MODELLING

Mathematical Models of water quality are simplifications and approximations. They can aid decision making, and assess options for action, provided that the model is verified and the decision maker knows (or the model calculates) the effects of the limitations of the approximations and data in the model.

19 EUROPEAN SCALE MODELLING

At the EU level extensive use is made of mathematical models in the planning of future legislation and in the review of success of extant legislation.

19.1 ORGANIZATIONAL FRAMEWORK

In planning legislation the focus of modelling is on prediction of environmental and regulatory impact. In review the focus is on reducing very detailed data from Directive related monitoring and implementation information in Member States to produce an overall European picture.

The European Environment Agency (an Agency of the European Union, serving the European Parliament, Council Commission and Member States) and the European Commission's Joint Research Centre lead in the transforming of detailed scientific data into information accessible by policy makers and the public. Extensive use is made of mathematical models, statistical data reduction techniques and GIS to present the information in a readily understandable manner. Both are key players in managing the WISE network, the Water Information System for Europe.

WISE is a partnership between the European Commission (DG Environment, Joint Research Centre and Eurostat) and the European Environment Agency, known as 'the Group of Four' (Go4). The main roles and responsibilities of the partners are:

- **DG Environment**, leads the policy and strategic aspect of WISE. It liases with Member States, especially on official reporting requirements of EU water legislation.
- The **European Environment Agency** hosts the Water Data Centre and the thematic WISE webpages.
- The **Joint Research Centre** conducts environmental monitoring and water resources modelling including nowcasting and forecasting services.
- **Eurostat** collects and disseminates water statistics, also as a part of WISE data and themes, and provides significant input in the development of the GIS part of WISE and, in particular, provides overall implementation co-ordination for the INSPIRE Directive of May 2007. This Directive establishes an infrastructure for spatial information in Europe to support Community environmental policies, and policies or activities which may have an impact on the environment.

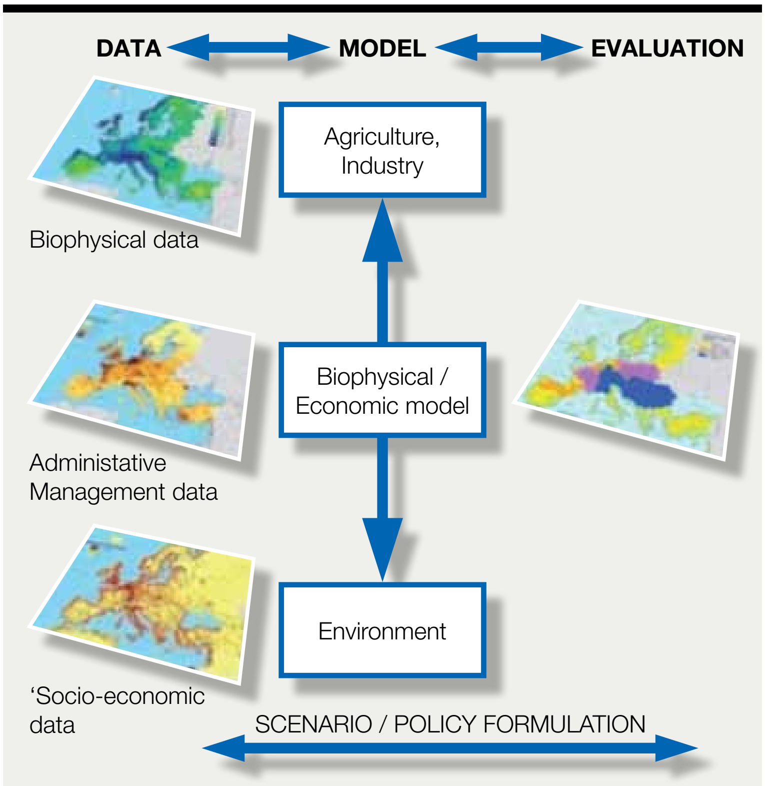


Figure 19.1 FATE Modelling Approach

19.2 EEA AND FATE

EEA and JRC play a major role in the planning at European scale of environmental regulatory initiatives and in the evaluation of progress and success of those initiatives. Modelling is a key element of this work.

One of the groups working within JRC at European level is the Rural, Water and Ecosystems Resources Unit. The Unit has a high degree of experience and competence in the development of models for environmental impact studies which predict the concentrations and transport of nutrients, pesticides and other chemical pollutants in soils, ground- and surface waters from point and non-point sources.

One of its groups is FATE, the ensemble name for the pool of activities related to the assessment of fate and impacts of pollutants in terrestrial and aquatic ecosystems carried out at the JRC's Institute for Environment and Sustainability (IES). IES.

FATE modelling activities are focused on:

- Nutrients (nitrogen and phosphorus)
- Persistent Organic Pollutants and industrial chemicals (e.g. PCBs, PCDDs/Fs, perfluorinated compounds)
- Polar compounds
- Pesticides and herbicides
- Pharmaceuticals

The FATE modelling approach is shown in Figure 19.1.

19.3 WHY MODEL POLLUTANTS?

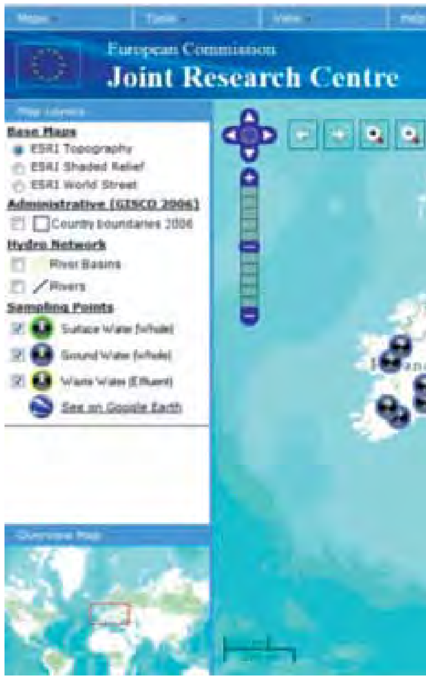
Environmental pollutant models are a simplification and abstraction of the real world and they are used across a broad spectrum of disciplines. Models are efficient tools to evaluate sources of pollution, propose sustainable alternative management practices to alleviate such pressures on water, soil and air, assess the impact of contaminant losses on ecosystems, and develop appropriate sampling strategies for monitoring the impact of implementation of best management practices.

The implementation of the European environmental legislation raises new challenges for the research community and models have been identified as tools to fulfil the requirements stated in the policy framework. Several models have been developed within FATE, covering a wide range of spatial and temporal scales and level of processes, with representation according to the scope of application.

The FATE Interactive Map Viewer can be used to explore results of pollutant fate modelling across Europe.

The FATE interactive map viewer was designed to display thematic maps of pollutants at the European scale. Various tools were implemented to allow the user not only to view the pollutants modelled and the data monitored, but also to perform simple queries against the data and generate simple user commented WYSWYG (What You See is What You Get) reports.

