-	-	-

However the Agency is also bound by the earlier River Basin Planning Guidance, Vol. 2 (August 2008)⁷, which included instruction for the Agency to comply, pending their formal adoption, with the draft UKTAG standards for temperature for rivers, lakes estuaries and coastal waters in making regulatory decisions. The UKTAG report on draft physico-chemical standards in the Chapter on Temperature (pp. 20 – 27)⁸ recognised deficiencies in knowledge regarding the impact on temperature and temperature change on the ecology of estuaries and coastal waters. It recommended use of the river standards in regulatory permitting pending information expected to be delivered through investigations needed in the first River Basin plans. This is repeated in the Defra River Basin Planning Guidance.

⁶ <http://www.defra.gov.uk/environment/quality/water/wfd/documents/river-basin-typology-standards.pdf>

⁷ <http://www.defra.gov.uk/environment/quality/water/wfd/documents/riverbasinguidance-Vol2.pdf>

⁸ http://www.wfduk.org/UK_Environmental_Standards/LibraryPublicDocs/UKTAG_Report_Surface_Water_Standards_and_Conditions

The Environment Agency has recently (June 2010) published a report on 'Cooling Water Options for the New Generation of Nuclear Power Stations in the UK'⁹. Section 6.3 addresses the effects of thermal discharges and section 6.3.2, repeated below, covers water temperature standards.

Water temperature standards

'The legal status of water quality standards for temperature applicable to the licensing of new nuclear stations is somewhat unsatisfactory at present. In the past, in the absence of national or European standards for ecosystem protection, temperature guidelines based on the European Freshwater Fish Directive have sometimes been used to provide ad hoc operational standards for estuaries and coastal water, but without legal standing. Also, the EC Shellfish Directive places a 2°C limit for a rise in temperature within EC-designated shellfisheries and this has sometimes been adopted as a standard for marine waters generally, although it is a guideline value only and is not enacted into English and Welsh law; the directive sets no imperative value for temperature. The UKTAG report on Surface Water Standards and Conditions (UKTAG, 2008) acknowledges, based on consultation responses, that: *"the power industry has pointed to the natural establishment and continued development of clam and oyster beds in transitional waters around the outfalls from power stations although temperature increases greater than 2°C are routinely observed"*, which casts doubt on the validity of this guideline. Further guidance was given under a Review of Consents for the Habitats Directive in which an interim 2°C uplift standard was adopted for marine special protection areas and marine special areas of conservation designated under the Habitats Directive.

Efforts have been made to make sense of UK temperature standards to meet requirements of the WFD. Following Department for Environment, Food and Rural Affairs (Defra) guidance, temperature rises caused by power stations will be assessed against draft WFD standards published by UKTAG¹⁰ (2008) on the requirements for coastal and transitional waters to have good ecological status. Table 3 lists maximum temperatures that should not be exceeded for more than 2% of the time (annual 98th percentiles) for each level of ecological status at the edge of a mixing zone. The two percent allowance takes account of the fact that the plume will spread for a short time around slack-water periods. Transitional and coastal waters will generally support runs or populations of cold-water species such as salmon, sea trout and smelt, and therefore the 'cold water' values apply and will be subject to a 98th percentile temperature limit of 23°C.

An additional requirement of the draft standards is that, outside the mixing zone, a maximum temperature uplift relative to background (ΔT) of +3°C is allowable, except for waters of high ecological status where a 2°C uplift limit is proposed.'

Table 3 Draft WFD standards against requirements for transitional waters to have good ecological status

Temperature (°C) (annual 98 th percentiles)				
	High	Good	Moderate	Poor
Cold water	20	23	28	30
Warm water	25	28	30	32

⁹ <http://publications.environment-agency.gov.uk/pdf/SCHO0610BSOT-e-e.pdf>

Executive Summary: <http://publications.environment-agency.gov.uk/pdf/SCHO0610BSOU-e-e.pdf>

¹⁰ United Kingdom Technical Advisory Group (UKTAG) for the WFD;

http://www.wfduk.org/UK_Environmental_Standards/LibraryPublicDocs/UKTAG_Report_Surface_Water_Standards_and_Conditions

B.3.3 Environment Agency requirements for thermal discharges to estuaries and coastal waters

- ▶ the Environment Agency will use the cold water draft UKTAG (WFD) standards as the basis for determining conditions for environmental permits for cooling water discharges from new nuclear power stations
- ▶ the temperature at the edge of the allowed mixing zone shall not exceed an annual 98th percentile of 23°C
- ▶ outside the mixing zone, a temperature uplift in the thermal plume above ambient background shall not exceed 3°C. In waters of high ecological status, the uplift shall not exceed 2°C
- ▶ in addition to the above draft WFD standards, other temperature standards may need to be considered in relation to conservation designations and specific conservation objectives
- ▶ the Environment Agency will consider evidence pertinent to the proposed discharge location provided by the applicant supporting different temperature standards, and may adjust its permitting requirements accordingly if persuaded by that evidence

Appendix C Technical guidelines for the identification of mixing zones pursuant to Art. 4(4) of the Directive 2008/105/EC



EUROPEAN COMMISSION

Brussels, 22 December 2010
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TECHNICAL GUIDELINES FOR THE IDENTIFICATION OF MIXING ZONES
pursuant to Art. 4(4) of the Directive 2008/105/EC

TABLE OF CONTENTS

1.	Executive Summary	6
2.	Definitions.....	6
3.	Introduction	8
4.	Proposed Approach	11
4.1.	Purpose.....	11
4.2.	Tiered Approach.....	11
4.3.	Tier 0 - Contaminant of Concern present?	12
4.4.	Tier 1 – Initial Screening.....	12
4.5.	Tier 2 - Simple Approximation of Mixing Zone.....	13
4.6.	Tier 3 - Detailed Assessment of Mixing Zone	13
4.7.	Tier 4 – Investigative Study (Optional)	13
5.	Acceptability	13
5.1.	Initial considerations and assumptions.....	13
5.2.	Key Questions	14
5.3.	Factors and assessments underlying acceptability of Mixing Zone extents	15
6.	Scientific and Regulatory Background to Mixing Zone Designation.....	20
6.1.	Regulatory Background	20
6.2.	Range of Factors	20
6.3.	Monitoring and Modelling	21
7.	Tier 0 Assessment	23
7.1.	Liable to Contain.....	25
7.2.	Is CoC >EQS?	27
8.	Tier 1 – Initial Screening.....	28
8.1.	Tier 1a Assessment - Inland Surface Waters (Rivers and Canals).....	29
8.2.	Tier 1b Assessment – Inland surface waters (Lakes).....	33
8.3.	Tier 1c Assessment-Other surface waters (Transitional)	34
8.4.	Tier 1d Assessment –Other surface waters (Coastal)	35
9.	Tier 2 - Simple Approximation of Mixing Zone.....	40
9.1.	Summary of approach	40

9.2.	Rivers	41
9.3.	Other Surface Waters (Coastal)	43
10.	Tier 3 – Detailed Assessment of the size of Mixing Zone	44
10.1.	Introduction to the needs for complex or detailed assessment.....	44
10.2.	Dealing with seasonal conditions.....	47
11.	Tier 4 – Investigative study (optional)	50
12.	Dealing with multiple discharges	53
13.	Trans-boundary pollution.....	55
14.	Strategies to reduce mixing zones.....	57
15.	Conclusions and Recommendations	59
16.	References	60

FOREWORD

The Water Directors of the European Union (EU), Acceding Countries, Candidate Countries and EFTA Countries have jointly developed a common implementation strategy (CIS) for supporting the implementation of the Directive 2000/60/EC, “establishing a framework for Community action in the field of water policy” (the Water Framework Directive). Focus is on methodological questions related to a common understanding of the technical and scientific implications of the Water Framework Directive. In particular, one of the objectives of the strategy is the development of non-legally binding and practical Guidance Documents on various technical issues of the Directive. These Guidance Documents are targeted to those experts who are directly or indirectly implementing the Water Framework Directive in river basins. The structure, presentation and terminology are therefore adapted to the needs of these experts and formal, legalistic language is avoided wherever possible.

Directive 2008/105/EC sets the environmental quality standards for the 33 priority substances in Annex X of the WFD and 8 other pollutants that were already regulated at EU level by Directive 76/464/EEC. Its article 4 introduces the concept of mixing zones, areas adjacent to the point of discharge where concentrations of one or more substances may exceed the environmental quality standard if they do not affect the compliance of the rest of the water body. Paragraph 4 requires technical guidelines for the identification of mixing zones to be adopted by the regulatory procedure without scrutiny. These guidelines respond to this requirement.

The current guidelines are the outcome of the work by a drafting group established in June 2008 by the Working Group E on Chemical Aspects working under the umbrella of the CIS. It builds on the input from a wide range of experts and stakeholders that have been involved throughout the procedure of Guidelines development through meetings and electronic media.

It should be underlined that according to Article 4 of Directive 2008/105/EC, there is no obligation for Member States to designate mixing zones. If they decide to do so, it is expected that they will follow these guidelines. However, a guideline, by definition, is not legally binding. In addition, there is a large variety of situations across the EU, and the guidelines have been written to cover the majority of those, but not all. Therefore, Member States may depart from it where necessary in order to ensure that the objectives of Directive 2008/105/EC are fulfilled.

Where Member States designate mixing zones, a description of the approaches and methodologies applied to define mixing zones and measures taken with a view to reducing the extent of the mixing zones in the future must be included in River Basin Management Plans. The guidelines will be applicable for the second River Basin Management Plan cycle and thereafter. The precautionary principle should be considered as a guiding rule.

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Why are these guidelines needed?

EQS Directive (2008/105/EC) Article 4(4) states that:

Technical guidelines for the identification of mixing zones shall be adopted in accordance with the regulatory procedure referred to in Article 9(2) of this Directive.

The mandate for these guidelines (see reference 16(27), page 30), agreed by Water Directors at their meeting of 24/25th November 2008, establishes activities on mixing zones in order to support the work on Priority Substances and therefore of the Common Implementation Strategy of the WFD (2000/60/EC).

The primary focus has been the development of these technical guidelines for the identification of mixing zones under Article 4(4) of the EQS Directive (2008/105/EC).

1. EXECUTIVE SUMMARY

Water quality in Europe has improved dramatically in recent years aided by the adoption of an underpinning philosophy to reduce, or where possible, eliminate pollution at source. At a European level, this so called “combined approach”, forms the basis for Water Framework Directive (2000/60/EC).

Compliance with environmental quality standards (EQS) is an essential part of this strategy and effluent discharge control regimes are normally designed to ensure that concentrations of polluting substances in the receiving water do not exceed the EQS. However if the concentration of the contaminant of concern (CoC) in the effluent is greater than the EQS value at the point of discharge there will be a zone of EQS exceedence in the vicinity of the point of discharge. Directive 2008/105/EC allows Member States to permit such zones of exceedence in water bodies when a number of criteria are met. Understanding these is important as it enables the Competent Authority first to identify whether this level of exceedence is acceptable for a proposed mixing zone and then to identify the appropriate location for monitoring points. These guidelines have been designed to assist Member States to complete this process using a Tiered Approach to provide an appropriate level of scrutiny. These guidelines should be used in the determination of mixing zones for substances listed in Annex 1A of Directive 2008/105/EC.

2. DEFINITIONS

(1) **Pollution:** Directive 2000/60/EC Article 2(33) specifies:

"Pollution" means the direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic

ecosystems, which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment.

(2) **Environmental Quality Standard:** Directive 2000/60/EC Article 2(35) specifies:

Environmental quality standard means the concentration of a particular pollutant or group of pollutants in water, sediment or biota¹ which should not be exceeded in order to protect human health and the environment.

(3) **Mixing Zone:** Directive 2008/105/EC Article 4 specifies:

1. Member States may designate mixing zones adjacent to points of discharge. Concentrations of one or more substances listed in Part A of Annex I may exceed the relevant EQS within such mixing zones if they do not affect the compliance of the rest of the body of surface water with those standards.

2. Member States that designate mixing zones shall include in river basin management plans produced in accordance with Article 13 of Directive 2000/60/EC a description of:

(a) the approaches and methodologies applied to define such zones; and

(b) measures taken with a view to reducing the extent of the mixing zones in the future, such as those pursuant to Article 11(3)(k) of Directive 2000/60/EC or by reviewing permits referred to in Directive 2008/1/EC or prior regulations referred to in Article 11(3)(g) of Directive 2000/60/EC.

3. Member States that designate mixing zones shall ensure that the extent of any such zone is:

(a) restricted to the proximity of the point of discharge;

(b) proportionate, having regard to the concentrations of pollutants at the point of discharge and to the conditions on emissions of pollutants contained in the prior regulations, such as authorisations and/or permits, referred to in Article 11(3)(g) of Directive 2000/60/EC and any other relevant Community law, in accordance with the application of best available techniques and Article 10 of Directive 2000/60/EC, in particular after those prior regulations are reviewed.

4. Technical guidelines for the identification of mixing zones shall be adopted in accordance with the regulatory procedure referred to in Article 9(2) of this Directive.

(4) Working Definitions

While the EQS Directive sets out options it does not provide a specific definition of “mixing zone”. In the absence of formal definitions the drafting group agreed working definitions to aid the development of these guidelines. The working definitions developed are:

¹

Directive 2008/105/EC sets EQS values for substances on the priority list. These values, when set in the water compartment, are deemed to provide protection in all compartments. These guidelines have therefore been primarily designed to provide mixing zone guidelines for water EQS values. However in those cases where the competent authority is required to consider mixing zones for biota or, (when available) sediment standards these should be considered on a case by case basis and may require immediate consideration at Tier 3.

"A **mixing zone** is designated by the Competent Authority as the part of a body of surface water which is adjacent to the point of discharge and within which the concentrations of one or more contaminants of concern may exceed the relevant EQS, provided that compliance of the rest of the surface water body with the EQS is not affected."

Where the guidelines adopt the term 'Mixing Zones', it may be necessary to assess the size of the mixing zone based on AA-EQS and/or MAC-EQS.

Contaminant of concern (CoC): In this document, contaminant of concern refers to the substances that are listed in Annex 1A of Directive 2008/105/EC. Please note that wherever this term is presented in square brackets [Contaminant of concern] or [CoC] it means concentration of contaminant of concern.

3. INTRODUCTION

Water quality in many surface waters across Europe has improved dramatically in recent years aided by the adoption of an underpinning philosophy to reduce, or where possible, eliminate pollution at source. At a European level, the so called "combined approach", forms the basis for Water Framework Directive (2000/60/EC - Article 10) and builds upon an approach that requires establishment of emission controls based on best available techniques (BAT) or setting of adequate emission limit values together with environmental quality standards. If an environmental quality standard requires stricter conditions to be met, more stringent emission controls shall be set accordingly.

First introduced under 76/464/EEC Dangerous Substances Directive² (DSD), the Environmental Quality Standards deliver a management platform to provide:

- The primary mechanism for setting quality objectives for water bodies
- The means of assessing compliance for such waters
- A basis for calculating permit conditions for discharges into such waters

Compliance with environmental quality standards (EQS) is an essential consideration, when deciding appropriate regimes for wastewater and effluent treatment. Discharge control regimes are normally designed to ensure that [CoC] in the receiving water does not exceed the EQS, but if the concentration in the effluent is greater than the EQS value there will be a zone of EQS exceedence in the vicinity of the point of discharge. Directive 2008/105/EC allows Member States to permit such zones of exceedence in water bodies when a number of criteria are met (see Section 2.3). Understanding these is important as it enables the Competent Authority first to identify whether this level of exceedence is acceptable before designating a mixing zone and then identify the appropriate location of monitoring points.

Look Out!

For those point source discharges that must comply with IPPC, implementation of best available techniques (BAT) is a prerequisite for the designation of mixing zones.

²

codified as Directive 2006/11/EC

Member States must apply the combined approach laid down in Article 10 of Directive 2000/60/EC and Directive 2008/1/EC. This means that measures, compliant with best available techniques (BAT), have to be taken. This is compulsory when BAT applies, regardless of whether or not mixing zones are designated. BAT for industry sector groups are described in the appropriate BREF-notes³. Moreover, more stringent emission controls than those resulting from application of BAT may need to be applied in order to meet the EQS⁴.

The Competent Authority must be satisfied that the relevant Water Framework Directive objectives for the water body set out in the River Basin Management Plan will be met, when establishing the acceptability of the extent of a proposed mixing zone. This includes having due regard for possible effects on protected or sensitive areas. It must be recognised that, dependent upon water body type, these considerations must include the potential for flow reversal and the buoyancy of effluents.

It is appropriate at this stage to consider the data that should be used to characterise the effluent and receiving waters when considering the extent of the mixing zone.

Clearly a harmonised approach is preferable, particularly as many water bodies in Europe cross international boundaries.

Mixing Zones, widely used since the 1980s, have both spatial and temporal dimensions, and may be affected by hydromorphological considerations. Physically, mixing will take place longitudinally, transversely and vertically in the receiving water and may also be affected by seasonal, meteorological or other temporal changes. Thus an appropriate level of consideration of the statistics (or probabilities) of frequency of possible EQS exceedence over space and time must be taken into account, in conjunction with spatial and temporal distribution of potential receptors, the variability of discharge and receiving water flow, and the quality of both emissions and the receiving water. In tidal waters⁵ there are additional complications - reversing flows, seasonality, waves and the potentially very large receiving waters involved.