Figure 19.3 Chemicals Monitoring Map



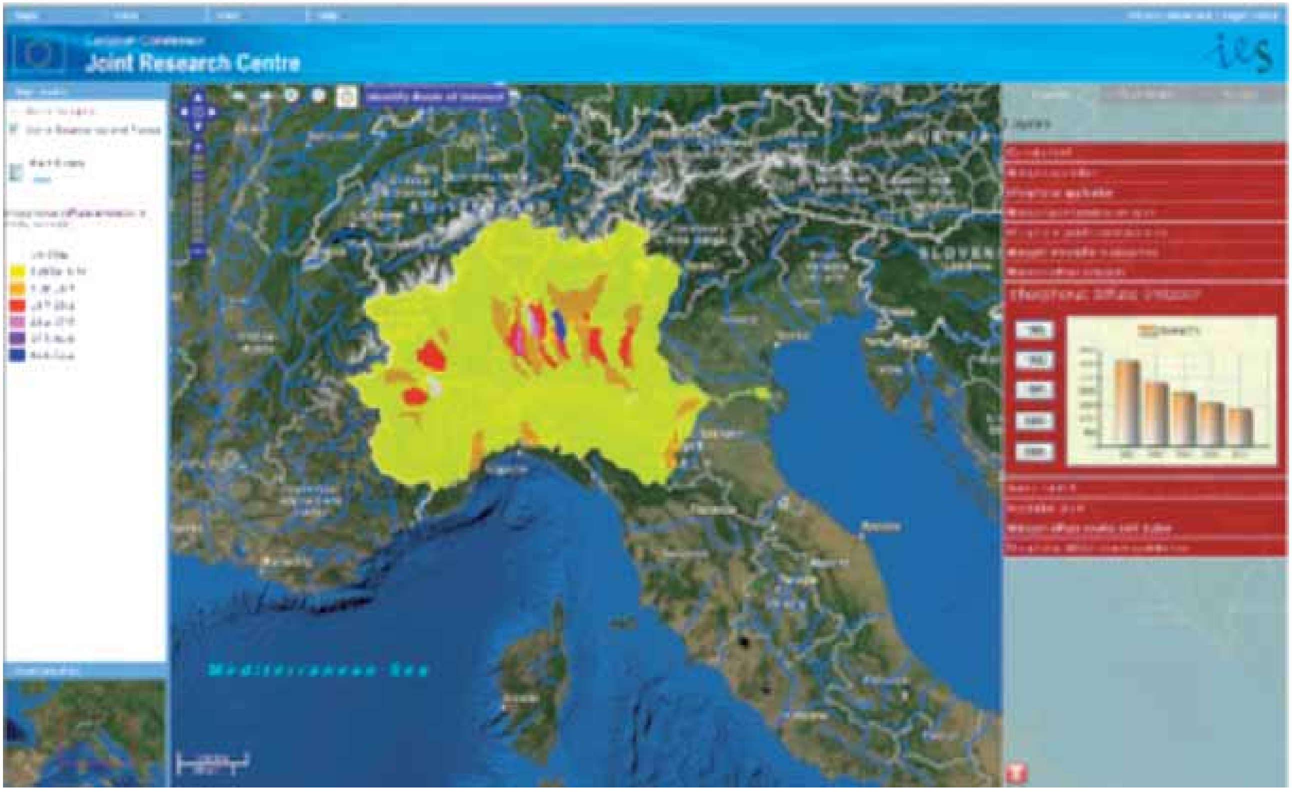


Figure 19.2 FATE Nutrients (Modelling) Map

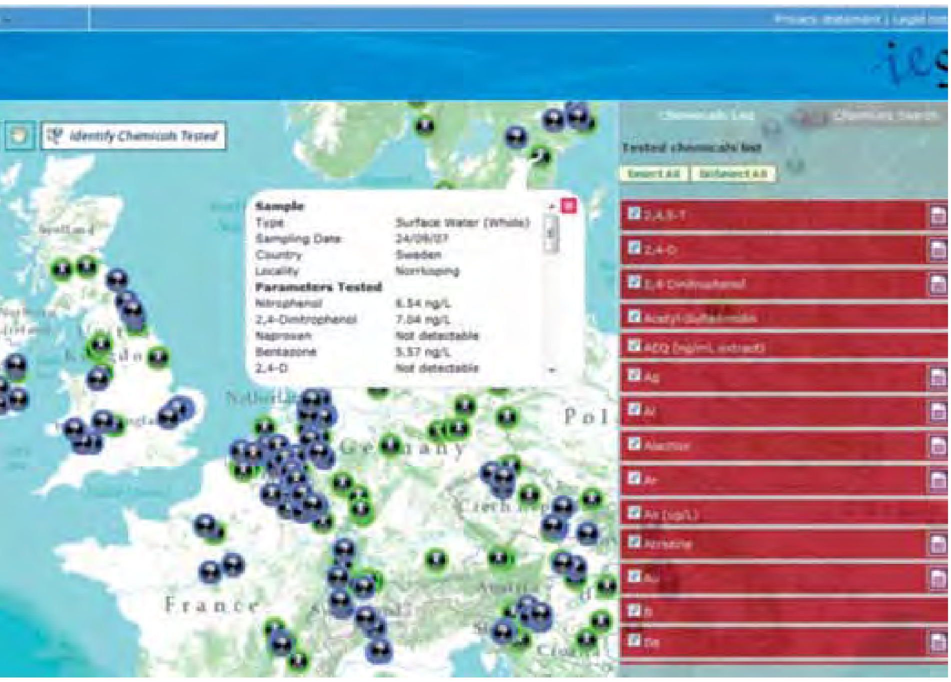
19.4 NUTRIENTS (MODELLING) MAP

The FATE Nutrients (Modelling) Map is an example of the output.

The viewer displays at river basin scale major environmental information linked to climate, landuse, nutrient discharges from wastewater treatment plants, application of fertilizers, diffuse sources of nitrogen and phosphorus, and loads to European rivers.

The Map Viewer allows you to select a point location and provides the option to display spatial information relative to the full river '**basin**' or to the drainage area '**upstream**' of the selected point. Various data layers and time series will then become available for mapping over a time period ranging from 1985 to 2005.

To start the process please launch the FATE Nutrients Modelling Map and use the button 'Identify Basin of Interest' in the map toolbox and then click over your chosen point in Europe.



19.5 CHEMICALS (MONITORING) MAP

The FATE Chemicals Monitoring Map viewer displays the results of pan-European screening exercises on whole water samples in 2007, on unfiltered groundwater samples in 2008, and on effluents from selected waste water treatment plants in 2009. The Map Viewer allows you to select a sampling point location and provides the option to display various chemical concentrations from a specific water sample.

20 UK NATIONAL SCALE MODELLING (ENVIRONMENT AGENCY)

At the national scale the Environment Agency makes use of models in a range of activities, from flood forecasting to demand management, and from discharge permitting to pollutant plume movement.

For water quality planning and discharge permitting, the key concept is to set environmental standards as percentiles to be achieved in the watercourse with defined confidence based on available monitoring data. Calculating the discharge that can be permitted and still meet the standard can be done by a series of basic mass balance calculations applied in a statistical framework. Various tools have been produced to assist the process of making these calculations. The complexity of the calculations varies on whether a discharge can be considered in isolation, as part of a river network, or as part of an integrated land and river catchment.

For the case of a single discharge to a watercourse the River Quality Planning (RQP) suite of software was developed by the Environment Agency. RQP contains systems to calculate confidence of compliance with a standard, the assurance that water quality is in or out of a particular class, and permit limits needed to meet standards in rivers. RQP also provides a suite of programs to calculate mathematically correct permit limits based on the mass balance equation for all sorts of statistical distributions of river and effluent flow and quality. The data that is to be used for these calculations needs to be carefully prepared to ensure that it is representative of the current river conditions, and not biased by a few rogue readings or historical changes in the catchment, and allows for various forms of correlation. Details of how this process fits to the Environment Agency's overall H1 environmental risk assessment process can be found in H1 Annex E – Surface Water Discharges (Complex), and how this has been implemented in Scotland is described in the SEPA WQ Discharge modelling Supporting Guidance from April 2013.

RQP only really applies in quite simple river sections with few discharges. In most cases a river network approach is required. To do the calculations for this the 'SIMulation of water quality in river CATchments' (SIMCAT) model was developed and is described later in this chapter. This model provides estimates of catchment-wide and national scale responses to different pollutant loadings and to various management options and scenarios.

More recently the capabilities of SIMCAT have been extended to include more consideration of the runoff from different land uses and also multiple sources of pollution and the factors affecting how pollutants reach watercourses. For this the SAGIS (Source Apportionment Geographical Information System) may be applied and is described further in following sections.

20.1 MIXING A DISCHARGE WITH A RIVER

When an effluent enters a river it is mixed with river water in a way that depends on factors such as type of outfall, the river flow, turbulence in the river, and the nature of the river bed. The mixing process may be complex:

- if the discharge is denser than river water it may have a tendency to hug the bottom
- a warm discharge may tend to rise to the surface
- if the discharge enters one side of the river the pollution may stream down that side of the river for some distance

- sediment may settle on to the river bed at low river flow only to be picked up again when river flow increases

In nearly all cases we can ignore these complications. Enormous simplification follows if we can allow some sort of Mixing Zone, and assume complete mixing downstream of this. So much so that it makes sense (both for the calculations and for the environment) to obtain good and rapid mixing by the choice of outfall arrangements. Determination of mixing Zones is further discussed in chapter 21.1.

In addition, the error in calculating the impact of an effluent is almost always dominated by the low sampling rates used for the river and effluent. This makes it pointless to over-elaborate on the more physical complexities.

The mixing of a discharge with a river is described by the Mass Balance Equation:

$$T = \frac{FC + fc}{F + f}$$

In this:

- **F** is the river flow upstream of the discharge
- **C** is the concentration of pollutant in the river upstream of the discharge
- **f** is the flow of the discharge
- **c** is the concentration of pollutant in the discharge
- **T** is the concentration downstream of the discharge.

If values of F, C, f and c refer to the same instant of time, we can calculate the value of T at that time. A single application of this equation cannot calculate a permit limit, c, needed to meet a river target, T. This is because the standards for rivers and discharges must be annual means or percentiles and the Mass Balance Equation does not work with summary statistics.

We have to use something like **Monte-Carlo Simulation** to do the correct arithmetic. In this, we create thousands of sets of values of F, C, f and c, and use each set to calculate the thousands of values of T.

In its simplest form, the Monte Carlo calculation extracts its thousands of values of F, C, f and c from distributions assumed to be log-normal. But all forms of distribution can be used, including non-parametric (ones that make no assumptions about shape).

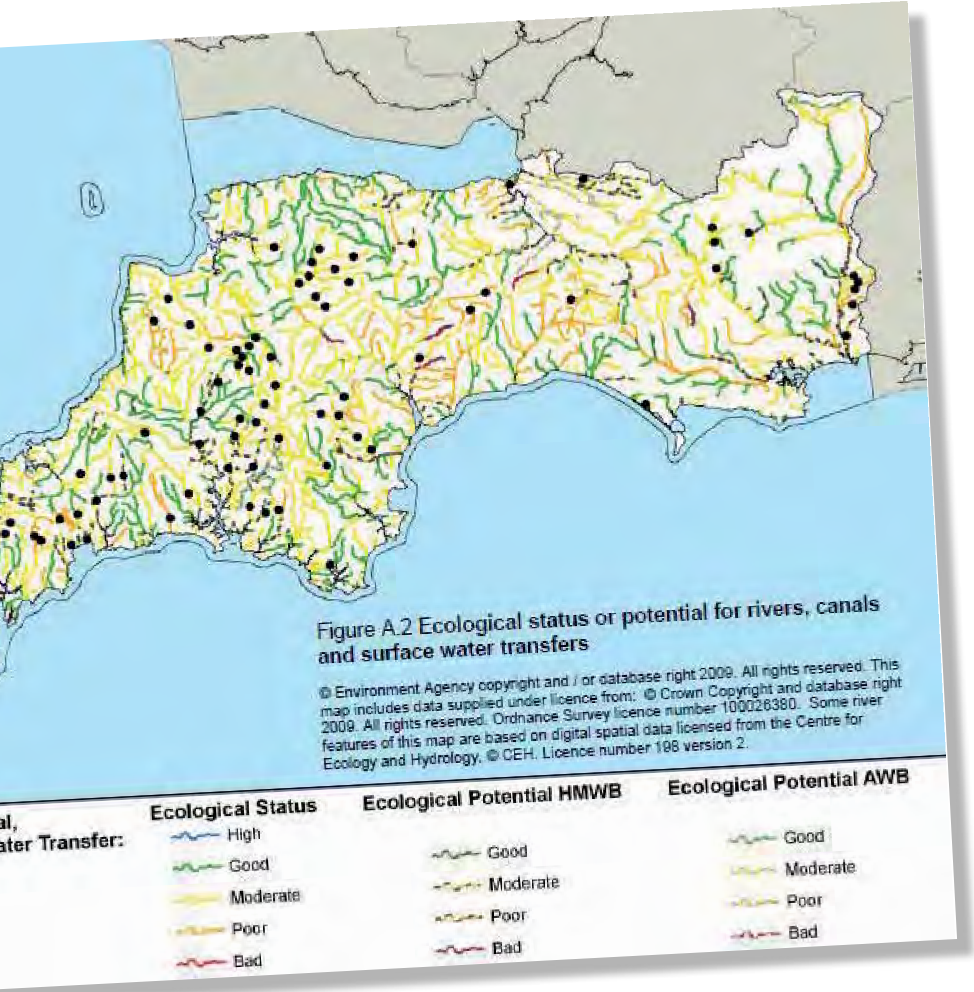
The results of the calculation define the link between the distributions of c and T and, accordingly, how the mean and percentile values of T vary with the mean and percentile values of flow and quality for the discharge and the upstream river.