The way in which a discharge mixes with the receiving water will be case-specific. For linear water bodies such as rivers (or narrow estuaries) complete mixing of a point source discharge over the cross section may, in some circumstances, take kilometres to achieve and in some cases where there is strong stratification it may not occur at all. In considering the acceptability of a mixing zone several other factors may play a role, like the presence of protected or sensitive areas. As an example, in case a mixing zone intersects with drinking water intakes, stricter quality standards than the EQS set in Directive 2008/105/EC are required in order to meet the drinking water obligations. In such a case the extent of the mixing zone should be reduced in order to respect the “drinking water protected area requirement”. Restriction of the extent of the mixing zone should also be considered if the exceedence of the EQS for substance in Annex A of Directive 2008/105/EC has a negative impact on sensitive area such as a spawning area for fish. In Paragraph 5.3 this is further elaborated. The potential for, extent, degree, duration and reversibility of any adverse effects within the mixing zone (e.g. on amenity value or on any of the quality elements of

³ available at <http://eippcb.jrc.es/reference/>

⁴ See Article 10(3) of WFD and article 10 of Directive 2008/1/EC.

⁵ This category includes those freshwaters that are subject to significant tidal oscillations.

2000/60/EC (Annex V)) are key elements in the decision making process. The aim should be to limit adverse effects in the mixing zone especially any acute impact from the discharge concerned.

Any new discharge may lead to increased concentrations of bound CoCs (as dictated by the substance specific partitioning which may vary with salinity, pH, temperature etc) either in the suspended particulate matter or sediment. Such solids will usually be transported away from the discharge point but may deposit locally if discharged in an accretion zone. In tidal areas or in seasonal flows a given location could be accretionary, eroding or neutral at different times. While being transported the suspended particulates will continue to interact with the aquatic phase which could lead to the possibility of re-partitioning, or the solids may change in nature (e.g. if flocculation occurs) both leading to changes in particulate phase substance concentrations. Once deposited, additional physical, chemical and biological processes come into play which can affect sediment phase concentrations and influence the bioavailability of the substance concerned.

A new discharge may also affect local sessile biota (depending on their location relative to the discharge plume) which may be exposed to higher aqueous phase substance concentrations leading, in some cases, to higher concentrations of that substance in the biota concerned. Mobile biota may be exposed to higher aqueous and particulate phase EQSs for only some the time. In some cases the movement of biota may be affected by the presence of the discharge but this is not always the case.

Thus, a permitted extent (expressed as any/ all of: length, width, cross sectional area, plan area or volume as it varies in time) of aqueous phase EQS exceedence should consider the potential for increased suspended particulate, sediment and biota phase concentrations both within and outside the extent of the mixing zone permitted in the aqueous phase. Furthermore where the CoC partitions readily into sediment it will be important to ensure that any discharge will not lead to a significant increase in sediment contamination to ensure compliance with Article 3(3) of Directive 2008/105/EC.

River Basin Management Plans should identify pressures from priority and other specific polluting substances, identify sources, and set out programmes of measures designed to reduce emissions of these substances. For priority hazardous substances, these should also include measures with the aim of ceasing or phasing-out anthropogenic emissions, discharges and losses (see reference 16(10)). In every case, justification must be given for the measures to reduce emissions of these substances from sources. Article 4 of Directive 2008/105/EC introduced the mixing zone concept for discharges of polluting substances into EU legislation. Effectively mixing zones will be restricted to the proximity of the point of discharge and must be proportionate, having regard to the concentrations of pollutants at the point of discharge and to the conditions on emissions of pollutants contained in the prior regulations in accordance with the application of best available techniques. In addition a description of the approaches and methodologies applied to define mixing zones and measures taken with a view to reducing the extent of the mixing zones in the future must be included in River Basin Management Plans.

Extensive research now provides a sound understanding of the hydrological and dynamic processes involved (see chapter 16.0 References on Modelling & Models) with a number of mathematical models widely available that predict effluent mixing. Some Member States have already adopted rules for designating mixing zones. Where appropriate these Guidelines use or provides reference examples of such models and rules.

The Competent Authority is responsible for the designation and development of mixing zones under Directive 2008/105/EC and will need to deliver a risk-based, proportionate approach such that all relevant factors are considered in appropriate detail. While a uniform screening approach can be provided that should allow efficient determination and administration of a large proportion of cases, the inherent complexity and variability of both discharge types and receiving waters across Europe means that in some instances simple solutions are not possible and this necessitates the derivation of case-specific acceptability criteria. A tiered approach has been developed to meet all such circumstances. In the following chapters the approach is set out to assist Member States in selecting an appropriate level of consideration.

Investigations and modelling in Tiers 3 and 4 may be expensive, and thus it may be appropriate for the Competent Authority and the discharger to reach agreement upon who will be responsible for the provision of data needed to complete the exercise, and also who will undertake the modelling required. At the later tiers industry may be required to provide data on the impact of the discharge on the environment.

4. PROPOSED APPROACH

4.1. Purpose

The purpose of these guidelines is to assist Competent Authorities to first establish where a mixing zone is required and to then determine its size and acceptability using a “tiered approach” designed to apply an appropriate level of detail and scrutiny.

When assessing acceptability of the proposed mixing zone, the Competent Authority must consider EQS compliance at water body scale, plus any specific issues, such as the protection of potable water supplies, and other sensitive areas. Where potential difficulties are identified, such that the discharge will not comply with these guidelines, the Competent Authority may also need to consider the exemption provisions of 2000/60/EC Article 4⁶ as part of the assessment, as long as all the conditions in these provisions are met.

The guidelines may assist Member States with the selection of monitoring points and thus inform the design of monitoring programmes in line with existing CIS Guidances (No’s 7 & 19).

These guidelines will apply under the provisions of Directive 2008/105/EC for the substances contained in Annex 1 Part A. However, the principles explored can be applied to National, Regional or local lists of Specific Pollutants under Annex VIII of Directive 2000/60/EC.

4.2. Tiered Approach

A “Tiered Approach” has been developed to document the policy decision tree that may be adopted by Member States when setting Mixing Zones under Directive 2008/105/EC. It provides a tailored solution with an appropriate level of detail in the form of schematic flow diagrams; these are set out in more detail in Chapters 7-11.

⁶ Water Framework Directive Article 4 provides the basis for setting environmental objectives but also includes important exemption provisions that set out the basis for:

- I. the relaxation of deadlines (Article 4 (4)) or
- II. less stringent objectives (Article 4 (5)) in cases where the improvement required is either technically infeasible or disproportionately expensive

At each tier the aim is to identify those discharges that do not give cause for concern, and also to highlight discharges that require action to reduce the size of the mixing zone. The Guidelines promote a uniform and soundly-based framework for such determinations to provide solutions which are:

- Efficient - resources are used only when necessary and then are commensurate with the environmental concern being addressed in line with a modern risk-based regulatory approach
- Robust - leading to sound reproducible decisions contributing to sustainable use of the aquatic environment
- Flexible - to meet the needs of Europe's aquatic environment.

The tiered approach may be summarised as follows:

- Tier 0 Contaminant of Concern present?**
- Tier 1 Initial Screening**
- Tier 2 Simple approximation**
- Tier 3 Detailed assessment**
- Tier 4 Investigative Study /Validation of the models**

Look Out!

Because BAT must be applied at all IPPC point sources, any reduction of the mixing zone for these point sources must involve measures beyond current BAT. This may trigger a disproportionate cost test as part of these considerations.

See CIS Guidance No.20 (Exemptions to the Environmental Objectives) for further information.

4.3. Tier 0 - Contaminant of Concern present?

Tier 0 is a high-level filter designed to identify the presence of discharges with the potential to cause EQS exceedance for CoC. As EQS values set in water are designed to ensure that compliance provides an adequate level of protection for all compartments of the water environment any effluent discharges that do not contain concentrations above EQS need not be further considered and will not therefore require the determination of a mixing zone.

4.4. Tier 1 – Initial Screening

Tier 1 is designed to establish whether the discharges identified in Tier 0 require further attention, and remove from further consideration those discharges that are trivial using simple tests. A set of precautionary filters allow the determination of acceptability of mixing zones associated with discharges so small that quantification of the extent of exceedance would be an inappropriate burden for regulators and stakeholders.

4.5. Tier 2 - Simple Approximation of Mixing Zone

The purpose of Tier 2 assessment is to eliminate those discharges that are clearly either acceptable or unacceptable on the basis of a simple case-specific assessment, using an initial indicative assessment of the size of the extent of EQS exceedence. A number of suitable tools are available commercially for this exercise - a reference list is provided in chapter 16.0. However, as an auxiliary tool for these guidelines, the Discharge Test software is provided in MS Excel Workbook format.

4.6. Tier 3 - Detailed Assessment of Mixing Zone

In complex cases a more detailed assessment may be required. Tier 3 provides this, often involving the use of computer-based modelling techniques, to consider the individual circumstances for the discharge (or groups of discharges) concerned. In this tier the approach required may be very much more sophisticated than that applied at Tier 2, with detailed consideration of the spatial and temporal variation in extent of EQS exceedence.

4.7. Tier 4 – Investigative Study (Optional)

If after assessment there is still uncertainty it may be appropriate to conduct investigative studies to validate the outputs, refine the approach taken or to characterise the actual impacts occurring within extents of EQS exceedence. Where such studies illustrate a potential discrepancy with predicted outputs it may be necessary to return to the appropriate tier and check/refine the approach accordingly.

N.B. Although presented here as Tier 4, investigative studies may also contribute in any of Tiers 0-3. If information is available it can be used and these Guidelines are not intended to deter gathering and use of relevant information to inform decisions.

Such studies may also prove useful in reviewing whether or not the extent of EQS exceedence is acceptable for an existing discharge. If extensive monitoring data is available, it may be possible to reach a decision using investigative studies alone. Field studies into the nature of the receptors adjacent to a proposed discharge location may have a role to play in allowing determination of whether or not the extent of EQS exceedence anticipated on the basis of the Tier 3 assessment can be regarded as acceptable.

Look Out!

The adoption of any investigative study is a matter for Member State discretion. It is not intended to introduce, and should not be interpreted as an attempt to require, additional monitoring.

5. ACCEPTABILITY

5.1. Initial considerations and assumptions

The WFD sets obligations on the results (i.e. the environmental objectives), not the means of achievement. It builds on existing Community legislation, in particular the IPPC directive 2008/1/EC and the Urban Waste Water directive 91/271/EEC, which establish minimum

emission controls for certain installations. Both directives, though, oblige to set more stringent controls in case required to achieve environmental objectives established under other legislation⁷. These two directives are included in the combined approach of WFD Article 10, which in paragraph 3 requires as well stricter controls in case it is needed to meet the environmental objectives in accordance with article 4 of the WFD.

In these guidelines it is assumed that the requirements of directives 2008/1/EC and 91/271/EEC are fulfilled before any consideration is given to the designation of mixing zones.

The obligation on the results means that the effort to achieve the environmental standards may vary greatly from one place to another. The impact on the environment of the same discharge into the open sea or an enclosed bay with poor water exchange may differ significantly. If there are several installations discharging a pollutant into the same water body the individual requirements for discharge may need to be stricter.

By allowing mixing zones Directive 2008/105/EC implicitly recognises that there are cases where the concentration of pollutants in the effluent is higher than the EQSs. Whenever effluent concentrations are higher, there will be an area around the discharge where concentrations will be higher than the EQS. The concentrations in the effluent may be higher than the EQS because it is not possible by technical means to reduce it further, or this would be prohibitively expensive.

While the mixing zone is, by definition, an area where the EQS is exceeded the EQS is established to ensure that the aquatic ecosystem is adequately protected. The establishment of mixing zones should be underpinned by the principle that preventive action should be taken and that environmental damage should as a priority be rectified at source and thereby aiming at limiting the spatial and temporal extent of the exceedance to the minimum possible.

When establishing mixing zones, particularly those in the most complex environments, careful judgement is needed to strike a balance between the need for more stringent emission controls and the size of the mixing zone. The designation of mixing zones should include the assessment of more stringent emission controls which are technically and economically feasible against the benefits in terms of reduced impacts on the environment.

In cases where the discharge jeopardises the achievement of the WFD objectives at water body level and there are no technically or economically feasible options to establish more stringent emission controls, the possibility to apply the exemptions in article 4 of the WFD may be carefully considered. Such exemptions may be applied only if all conditions set in the WFD are fulfilled.

Ultimately, in the most complex situations, case by case assessment will be necessary. The present Guidelines provide some elements that need to be considered in decision making.

5.2. Key Questions

The Competent Authority must first be satisfied that the relevant Water Framework Directive objectives for the water body set out in the River Basin Management Plan will be met when establishing the acceptability of the extent of a proposed mixing zone. This includes having due regard for possible effects on protected or sensitive areas and potential sediment

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See article 10 of Directive 2008/1/EC and Annex I.B.4 of Directive 91/271/EEC.

accumulation outside the mixing zone. It must be recognised that the criteria for determining acceptability will be case specific, may vary by tier, and be dependent upon water body type.

There are a number of questions that should be considered by the Competent Authority when assessing acceptability. These may concern the extent of the distribution in both time and space of the EQS exceedence:

1. **Proximity** - Is the extent of exceedence restricted to the proximity of the point of the discharge (concept applicable to each single point discharge) under 2008/105/EC?
2. **Proportionate** - Is the extent of exceedence proportionate having regard to the concentrations at the point of discharge and to conditions on emissions in prior regulations? (BAT etc) (Concept applicable to each single point discharge)
3. **Attainment of Good Chemical Status** - Does the extent compromise the attainment of appropriate chemical status for the relevant water body under 2000/60/EC (in particular Article 4), and 2008/105/EC, (in particular Annex I Part B).
4. **Attainment of Good Ecological Status** - Does the extent compromise the attainment of appropriate ecological status for the relevant water body under 2000/60/EC (in particular Article 4).
5. **Consistency** - Is the extent consistent with requirements adopted for other point source discharges under other Community legislation (e.g. 2008/1/EC) and interplay with 2000/60/EC and 2008/105/EC?

5.3. Factors and assessments underlying acceptability of Mixing Zone extents

The range of factors considered will vary and may be more extensive in the later tiers. It is thus impossible to provide the reader with a definitive list. This section provides a ‘checklist’ of factors from which the appropriate level of detail can be drawn depending on the specifics of the case in order to provide a robust evidence-based approach to decision making. It is important to acknowledge the variation in concentration distributions that may arise in practice.

Relevant factors and assessments include:

a. Characterisation of extents of EQS exceedence

Characterisation of concentration requires consideration of extents in two dimensions (2D) (horizontal or vertical) and/or three dimensions (3D) including all sources of variability that lead to variations of spatial extent in time. In many cases it is impractical and unnecessary to seek to cover all possible instances to build up robust statistics of concentration variation at all points (in 3D).

There are also potential deficiencies if one adopts a worst-case scenario, as there may be no unique ‘worst-case’ – different receptors may experience their highest exposure in different scenarios. Under such circumstances, care should be taken to ensure that the scenarios evaluated adequately reflect variation and hence are protective of the environment, whilst not imposing unwarranted restrictions on discharges, through compounding worst-case assumptions.

Often, an approach is taken whereby through discussion between discharger, regulator and stakeholders a set of cases (e.g. combinations of receiving water flows, discharge flows and concentrations, wind conditions, ambient concentrations, ambient stratification etc) is identified and modelling undertaken to quantify concentration distributions occurring. One important consideration will be the characterisation of extents of EQS exceedence in the context of the dimensions of and distribution of potential receptors (see (b) below) within the water body(ies) potentially affected, taking into account the 3D and temporal variation of the extent of EQS exceedence.

b. Identification of potentially affected receptors

A set of receptors, which may be affected by the discharge, should be identified. These might be drawn from designated area use and protection as well as interest features (bathing, boating etc.), drinking water abstractions, and areas indicated in the RBMP Protected Area Register etc. From this a number of particular locations of interest may be identified which may be representative (or protective) of receptor groups. Model output (and/or fieldwork observations) may usefully be linked to these locations. The need for identification of the specific potentially affected receptors occurring (or in some circumstances which would occur were the water body to be achieving its target objective) stems ultimately from the underlying definition of pollution (2000/60/EC Article 2[33]) in terms of harm (including impairment of ecosystems and uses of the environment) and from the specific WFD biological elements which contribute to the evaluation of ecological status.

In identifying the receptors, it is important to take into account the overall objectives of the WFD for the water body. The existing situation in the water body might be far from what the WFD expects in terms of diversity, distribution and abundance of species that are potentially sensitive to the pollutant discharged and therefore could qualify as receptors. Measures taken may bring back some species that need to be considered in the decision making. For example if a certain fish species is not present in the water body due to migration obstacles downstream which are expected to be overcome through the construction of a fish pass, the future presence of fish needs to be taken into consideration in deciding on the acceptability of the mixing zone. If higher plants or algae are not present due to hydromorphological modifications of the embankments that need to be restored to achieve the WFD objectives, the future presence of those WFD biological quality elements also needs to be taken into account.