The results also depend on correlations between F, C, f and c. These correlations describe, for example, the extent to which discharge flow increases with river flow, or how river quality varies with the time of year.

In most cases the data can be presumed to be log-normal. In this case only two summary statistics are needed to define the distribution. Any two statistics may be used, so it is best to use those readily available. These are:

- River flow: mean and 5-percentile
- Upstream river quality: mean and standard deviation
- Discharge flow: mean and standard deviation
- Discharge quality: mean and standard deviation

When a river receives many effluents, the decisions at one location can depend on the choices to be made at those upstream. For such rivers, the calculations can be complex and time-consuming because we have to



compute how river quality upstream of one discharge is affected by the decisions we may make at the upstream discharges.

It is therefore attractive to provide an automatic method of doing all the calculations for an entire catchment in one go. Not only does this save a lot of time, it helps plan improvements to river quality which are optimal in terms of their cost. An obvious development was to apply Monte-Carlo Simulation to an entire catchment. This led to models like SIMCAT.

20.2 SIMCAT

SIMCAT is a mathematical model that calculates the statistical distributions of the quality of river water throughout a river catchment. SIMCAT calculates summary statistics of water quality such as means and percentiles. This allows it to deal properly with issues of compliance and with the action needed to secure compliance.

Increasingly, data files for SIMCAT are being produced by databases and mapping systems such as SAGIS (Source Apportionment Geographical Information System), and SIMCAT's results are passed back to such systems for display and ease-of-use. Further information on SAGIS can be found at http://sagis.ukwir.org

SIMCAT has special features such as 'gap filling', which help produce quick results and display where knowledge of sources and sinks of pollution is incomplete. SIMCAT also calculates compliance with standards and displays the effect of the statistical uncertainties associated with water quality data and with other data.

At any points in the catchment, SIMCAT calculates the load of pollution and breaks it down into contributions from different types and sources and from any or all of hundreds of upstream discharges and sub-catchments. This helps us to decide where to act in order to protect water quality. The results can be displayed and interpreted by SAGIS.

20.2.1 SIMCAT CALCULATIONS

SIMCAT calculations start at the upstream end of the river. Packages of shots are extracted from each of the distributions of flow and quality, and start a journey which takes them all the way downstream.

At any point where effluent enters the rivers, SIMCAT uses the Mass Balance Equation to mix the sets of shots for the flow and quality of the discharge with the shots for the flow and quality of the upstream river. This gives the shots for river flow and quality downstream of the discharge. These shots are adjusted to take account of effects such as diffuse sources of pollution and natural purification as the river flows downstream. They will then define the upstream quality for a subsequent discharge.

At a confluence, SIMCAT has to remember the quality of the river and divert its attention to the top of the new tributary. The sets of shots for the tributary are processed down to the confluence, at which point the sets of shots for the main river and tributary are mixed together using the Mass Balance Equation. At abstractions the values of flow associated with the shots may be reduced according to the scale and type of abstraction.

In this manner, SIMCAT crunches its way downstream , perhaps dealing with hundreds of kilometres of river and hundreds of tributaries and discharges. Water quality, as assessed by the values of the shots, is calculated down the whole length.

20.2.2 SAMPLING ERROR

As noted above, a major source of error in taking decisions lies in the sampling rates for water quality and discharges. We only have a small number of samples over the year e.g. one or two samples per month, each with different values. These only give an indication of the true mean value and we can calculate the statistical range in which the true mean might lie if we had had an unlimited number of samples. This is called Sampling Error. Such errors must be quantified, if not directly within SIMCAT, then afterwards when we use the results to take decisions. Sampling Error should also make us think hard about the time we need to devote to details. There may be little merit in researching the intimate details of the in-river processes which affect water quality, or in identifying the subtleties in the input distributions, if the effect on results is a lot smaller than the size of the Sampling Error.

In SIMCAT, Sampling Error is modelled directly. SIMCAT will calculate not only that the mean is say, 6.1 mg/l, but will also give a range, say 4.9 to 7.5 mg/l. If it were vital to guarantee a mean BOD in the river of 5.0 mg/l, we would need to work out the measures needed to reduce the Pessimistic Confidence Limit from 7.5 mg/l to 5.0 mg/l. If, in contrast, it were vital that we waste no money, then we would calculate the measures needed to reduce the Optimistic Confidence Limit, 4.9 mg/l, to 5.0 mg/l. (In this particular case we spend nothing - the Optimistic Confidence Limit is already less than 5.0 mg/l).

20.2.3 GAP FILLING

When we put together the data for a catchment we are very lucky if the results of a first run of SIMCAT agree with the measurements obtained from flow gauges and monitoring stations. We need to make adjustments or get more data in order to secure a fit. This process is called calibration.

When the model has been calibrated we can think about using the model to predict the effect of new discharges and new permit limits. SIMCAT can calibrate automatically using Gap Filling. This reduces the time taken to produce results. As implied above, SIMCAT includes equations to describe processes like natural purification and (15 types of) diffuse sources. Gap Filling can be used to mop up any shortfall in the results of applying them.

In its subsequent outputs on apportionment of the sources of pollution, SIMCAT lists separately those added by gap filling. It is important to take these gaps into account when deciding on actions to improve water quality. It would be foolish to report that 70% of the load in the river is due to discharges if, within this estimate, we have made no estimate of what caused the 'gaps'.