There may also be a risk of sediment accumulation outside the mixing zone which should be considered.

Look Out!

Remember – For discharges near the boundary of two water bodies, potentially affected receptors may be located in the adjoining receiving water body (ies).

Look Out!

The Competent Authority must take care when setting mixing zones to ensure that the quality at any drinking water abstraction point is not compromised.

c. Identification of impacts occurring or anticipated to occur

By combining knowledge of the concentration distributions in space and time with knowledge of spatial and temporal distribution of receptors and their sensitivities to the substance(s) of concern, an understanding of the likely exposure and responses of the receptors to the discharged substances can be built. By definition, allowing an exceedance of the EQS, some ecological impact can be permitted to occur within a regulatory acceptable mixing zone. Furthermore, the variability occurring in the field may result in intermittent exposure of the receptors leading to a different response to that expected if continuously exposed to concentration at the long-term average. For some substances, concentrations at EQS and above in the field may produce avoidance responses in some motile organisms rather than lethal or sub-lethal organism level effects. In this case the ecological impact resulting could be denial of habitat rather than the end point assessed in the laboratory toxicity experiment. This sort of consideration is also relevant in considering the potential for impairment of migration of non-resident species. Some receptors may only be present seasonally at a time when ambient concentrations are low because of seasonal discharges or natural variations! Moreover, some receptors may not be present due to existing pressures that will be addressed under the WFD programmes of measures and therefore may be present in the near future and need to be considered.

Denial of habitat due to EQS exceedance could have detrimental effects on aquatic species populations with complex habitat requirements (e.g. specific larval settlement and recruitment sites, adult oviposition sites etc.) and thus may lead to local loss of populations and ecosystem integrity. Such cases may require detailed investigation.

d. Establishing the significance of an impact

This assessment encompasses all the relevant legal requirements for protection of receptors and takes into account, as appropriate, protection of organisms, ecosystem functioning, human health, protection of commercial interests, other uses of the environment etc and includes appropriate protection of the integrity of Natura 2000 sites, Protected Species interests and other aspects of the RBMP Protected Area Register etc. The extent (as measured in spatial and temporal terms) of the acceptable mixing zone may be dependent on the nature of the impacts that are anticipated or observed to occur within the proposed mixing zone. Thus, mixing zones where the predicted concentrations of CoC might trigger significant sub-lethal or lethal effects will be significantly smaller than mixing zones where effects are limited to minor sub-lethal or non-critical habitat avoidance responses⁸. The precautionary approach should always be kept in mind.

Considerations of whether or not the mixing zone is in 'proximity' to the discharge and 'proportionate' are relevant here and it is not possible to characterise these considerations in rigid, explicit spatial, temporal and statistical terms. In some cases (e.g. for some coastal or transitional water bodies) it may be self-evident that a region of EQS exceedance is both in proximity to the discharge and proportionate whilst the same sized region dimensions would equally self-evidently be unacceptable for a small estuary. When considering the acceptability of a single discharge it is also appropriate to review the significance of the ambient

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The establishment of separate guidelines on 'MAC-EQS mixing zones' and 'AA-EQS mixing zone' extents is a possibility but in practice the demarcation between the two may be unnecessary and a more holistic treatment for ecosystem and organism response and impairment of 'uses' may be more appropriate in the first instance. Where a MAC EQS is set at EU level explicit consideration may be necessary

concentration (being the combination of natural concentrations and modifications due to other anthropogenic sources). Thus, the extent of exceedence of EQS for a given load will be considerably greater if the ambient concentrations are close to EQS than if ambient concentrations are very low. Therefore when considering the designation of a mixing zone care must be taken to ensure that this does not prevent the water body as a whole from being classified within the objective of good status. How to deal with multiple discharges is further elaborated in chapter 12.0.

e. Natural background concentrations

For metals and their compounds Member States may choose to take natural background concentrations into account in line with 2008/105/EC Annex I Part B (3) (see reference 16(27), page 6). Establishing such values in individual cases and the precise manner in which natural background are taken into account falls outside the scope of these guidelines. However in some cases natural background may be the dominant contribution to an EQS exceedence. Background values may certainly be taken into account at Tiers 2-4⁹.

f. Establishment of Acceptability of EQS Exceedence Extent

The extent of EQS exceedence regarded as acceptable by the Regulator in a water body will depend upon:

- the spatial and temporal variation of the extent;
- the magnitude of increase of concentrations above EQS,
- and the resulting nature and scale of potential adverse effects associated with the exceedence.

If all anticipated impacts are deemed acceptable, the corresponding extent of exceedence of EQS concentrations may be accepted and the mixing zone designated.

In permitting the discharge the Competent Authority may choose (or be required) to set permit conditions to ensure that the discharge is operated in line with the range of emissions and ambient conditions assessed. In most cases it would be expected that the extent of the mixing zone would not be quantified in rigid spatial, temporal and statistical terms but rather implied through the restrictions imposed on the point discharge and their interplay with ambient conditions and processes.

Directive 2008/105/EC does not require Member States to record the extent of the designated mixing zones either individually or in combination – it requires Member States to describe the approaches and methodologies used to define such zones and to describe the measures taken with a view to reducing the extent of the mixing zones in the future.

In some cases, it is possible that a Competent Authority may deem a discharge to be acceptable because of measures in place within a RBMP which would affect the extent of other mixing zones or ambient concentrations occurring and without which the proposed mixing zone in question would be unacceptable. Whilst the factors affecting such

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More information on background concentrations may be found at Annex 17.5 and <http://www.gtk.fi/publ/foregsatlas/index.php>

determination would include those discussed above, wider WFD RBMP considerations would also be influential.

Overall for Tier 2 assessment purposes Competent Authorities may choose to use 'default' acceptable extent criteria in order to best focus available resources for screening purposes. Given the variability of European waters it is not possible to set default values applicable to all water body types. Competent Authorities may wish to set down their own values for screening purposes either by water body type, or by River Basin District or by a combination of the two. Alternatively, other Competent Authorities may feel able to apply screening methodologies using case by case extent criteria. Such precautionary extents could be set down with a degree of adaptation to water body extent 'built in'. For example, one such approach might be for rivers and narrow estuaries, with AA referring to annual average and MAC to maximum allowable concentration:

- for screening purposes an along stream AA [MAC] exceedence zone of ' $X_{AA} * W$ [$X_{MAC} * W$] m may be regarded as acceptable, where X_{AA} and X_{MAC} are numbers and W is the water body width (m).

There are some Member States, including Denmark, that apply a mixing zone with an extent only a small distance beyond the initial dilution zone. In coastal waters this is 50-100 m from the discharge point. In other member states the maximum extent of the acceptable mixing zone is proportionate to the width of the water body and limited to a chosen fixed maximum value. For example in the Netherlands for linear water bodies the maximum length (L) of the acceptable mixing zone for chemical substances is proportionate to the width of a water body and equals $10 * W$ (width) with a maximum of 1000 m. For coastal waters a maximum volume is used. For deep coastal water this corresponds with a length (L) of 150 m. In Austria for water bodies with up to 100 m width, L is limited to 1000 m, for water bodies with a width (W) larger than 100 m, L is set to $10 * W$.

In order to ensure that EQS exceedence does not impair the quality of the overall water body and to ensure that the extent of the mixing zone is restricted to the proximity of the discharge point, it is therefore recommended that a precautionary approach is taken at Tier 2 so that the extent of EQS exceedence in rivers that can be considered acceptable without further assessment should be the lesser of $10 * W$ (river width) or 1 kilometre provided that the extent of mixing zone does not exceed 10% of water body length overall. How to deal with multiple discharges is further elaborated in chapter 12.0.

6. SCIENTIFIC AND REGULATORY BACKGROUND TO MIXING ZONE DESIGNATION

6.1. Regulatory Background

The inherent complexity and variability of discharges and receiving waters across Europe will mean that, where Competent Authorities choose to adopt Mixing Zones, a tailored approach in their determination will prove beneficial.

While a large proportion of determinations will be made with minimal use of resources, the development of case-specific mixing zone acceptability criteria may still be required.

6.2. Range of Factors

Any effluent discharge may introduce a number of CoCs into the water body. Each may need consideration, and the range of factors considered will depend on the particular tier with more factors coming into play in each successive tier. However the mixing zone assessment is normally completed for the CoC where the ratio of Concentration: EQS is greatest.

A wide spectrum of circumstances will be encountered across Europe, from single discharges consisting of a few litres per second into minor fluvial waters only metres wide to multiple discharges of say $10 \text{ m}^3\text{s}^{-1}$ into coastal water bodies. Any point source discharge may introduce changes in the spatial and temporal distribution of substances in the receiving water. These result partly from the load of the discharge and partly from the modification of flows in the water body resulting from the discharge. This may change to some degree the local flows and also the mixing characteristics of the water body.

Once discharged the ‘load’ will disperse within the receiving waters and, depending on the substance concerned it may:

Biodegrade;

React chemically;

Partition between sediment and aqueous phase;

Volatilize, and undergo complexation or other changes.

These processes may affect the amount of the substance remaining in the aquatic environment, the distribution within that environment and its bio-availability to organisms.

For unidirectional flows the zone of influence of the discharge will extend some distance downstream though the downstream extent and cross-stream penetration distance of a given concentration isoline may vary considerably in time, e.g. as a result of variation in river flows, discharge flows and concentrations, wind, seasonal or diurnal variation in ambient concentration etc. In the case of discharges into waters with low ambient flows it is possible that the region of influence of the discharge may extend upstream.

For waters in which flows are not unidirectional, the location of the zone of influence relative to the point of discharge will vary with time. Hence the long-time average may ‘surround’ the

discharge point and be quite different to the concentration field occurring at any instant. Thus, the isolines and isosurfaces of concentration fields are inherently time-variable in ways that are case specific.

In Tiers 1 and 2, particularly where there is limited data available, it may be reasonable to assume ‘conservative’ behaviour for many CoCs (i.e. no decay or loss mechanisms occur) though the validity of such an assumption should be carefully considered within the context of the particular assessment. It may be appropriate to assume conservative behaviour for a substance with an aqueous phase half-life of several hours, when assessing the short-term plume but not when considering the possibility of the accumulation of such a substance in reversing tidal flows over a period of days.

6.3. Monitoring and Modelling

It is important to understand the strengths and weaknesses of monitoring and modelling exercises and bear these in mind when interpreting the outputs produced.

Monitoring: Whilst in principle the concentration distribution in the receiving waters can be measured at any location at any instant, the reality is that samples must be taken and sent for subsequent laboratory analysis. Monitoring programmes are typically limited to ‘spot’ samples at monthly frequency (see e.g. CIS Guidance no 7). Thus, information on actual distributions will necessarily be limited and the results from a monitoring programme will only approximate the actual annual average for comparison with an EQS value. An improved level of confidence may be obtained using composite sampling at a specific location to construct a sample representative of time-averaged concentrations at a location (at least for substances that behave conservatively), though as a result the time variation occurring at that location is lost. The best solution is to undertake continuous monitoring but this is so expensive that it may not be possible.

Modelling: In contrast, modelling may offer a continuous concentration prediction over space and time subject to a number of simplifying assumptions. For example, most operational models seek to predict the ensemble average concentrations (i.e. the average concentration occurring at a prescribed point in space and time that would occur in many instances of the flow field, i.e. ‘averaging out’ the turbulent fluctuations that occur in practice - see Rutherford J.C.(1994) p15. Whilst there are research models under development capable of predicting the probability density function arising from small scale turbulent fluctuations of concentrations, these are not yet suitable for use in practical regulation.

Any new model developments must be accompanied by an appropriate system of calibration and verification. Also, it has to be recognised that models will require a high quality of data input.

The fluctuation in concentrations occurring in the field should be borne in mind when interpreting the results of field observations. In the majority of cases sampling programmes will consist of relatively few samples of the concentration field and may not therefore characterise the range of turbulent variations actually occurring.

Monitoring Requirements

– *Programmes established under Directive 2000/60/EC*

WFD Article 8 provides the basis for the establishment of monitoring regimes that support the overall river basin planning process. Such regimes must provide a coherent and comprehensive overview of the ecological and chemical status within each river basin district. In summary surveillance monitoring provides a high level periodic review of the overall quality which in turn informs the development of the operational monitoring programme. The operational programme is used to establish the status of those bodies identified as being at risk of failing their objectives. Annex V provides guidance on the design of such programmes. In reality while the surveillance monitoring regime was designed to provide a periodic review of overall quality any of the WFD monitoring regimes may deliver additional data to inform the Competent Authority in their deliberations on mixing zones.

– *The selection of representative monitoring points:*

Under Annex V (1.3.2) member states must monitor (operational monitoring) water bodies which receive point source discharges containing priority or priority hazardous substances, and other water bodies identified as being at risk of failing their Article 4 objectives. For water bodies at risk from significant point source pressures sufficient monitoring points are required within each body in order to assess the magnitude and impact of the point source.

Decisions on mixing zones will be informed by monitoring data. Clearly the approach for existing discharges will differ (from that for a new or proposed discharge) because existing effluent or plume data will be available. In the latter case there will only be ambient data available.

Where a body is subject to a number of point source pressures monitoring points may be selected to assess the magnitude and impact of these pressures as a whole. The guideline monitoring frequency is monthly but may be amended to give appropriate confidence in the light of variability.

EQS Directive (2008/105/EC) requires that for each ‘representative’ monitoring point the arithmetic mean of observations should not exceed the AA-EQS. While the term ‘representative’ is not defined, the implication is that a water body is compliant with the EQS only if all representative monitoring points are compliant.

The question of what is representative cannot always be resolved through the development of rigid spatial extent criteria and may need to take into account:

- The three dimensional nature of the water body;
- The spatial and temporal distribution of its properties/receptors including biological physical and chemical elements.

In some cases, especially in larger water bodies where there is little EQS exceedence in either space or time, it may be clear that the water body as a whole is compliant even though one of the existing monitoring points happens to be located within an area of EQS exceedence. This may indicate that for the substance concerned the monitoring point is located within the mixing zone and may need further investigation. In such circumstances a pragmatic approach may be to declare that the monitoring point is ‘no longer representative’ for that (those) substance(s), though it may remain representative for others. Its retention may still be advantageous to continue trend analysis, particularly if that location is long-established.

Similar considerations apply in the case of a proposed new discharge that would not lead to the compromise of any other Water Framework Directive requirement but would be located at a point such that the mixing zone would include an existing surveillance monitoring point.

Further, let us consider a river water body where there are several point sources each that generate self-evidently small areas of EQS exceedence -when judged both in the context of the receiving water body extent and through the limited significance of the localised impacts associated with the emissions. It would be consistent with guidance on operational monitoring that the monitoring point be sited downstream of each of the individual mixing zones. At such a point the mixing would be such that there would be compliance with the EQS at the monitoring point, which would be deemed representative of the water body as a whole.

Look In!

Reference 16(27), page 8 for existing guidelines on ‘scale’

- Water body definition (CIS Guidance No 2)

7. TIER 0 ASSESSMENT

Tier 0 is designed to identify the presence of discharges made to the water body with the potential to cause EQS exceedence for CoC, and there are two main stages.

Firstly, a check is made to see if the discharge is “liable to contain” any CoC. If this is the case, then the second stage is to check whether the concentration exceeds the EQS. This may involve the introduction of monitoring, but it is important to recognise that a risk-based approach should be adopted in line with Directive 2000/60/EC and thus the guidelines do not require Member States to monitor every point source discharge for the entire suite of substances, but only those introduced by the process concerned.