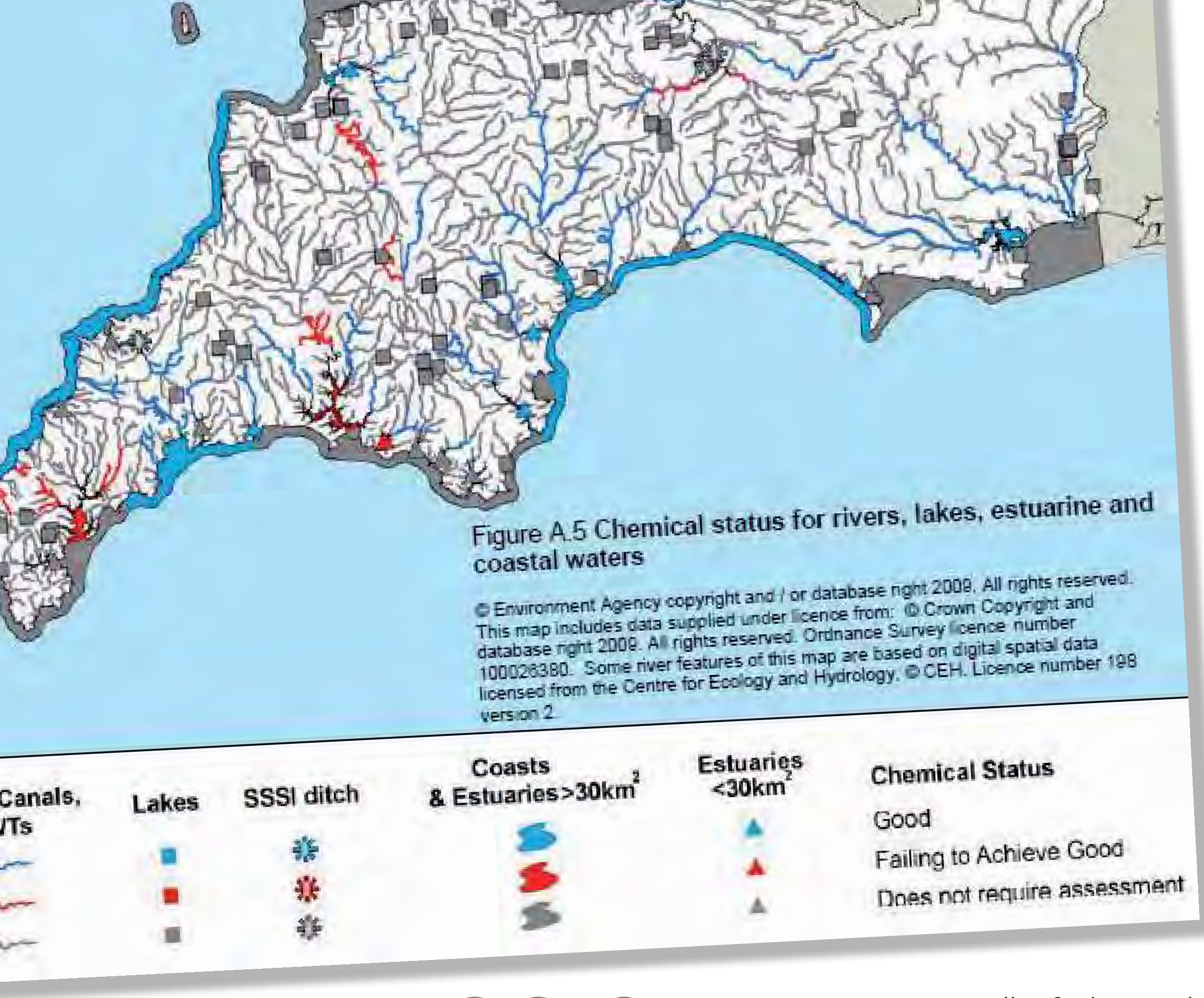


Figure A.5 Chemical status for rivers, lakes, estuarine and coastal waters

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20.2.4 AUTOMATIC CALCULATION OF THE LIMITS FOR DISCHARGE PERMITS

To calculate the discharge limit needed to achieve a river quality standard, SIMCAT compares the river quality target with the percentile value of the calculated distribution of the downstream river quality. If these values are nearly equal, the discharge quality distribution used to compute T gives the required discharge standard. Otherwise SIMCAT adjusts the discharge distribution until the standard is met.

The discharge quality distribution that gives the required river quality distribution is passed downstream. In this way SIMCAT can work down the catchment, calculating the permit conditions required for all discharges to seek to meet targets at any points in the catchment.

20.2.5 OTHER MODELLING SYSTEMS

There are many other river basin water quality modelling systems that have been developed by many different organisations and individuals to address specific aspects of water quality management.

Most of these are time series models which try to simulate the flow and quality of rivers and lakes over a specified period of time producing results for incremental timesteps which may be years, months, hours or seconds. Examples of such models are the DHI MIKE family of models, InfoWorks developed by Wallingford Research, The INCA catchment source and fate model (described further in chapter 22.4 below), and the US EPA QUAL2K stream fate model. Though very useful for understanding the processes in the River system and for simulating and testing solutions to specific problems it is difficult to use time series models as effective regulatory tools for general river basin water quality management. To fit to the statistical framework of water quality standards based on percentiles the time series results would have to be statistically summarised and analysed and understanding of the effects of sampling error incorporated to this analysis.

Generally time series models, and especially dynamic models incorporating solutions of advection dispersion are best suited to the detailed examination of local problems over relatively short time periods especially for understanding effects within mixing zones (see Chapter 21.1) and intermittent discharges (see chapter 21.2).

There are also alternative Stochastic probability function models such as SimBasinQ which is a spreadsheet based model in principle similar to SIMCAT but using the Monte-Carlo modelling package Crystal Ball to allow for much more sophisticated mathematical treatment of correlated Monte-Carlo sampling.

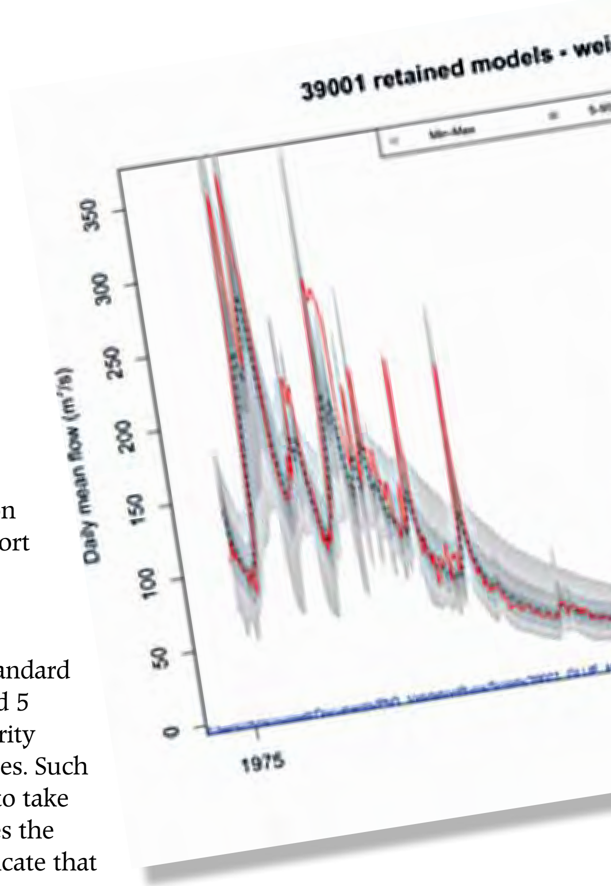
21 MODELLING AND POLLUTION LOAD INCORPORATION IN PERMITS

The mathematical modelling of the fate and behaviour of pollutants is used to help decide which chemicals need to be controlled via European legislation or at a national or local scale; models are also used to justify the controls needed to protect the environment.