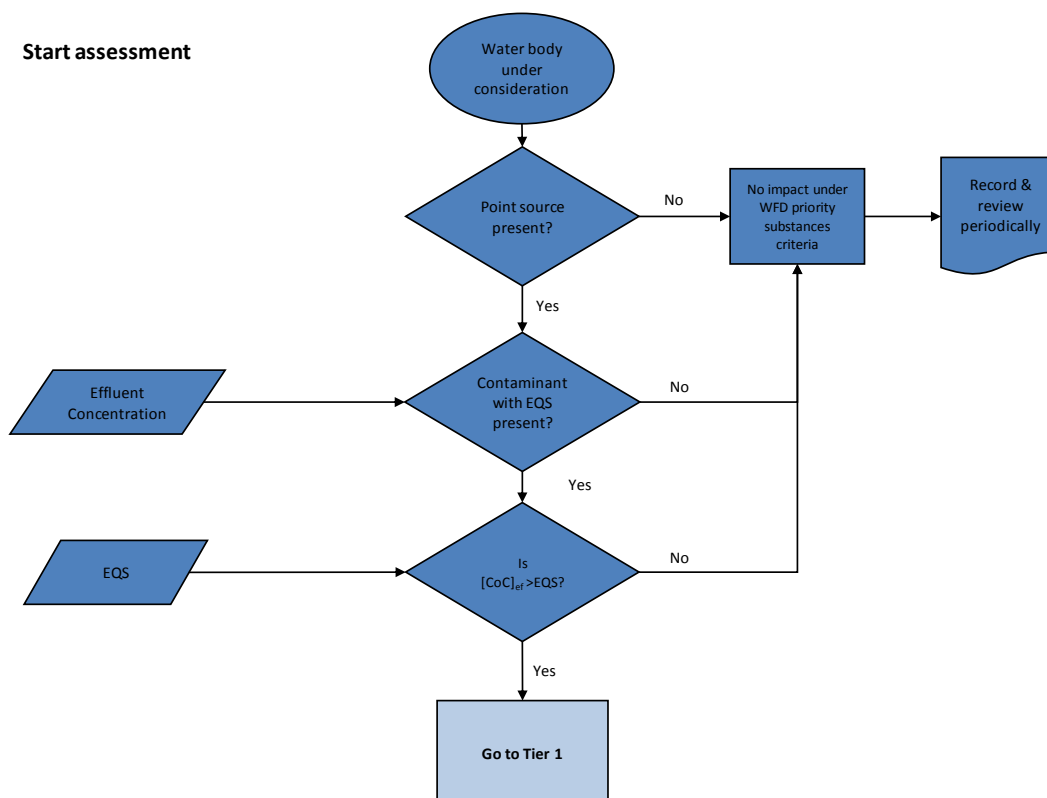
The chemical status of a water body is determined by procedures described in Common Implementation Strategy Guidance N^o7 (Monitoring under the Water Framework Directive). Where the results of such investigations demonstrate an exceedence of one (or more) EQS value(s) as defined in Directive 2008/105/EC, an investigation of all known discharges liable to contain CoCs may be required and the mixing zone procedure should be commenced. If there is no demonstrable exceedence, this is not necessary. However for new, or proposed, discharges such monitoring data will not be available. In these cases the Competent Authority should endeavour through dialogue with the discharger to establish the level of contamination present in the discharge to enable an initial assessment to be made.

In the Tier 0 schematic diagram, below, the box marked “Contaminants with EQS present” means that the discharge is liable to contain at least one contaminant of concern for which an EQS exists, a concept originally introduced under Directive 76/464/EC (See Section 7.1 below for more information).

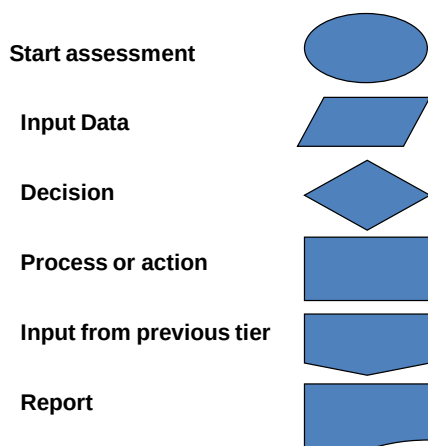
It must also be appreciated that an EQS is expressed as a concentration in a specific matrix against a specific return period (e.g. annual average), and thus the Competent Authority may

also need to consider the effluent statistics. For example if there are periods within the time period in which the instantaneous effluent concentration exceeds the EQS-MAC concentration, yet the annual average effluent concentration is less than the AA-EQS concentration the Competent Authority must use its discretion as to whether the discharge is passed through to Tier 1 or is screened out from further consideration at Tier 0.

Tier 0: Presence of discharge with EQS exceedance



Conventions Used



7.1. Liable to Contain

This concept has been developed to identify those discharges that contain substances at a discernible concentration sufficiently often that the identification of a mixing zone may be appropriate. **It is designed to obviate the need for additional monitoring wherever possible.** Considerable practical regulatory experience in the application of this approach has been established in Europe and for the purpose of these guidelines a discharge is 'liable to contain' a CoC if it is:

Test 1

- a) consented or otherwise allowed to be discharged into a sewerage catchment upstream of the discharge
- b) known to be added as a result of activities within the sewerage catchment upstream of the discharge;
- c) known to be added at the discharger's site;
- d) detected by chemical analysis, in the discharge, or within the sewerage catchment or process stream upstream of the discharge

This approach uses knowledge of the process or the circumstances of the discharge. These steps should not be carried out in sequence - They are 4 distinct routes by which a discharge may be regarded as liable to contain a substance. Thus if there were no grounds for believing a substance was present in the discharge there would be no grounds for carrying out the monitoring implied in step d. above.

Discharge monitoring for a substance might be required if:

- knowledge of the process (or the upstream sewerage catchment) was considered insufficient or;
- there were elevated concentrations of that substance detected in routine surveillance monitoring of the water body or
- operational monitoring in the water body suggested that the discharge of interest may be contributing to the elevated concentrations or
- prior knowledge of the pressures on that water body (including knowledge of natural processes) was insufficient to explain the elevated concentrations.

Thus, if:

- knowledge of the process or upstream sewerage catchment gives no reason to anticipate that a discharge would be 'liable to contain' a substance; and
- there is no water body monitoring that suggests the discharge may be contributing to elevated concentrations in the water body

then there is no reason to carry out monitoring of the discharge for that substance.

Furthermore if a discharge is not liable to contain a Substance under steps a, b or c above then the discharge will not be classed as liable to contain Substances under point d above where the discharger:

Test d1

- (a) discharges effluent to the same body of water from which it was originally abstracted, and
- (b) does not introduce any additional load of CoC to the abstracted water.

Thus simply re-introducing substances abstracted from the same water body does not constitute an emission for these purposes (e.g. one-pass cooling systems).

It is important to address the variability of emission concentrations in the context of whether or not a discharge concentration is reported above the level of quantification (2009/90/EC) for the regime. A discharge is liable to contain a CoC if any of Test 1 a-c is found true even if the substance is not detected in available monitoring in the discharge. However, in step d the discharge is regarded as liable to contain a CoC only if there is 95% confidence that the effluent concentration is above the level of quantification for 10% of the Assessment period¹⁰.

It is next necessary to consider the possibility that a discharge is liable to contain a substance but that there is high confidence that the concentration in the discharge is less than the value associated with the AA or MAC EQS (and therefore no reason to consider further the determination of a mixing zone).

Feeding into this test the box labelled 'effluent concentration' should include consideration of Test 1 steps a-d above (and the subsidiary Test d1). If step d is the effective one [CoC]>EQS should be interpreted in the statistical sense of 95% confidence.

The Competent Authority should also have regard to other information which provides sufficient confidence that although the discharge is 'Liable to Contain' a substance, there is high confidence that it would be at concentrations less than the relevant EQS for, a sufficiently high proportion of the time (say 90%). This information might include:

- effectiveness of inherent plant processes and/or emission abatement technology employed (e.g. water treatment plant for which relevant BAT Ref documents (European IPPC bureau - eippcb.jrc.ec.europa.eu) would be primary sources)
- historical effluent measurements for the effluent of interest and knowledge that there has been no relevant change of circumstances (e.g. feedstocks, process, sewerage catchment developments etc) which could lead to a change sufficient to increase effluent concentrations sufficiently
- knowledge of similar effluents (e.g. data from other plants/processes) sufficiently similar to the case of interest to give high confidence on effluent concentrations for the discharge of interest.

¹⁰

UK Environment Agency Guidance includes a table illustrating how many instances of detection are required from a given number of samples in order to establish a sound statistical basis. Advice is also given on the representativeness of the sample set.

- Relevant laboratory studies or materials characterisation studies.

Where a discharge is regarded as not liable to contain a substance or there is high confidence that although it is liable to contain the substance it would have effluent characteristics (i.e. statistics of concentration) such that determination of an associated mixing zone was not appropriate, the Competent Authority should record the position and take no further action with regard to mixing zones for that substance. Otherwise consideration passes to Tier 1.

7.2. Is CoC >EQS?

Before taking this decision it is sensible to consider the statistics of the test concerned. It is suggested that we should be sufficiently confident (say 90%) that the effluent concentration is above the AA-EQS or that the maximum effluent concentration exceeds the MAC-EQS.

8. TIER 1 – INITIAL SCREENING

Tier 1 is designed to provide a rapid estimate as to whether discharges identified in Tier 0 require further attention. It is designed to remove from consideration all discharges that are trivial using only simple tests.

The criteria used to differentiate between discharges with the potential to cause quality problems (that will consequently require the assessment of mixing zones), and those discharges that are not problematic are contained in reference 16(27) page 9.

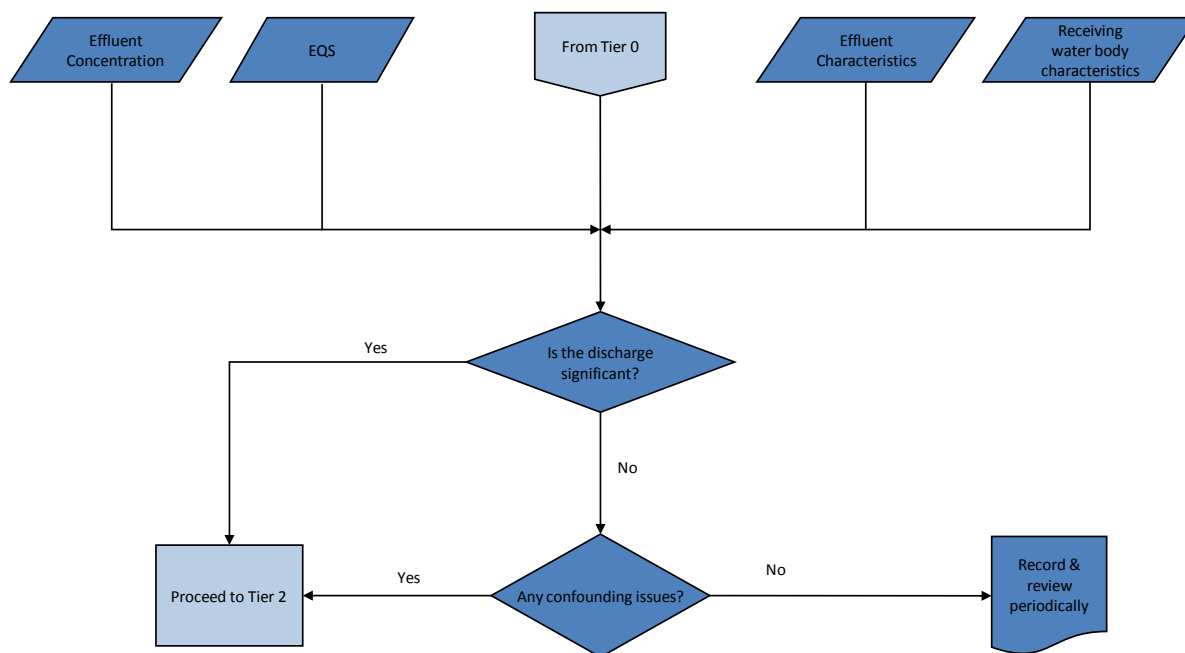
Four additional schematic diagrams have been produced for discharges to rivers, lakes, transitional and coastal waters. The tests for “other” waters must be different to those for rivers, as there may be effectively no (or only partial) physical restrictions on the extent of the water in which mixing takes place, or greater complexities of the hydrodynamics such as flow reversal, variability, etc.

The distinguishing feature of the Tier 1 assessment is that it is concluded without the need to evaluate in detail the extent of the EQS exceedence. Thus, it is sufficient to record that the Tier 1 process has been completed. No indicative spatial or temporal extent of EQS exceedence is necessary.

Significance Criteria

In the generic schematic below the Competent Authority is required to assess whether the discharge is significant. To assist in this appraisal a matrix has been prepared to set out values for a range of types and size of water bodies. It is clear from the study undertaken that the thresholds for canals differ from those for rivers. For this reason a separate approach for rivers and canals has been prepared (see reference 16(27), pages 9-13) in Table 8.0. This approach applies equally to both tidal rivers and fresh water rivers, where the allowable increase can be related to the net flow of the water body concerned. Reference 16(27), page 14 sets out predicted thresholds for lakes, but it is clear that mixing in lakes is not readily predicted by very simple models. Hence competent authorities are asked to apply the criteria for Tier 1 in lakes with caution, and where there are remaining doubts consider such cases in more detail at Tiers 2 or 3.

Tier 1: Initial Screening - Generic Approach



8.1. Tier 1a Assessment - Inland Surface Waters (Rivers and Canals)

Summary of assessment

The Tier 1a significance test for discharges to rivers is based upon the impact of the discharge after complete mixing. Background concentrations in the river are not considered in any detail at this stage. The action required is dependent upon the result of the test.

The competent authority should refer to Table 8.0 (and/or reference 16(27) pages 9-13) and if the contribution of the discharge to the EQS after full mixing (the process contribution) is less than the value for the proposed allowable increase in concentration, given for the appropriate flow band, then the discharge can be considered trivial with no further action required, regardless of the upstream concentration or the presence of multiple discharges.

Table 8.0 Proposed indicative 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 (Q90 flow) [m ³ /s]	Proposed allowable increase in concentration after complete mixing as % EQS ¹⁾ ²⁾ ³⁾
Fresh water 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

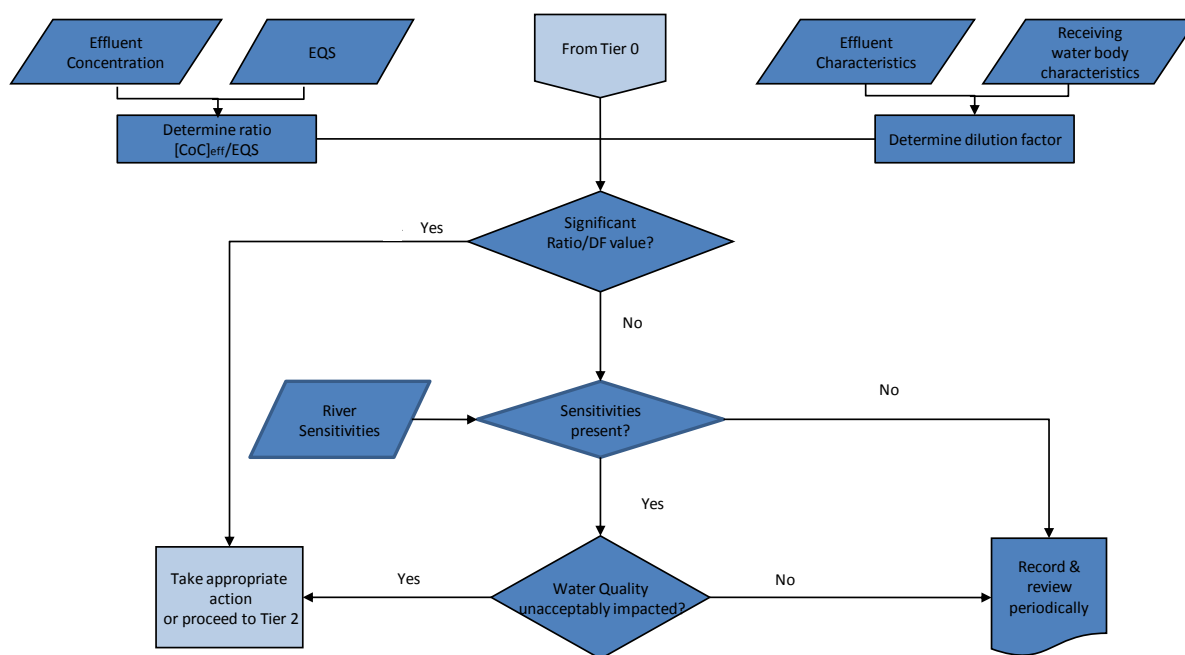
¹⁾ based on net flow

²⁾ if increase in concentration after complete mixing exceeds the percentage taken up in Table 8.0 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.

If the process contribution is above this threshold, then the discharge cannot be considered trivial and either appropriate action must be taken or consideration moves to Tier 2.

Tier 1a: Discharge to inland surface waters (River)



Calculating the Process Contribution¹¹

The Process Contribution (PC) is defined as:

$$PC = ([CoC]_{eff}/DF),$$

$$\text{where } DF \text{ (the dilution factor)} = (Q_{river} + Q_{eff}) / Q_{eff}$$

This test is applied to the AA-EQS only. Where maximum or 95%ile limits for the CoC are set on the discharge licence, then this is the value that can be used in the calculation. Otherwise, and if sufficient effluent quality data are available, the mean concentration should be used. The mean effluent flow and the Q90 river flow (flow exceeded for 90% of the time) should be used for this test.

(N.B. See also the section on dealing with seasonal drought conditions in Chapter 10.2).

The Significance Test in practice

The objective of the significance test in Tier 1a screening process (see diamond box “Significant Ratio/DF Value?”) is to determine the contribution of the discharge to the EQS after full mixing (the process contribution).

¹¹

The selection of the most appropriate value here is important as there may be certain circumstances where a considerable difference is observed between actual recorded concentrations and the appropriate permit condition. This may occur for a number of reasons including poor permit management, but for waste water treatment effluents this “headroom” may well reflect the fact that the design loading has not yet been reached.

If the increase in concentration after full mixing (Process Contribution) is less than % EQS value in Table 8.0 then the discharge is insignificant. However, before it can finally be accepted, a check should be made to determine whether there is the likelihood of an adverse impact on any sensitive area (the discharge would need to be direct or very close to the sensitive area concerned).

Where the upstream concentration is already near the EQS value, and in cases where multiple discharges are made into the same water body, depending upon the way in which the downstream concentration varies in response to additional discharges, river tributaries etc., the Competent Authority may wish to consider cumulative impacts of discharges, as a supplement to, or a replacement of, Tier 1a.

In such cases the Competent Authority may consider progression to Tier 2, or Tier 3, level assessment for the discharge under consideration, or may even undertake a wider consenting policy review throughout the catchment. Additionally the Competent Authority may require progression to Tier 2 because of the presence of sensitive areas.

Sensitivities present?

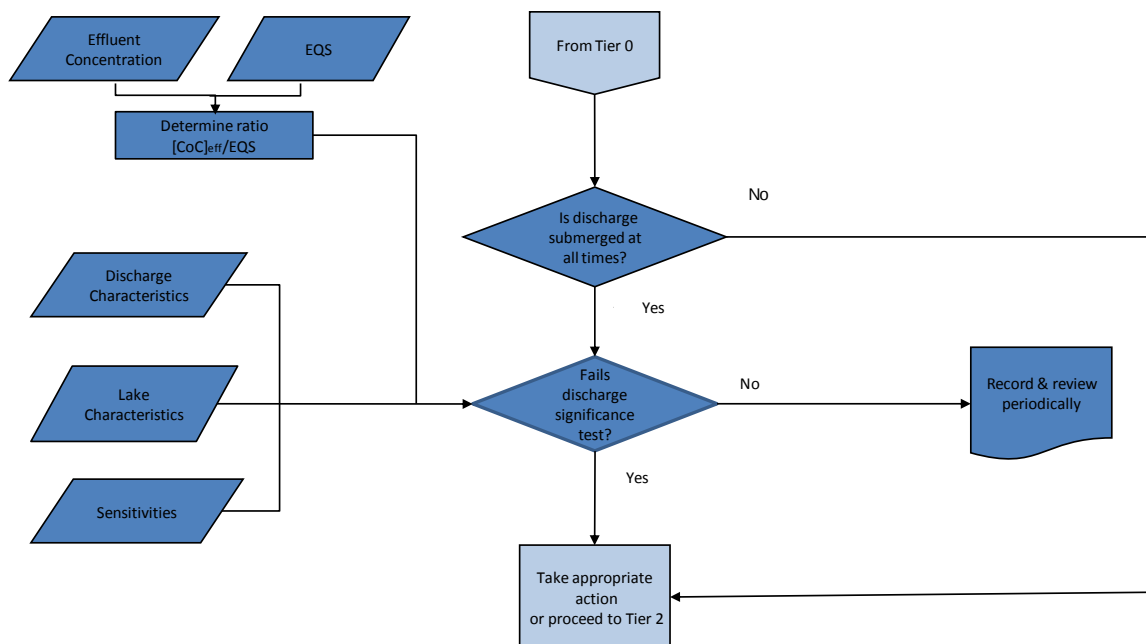
Where a sensitive receptor is identified (i.e. a receptor which is potentially affected by the CoC and for which the determination of significance of impact may be different to that of the water body in general because of the designating regulations) a modified procedure may need to be adopted.

There are two cases to consider:

- I. where the sensitive receptor occurs downstream of the point at which complete mixing occurs and
- II. where the sensitive receptor occurs upstream of that point, but downstream of the discharge.

Where the sensitive receptor is located below the point of complete mixing then the discharge should have no impact on that receptor and can usually be considered to be acceptable. Where the sensitive receptor occurs before the point of complete mixing, the case would normally be referred for consideration under Tier 2, unless, for example, the sensitive receptor is clearly not impacted as it lies on the opposite bank of the river (which means there is either no impact, or if there is an impact then complete mixing must have taken place).

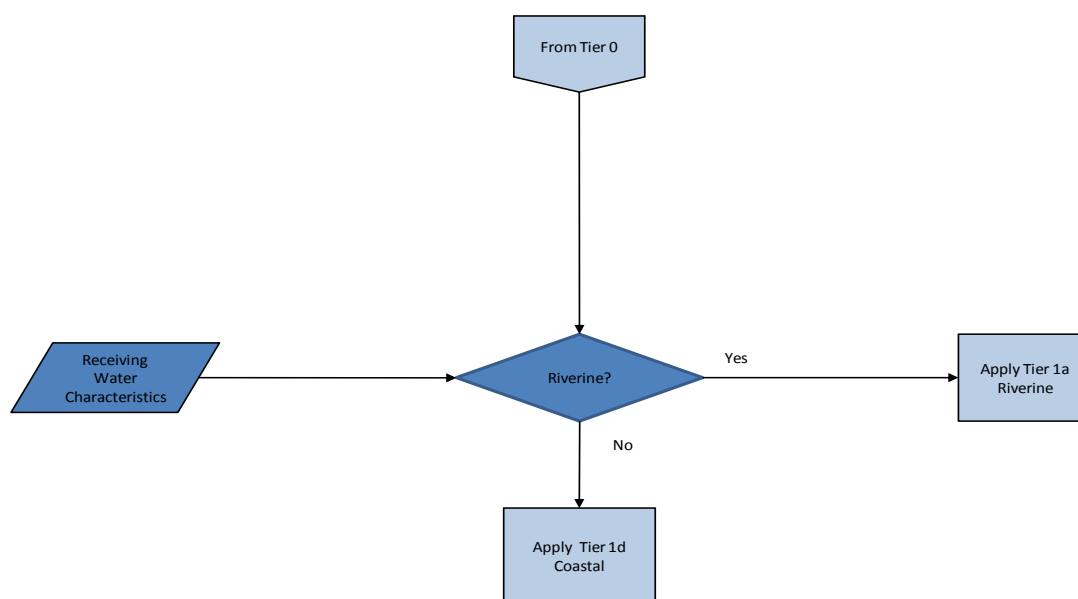
8.2. Tier 1b Assessment – Inland surface waters (Lakes)



In lakes the discharge arrangements and outfall provisions may present particular problems. If the discharge is not submerged at all times, then the nature and size of the mixing zone **must** be established.

Because of the difficulty in providing generic characterisation of flow and dispersion in lakes, it has only been possible to develop an indicative screening tool to support Tier 1b. This is provided in reference 16(27), pages 14-15. As stated above Competent Authorities are requested to use this test with caution, but it is clear that there will be some discharges of sufficiently small load into certain lakes whose associated extent of EQS exceedences can be regarded as acceptable without seeking to quantify the extent. In such cases the test given may assist the Competent Authority to make a judgement. Where the Competent Authority is unable to conclude acceptability on the basis of load alone, consideration should proceed to Tier 2.

8.3. Tier 1c Assessment-Other surface waters (Transitional)

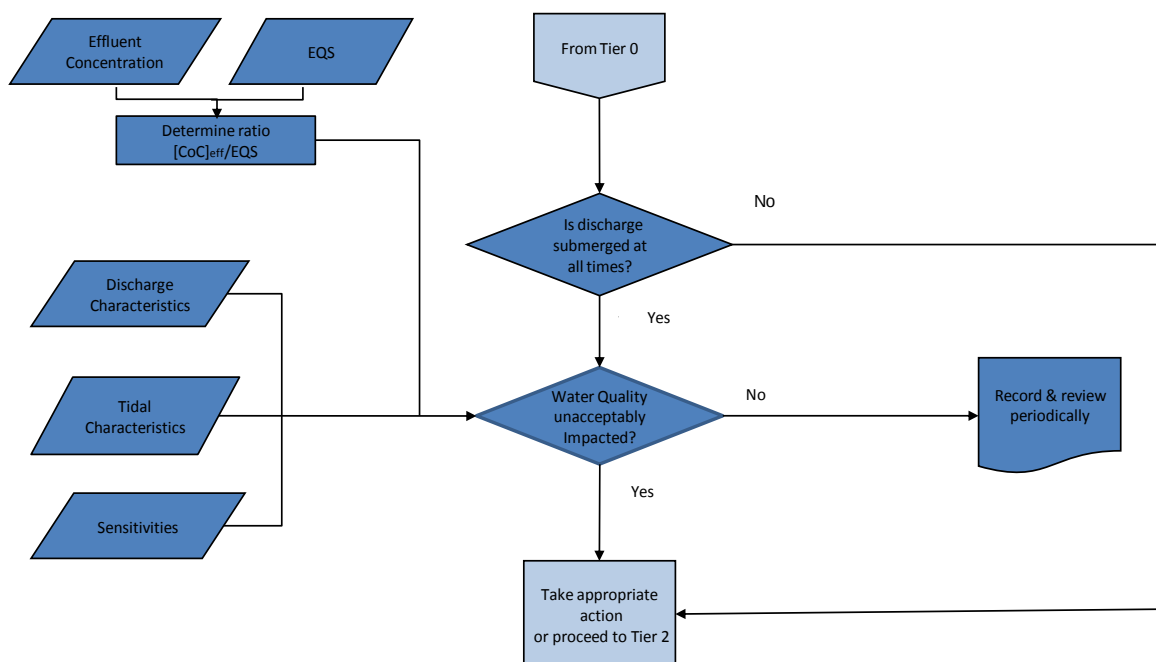


There may be a range of scenarios that must be considered in transitional waters. Depending upon local circumstances these may tend towards either the river or coastal water scenarios. If this tends towards a riverine water body then the thresholds given in Table 8.0 may apply but the decision may require local expert knowledge to establish the best course of action.

A simple and effective approach to Tier 1 for some estuaries may be to undertake the assessment based only on the freshwater flow into the estuary upstream of the discharge. This is conservative, as it ignores the additional mixing afforded by the tidal exchange, but offers a first-order assessment of significance. This approach should only be used for relatively narrow estuaries within which the flows are essentially rectilinear, even if they reverse on the flood tide. In these situations, one undertakes the assessment as if the estuary were a simple river using the total freshwater flows to the estuary upstream of the discharge point. The methodology in Section 8.1 can be followed without any further consideration of the impact of the tidal exchange.

If the estuary is not considered sufficiently 'riverine' to adopt the above approach, then one should either consider using the significance test for coastal waters outlined in Section 8.4, or move straight to Tier 2.

8.4. Tier 1d Assessment –Other surface waters (Coastal)



For simplicity, the text in this section refers to coastal waters only, but may be taken to include transitional waters (effectively estuaries) when it is considered appropriate. It provides a simple approach to assist the Competent Authority decide whether a discharge to coastal waters needs to be passed forward to Tier 2.

Coastal waters are inherently different to rivers. A river has a defined flow regime, and for a given discharge, once there is full mixing, then no further dilution can be achieved downstream (ignoring the influence of tributaries etc.). Tier 1 assessment for rivers is based on the contribution of the discharge to the concentration of the priority substance following full mixing. This is not possible for discharges to coastal waters, as mixing will continue, for all practical purposes, ad infinitum, and so a different approach has been developed, based on a simple approximate estimate of the size of the zone of EQS exceedence (mixing zone). This does not require actual calculation of the extent but is based on the “Effective Volume Flux” (EVF) which is the product of the discharge flow rate and the ratio [CoC]/ EQS.

There are four stages to the coastal waters test:

1. Check that the discharge is well covered at all stages of the tide and is ‘offshore’;
2. Check that the discharge is buoyant;
3. Simple significance test based on the EVF;

4. Check to see if EQS is exceeded after initial dilution.

Stage 1 - Is the discharge covered at all states of the tide?

If the discharge is not covered by a reasonable depth of water at all states of the tide, then the discharge may run undiluted across the foreshore or may mix immediately to the sea bed, and once in the receiving water the rate of dilution may be very low, leading to a mixing zone whose size and impact are out of proportion to the size of the discharge. For such a discharge, the nature and size of the mixing zone must be established, and the discharge should not be considered trivial at this stage, and must proceed to Tier 2.

Stage 2 - Buoyancy test

For many discharges to coastal waters, the effluent will be buoyant due to salinity and temperature differences between the effluent and the receiving water. If this is not the case then proceed to Tier 2, as the discharge may have a significant impact on the seabed.

Stage 3 - Simple significance test

The basis of the test is that buoyant discharges which are unlikely to have a mixing zone with a volume of more than about 2000 m³ can be considered to be insignificant, and can be accepted without further analysis. Such a mixing zone would be perhaps 200m long x 12m wide (max) and 1m deep. In the context of coastal waters, this is small. For example, a mixing zone with a volume of 2000m³ would represent just 0.04% of the volume of a small area of sea 1Km x 1Km x 5m deep. In addition, assuming the water depth is sufficient, then the mixing zone is likely to be entirely at the surface, not impacting on the sea bed at all.

The significance test for coastal waters is based on a simple approximation of the overall volume of the mixing zone, based on the Fischer equation. It should only be applied to discharges that are both buoyant and well covered at all stages of the tide.

The factors that affect the volume of a mixing zone, based on the Fischer equation, are:

- The flow rate of the discharge;
- The concentration of the priority substance in the effluent when compared to the EQS (CoC/ EQS), referred to from here onwards for simplicity as the “Ratio”;
- The receiving water characteristics (current speeds, dispersion characteristics).

A buoyant discharge will, after initial dilution, form a well-defined surface layer. Under the influence of currents in the receiving water, this mixed layer will then move down-current, developing into an effluent ‘plume’ that widens with distance from the discharge, due to horizontal mixing. It will also mix vertically, but for a buoyant discharge, this vertical mixing is generally much slower than horizontal mixing, which in the near-field is the principle mechanism for further dilution.

The test is based on the value of the Effective Volume Flux, or EVF. This is defined as:

$$EVF = Q \times ([CoC] / EQS) \text{ cubic metres/sec (cumecs)}$$

where Q is the effluent discharge rate (cumecs)

[CoC] is the concentration of the priority substance of concern in the effluent

EQS is the EQS (AA) of the priority substance of concern.

The size and shape of the mixing zone associated with a particular discharge will be (to a first order approximation) the same for all combinations of Q and [CoC]/ EQS which give the same value of EVF. Hence, a discharge of 0.5 cumecs with a Ratio of 10 will have the same size mixing zone as a discharge of 1.0 cumecs with a Ratio of 5. They both have an EVF of 5.0 cumecs.

For a given EVF, however, the absolute size of the mixing zone will vary with the receiving water characteristics. Taking a precautionary approach to mixing rates and current speeds (current speed of just 0.1 m/s), to give a mixing zone with a volume of about 2000m³, the EVF needs to be about 5.0 cumecs.

The significance test is therefore as follows:

If EVF ≤ 5.0 cumecs, then the discharge can be considered to be insignificant¹².

The exact statistics of Q and [CoC] to be used will vary depending on the data available, but the precautionary approach should be protected by ensuring that the value of Q.[CoC] that is used represents a high load, for example the 95%ile load. The test need only be carried out for the priority substance with the highest value of Ratio ([CoC]/EQS).

Stage 4 - Initial Dilution

If the discharge fails the simple significance test, then the next stage is to test whether the EQS-AA is met after initial dilution (ID). The tests are carried out in this order as the ID test is more complex, requiring more information regarding the discharge and the receiving water.

A buoyant discharge made at the seabed will entrain 'clean' water as it rises, due to turbulent mixing, and by the time it reaches the surface it will be diluted by a factor which is dependent on a number of variables:

- The discharge flow rate
- The density difference between the discharge and the receiving water
- The depth of the discharge below the surface
- The outfall characteristics
- The flow rate of the receiving water

The dilution achieved at the surface is known as the initial dilution. The instantaneous initial dilution can be easily calculated from the parameters listed above, and hence the achievement of EQS after initial dilution can be tested. If all EQSs are achieved after initial dilution, then the mixing zone can be considered to be acceptable, and no further assessment is needed.

¹² The maximum EVF for sheltered coastal waters such as those found in parts of the Baltic Sea may be significantly lower than 5.0 value given here and thus care should be taken in such cases

Comparison with the approach for rivers

The test for rivers is based on the size of the process contribution (PC) where:

$$PC = [CoC]_{eff}/DF \text{ (see section.8.1)}$$

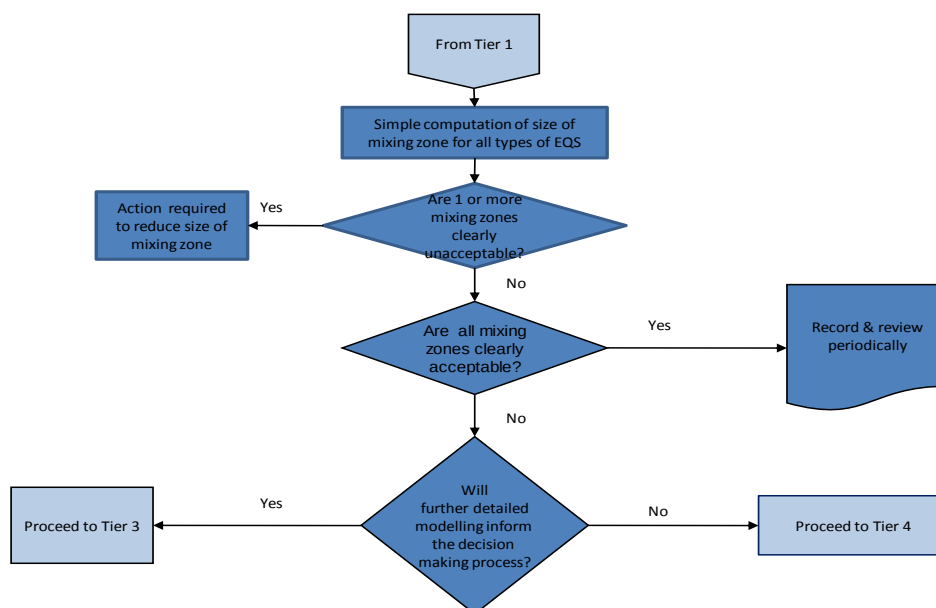
For a river, the allowable EVF in relation to the river flow rate varies as shown in Table 8.4 below.