This chapter summarises the use of models in planning and delivering water quality regulation. It provides links to published expertise at EU and national level, but does not provide a detailed technical appraisal of the techniques. It draws on the web pages of EU and national specialist bodies.

There is never enough information for certainty. Decisions that affect the environment have to be made on the basis of the best available data and an awareness of the level of confidence provided by such information. Modelling involves approximations and simplifications of real and complex systems whilst including all the factors which are significant for the decisions at hand. Models add value to the data produced by monitoring.

Confidence in a model is generated by comparing its output



(for example the estimates of water quality) with available data (observed water quality and components that affect it such as topography, rainfall, temperature, flow, industrial discharges, etc.). Models shown to fit and link the data may then be used to predict changes in water quality that would occur if one or more of the components were to change. A model that is validated using data from one catchment may also be suitable for another catchment of similar characteristics.

Environmental regulators frequently use models that deal with, and combine, the full statistical distributions of flows and quality. These models address the variations in environmental parameters and levels of pollution. They deal correctly with standards, and calculate the effect of the uncertainties in data. Such models can determine unbiased and statistically robust limits for substances to be discharged under environmental permits.

The complexity required of modelling, and therefore the data and assumptions, is affected by the sensitivity of the receiving water to pollution, and the potential costs of action. In general, simple modelling of mixing in close-to-worst-case conditions is of use only in scoping further work. Such models result in errors. Further detailed modelling of discharge and environmental parameters and distributions, and how these vary, is needed to produce correct results, to reduce the risk of wasted action, and to decide on appropriate action.

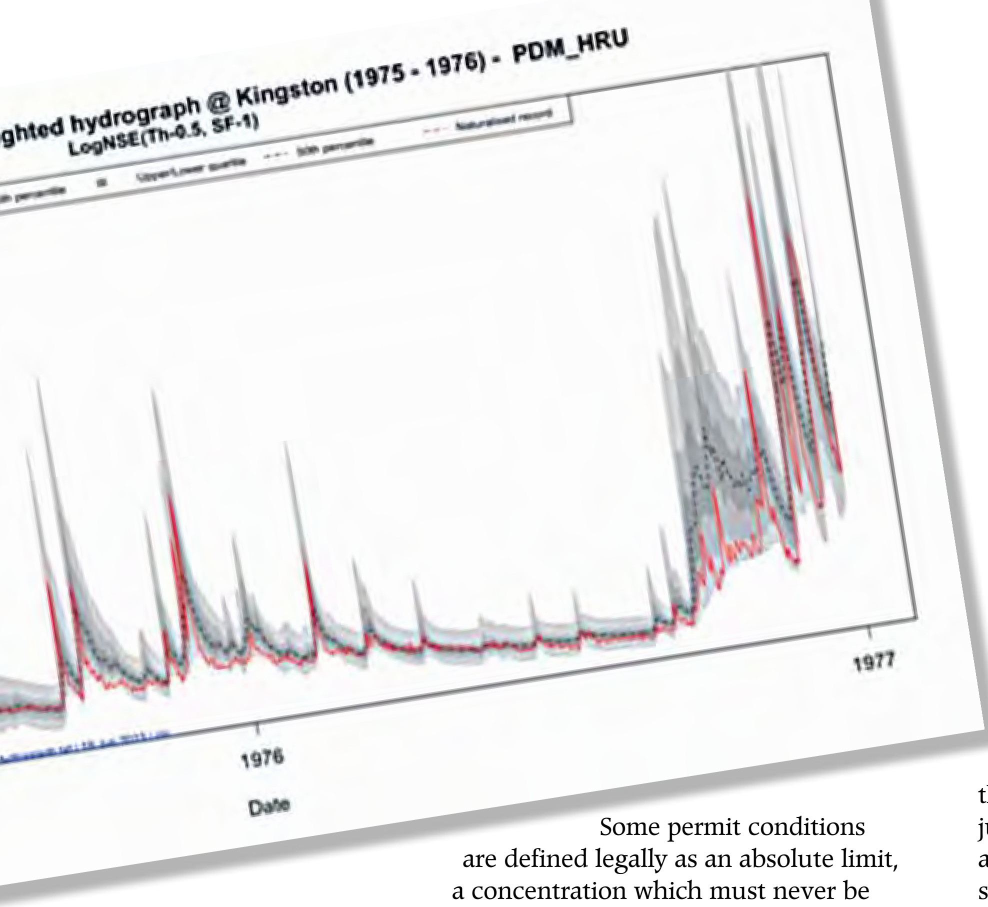
The disciplines used to assess compliance and calculate action demand that environmental standards and discharge limits are specified in a full and correct form. They need to be, at their simplest, summary statistics such as the annual mean or an annual percentile. This is required because a proper standard comprises not just a concentration, but a clear statement of how often this concentration can be exceeded. Anything short of this combination is an incomplete standard and will lead to incorrect decisions.

An absolute water quality standard such as 'no sample shall exceed 5 mg/l', is a standard whose severity varies with sampling frequencies. Such standards should not be used to take serious decisions. In some cases the toxicological evidence will indicate that the ecology can withstand short term exposure at certain levels and this evidence, and knowledge of the potential variability of the substance in rivers and discharges, may help choose the type of summary statistic to use as part of the standard.

The use of the annual mean and annual percentile relies on the similarity of statistical distributions of a substance. The measures that achieve a standard of an annual 95-percentile of 10 mg/l is a firm basis for knowing that concentrations of 20, 50 and 100 mg/l will be of sufficiently rare risk. But there will always be sources of pollution that require more complex regimes.

In any case, the modelling process must involve simulating the combinations of the full range of environmental and discharge conditions to generate summary statistics of river and discharge flow and quality over one or more years.

A standard expressed as an annual mean or an annual percentile may benefit from extra rules and limits to detect things such as accidents and illegal or intermittent discharges. We might suggest that 'the annual 95 percentile should not exceed 5 mg/l and a single sample that exceeds 10 mg/l will lead to investigation and extra monitoring'. The value of 10 might have been chosen as the equivalent of an annual 99.5 percentile under the current annual rates of sampling of 12.



Some permit conditions are defined legally as an absolute limit, a concentration which must never be exceeded. When calculating the permit limits needed to meet river targets, these too are treated as the percentiles, despite the way the standard is described in the permit. In the event of a 'breach of the absolute limit', the background percentile should be taken into account in deciding on enforcement action.

The UK Technical Advisory Group on the Water Framework Directive has produced a useful technical report UK Environmental Standards and Conditions (Phase 1).

The report sets out the requirements for meeting Good Ecological Status, and is aimed at technical specialists. The Introduction in particular is easy to read and provides an excellent summary of how data, or the lack of it, can be used in the derivation of standards upon which sound decisions, such as permit limits, can be made.