Table 8.4: Tier 1 Screening - Comparison of the maximum allowable Effective Volume Flux (EVF) at different river flow rates with the maximum allowable EVF for coastal waters

Water type	River Q90 flow m³/s	Range of Maximum allowable EVF m³/s
Small River	0 -100	0.0 to 4.0
Medium River	100 - 300	1.0 to 3.0
Large river	>300	>1.5
Coastal Water shallow sheltered	-	0.0 to < 5.0
Coastal Water Exposed	-	5.0

This table shows that even for the very largest rivers, the maximum allowable EVF is less than that for open or exposed coastal waters, which is what we would realistically expect. Note however, that for a small river of 100 m³/s, the allowable EVF of 4.0 is quite similar to that for coastal waters.”

9. TIER 2 - SIMPLE APPROXIMATION OF MIXING ZONE



9.1. Summary of approach

At this stage the purpose is to eliminate those cases at the ends of the spectrum that are “clearly” either acceptable or unacceptable. Where the Competent Authority is unable to reach such a conclusion it is recommended that the investigation should proceed to the next tier. Such an approach will normally involve close liaison with the discharger to enable the provision of further evidence for consideration.

In contrast to Tier 1, this assessment includes an initial indicative estimate of the extent of EQS exceedence. This may be achieved using a range of tools such as The Discharge Test provided in these guidelines, simple spreading disc models, or commercially available packages such as CORMIX¹³, and PLUMES¹⁴. Where the term ‘Mixing Zones’ appears in the text it has been used to indicate that it may be necessary to assess the size of the mixing zone based on AA-EQS and MAC-EQS.

If any of the proposed zones are clearly unacceptable (i.e. a more accurate and detailed analysis will not change our view), then action to reduce the extent of the EQS exceedence is required. Clearly, the determination of what action may be appropriate could be informed by use of more sophisticated assessment, though that would be a matter for the Competent Authority (see also chapter 14.0 Strategies to reduce Mixing Zones in these Guidelines).

¹³

www.mixzon.com/

¹⁴

www.epa.gov/ceampubl/swater/vplume/

Conversely, if all the proposed zones are clearly acceptable, then the mixing zone may be defined as such without further effort and permit conditions may be determined for the discharge concerned.

In some cases the extent and variability of the indicated exceedence of EQS may be such that, with this level of analysis, it is not possible to be confident that the extent is acceptable or not. In such cases a further assessment taking into account more detail of the case-specifics is required (Tier 3).

Simple assessment methods for estimating the extent of EQS exceedence are illustrated in reference 16(27), section 3.3 to this document, where methods, based on the Fischer equations, are included.

However other computational models may serve the same purpose. A range of outfall induced mixing and plume mixing models exist, that cover a variety of circumstances. Competent Authorities may make use of any such 'simple computational engines' that they judge fit for purpose. In some cases Competent Authorities may have more sophisticated modelling or fieldwork available from similar cases elsewhere and, consideration of such information may be sufficient to give confidence that a determination can be made at Tier 2. The value of the Discharge Test tool, provided in these guidelines, is that it offers an easily used convenient mechanism suitable for screening purposes in a wide variety of circumstances.

In establishing the acceptability of the mixing zone, the Competent Authority should have appropriate regard to the ecological quality and functioning of the banks as well as the bed and water column of the water body.

In some cases careful design of the outfall arrangements so as to minimise the length L of the mixing zone may be desirable although this may depend on the nature and distribution of other receptors to be considered.

To assess the possibility of acute toxic effects in the mixing zone one must establish whether acute toxic concentrations may be realised in the near vicinity of the point of discharge. It is suggested that, where available, the MAC-EQS is used as the guideline value for this purpose. Where a MAC-EQS has not been set, achievement of the AA-EQS on an annual average basis¹⁵ will be sufficiently protective against short-term toxicity.

9.2. Rivers

For fresh waters with unidirectional flow the extent of EQS exceedence normally lies downstream of the discharge point (Figure 9.1) though in cases of buoyant or dense discharges in weak ambient flow (or should a discharge be directed against ambient flow) this may not be always be the case.

In some member states the extent of the allowable mixing zone is proportionate to the width of the waterbody and limited to a chosen fixed maximum value. For example, in the Netherlands the length (L) of the mixing zone for chemical substances is proportionate to the width of the water body and equals 10*W (width) with a maximum of 1000 m. In Austria for

¹⁵

This approach reflects decisions reached by CIS Working Group E. MAC-EQS values were not established for a number of priority substances - the reasoning being that the compliance with AA-EQS on an AA basis was judged to be sufficiently protective for both chronic and acute exposure NB this is different to simply using the numerical value of an AA-EQS as a MAC-EQS

water bodies with up to 100 m width L is limited to 1000 m, for water bodies with width larger than 100 m L is set to $10 \times \text{width}$.

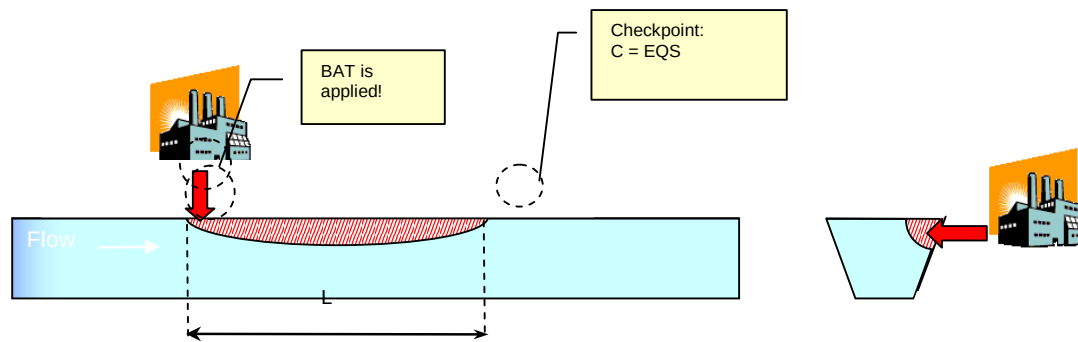


Figure 9.1 Mixing zone in flowing waters

In order to ensure that EQS-exceedence does not impair the quality of the overall water body, it is therefore proposed that at Tier 2 the extent of EQS exceedence should be restricted to the lesser of $10 \times W$ (river width) or 1 kilometre provided that this does not exceed 10% of water body length overall.

Where a water body contains multiple EQS exceedences, the interaction of these discharges should be considered. Note that this is distinct from simple juxtaposition of the individual mixing zones since the individual extents of EQS exceedence will be correlated. For example, in a unidirectional river at times of high flow (and increased water depth too) discharge plumes may be strongly deflected whilst at lower river flows the discharge plumes may penetrate further across the river depending on the discharge arrangements. Similar considerations may apply in stratified water bodies where discharges occur at different depths and buoyancies.

At Tier 2 one acceptability impact assessment that may be carried out is the potential impact of the discharge on the migration of fish species. By comparison of the discharge plume concentrations in cross section with the overall cross section available it may be possible to demonstrate that fish migration success will not be impaired. However, in such cases care must be taken to ensure that the appropriate quality and flow data are considered as the EQS may **not** have been based upon toxicological data for fish. Furthermore migration may occur only at certain times of the year with resulting flow statistics being different to the annual statistics. In complex cases such an assessment may be better regarded in Tier 3.

9.3. Other Surface Waters (Coastal)

In the north and west of Europe, open coastal waters are tidal with well-defined flow and level variations typically semi-diurnal in nature but modulated on an approximately two week period (the spring-neap cycle). Flows may be vigorous, leading to significant vertical and horizontal mixing, and typically will reverse but the combination of tidal forcing and local bathymetry leads to well-defined residual currents which result in the net transport of discharged substances away from the discharge location in the medium and long-term. Meteorological effects (pressure systems, wind stress, wave effects) and density currents may perturb, influence significantly or in locations where the tidal forcing is naturally weak (near amphidromic points) even dominate the tidal forcing in the short, medium or long-term.

In reversing flows there is the potential for long-term build up of the emitted substances with the long-term field magnitude and extent being determined by:

- The source volume flux and concentration
- The occurrence, magnitude and direction of residual flows
- The short-term flows (tidal and meteorological related)
- Mixing induced by the short-term flows

In many coastal water cases the timescale for vertical mixing may be relatively short (perhaps 1 or 2 days) and the long-term field may be considered to be well-mixed vertically.

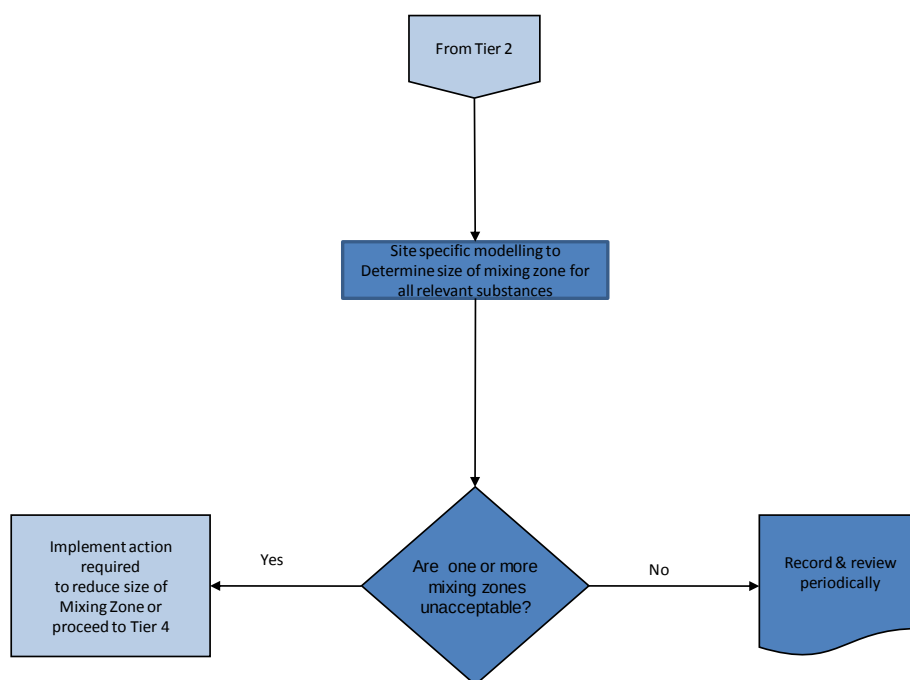
Superimposed on the long-term field is a short-term ‘plume’ in which vertical mixing is not complete within which the initial dilution of the effluent (as influenced by the outfall characteristics) occurs followed by initial mixing with receiving waters. In the plume, density differences between the plume and receiving waters may be important for the mixing processes (e.g. freshwater into saline water, effluents with raised temperature into cooler waters etc). Positive buoyancy will tend to enhance lateral spreading at the water surface but restrict vertical mixing. Thus, the ecological impacts associated with the plume will depend on the outfall and effluent characteristics.

Elsewhere in Europe (e.g. Mediterranean), tidal forcing is weak and coastal flows are defined by seasonal meteorological systems and/or density currents but may be modulated by short-term meteorological effects (e.g. diurnal sea breeze cycle, storm systems etc). In such circumstances the ambient flows may be essentially unidirectional in the short and medium term although seasonally there may be changes in direction. In such circumstances discharged substances will be transported away with the unidirectional current though there is essentially no bound to the offshore mixing. If currents do not reverse, there is no possibility of the build up of a long-term field but the flow related mixing will tend to be weaker than that occurring in tidally reversing flows. As previously, the nature of the initial dilution and buoyancy of the plume may significantly influence the plume dynamics. In many coastal waters the plume phase may lead to a subsequent ‘far-field’ phase in which vertical mixing is complete, the plume is attached to the shoreline but continues to mix and spread further offshore.

Should stratification occur in deep waters (e.g. fjords) special consideration is likely to be required (Tier 2 or Tier 3 assessment).

In all of the above, the dilution factor (DF) can be extremely variable in both space and time.

10. TIER 3 – DETAILED ASSESSMENT OF THE SIZE OF MIXING ZONE



10.1. Introduction to the needs for complex or detailed assessment

Where the simple appraisal conducted in Tier 2 leaves a measure of uncertainty, Tier 3 provides a detailed modelling based approach to consider the individual circumstances for the discharge (or groups of discharges) concerned. Here the modelling approach required may be very much more sophisticated, resulting in a detailed assessment of the spatial and temporal variation in extent of EQS exceedence. Competent Authorities should be aware that the availability of good monitoring and effluent assessment data is critical for both model verification and in deriving model input parameters. Investigations and modelling in Tiers 3 and 4 may be expensive, and thus it may be appropriate for the Competent Authority and the discharger to reach agreement upon who will be responsible for the provision of data needed to complete the exercise, and also who will undertake the modelling required. Industry may be required to provide data on the impact of the discharge to the environment at these later tiers.

The tiered assessment is designed to provide successive levels of screening to facilitate the determination of the acceptability or otherwise of proposed mixing zones (extents of a water body, related to areas, volumes, linear dimensions etc., where there is exceedence of EQS values). The criteria applied are designed to allow decisions to be made with the appropriate level of detail and scrutiny, whilst minimising assessment and regulatory effort.

Where assessments reach Tier 3 it is because the relatively simple screening thresholds and modelling approaches of Tiers 0-2 have failed to enable a decision to be made with sufficient confidence that a mixing zone is acceptable or not. Given the nature of such screening approaches, which are designed to avoid the risk of erroneously permitting a potentially harmful mixing zone, it is clear that there will be many circumstances in which a potentially acceptable proposed mixing zone cannot be permitted through use of Tiers 0-2 alone. Thus, progression to Tier 3 should not convey a presumption of likely ‘unacceptability’, merely that the circumstances are such that more detailed assessment than that in the screening approaches of Tiers 0-2 is required. The Competent Authority will need to consider more carefully on a site-specific basis a multiplicity of factors in the receiving environment and possibly the characteristics of the discharge in order to determine the acceptability or otherwise of the mixing zone. In Tier 3 it is expected that the Competent Authority, discharger(s) and relevant stakeholders will contribute to the definition of the scope of the study for site-specific Tier 3 assessments.

In Tier 3 the modelling approach required should be more sophisticated than in Tiers 1 and 2, resulting in a more detailed assessment of the spatial and temporal variation in the extent of EQS exceedence. This may include consideration of a wider set of cases (considering a wider range of combinations of receiving water flow, quality, density, mixing, and effluent characteristics etc., than undertaken at Tier 2) using the same modelling technique enabling more robust conclusions to be drawn than was possible in Tier 2. However, it could also include a change in modelling technique (e.g. increase in model dimensions, introduction of time varying modelling, more sophisticated representation of the mixing and decay-dispersion processes), it could include use of physical modelling (i.e. laboratory scale physical models of the mixing occurring). In parallel with this change, it may also be that the modelling has been better calibrated/validated against field data to allow increased confidence in results compared with that available in the Tier 2 assessment.

As a consequence, even within Tier 3 there may be levels of iteration and the need to consider greater levels of complexity, ranging from modelling based on simple worst case assumptions through to a more dynamic approach that considers greater complexity in the variability of discharges and associated receiving waters. In the schematic diagram this is effectively contained within the box “Site specific modelling to determine the size of the mixing zones for all relevant substances”. The required level of detail of the modelling is indeed site/case specific and it is not possible to prescribe particular model types to be applied in all circumstances.

Assessment methods are worked in reference 16(27), page 24 to this document, based upon Fischer equations.

It must be remembered that while these span a vast range of possible complexities, other approaches, such as physical modelling could be appropriate in some cases. In general, the level of complexity of modelling should be the simplest that permits sufficient confidence in the decision being made about the acceptability of a mixing zone. In practice the techniques used, and the way in which their fitness for purpose is evaluated, should be agreed between the Competent Authority, the discharger, and relevant stakeholders, during the course of the study.

In view of the inherent complexity and variability of discharge types and receiving water circumstances across the water bodies of Europe, it is not considered possible to set rigid

prescriptive limits on permissible extents of EQS exceedence to underpin the decision diamond in Tier 3 termed:

‘Is 1 (or more) of the mixing zones unacceptable?’

Competent Authorities should tailor their approach to acceptability by allowing consideration of all the relevant factors such as:

- The spatial (3d) and temporal extent of the regions of EQS exceedences (from the tier 3 extent assessment) including appreciation of the statistical variability occurring
- The nature and extent of the receiving water, its varying hydrodynamics and ambient chemical and physico-chemical quality
- The locations of the water body boundaries
- The distribution and statistics of concentrations within the regions of EQS exceedences
- The distribution of receptors within the receiving waters with particular regard to the distribution of receptors within the extent of EQS exceedences and Protected Areas
- The sensitivity of the receptors to the substance(s) of interest
- The anticipated impacts within the extents of EQS exceedence
- The significance of the anticipated impacts with particular regard to the ecological and chemical objectives set for the water body (ies) of interest through the RBMP process in line with all provisions of Article 4 of Directive 2000/60/EC.

Whilst these factors may contribute at all levels, the way in which they are represented, characterised and subsequently used in a quantified or semi-quantified manner may be very different to that in Tier 3, where improving confidence in the uncertainty ranges for some of the factors may be important since the assessment will tend towards the ‘real case’ rather than ‘worst case’ assumptions.

For AA - EQS values it is possible to estimate the long-term average position of the EQS-isosurface/isoline, and isosurface/isolines for other concentrations. For MAC - EQSs it is important to recognise that at least two distinct types of extent that may need to be considered by Competent Authorities. Firstly there will be an instantaneous concentration field that will define a boundary of the extent of exceedence of the MAC - EQS. The relative size of this instantaneous mixing zone to that of the water body may give some indication of the area/volume exposed to potential short term impacts at any one time. As the mixing zone moves, e.g. from flood tide to ebb tide, over different lunar and seasonal cycles, and for varying meteorological conditions a much larger area/volume may be determined where the EQS may be exceeded, but for perhaps only short periods during a year. This may be of particular interest if this area extends over protected areas or particularly sensitive areas of concern.

10.2. Dealing with seasonal conditions

It is clear that Europe embraces a wide range of climatic conditions. In some circumstances such conditions may impact on mixing arrangements, such that very different scales of mixing may be encountered. Where difficulties are identified, such as drought periods, temporary streams or freezing conditions, the Competent Authority may also need to consider the exemption provisions of 2000/60/EC Article 4 as part of the assessment, as long as all the conditions in these provisions are met.

In the event of drought conditions, the available dilution in a receiving stream may be greatly diminished, or cease to exist altogether, perhaps for several months of the year. In such circumstances it will prove impossible to adopt a mixing zone approach and remain compliant with the directive as the receiving water may consist solely of the treated effluent. This may apply as well to the case of temporary streams, in particular in the Mediterranean area, which dry every year for natural causes. These situations may require careful consideration on a case by case basis using EQS as a potential starting point for setting permit conditions.

There may be some merit in the development of seasonal permit conditions if such occurrences take place on a regular basis.

Seasonal permit conditions may also be appropriate in other parts of Europe, such as Scandinavia, where low winter temperatures cause rivers and lakes to freeze. One such case in a Finnish lake is illustrated below:

The mixing mechanisms at Suur-Saimaa (see reference 16(8)) are unusual and affected by hydrology, morphology, seasonal variations and the density difference between effluent and lake water. In summertime, warm wastewater from pulp mills near Lappeenranta and Joutseno are found at the surface and mix along the south coast of the lake, although winds can occasionally move them to the north. However during the winter months, the waste water from Joutseno Pulp is warmer and heavier than the waters arriving from west from Kaukaa mills. Kaukaa waters then travel in surface layers while the Joutseno Pulp waste waters sink down to flow close to the bed of the lake, past and north of Päihänniemi, about 20 km against the natural current (flow rate 600 m³/s) in the lake. The depth profile of the lake bottom is important in understanding the phenomenon (Figure 10.2).

Such dramatic changes illustrate admirably the often complex reality of assessment and calculation of mixing. This study exemplifies how entirely natural processes can impact upon the process of mixing and necessitates the development of a flexible regime.

In our example the understanding of the mixing zones has been developed through an extensive programme of monitoring and research. However in the case of a new discharge it may be necessary to undertake predictive modelling exercise to assist the River Basin Management Team to compute the dilution of underflow in such a stratified lake (see reference 16(9))¹⁶.

¹⁶

Mixing in Inland and Coastal Waters Fischer et al 1979 ISBN 0-12-258150-4

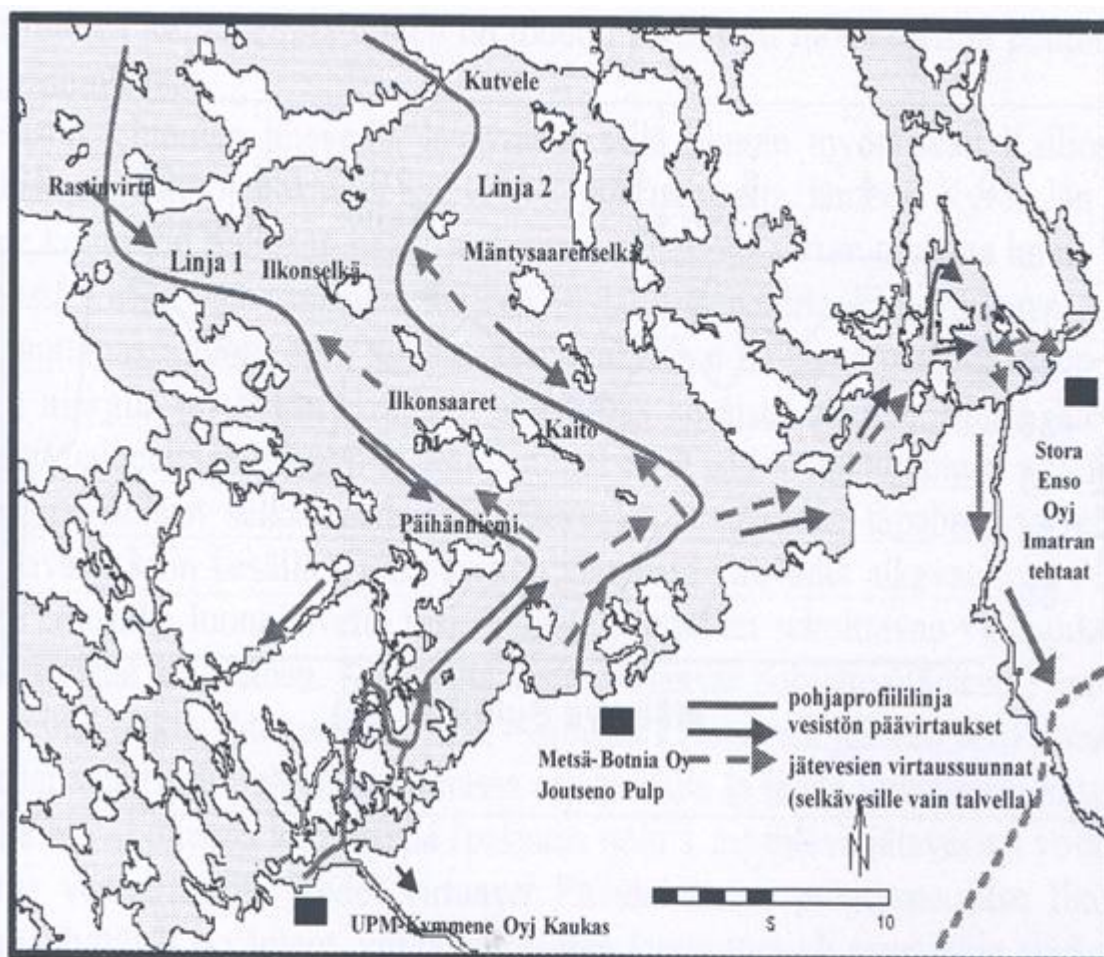


Figure 10.1. Mixing principles of wastewaters at Suur-Saimaa.
The distance bar is expressed in kilometers.

- ▶ Wastewater flow direction (past Päihänniemi only in the winter)
- Main currents in the lake
- Depth profile line (see Figure 10.2)
- Source of discharges

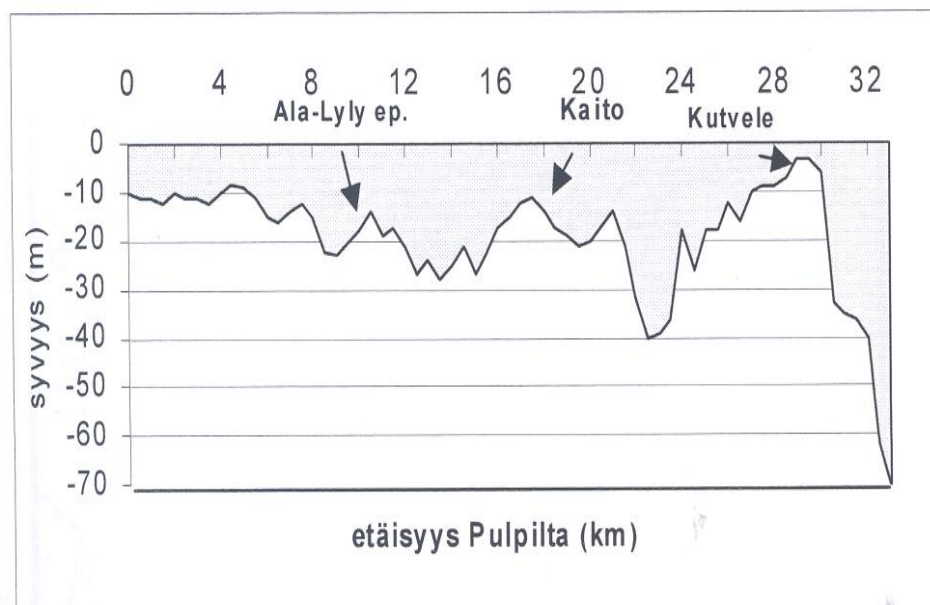
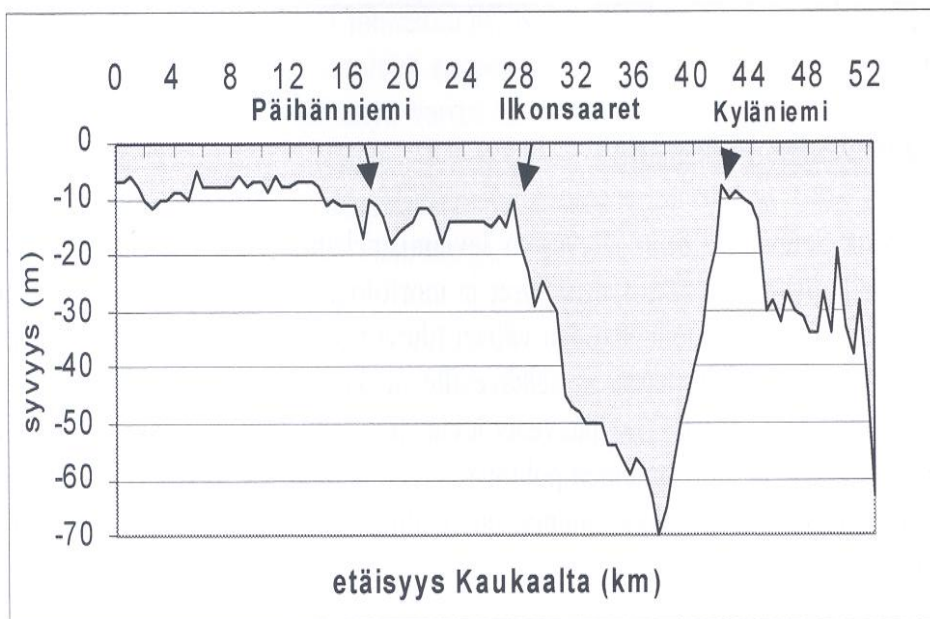
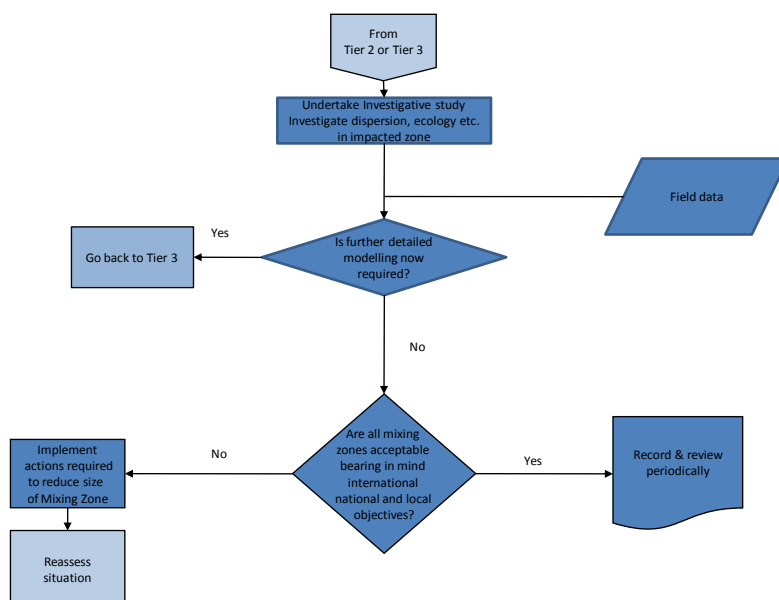


Figure 10.2. Depth profile of the lake bottom at line 1 and 2 (see Figure 10.1) (syvyys = depth, etäisyys = distance)

11. TIER 4 – INVESTIGATIVE STUDY (OPTIONAL)



For the purposes of these guidelines ‘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 these Guidelines are not intended to deter any party from gathering and using relevant information to support this process. As a general rule, guidelines 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 exceedance as unacceptable.

It is not necessarily the case that the studies falling within Tier 4 scope are new. For example, relevant data may be obtainable from routine, surveillance or investigative monitoring conducted by other parties for other purposes. For an existing discharge, studies may be available from the original permitting studies, perhaps many years ago. In order to use assessment resources responsibly, it may be appropriate to make use of proxy data obtained in similar circumstances from other locations. Although clearly not as 'powerful' as case-specific data, there may be reasons for looking to other sources (e.g. if there is a long-term record available allowing reliable inference of long-term variability where no such record exists for the location of interest).

In some cases the gathering of field data in order to calibrate and validate some of the hydrodynamic and dispersion models typically used at tier 3 would be in line with normal modelling practice. However, the precise way in which data of all kinds may be required or used within a determination would depend on the prevailing Member State approach to discharge permitting.

The rationale for item c is to allow a priori consideration of potential for biological impact for a new discharge. Item d allows consideration of actual impacts for an existing discharge. In carrying out items c&d the logic is not to attempt to derive a new, less stringent EQS to apply in local waters, but to allow consideration of whether or not the extent of EQS exceedance predicted to occur or actually occurring (including its 3d spatial and temporal variability) would or is affecting the water body biological status. Carrying out items c&d will not affect the strictly chemical measures of impact (e.g. areas, volumes, lengths, and proportions of bank, bed, proportions of reef habitat, and proportions of sandbank habitat) experiencing above EQS concentrations but this is only one input into the extent acceptability decision. The biological characterisation work supplies the biological input in acceptability determination at tier3. Where there is sufficient knowledge of the biology and the likely impacts of chemical concentrations on this biology the biological considerations can be factored into tier 3 decision making without recourse to specific fieldwork. However, in a particular case a regulatory authority may require site-specific fieldwork from a prospective discharger or a discharger may elect to carry it out prior to application in the hope that it will strengthen the acceptability case. It may not strengthen such a case and may reinforce a decision that the extent of EQS exceedance is not acceptable.

All modelling and assessment studies are subject to uncertainty and Competent Authorities will have long experience with balancing the level of uncertainty in assessment, societal cost and societal and environmental risk in exercising their regulatory functions. In this regard, the determination of acceptable mixing zone extent is no different to any other regulatory function. In some cases, having proceeded through tiers 0-3 without recourse to new investigative studies, it may be that new investigative studies could assist in reducing residual uncertainty. Where fieldwork is contemplated it is also important to factor into consideration the associated health and safety risks in its execution.

In any determination there may be a degree of residual uncertainty and, in order to ensure protection of the environment, particularly in the case of a new discharge of sufficient scale to have led to tier 3 assessment, a Competent Authority may choose to require investigative

studies to confirm that modelling or other assessment of harm assumptions are valid in the specific case. Such studies may include validation of the predicted dispersion of the discharge, monitoring of the water quality, sediment type and quality, and biological receptors within and outside the determined mixing zone etc. However, fieldwork has its limitations and the variability of the real world is such that differences between field observations and assessment assumptions are inevitable. Thus, care in interpretation of the findings of such investigations is important not least to ensure that the any apparent impacts inferred are correctly attributed. It is not the case that changes inferred in an investigation of a particular discharge necessarily have arisen because of that discharge but could have arisen as a result of other influences on the environment. Clearly, the design of the studies should have regard to allowing discrimination of change (e.g. through the use of appropriate controls) though in practice the feasible approaches may be limited.

It should be stressed, however, that practical difficulties may limit the scope for such studies. In particular studies conducted in the water column in coastal waters, may require measurements in such dynamic conditions that it may be very difficult or extremely expensive to secure robust and reliable results.

In some circumstances it may be appropriate where adequate field information is available for the determination of acceptability to be made through use of such data without use of new modelling. For example, where there is ample data on chemical concentration distributions occurring within the water body and evidence of impact (or lack of impact) on relevant receptors at appropriate locations. In such cases the mixing zone determination can be regarded as having taken place in tier 2 or tier 3 depending on whether the extent acceptability has been judged on the basis of the precautionary extents of tier 2 or the more considered approach of tier 3.