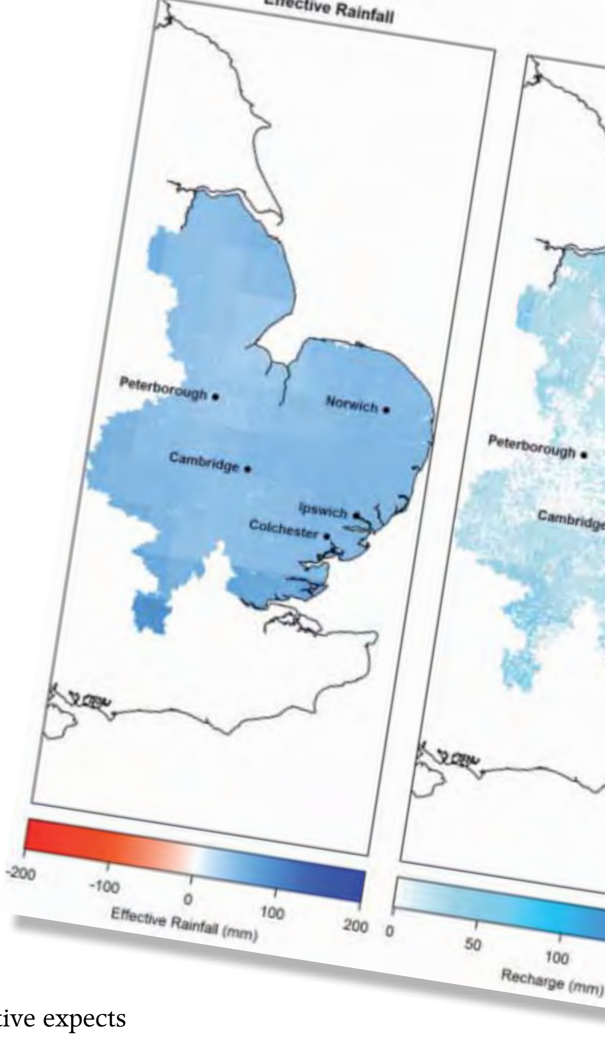
Most EU Environmental Directives specify environmental standards or emission standards but provide little flexibility to set other objectives. The Water Framework Directive allows an approach that is based on risk, where action can be taken in proportion to what it can achieve and what it will cost.

There are at least two distinct ways in which environmental standards are used to take decisions. Both have been used to establish large programmes of investment over the past two decades. An important consideration in using standards is to specify the rules by which the standards will be used to take decisions.

The first approach is called the Direct Model. It applies where regulators are able to estimate, with high confidence, the actual impact of an activity on the receiving water. This means they can judge the effect of the activity by looking at compliance with the environmental standard. The Direct Model applies where there is confidence that compliance with the standard defines all that is needed from the activities that cause failure. There is no need, for example, to seek corroboration by looking at biological data. An example of the Direct Model is setting numeric limits in discharge permits for ammonia, in order to meet an environmental quality standard (EQS) for ammonia in a river. Another might be the control of abstractions so that no more than a set proportion of the natural flow is taken.

The second approach is the Indirect Model. This applies where there is not so much confidence that failure of the standard is enough to judge the cause of damage or risk. We may need local supporting evidence. The Indirect Model applies where the regulator is less able (than for standards that can use the Direct Model) to calculate the impact of an activity on the receiving water – failure of the standard does not always guarantee damage.

Using the Indirect Model the regulator might propose the use of a checklist to confirm whether the water is damaged or at risk. This checklist may include compliance with a numeric standard as in the Direct Model but it will require more than this. It could include, for example, the absence of key species, or the occurrence of nuisance species. The checklist might lead to action such as uniform emission standards for particular discharges, or uniform controls on particular abstractions. It might not



be possible to calculate directly whether this action is enough. It might be treated as a 'step in the right direction' that will be reviewed at a future opportunity, using data collected on the status of the environment.

As an example of the Indirect Method, a chemical standard is used to help decide when to designate Sensitive Areas under certain Directives. Failing the standard is taken with other indicators, some biological, as indicating that action is needed. The action that follows a decision that the water has 'failed' is not always calculated in as precise a manner as the action needed to meet the standard in the receiving water. It may be that a uniform emission standard is imposed at all discharges above a certain size, or that a ban is applied to activities that pose risks to groundwaters.

In the Indirect Model the scale of action is a balance of the confidence that the level of risk is real, and the confidence that the action will help. In the Water Framework Directive such matching of 'action' to 'failure' will be developed under the Directive's Programmes of Measures. One problem with Indirect Methods is that total numbers of reported failures of a standard will tend to be a pessimistic estimate of the true problem.

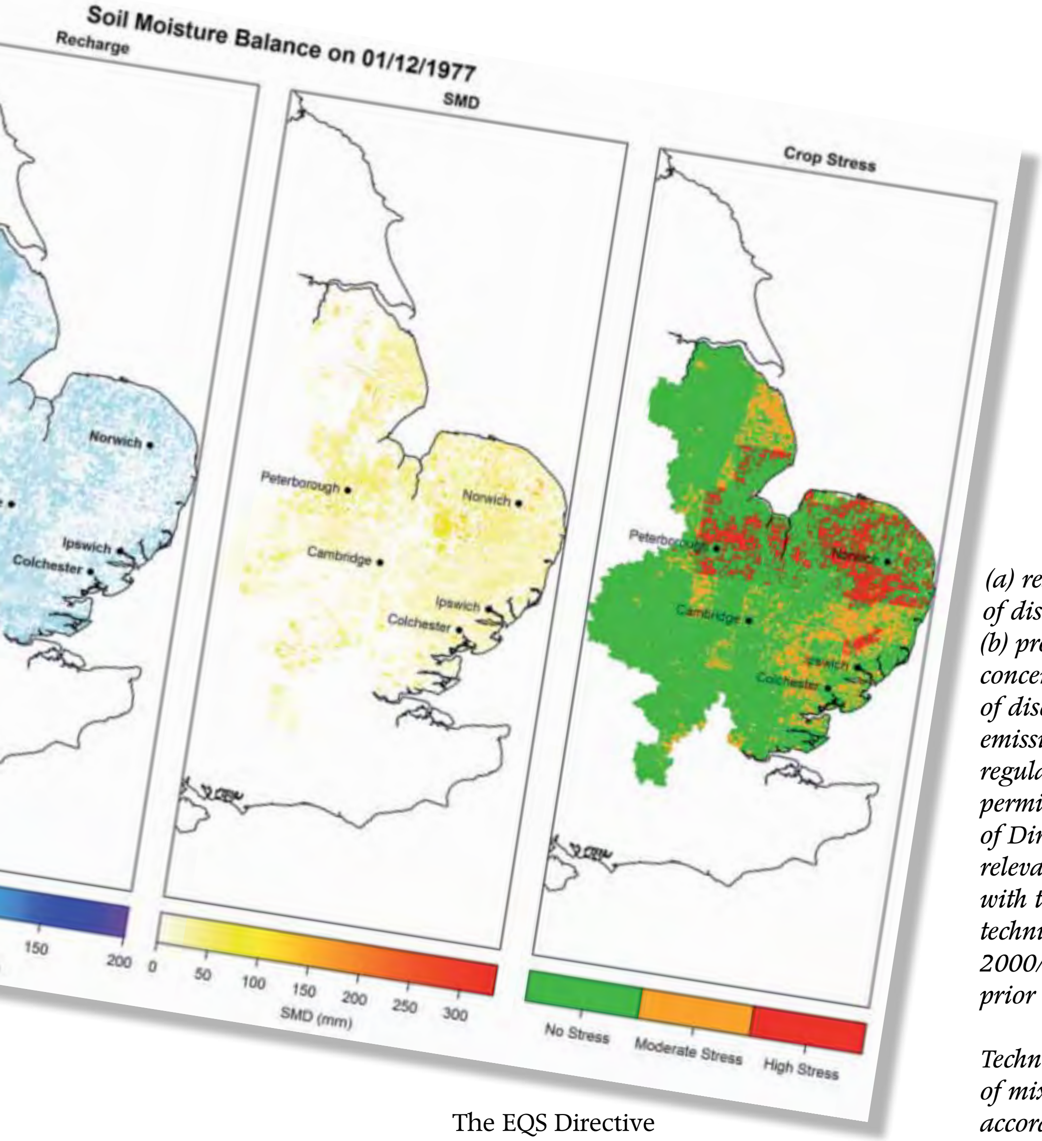
UKTAG has provided this discussion on the Direct and Indirect Models because it is critical to explain how standards lead to decisions. In the past, standards with an established effect on the environment have been associated with the Direct Model. Standards associated with more complex or subtle impacts have used the Indirect Model.