Look Out!

The use of investigative studies is a matter for Member State discretion. It is not intended to introduce and should not be interpreted as an attempt to require additional monitoring.

12. DEALING WITH MULTIPLE DISCHARGES

In urban areas, particularly industrialised ones, numerous individual discharges may mean that mixing zones can overlap. However this issue may not only arise through the overlap of individual mixing zones but also where non-intersecting mixing zones may warrant further assessment to determine whether the cumulative effect can be regarded as acceptable (Individually each may be acceptable and none overlap). A given discharge may also affect the concentrations occurring as a result of the discharge of another effluent through its effect on the background concentration. The initial focus will be the consideration of discrete point source discharges but in certain urban catchments there may be numerous very minor point sources that also demand consideration collectively.

Further, in some cases, a single discharge will give rise to several extents of EQS exceedence nested within one another (each associated with different components of the effluent). Clearly, these are not independent since the physical dilution occurring will be the same for each. However, their relative extents may vary (e.g. with variations in the composition of the effluent and the receiving waters and in response to any decay process occurring (e.g. photochemical reactions whose rate depends on the season and time of day of release, volatilisation (which may depend on temperature and wind-speed etc). In such cases it may be necessary for the Competent Authority to consider the possibility of synergistic or antagonistic effects.

In more complex cases it may be appropriate to consider the combined effects by 'superposition' of individual assessments. For example, this situation may arise if the Competent Authority has received separate modelling and assessment reports for individual discharges or groups of discharges. However, when there are multiple sources care must be taken if any of the dispersion or loss processes are non-linear as in such cases, the effect of the combination of discharges may be different to the combination of the individual effects.

Alternatively, it may be appropriate to explicitly model the combined discharge consequences by modelling each individual discharge taking into account any correlation between discharges and the receiving waters and directly assessing the combined effects through use of the single model output.

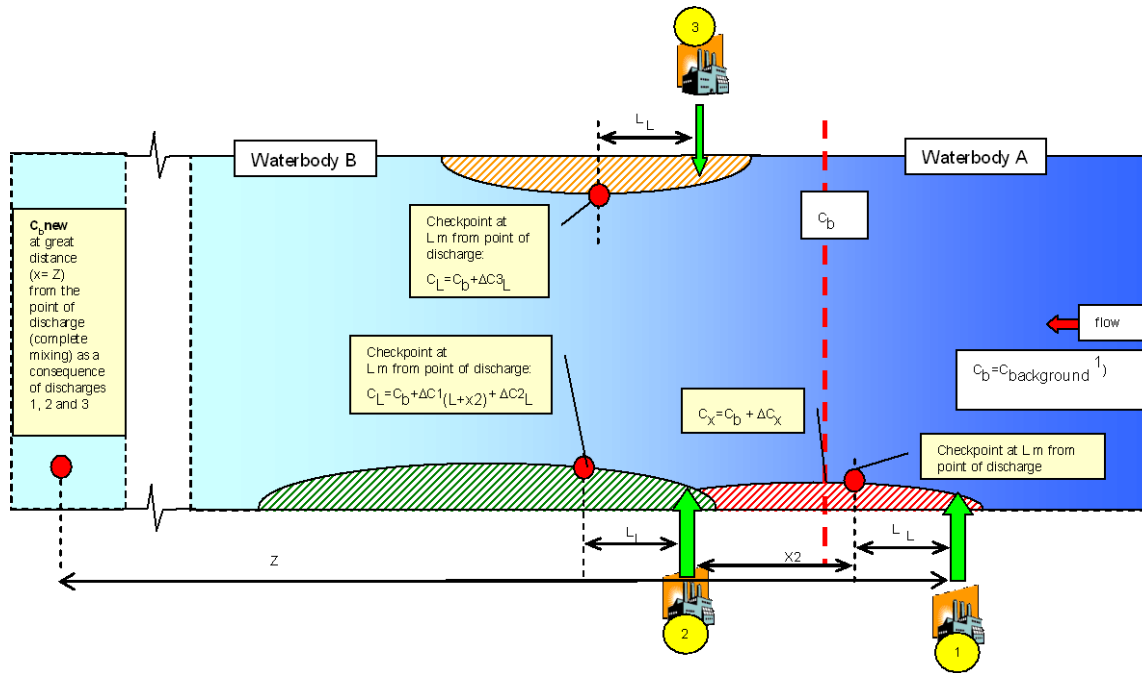
However, the basis for determining the acceptability or otherwise of the combined discharges remains precisely as it was for a single discharge i.e. it should be determined by the Competent Authority taking into account the range of case-specific factors listed previously.

Additional factors that may be appropriate for multiple discharges include:

- Possible non-linearity, existence of thresholds
- Correlation between discharges

An example of how to evaluate combined concentrations, based, for simplicity, on the use of Fischer equations, is given in Figure 12.1.

Figure 12.1 Interaction between point sources on adjoining water bodies



In this example the river is flowing from right to left with three discharges 1, 2 and 3. As a consequence of discharge 1 the background concentration for the second discharge increases and the acceptable load to be discharged, based on water quality arguments, decreases. This illustrates how discharges to one water body, may impact on the quality in an adjoining water body. Water quality is influenced by discharges upstream, resulting in C_b as background concentration. The assumption is that the concentration is already fully mixed over the entire cross section.

Near the border the concentration in water body A is influenced by the discharges originating from plant 1. The mixing zone crosses the border of the water body and influences the background concentration in the vicinity of discharge 2. In this case, as the mixing zones originating from discharges 1 and 2 do not reach the other side of the water body the background concentration in the near vicinity of discharge 3 equals C_b .

Discharge 2 is influenced by the background concentration C_b and the increase of the concentration due to discharge 1 in the near vicinity of the border between water body A and B. The background concentration at the discharge point 2 is given by $C_b + \Delta C_1(L+x_2)$

The increase in concentration (ΔC) can be given by:

$$\Delta C_1 = C_{\text{effluent-1}} / M_1$$

with M_1 (Mixing Factor) = $M_x^{2D\text{-plume}} = \frac{\varphi_0}{\varphi(x,0)} = \frac{a \cdot \sqrt{\pi \cdot K_y \cdot u \cdot (L+x_2)}}{Q}$ (see equation 9 of reference 16(27) to this document).

As a consequence of the discharges 1, 2 and 3 the background concentration increases. At greater distance, where mixing is complete, the new background concentration $C_{b\text{-new}}$ ¹⁷ can be given by:

¹⁷

Assuming inert behaviour: evaporation, degradation (biological and chemical) does not take place. Depending on the scale of the water body under consideration and the mixing and advection processes occurring and the nature of the contaminants of concern

$$C_{b-new} = C_b + \frac{(W_1 + W_2 + W_3)}{\text{flow} - \text{waterbody}_{x=z}} \quad [12.1]$$

With: W = load of the discharge [$\mu\text{g/s}$]; C_b = background concentration [$\mu\text{g/m}^3$]; Flow of water body in [m^3/s].

13. TRANS-BOUNDARY POLLUTION

EQS Directive (2008/105/EC) Article 6(1) states that:

A Member State shall not be in breach of its obligations as a result of an exceedence of an EQS if it can demonstrate that the exceedence was due to a source of pollution outside its national jurisdiction.

The ambient upstream water quality may therefore be a critical factor when determining the extent of EQS exceedence in water bodies that cross national boundaries and how to take this into account may be an important aspect of mixing zone acceptability determination.

For example in the 1990s the levels of diuron found in the River Meuse temporarily prevented the abstraction of water for potable supply in the Netherlands. A significant proportion of this diuron was of foreign origin.

In fact all (point) sources discharging to water bodies situated upstream influence the water quality downstream. These sources can be located in different water bodies. The border between two water bodies may also be a national border between countries.

The example shown below in Figure 13.1 illustrates that a river basin can be built of several water bodies. The background concentration of a substance at the border of water bodies A and B depends on the flow of the water body and the total load discharged upstream.

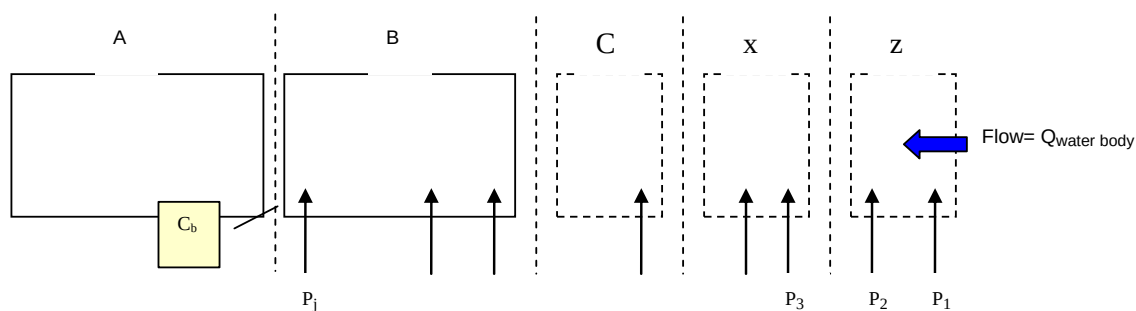


Figure 13.1 Interaction between (point) sources located at great distance and water bodies

Where a new discharge is planned just upstream of a national boundary (i.e. complete mixing will not be possible within the extent of national jurisdiction) there is an implicit requirement for the Competent Authority to involve representatives from the neighbouring CA to participate in the decision making process wherever possible.

this assumption may not be appropriate and may be substantially pessimistic. Whilst some substances may be regarded as inert others may have half-lives in the water phase of only a few minutes.

When assuming complete mixing and ‘inert’ behaviour of the discharged substances such as no evaporation, no biological and chemical degradation, the background concentration at the border of water body A and B is given by:

$$C_b = \sum_1^j P_j / Q_{\text{waterbody}} \quad [13.1]$$

where P_j = the individual load discharged in kg/s at a source situated upstream and $Q_{\text{water body}}$ is the flow of the water body.

Assuming ‘inert’ behaviour of a substance leads to a worst-case approach. This may prove inappropriate on a river basin district scale since over large distances and transit times a variety of water quality processes may influence concentrations. When monitoring data for the concentration of a substance in surface water in a water body are available these data can be used for C_b .

14. STRATEGIES TO REDUCE MIXING ZONES

Article 4(2) of Directive 2008/105/EC states that:

Member States that designate mixing zones shall include in river basin management plans produced in accordance with Article 13 of Directive 2000/60/EC a description of:

(a) the approaches and methodologies applied to define such zones; and

(b) measures taken with a view to reducing the extent of the mixing zones in the future, such as those pursuant to Article 11(3)(k) of Directive 2000/60/EC or by reviewing permits referred to in Directive 2008/1/EC or prior regulations referred to in Article 11(3)(g) of Directive 2000/60/EC.

A reduction in emission concentrations using Best Available Techniques should reduce the level of EQS exceedance in the receiving water and thus secure a reduction in the extent of mixing zone. However it must be recognised that a mixing zone cannot be completely eliminated if a discharge containing the contaminant of concern at levels above the EQS remains active. Furthermore, as recognised in Recital 10 of Directive 2008/105/EC, the complete cessation of discharges of naturally occurring substances, or those substances produced through natural processes, such as cadmium, mercury, and PAHs is impossible.

It must be remembered that our aim is to limit adverse effects, especially any acute impact from the discharge concerned and it is also important to ensure that any discharge will not lead to a significant increase in sediment contamination in the mixing zone that could jeopardise compliance with Article 3(3) of Directive 2008/105/EC.

Clearly the way in which Competent Authorities set Water Framework Directive objectives and their subsequent management towards achievement remains primarily a matter for the River Basin Management Programme process at Member State level. Therefore in these guidelines an indication of the options available have been provided rather than set out binding principles that must be followed.

The extent of EQS exceedance may be reduced by:

- application of changing BAT (by the process operator or upstream within the 'catchment' of the discharge leading to reduced loads, flows or concentrations in the effluent, either by treatment or substitution)
- permit reductions of load, volume flux and/or concentration including timing constraints perhaps dependent on receiving water characteristics (flow, ambient quality, temporary presence of sensitive receptor) not associated with BAT revisions
- management of other emissions to water so as to reduce background concentrations

- revisions to outfall arrangements¹⁸ (including its location, both in plan and in the vertical, and its design (e.g. number and orientation of ports, effluent exit velocity etc) so as to modify initial mixing characteristics (e.g. through modifications to effluent velocity and outlet distribution) so changing the distribution of concentrations in the receiving waters. (This does not affect the far-field concentrations resulting from the discharge – it is important to consider all 3 dimensions in the region of the water body affected by the short-term plume)
- management of flow in receiving waters to create more flow or revised mixing arrangements.

The above options should be considered in order to change the extent of EQS exceedence associated with a discharge. Whether any of those are appropriate or possible for a given discharge should be assessed on a case by case basis.

In complying with the requirements of Directive 2008/105/EC Member States should have regard to the three dimensional nature and time variable nature when designating mixing zones and considering the associated impacts. Thus, in some circumstances, the significance of a mixing zone could be reduced by adopting revised discharge arrangements that give rise to a larger surface extent of EQS exceedence while reducing the extent in the underlying waters or in order to promote reduced concentrations occurring at particular receptors.

In considering the available options for outfall design and location, it is necessary to have regard to the full range of process and environmental factors which may limit the practical options available. The traditional flexible regulatory approach to discharge consenting leads to ways in which outfalls can be designed to minimise impacts on the environment arising from a given load. There is no unique best outfall design – the factors which influence design may lead to very different arrangements in different local circumstances. Within the available feasible locations (which may be constrained by other interests such as safety of navigation, flood risk issues, access to land etc) it may be possible to optimise the outfall location and design to minimise impacts on the local receptors.

In some cases environmental optimisation may be achieved by **maximising** the initial mixing at the outfall (e.g. by use of high velocity diffuser arrangement). This will minimise concentration changes in the immediate vicinity of the outfall and will also tend to reduce the significance of any buoyancy effects associated with the discharge. However, it may also increase the exposure of the benthos compared with other options and in addition may give rise to localised scouring etc.

In other cases environmental optimisation may be through seeking an outfall arrangement which **minimises** initial mixing. This may be particularly appropriate for buoyant discharges where circumstances may be such that it is preferable to minimise residual impacts and ‘float’ the discharge plume over the receiving waters through use of a low velocity, near surface outfall leading to a wide and elongated surface plume of small depth compared with the depth of the receiving waters. This will both restrict and possibly avoid altogether exposure of the benthos, restrict exposure of those parts of the banks located deeper in the water column and allow passage of migrants underneath (and offshore of) the plume. In some cases it may also allow more rapid surface related processes (e.g. atmospheric exchange, volatilisation,

¹⁸

See Annex 17.7 and 17.8

photochemical degradation etc to occur), which reduce overall concentrations in the aquatic phase.

Look Out!

Additional information on options used in USA – see extract reproduced in reference 16(27), page 29 of this report.

15. CONCLUSIONS AND RECOMMENDATIONS

The huge variability of European waters is well documented. It provides a wealth of environmental riches that the Water Framework Directive sets out to protect and improve. However it was always recognised by the Drafting Group that the development of harmonised Mixing Zone guidelines would need to consider carefully how best to design mechanisms that would address this variability and provide an appropriate level of protection for all the waters of Europe from Scandinavia to the Mediterranean. This proved a considerable but worthwhile challenge. The Tiered Approach developed has to date been well received and we hope that it will provide Competent Authorities across the EU with the necessary information to meet their obligations under EQS Directive.

The Drafting Group suggests a review of these guidelines in two or three years time when Member States have become more familiar with the concept of setting mixing zones. Such an approach may identify ways to improve harmonization of approaches.

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²⁰ under the review

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Modelling & Models

(15) CORMIX is a [USEPA](#)-supported [mixing zone model](#) and decision support system for environmental impact assessment of [regulatory mixing zones](#) resulting from continuous [point source discharges](#). The system emphasizes the role of [boundary interaction](#) to predict steady-state [mixing behavior](#) and plume geometry. <http://www.cormix.info/>

(16) Danish Hydraulic Institute MIKE Software is the result of years of experience and dedicated development. DHI Software models the world of water - from mountain streams to the ocean and from drinking water to sewage. <http://www.dhigroup.com/>

(17) Deltares produce a range of software packages including Delft3D, a 2D/3D modelling system to investigate hydrodynamics, sediment transport and morphology and water quality for fluvial, estuarine and coastal environments. <http://www.wldelft.nl/soft/>

(18) The USEPA Visual **Plumes model** system is a Windows-based software application for simulating surface water jets and **plumes**.

<http://www.epa.gov/ceampubl/swater/vplume/>

(19) The TELEMAT-2D mathematical model is based on the finite element approach, and was designed to solve several depth-integrated transient nonlinear partial differential equations (pde's). The model is actually used to study one or more physical processes including the transport of water (conservation of the water mass). <http://www.telematssystem.com/>

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British Energy Estuarine and Marine Studies (BEEMS) is a research programme funded by EDF Energy to provide scientific background for the marine issues surrounding new nuclear build.