There is also the issue of assessing compliance with standards. In most cases this uses data from monitoring. In other cases it might involve calculations using models. These data or models have errors and uncertainty which need to be translated into statements of confidence that a standard has been met or failed. Knowledge about whether a standard is met or failed with a particular degree of confidence, perhaps 95% confidence, is crucial where compliance is used to issue blame or praise, and to take serious decisions. Particular degrees of increased confidence are provided by calculated levels of extra monitoring (or better models).

The Water Framework Directive expects us to know and report these levels of confidence. The outcome, the confidence that the standard has been failed, is considered when deciding on action. Such action might, for instance, be to require improved effluent treatment, or to intensify monitoring and sampling to provide a higher level of confidence of failure, prior to committing resources to remediation.

21.1 MIXING ZONES

A mixing zone is the region in receiving water where the initial dilution of an effluent takes place. If the permit allows the effluent concentration of a substance to exceed the EQS for the receiving water, then the permitted mixing zone will be that region or volume of water in the vicinity of the outfall that exceeds the EQS when the effluent contains the maximum permitted amount of the substance. Such a mixing zone is legitimate, provided it is not of such an extent that it threatens the compliance of the receiving water body as whole. Because water is mobile, mixing zone dimensions can vary spatially and temporally. It can be problematic to define the boundaries of permitted mixing zones, and also, therefore, monitoring points for permit and EQS compliance assessment.



The EQS Directive 2008/105/EC Article 4 specifies:

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.

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 Directive2000/60/EC.

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.

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.

While the EQS Directive sets out options it does not provide a specific definition of 'Mixing Zone'. The need for guidance on Mixing Zones was recognised in the WFD Common Implementation Strategy, and a Working Group was established to draft it. The guidance has now been published on the Europa web site as two volumes – Technical Guidelines for the Identification of Mixing Zones, and Technical Background Document on Identification of Mixing Zones. Downloaded copies of the Technical Guidelines document and the Technical Background document are provided here.

In the absence of formal definitions, the drafting group agreed working definitions to aid the development of these guidelines. The working definitions developed are:

'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.

Whilst the guidance is directed at the requirements of the EQS Directive, and the substances listed in it for control, the principles set out in the guidance apply to any substance in, or attribute of (e.g. temperature), an effluent that has the potential to cause harm.

The purpose of the 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.

21.2 MODELLING INTERMITTENT STORM SEWAGE DISCHARGES (URBAN POLLUTION MANAGEMENT (UPM) MANUAL)

Fully separate foul and surface water collection systems can help to minimise wet weather discharge of sewage to rivers and lakes. Where systems are combined, which is still common in many areas, the system will be constructed with combined sewer overflows (CSOs) at critical points to discharge diluted sewage to the river during storm events. The proper design of this is crucial to preventing acute pollution of the water course during storms. Much work has been done in the UK on improving the design of CSOs and using sewer network models to understand system behaviour and so optimise the design of measures to reduce the frequency and severity of spills.

This process is described in the Urban Pollution Management (UPM) Manual, the product of collaborative research by the whole of the UK water industry to provide a best practice manual on control of intermittent wastewater discharges. It was reviewed in 1998, to produce UPM2, sponsored by the environmental regulators OFWAT and the water industry. It has again been reviewed to reflect technological changes and emergent regulatory pressures such as climate change, population growth, and legislative changes such as the Water Framework Directive. The latest edition of the Urban Pollution Manual (UPM3) was published in 2012 as a web-based electronic book, which apart from making it more widely accessible, should also facilitate periodic updating. It is published by the Foundation for Water Research (FWR). (To access it click on the link above, and then the UPM Manual tab at the top of the page.)

The sectors which have been identified as most likely to be impacted by intermittent sewage discharges are:

River aquatic life
Frequent short periods of low DO (dissolved oxygen) or high unionised ammonia concentrations in a river or other freshwater body can affect invertebrates and fish and so hinder the establishment of a sustainable fishery. Wet weather discharges can be the cause of such events.

Bathing and Shellfisheries
This use applies to identified bathing waters and shellfish waters where there is a requirement to ensure compliance with the EC Bathing Water or Shellfish Waters Directive. Intermittent discharges of storm sewage can increase the risk of non-compliance with microbiological standards in these Directives.

General amenity
The amenity value of a body of water is affected by many visual factors including

the presence of gross sewage solids. Discharges from CSOs are often a major source of gross solids.

Most storm sewage discharges are of relatively short duration, although if there is low river dilution they can be very polluting. Two approaches are available to identify standards for oxygen and ammonia concentrations to protect freshwater aquatic life from wet-weather pollution episodes. These are:

Intermittent standards which are directly related to the characteristics of events which cause stress in river ecosystems. These standards are expressed in terms of concentration-duration thresholds with an allowable return period or frequency;

High percentile standards (such as *99* percentiles) based on an extrapolation of the *90/95* percentile thresholds used for protecting ecosystems which receive polluting discharges.

Demonstration of compliance with either or both types of criteria may be required, depending on environmental policy with respect to site-specific conditions.

GOOD REGULATION MUST CONSTANTLY RESPOND TO NEW AND EMERGING CHALLENGES